Franco Postacchini

Lumbar Disc Herniation

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To my family, to the teachers who guided me
in the medical arts and to all those friends
and colleagues who have contributed
to the advancement of my scientific
and professional formation.

FOREWORD

In the past ten years, there has been an explosion in the material published on low back pain. Franco Postacchini and his group have been active in this area for some twenty years. This book represents the experience of Professor Postacchini and his co-authors and their vast exposure to the lumbar disc. This unique textbook offers a broad yet concentrated look at the single topic of lumbar disc herniation. While it is rare indeed to devote a full textbook to a single topic, lumbar disc herniation deserves such attention. It is the most common diagnosis for which operative intervention occurs, yet on the other hand we know, given time, that lumbar disc herniation can be treated non-operatively in many patients with equal success. Franco Postacchini and his colleagues have provided us with 24 unique chapters ranging from a wonderful historical perspective through anatomy, pathophysiology, biochemistry and biomechanics, and ending with diagnostic imaging treatment algorithms and complications. Further, they have broadened the horizons of the usual discussion of the lumbar disc to provide an insight into the issues of professional liability co-authored by a physician. The wonderful figures, short tables, and easily read text make this an exceptionally useful book for those practicing and treating patients with lumbar disc herniations. The breadth of references in this book are second to none on this single topic. There has been ample space devoted to and information provided on not only the background of lumbar radicular syndromes associated with herniated disc, but also the techniques, both past and future, in the diagnosis and treatment of this common problem, as well as their current status.

I have enjoyed reading Franco Postacchini's textbook and applaud him and his small number of colleagues on providing us with over 500 illustrations, 2800 references and significant perspective on a common clinical problem for which there remains much uncertainty and much variation in practice. It is only through a common understanding of the epidemiology, the pathogenesis and the natural history of disc herniation that we can provide medical decision models, using Bayesian theory, which will enable our patients to understand the probabilities of their treatment options. Furthermore, it should be our goal to incorporate into our practice and treatment patient utilities derived from evidence based medicine. This approach will allow us to narrow the variation patterns currently seen in practice and should get us the right rate of intervention and the best outcome for patients with herniated disc as their primary diagnosis. I am grateful for being given the opportunity to congratulate Franco Postacchini and his colleagues on this excellent textbook.

James N. Weinstein

PREFACE

In recent years many monographs have been published on the pathologic conditions of the lumbar spine or on the surgical techniques used in their treatment. Few books, however, have been devoted to lumbar disc herniation and perhaps even then the analysis of the condition has, as yet, not been really exhaustive. This volume was initially conceived as a text that might gather together all the available information on lumbar disc herniation. While writing the chapters, this aim proved to be almost unattainable, at a time when scientific literature becomes more and more thorough. Nonetheless, I am of the opinion that this monograph has to a large extent fulfilled its aims. In fact, an attempt has been made to analyze, by means of a large number of bibliographic references, all the aspects related to the etiopathogenesis, pathomorphology, diagnosis and treatment of lumbar disc herniation, as well as to the history of knowledge on sciatica that has been gathered over the centuries and the medicolegal implications in the treatment of this pathologic condition.

Needless to say that the aim of accomplishing an exhaustive medical monograph can be achieved more easily with the involvement of various authors, each specializing in a particular aspect of the pathologic condition. On the other hand, a monograph written by a single author often has the advantage of providing greater uniformity in the analysis of a given topic; moreover, it has the prerogative of expressing the scientific thought and experience of a single individual. In this volume, I endeavored to harmonize both approaches. In drawing up certain chapters, I sought the precious help of co-authors, experts in the anatomy and pathomorphology of the lumbar spine or in the various physiopathologic and clinical aspects of lumbar disc herniation, whilst in other chapters I resorted to my own experience, built up over decades devoted to the everyday treatment of patients with pathologic lumbar conditions. In this respect, this volume perhaps has no equal in its kind.

A monograph on one particular pathologic condition may be adressed to a public of experts or to young specialists or clinicians with little experience, willing to broaden their knowledge in that field. In the first instance, some aspects of the condition are concisely analyzed, whereas ample space is reserved for others, which may appear marginal. In the second, the fundamental aspects of the issue, already widely known to the expert, are analyzed. The ambition of this monograph is to satisfy the requirements of both the expert and neophyte. Thus, some chapters, or parts of them, may not be of particular interest to the spine specialist, whilst they are useful to the newcomer to gain insight into the topic. It should be pointed out, however, that lumbar disc herniation is the subject of interest of several specialists, including biochemists, pathologists, radiologists, neurophysiologists, rheumatologists, physiatrists and orthopaedic surgeons and neurosurgeons. Therefore, an expert may also find it useful to refresh his memory on some general aspects, not closely related to his speciality, but which could, nonetheless, be necessary for a more complete mastery of the topic or for the diagnosis or treatment of particular patients.

Over the last two decades clinical research and, in particular, the new imaging techniques, have shown that disc herniation may be associated with numerous other pathologic conditions, especially lumbar spinal stenosis. In this volume, stenotic conditions have also been analyzed both as far as concerns the pathomorphologic and diagnostic aspects as well as the indications and modalities of surgical treatment. The analysis has inevitably been limited, though it is probably sufficient to clarify the reciprocal role of the two conditions in the etiology and evolution of lumboradicular syndromes, as well as in the results of treatment. Meanwhile, various methods of percutaneous treatment of lumbar disc herniation have been developed. Some of these techniques, after a period of considerable success, have become less and less popular to the point of being only very occasionally used and, even then, almost exclusively by spine specialists. In this book, I have deliberately given ample space also to these techniques both on account of their historical importance in the treatment of lumbar disc herniation and because they are still therapeutically valid, albeit with more limited indications than in the past. Yet another important reason was to give the volume the necessary completeness to make of it a useful reference book for those wanting an overall view of the various aspects of lumbar disc herniation.

Rome, October 1998 *Franco Postacchini*

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I am deeply indebted to all those who, directly or indirectly, helped to conceive and realize this volume. However, a few persons deserve special thanks, since without their efforts these endeavors would probably never have been accomplished. I should thank Gianluca Cinotti and Stefano Gumina who were not only my co-authors in several chapters, but also greatly contributed, with their patient and seemingly obscure work, by reviewing the pertinent literature of most chapters, preparing the subject index and discussing with me various aspects concerning not only basic science but also the clinical topics involved here. Salvatore Urso deserves special thanks for providing most of the myelograms reproduced in Chapter 9, as well as for counseling in the preparation of the part concerning myelography.

I am extremely grateful to Silvia Diracca who tried her best in producing the excellent drawings for the text and to Mario Termine, responsible for printing the photographs, often several times in order to obtain excellent prints from, at times, radiographs, CT or MRI films not of an excellent standard. I greatly appreciated the paintaking work of Cristina Bugno in reviewing the text and checking the correct citation of the large number of references. I am indebted to Rita Lieri who posed for the gymnastics. Marian Shields deserves my greatest and more sincere gratitude for her tremendous help in editing the English translation of the Italian version of the book. Outstanding help, in this respect, was also provided by Adriana Shields, Amy Trustman Eve, Anna Connealy and Debra Gledenning. Without the extraordinary cooperation of all these friends and collaborators, this book would never have been possible.

May I take this opportunity to acknowledge Raimund Petri-Wieder and Franz Schaffer from Springer Wien New York, who, respectively, accepted to publish, and spared no effort in organizing the printing of the English version of the volume.

Franco Postacchini

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CHAPTER 1

HISTORICAL PERSPECTIVES

F. Postacchini, S. Gumina

A historical study on the development of the concept of disc herniation has necessarily got to refer to the symptoms that it causes, since a prolapsed intervertebral disc has been identified as the most common cause of lumboradicular syndromes only in the second decade of this century.

The Egyptian–Hebrew period

A few thousand years before Christ, the Egyptians practised a type of medicine which was a mixture of religion and magical ceremonies. Long before the Greek and Roman scientific culture established the principles of medical art, the Pharaoh chief physicians used to write down on papyri anatomic, physiopathologic and clinical observations.

In 1930, Breasted (23) translated a papyri bought in Egypt by Edwin Smith and later donated to the New York Historical Society. The 377 lines of the papyri reported on 48 cases of pathologic conditions, such as wounds, fractures, dislocations and tumors. Seven cases dealt with the treatment of conditions of the spine (60). Unfortunately, the papyri is incomplete and only describes lesions to the thoracic and cervical spine. The papyri lists symptoms, such as "unconsciousness of the arms" or "of the legs" possibly resulting from traumatic cord lesions.

It is uncertain whether the Egyptians knew the real etiology of sciatica, however they were likely to be the first to describe certain clinical aspects of radiculopathies. Many human paleontological findings dating back to Ancient Egypt and Nubia, in fact, show evidence of spinal pathologic conditions, which may have produced radicular involvement (21, 24, 29, 43, 80, 103, 104).

In the Bible, there is what seems to be the first citation of radicular pain in the lower limb. An episode is described, which, according to historians, took place about 1800 years before Christ (Genesis 32, 23–33). It is the struggle between an angel and Jacob, which occurred when the latter crossed Jacob's stream on his way to his brother Esau. During the fight, the angel touched Jacob at the "commissura" (joint) of the hip, causing him a sharp pain along the "big nerve", which lasted a few days. Since then, the descendants of Israel – the name given by the angel to Jacob, which means "he that fights with God" – do not eat, for devotion, the "hip nerve", which crosses the hip joint. It has been hypothesized that the radicular-like pain might have been produced by a herniated disc caused by a physical strain, since, before the fight with the Angel, Jacob had helped his two wives, two servants and 11 children to cross the stream by lifting and carrying them on his arms (38, 73).

The Greek–Roman period

Hippocrates (460–357 B.C.) first used the term "sciatica", which comes from the Greek "ischios" (hip), in the "Treatise of Diseases" (61, 65). With this term, he indicated a pain in the joint "of the ischium with the femur" extending "to the buttocks, the protuberance of the femoral neck, the thigh and the leg". To treat pain in the acute phase, Hippocrates suggested hot water lotions on the sore area, fumigations and fasting. Once the acute phase was over, he prescribed a laxative and some boiled donkey milk. In the "Treatise of Predictions" (61, 65), in describing the natural history of sciatica, Hippocrates stated that in elderly patients with "cramps and cold at the loins and legs" the condition would last at least one year, whilst young people "whose pain was not less severe compared with elderly patients" would get rid of the illness in 40 days. Hippocrates also stated that, when cramps were associated with pain in the lower limb, the thigh would be tormented by "cold and heat".

Phyliston of Locri (370 B.C.), a Greek historian quoted by Caelius Aurelianus (30), wrote about a thaumaturgus musician, probably the Theban Ismenias, who cured sciatica by the sound of his bagpipes, which produced muscle contractions capable of removing the "infected matter" from the lower limb. This practice is also mentioned by Boëthius in the "Cronito" (20).

To cure pains in the lower limb, Cato the Censor (234–149 B.C.), in "De re rustica" (28), suggested to drink cold wine, previously boiled, together with branches of juniper.

Plutarch (1st century A.D.) reported that the Greek captain Agesilaus, complaining of sudden cramp-like leg pain, improved after a bleeding performed "by incision of the vein situated under the malleolus" carried out by a doctor of his army (95).

Pliny the Old (23–79 A.D.) was the first Latin author to use the medical term "sciatica" (94). Celsus, who probably lived between 14 and 68 A.D., spoke of "coxae dolor" (31). In the "Naturalis Historia" (Fig. 1.1), Pliny described the beneficial effect of a drink obtained from the ascyron seeds juice, diluted in water.

Fig. 1.1. *Pliny the Old. 14th century illuminated codex of the "Naturalis Historia". Milan, Ambrosian Library.*

Dioscorides (40–90 A.D.) (40), the physician of Nero's army, suggested to apply, on the patient's hip, some heated goat dung, contained in an oily cloth. These compresses had to be frequently changed until the appearance of an ulcer on the application area.

Galen (131–201 A.D.), a Greek who moved to Rome, where he became emperor Marcus Aurelius' physician, reaffirmed the usefulness of bleeding in the management of sciatica ("De sanguinis missione") (54). He described the case of a soldier, who recovered from sciatica after a wound at the ankle had caused the resection of a vein. Bleeding was aimed at removing, from the lower limb, those "noxious humors" described by Hippocrates in the "Treatise of Remedies" (61, 65). According to Hippocrates, these "humors roam around the thigh and in the hemorrhoidal vein and where they stop, they cause terrible pains, however with no danger of death". Furthermore, Galen first used tractions in patients complaining of low backache. In a Galen's "Opera", published in 1625 in Venice, an illustration shows the use of spine traction, carried out by hanging the patient by the ankles (53).

The Greek and Latin physicians, though they described in great detail the clinical features of lumbo-radicular pain, were far from understanding the real etiology of sciatica. The concept of "pain" or "irritation" according to Hippocrates (De natura hominis) (61, 65) and Galen (De ratione victus in acutis; De elementis iuxta sententiam Hippocratis) (54) was related to the philosophical concept of "passion". Furthermore, Galen initially believed that pain was caused by alteration of any of the primary qualities: heat, cold and dry (Ars Medicinales, chapter 80; De compos. medic., book II) (54); eventually, he reached the conclusion that the only cause of pain was "the solution of continuity" (De simpl. medic., chapter 2) (54).

Areteus (1st century A.D.) considered "ischiade" as a disease of the hip joint and the thigh (Of the causes and signs of chronic diseases; book II, chapter 12) (8). As in other forms of arthritis, he recommended taking white hellebore, as well as radishes and decoctions of comfrey and cinquefoil. In his work (book III, chapter 12), he described an unusual remedy for sciatica, which consisted in "letting a goat graze on iris grass to satiety and when the time necessary for the grass to reach the guts has passed, the goat is killed and the patient's feet are plunged in the goat's stomach". Areteus also recommended the application of "hot medications" on the sore area, except when sciatica was associated with perimalleolar edema. In this instance, he suggested the use of cold compresses.

Caelius Aurelianus (5th century A.D.) mistook sciatica for "psoitis" (Tardarum Passionum, book V, chapter I) (26) and, unlike his predecessors, he denied the usefulness of the frequent use of bleeding and reaffirmed the concept of applying warm ointment on the painful area (30).

Caelius Aurelianus and Themison of Laodicea (5th century A.D.) (the latter quoted by Caelius Aurelianus) (30) first gave importance to exercise therapy in the treatment of sciatica. Both of them recommended exercises on a stretcher or a horseback, thus anticipating the modern methods of chiropraxis and vertebrotherapy. These exercises caused the patient light shocks, similar to frictions and unctions, which were considered capable of removing the morbid matter from the limb.

The Byzantine and Islamic civilizations

After the fall of the Western Roman Empire (476 A.D.), Constantinople became the new scientific capital and the Hippocratic and Galenic medical tradition merged with the Eastern and African philosophy.

The Byzantine physicians got rid of many scientific conceptions based on philosophical principles and opted for pragmatic ones. Paul of Aegina (620–680), in his "Memorial" (119), which, according to Daremberg (35), was entirely copied from the "Medical Collection" of Oribasius of Pergamum (pages 324–403), described the practice of cauterization. In the "Memorial", however, there is no mention of cauterization carried out on patients complaining of lumboradicular pain. In fact, in the 76th chapter, entitled "Cauterization in Coxalgia", Paul of Aegina recommended cauterization on the hip joint, the superolateral region of the knee and the area situated proximally to the external malleolus, so as to cure the pain, probably of arthrotic origin, caused, according to the Hippocratic conception, by the large amount of "humidity present in the ischiatic joint".

Two Arab physicians, Avicenna and Albucasis, described a few therapeutic precepts for the treatment of the "ischiade", the term still used to indicate both sciatica and hip joint diseases. Avicenna (980–1037) had the merit of coming the closest to the idea of painful irritation, since he stated that "at times the pain that starts at the hip joint goes down the posterior aspect of the thigh, and at times spreads all over the knee, the heel . . . and occasionally it reaches the toes" (Canone, book III) (Fig. 1.2) (11, 15, 90). Probably, this statement was not supported by pathologic studies, since autopsy was not allowed by the religious laws (90). Avicenna believed that, to treat sciatica, the irritating substance had to be removed from the painful areas; he therefore recommended the use of bleeding, diuretics and mercurials, and substances capable of stimulating vomiting.

Fig. 1.2. *Avicenna. Canone, from a 14th century Jewish codex. Bologna, University Library.*

Albucasis (who lived between 986 and 1106), in the chapter on surgery of the book "Altesrif", dedicated a long description to the treatment of sciatica (5, 15, 90, 91, 118). He stressed the use of cautery and ignored bleeding, probably because the Moslem religion was against the shedding of blood. Albucasis recommended three types of treatment: cauterization in the hip region and the lower limb along the area of pain radiation; application on the hip region of three red hot, bottomless, iron cups; and poaring of a caustic substance, made up of a mixture of potassium and quicklime, into a bottomless cup, applied on the sore area. The author also described an ancient prescription, used by Galen to treat sciatic pain, consisting in lepidium (cruciferous) and absinthe, applied for 3 hours on the thigh and leg. This procedure was followed by a warm, and then cold, water bath.

The Middle Ages and the Renaissance

In the West, during the Middle Ages, the Medical School of Salerno excelled, which was still firmly linked to the Hippocratic and Galenic principles. It neglected some branches of the "art of curing", such as surgery and gynecology, since the monks, who translated and copied down the texts, did not consider such branches in keeping with their religious beliefs. Gariopontus (?-1056) in the "Passionarius" (128) described cauterization as one of the therapeutic modalities used by the physicians of the time. Musandinus (De cibis et potibus aegrotantium) (128) recommended bleeding in any part of the body, in patients aged over 15 years, for almost every kind of disease. In the Renaissance, Prospero Marziano (Hippocr. book de Affect., sect. 2), who referred to lumboradicular pain as "true sciatica", Jean Riolan (Enchiridion Anatom., book 5), who spoke of "known sciatica", Altimaro (De Medendis Hum.: corp. morb., chapter 18) and Adriaan van den Spiegel (De humani corpor: fabr., book X) were faithful to the Hippocratic conception (90). They believed that sciatica was caused by swelling of the veins in the lower limb. The treatments consisted in: bleeding (performed by Altimaro and Adriaan van den Spiegel near the popliteal vein), cauterizations (Zecchio Giovanni. Consult. Med., XLIII, quoted by Cotugno) (32), vesicatory therapy (carried out by Severino using an ointment called Arabic, applied on the trochanteric region) (111) and "seton". This consisted in introducing under the skin a silk thread, which was left on site till it suppurated. They believed that this could facilitate the discharge of the morbid matter responsible for the symptoms (88).

Between the 15th and the 16th centuries, there was a rediscovery of natural methods for the treatment of many pathologic conditions and there was also a strong criticism against Pliny and Theophrastus, who, in the past, had dealt with natural sciences. Many physicians in the 16th century dedicated themselves to the harvesting and classification of herbs. In 1544, Mattioli of Siena (Fig. 1.3 A), in his "Dioscoride" (translated in Latin under the title "Commentaria in sex libros Pedacii Dioscoridis") (79), listed the beneficial effects of some plant extracts used for many conditions, including sciatica (Fig. 1.3 B).

The 17th and 18th centuries

In the 17th century, the concept of radiculopathy had not yet been developed. Bellini (1643–1704) (17), in fact, stuck to the Galenic theory, according to which, pain should always be ascribed to "the solution of continuity". Borelli (1608–1679) did not agree with this and in his "De motu animalium" (78) stated that the sectioning of some tissues, such as bone and brain tissue, produces no pain. Nearer to the truth were Morgagni (1682–1771) (84) and Boerhaave. The latter, in the "Aphorism" (19), claimed that pain arises when a nerve fiber coming from the brain is stretched to the point of breaking and ends when the solution of continuity of the nerve fiber has occurred.

A B

Fig. 1.3. (A) *Petri Andreae Mattioli. Effigy of the 16th century.* (B) *A page from "Dioscoride", describing the use and effects of peucedanus for the treatment of many pathologic conditions, including sciatica.*

A B

Fig. 1.4. *Domenico Cotugno. "De ischiade nervosa commentarius".* (A) *Title page of the first edition of the book. Naples, 1764.* (B) *This drawing showed the leg areas where cauterizations and vesicatory therapies were performed.*

In 1764, the Italian Domenico Cotugno in "De Ischiade Nervosa Commentarius" (32) (Fig. 1.4) ascribed sciatica to the involvement of the sciatic nerve. He distinguished "arthritic sciatica", responsible for hip pain, from "nervous sciatica". This was identified as "sciatica postica", when pain was located above the sacrum, behind the greater trochanter, on the lateral aspect of the thigh and leg, and on the dorsum of the foot (sciatic pain) and as "sciatica antica", when pain was located in the groin and along the medial aspect of the thigh down to the calf (crural pain).

Cotugno described in detail the clinical features of sciatic pain. He distinguished it as continuous, intermittent or cramp-like and reported that its course could be clearly indicated by the patient's finger. The Italian physician also described the muscle wasting (chapter 6) and possible paresis, which may be associated with pain. However, he thought pain was caused by the presence, in the sheaths of the sciatic nerve, of a humor coming from the brain or the arteries of the nerve sheath. In patients suffering from sciatica, there would be an excessive amount of humor or there would be an acrid humor, irritating the nerve itself (chapter 27).

Among the causes of nervous sciatica, the author included "lifting of heavy things" which would favor an abundant flow of blood into the nerves of the thigh and, thus, of humors into the nerve sheath, or the presence of a venereal bubo at the groin, that would release a "bothering atmosphere" in the adjacent tissues (chapter 27).

Cotugno believed that the subjects most predisposed to sciatica are those with too thin or hard sciatic nerve sheaths (chapter 30); furthermore, he attributed the most frequent involvement of the sciatic nerve, compared with other nerves, to the presence of wider sheaths, not tightly compressed by muscles (chapters 28 and 29).

Cotugno had the intuition of considering sciatica similar to other radiculopathies. In fact, he did not use the expression "cubital nervous ischiade" to describe the radiculopathies in the upper limb only because the term "ischiade" would have aroused confusion with regard to the site of pain (chapter 31).

Cotugno studied the spinal canal and the confluence of the spinal nerve roots on many anatomic dissections; nevertheless, while performing an autopsy on a man who had complained of sciatica, he analyzed only the macroscopic features of the sciatic nerve of the affected limb. He regretted not having had time to examine the contralateral nerve, because of "the smell of the ulcers and the fear of infection" (chapter 35).

The treatments that he recommended for sciatica were: bleeding (chapter 39), to be performed on the affected side, unlike that practised by Caelius Aurelianus (30); "purgation of the bowels" with emetics and enemas (according to Caelius Aurelianus, Hippocrates believed that dysentery was an effective remedy for those who suffered from sciatica); "rubbing of the affected part" with cold oil; cauterizations and vesicatory therapy. Cotugno believed that the effect of these treatments was to decrease the amount of sour fluids in the sciatic nerve sheaths.

Cotugno also brought an important contribution to the history of sciatica. He quoted a Mr. Veratto (Physical and Medical Observations on Electricity in Bologna, 1748, page 99), who treated sciatica with electricity. According to Cotugno, the effect of electricity was "to excite palpitation of the muscles which surround the sciatic nerve and to favor the removal of the stagnant humors" (chapter 41). Cotugno also refers to Boerhaave, who experimented the effect of opium on himself (chapter 42), and some Franciscan monks, who, once back from Jerusalem, performed cauterization with a small pointed cautery that the Italians called "saetta".

Zecchio (cited by Petrini) (92) believed that sciatica might at times be caused by a liquid, which, descending from the brain, reaches the femur. The treatment consisted in using a cautery on the nape "to intercept the new inflow" and one on the leg "to make the humor flow out".

Van Swieten (1700–1772) (124) performed cauterizations along the lower limbs, by burning, on the skin, triturated leaves of artemisia, a plant which had been used in ancient times by the Chinese.

In 1784, Giuseppe Petrini, a follower of Cotugno, published a small monograph entitled "On the nervous sciatica and the new method to cure it" (92) (Fig. 1.5). The author, whose importance has been underestimated, identified nervous sciatica as tibial (lateral aspect of the leg and dorsum of the foot), sural (thigh, popliteal region, calf and heel) and combined. He thought the tibial sciatica to be more frequent than the sural, since the sheaths of the posterior branch of the sciatic nerve are more tightly compressed by the calf muscles, which thus hinder stagnation of the acrid humor.

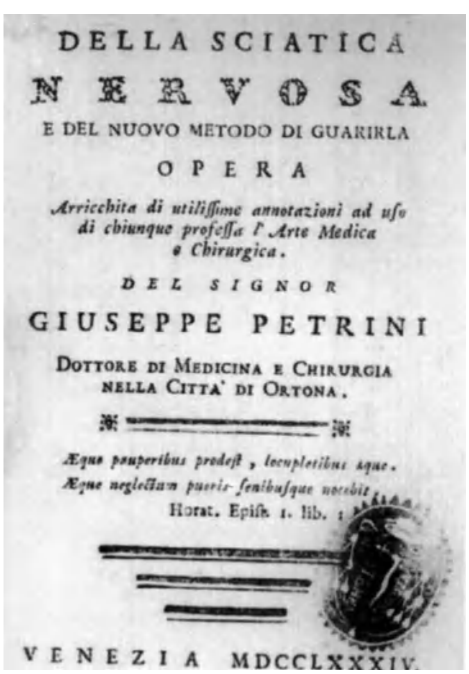
DELLA SCIATICA
NERVOSA
E DEL NUOVO METODO DI GUARIRLA
OPERA
Arricchita di utilissime annotazioni ad uso di chiunque professa l'Arte Medica e Chirurgica.
DEL SIGNOR
GIUSEPPE PETRINI
DOTTORE DI MEDICINA E CHIRURGIA NELLA CITTA' DI ORTONA.
Æque pauperibus prodest, locupletibus æque.
Æque neglectum pueris senibusque nocebit.
Horat. Epist. 1. lib. 1
VENEZIA MDCCLXXXIV.

Fig. 1.5. *Giuseppe Petrini. Title page of the monograph "On the nervous sciatica and the new way of recovering from it". Venice, 1784.*

Petrini described all the treatments known for the cure of sciatica, which, according to the author, were aimed at favoring the resorption of the stagnant humor. He quotes bleeding, purgation, enemas, frictions (dry and humid), the taking of mercury extract, antimony, opium (capable of slowing down the action of the nerves and decreasing their sensitivity), hemlock or aconitum [(these already successfully used by Storck (1731–1803), however in the treatment of arthritic sciatica)]. Petrini also described the action of "electricism", successfully experimented by Van Swieten at the Upfal hospital, and of cold baths and showers (used by Floyer to treat many "obstinate diseases"). However, he criticized these procedures, since they would cause, respectively, migration into the main organs, and coagulation, of the stagnant humor. Paragraph XII deals with the use of burns. The author denigrates this therapeutic modality and those who advocate it, including Hippocrates, who caused the death of Eupolemus by experimenting burns on several body regions (Epidem., book V) (65). Petrini stated that burns, performed with the Hippocratic method, would only "torment the inferm"; he recommended the gradual application of a small source of heat on the painful area, so as to melt the stagnant fluid in the sheaths. The author considered of no use the indiscriminate application of vesicants, capable, according to some physicians, of melting and modifying the morbid matter. However, he maintained that the management of sciatica had to be based on the concept of evacuation, rather than that of absorption, of the sour humor. Petrini also supported the method used by a minor friar, consisting in introducing a small saetta between the extensor tendons of the fourth and fifth toe on the affected side, 2 centimeters proximally to the metatarsophalangeal joint. The aim of this treatment was to favor the removal of the acrid humor through "a terminal branch of the anterior ramus of the sciatic nerve", and was therefore used successfully for tibial sciatica alone. The author, however, recommended the use of the saetta together with the seton and massage for other types of sciatica as well.

In a letter written in 1787 by an anonymous physician, a sciatica of unknown etiology is described, which was successfully treated with mercury, administered by means of friction and orally (14). However, no information is provided on the patient's history, and that does not allow a precise evaluation of the clinical case. The physician, besides, appears to agree with Sennert's doctrine (1572–1673), who attributed the onset of sciatica to the accumulation, in the hip joint, of a "pituitous, acrid and sharp humor" deposited by the arterial blood.

Roussett, in his doctorate thesis (1804) (102), reported that pressure on the posterior aspect of the thigh might produce pain along the whole lower limb. He also pointed out that sciatica might often be associated with sensory loss, unsteady movements and paralysis of the foot muscles.

In the "De morbis nervorum" (52), Johann Frank (1735–1821) stated that the causes of sciatica were refrigeration, traumas, "uterine vices" and laxity of the sciatic nerve sheaths. He also underlined that sciatica may be associated with gastralgia and nausea.

The 19th century

In 1848, the mechanic Baunscheidt, quoted by Savy (108), treated sciatica with the "dermabioticon", an instrument he invented, made up of a sort of brush, provided with needles that were inserted into the painful regions. The Western physicians considered this method as original; in effect, it followed the therapeutic principle of acupuncture, used for milleniums in the Far East.

From the second half of the 19th century, interest in sciatica grew rapidly. Bell (16), Key (66) and Virchow (127) reported on cases of vertebral traumas with disc lesions responsible for paraplegia.

Valleix (122) described in great detail the topography of the painful radicular points and, like Romberg (101), considered sciatica as a "functional neuralgia". He also studied the macroscopic and microscopic anatomy of the intervertebral disc and described what he called a "fractured disc", in a patient who had died following a trauma. To cure sciatica, Valleix recommended taking opiate and turpentine, warm baths, frictions, vesicants and moderate eating.

Luschka (77) was the first to detect (Fig. 1.6), in two autopsies, herniations of the nucleus pulposus, as large as a bean, that had perforated the posterior longitudinal ligament. However, he did not relate the pathologic findings to the clinical features of the disease.

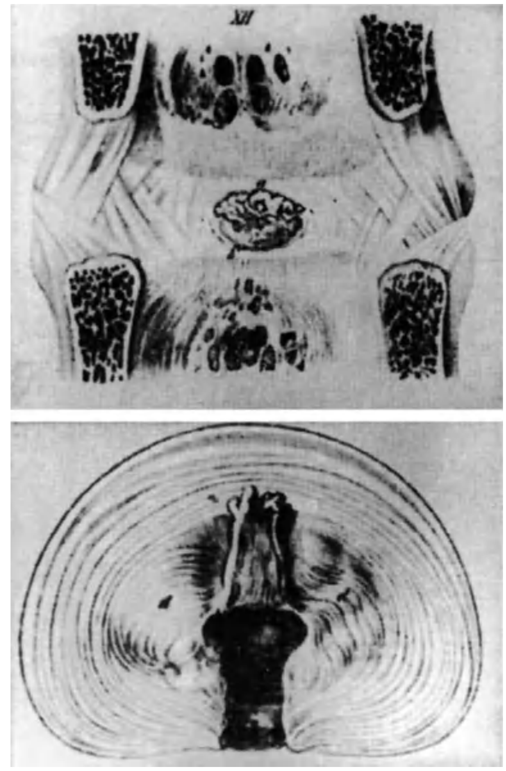

Fig. 1.6. *First drawing showing a posterior disc herniation (1858), reported in Luschka's volume "Die Halbgelenke des menschlichen Körpers".*

In 1864, Lasègue (70) (Fig. 1.7 A) distinguished a neuritic, from a neuralgic, sciatica.

A  B

Fig. 1.7. (A) C. *Lasègue's portrait.* (B) *Drawing from J. J. Forst's doctorate thesis (29-1-1881), showing Lasègue's maneuver.*

In 1881 Forst (50), a student of Lasègue, described Lasègue's maneuver (Fig. 1.7 B) in his doctorate thesis. Lasègue, on the other hand, has never made any reference, in his writings, to the maneuver that bears his name. This maneuver was aimed at differentiating sciatic pain from hip pain. However, one year before Forst's doctorate thesis, the Serbian Lazarevic had described in Serb (71) and, a few years later in German (72), the maneuver of rising the lower limb with the knee extended and its clinical significance. He had realised, and demonstrated by anatomic dissections, that the pain caused by this maneuver was due to stretching of the sciatic nerve.

In the same period, Babinsky (12), Fernet (47), Nonne (85) and Phulpin (93) believed that suffering of the nerve (neuritis) was responsible for the symptoms. Furthermore, Babinsky (12) realised that the absence of the ankle jerk was not a physiologically inconstant phenomenon, as it was believed, but the expression of nerve dysfunction.

Landouzy (69), by contrast, reaffirmed the neuritic theory and described the topographic distribution of muscle wasting associated with pain.

Vulpian (129) illustrated a pathologic condition observed in a dog, corresponding to a lumbar herniated disc. The histologic examination revealed a fibrous-like tissue with the features of disc tissue.

In 1896, Kocher (68) added a case of isolated traumatic disc injury, with herniation of the nucleus pulposus, to those previously reported by Bell, Key and Virchow. In the same years, the venereologist Fournier (51) described sciatic pain due to blenorrhagia (starting during the acute or chronic phase of the disease) or syphilis (in the second or third phase of the disease). The recommended treatment for sciatica was, thus, the syphilitic therapy.

The modern period

In 1900, Davide Giordano (56) performed a T11-L1 laminectomy and sectioned the posterior nerve roots in the intrathecal course to eliminate the severe pain complained of by a 26-year-old man, who had already undergone numerous treatments, such as the syphilitic therapy, electric shocks, stretching of the sciatic nerve, medical therapies using iodide, bromide and analgesics, and injections of phenazone, heroin, urethane and phenol along the nerve. Bed rest was not recommended, in contrast to Bradford and Lovett (22), who gave great importance to it. Giordano sutured the dura mater with thin catgut stitches, put back in place the resected portion of the lamina and applied a starched corset. Some days later, he also resected the "saphenous nerve" just distally to the tibial plateau. Pain disappeared, together with most of the limb sensitivity.

In 1901, the Polish Izydor Fajersztajn (46) reported that hip flexion on the asymptomatic side was able to exacerbate pain in the symptomatic limb. This maneuver had already been presented by the author at the Lemberg Medical Society in 1899. Based on cadaver studies, Fajersztajn believed that hip flexion on the asymptomatic side could exert traction on the dura mater of the nerve roots on this side and traction could then be transmitted to the sciatic nerve on the symptomatic side.

In his doctoral thesis (1903), Laurent Dubarry (41) observed that sensory loss was present in almost half of the patients complaining of sciatica.

In 1904, Horsley (62) indicated the posterior dislocation of the intervertebral disc as one of the causes of cord, or nerve-root, compression. In the same year, Lampiasi and Lund (cited by Delitala and Bonola) (37) detected disc herniations, interpreted as post-traumatic, at autopsy. In the same period, Lortar-Jacob and Sabaréanu (74) added that, in patients with sciatica, the paresthesias and sensory loss have a clear-cut topographic distribution, and Sicard (113) expressed the convinction that irritation of the nervous structures occurs outside the thecal sac. He coined the term funiculitis, which was then changed into neurodocitis (114).

Hunt (64), in reviewing the literature from Cotugno's Ischiade Nervosa Commentarius up to 1878, found the description of 11 autopsies performed on patients complaining of sciatica. Only in three cases, histologic examination of the sciatic nerve had been performed, which showed no abnormalities. He also examined, at autopsy, a patient, who had died due to a polmonary disease, who in life had complained of sciatica. The histologic examination showed a jelly deposit within the sciatic nerve and no evidence of inflammation. Far from understanding the true etiology of sciatica, Hunt did not inspect the vertebral canal.

The first discectomy was performed in 1908 by Krause at the Berlin Augusta Hospital on advice of the neuropathologist Oppenheim (87). The patient obtained an immediate, complete relief of pain. The disc tissue responsible for the symptoms, however, was mistaken for an enchondroma.

In 1911, the early etiologic intuitions and pathologic knowledge were enriched with new clinical and etiopathogenetic information by Middleton and Teacher's observations (81). They described the findings observed in two subjects who had died due to the complications of paraplegia, which had been caused, in one, by a fall from a 30-meter height and, in the other, by lifting a heavy object. Autopsy showed rupture and herniation into the spinal canal of the T12-L1 and L5-S1 intervertebral discs, respectively. The authors found a roundish white mass, which compressed the nervous structures. Based on these observations, Middleton and Teacher reproduced disc herniation experimentally by applying increasing loads on a spine segment of a fresh cadaver.

In the same year, Goldthwait (58) reported the case of a patient with paresis of the lower limbs and sphincter disorders, which had appeared after lumbar manipulation. The patient was operated by Cushing, who performed laminectomy and found a disc protrusion and an abnormal narrowing of the vertebral canal at the lumbosacral level. Goldthwait hypothesized that a marked posterior protrusion of the intervertebral disc might impinge on the nervous structures, thus causing low back pain, sciatica and cauda equina syndrome. Furthermore, in 1911, Valentin (121), at the autopsy of a 36-year-old man who had a history of low back pain and bilateral spastic paralysis of the lower limbs, found an enchondroma of disc origin (D11-D12) in the intervertebral foramen.

Dejerine (36) preferred the term radiculitis to that of neuritis and stated that inflammation of the nerve roots in the intrathecal course can lead to motor loss and / or sensory impairment in the limbs.

With the discovery of X-rays (100) and the possibility of observing the vertebral column in the living subject, many lumbar radiculopathies were ascribed to lumbosacral anomalies [Adams 1910 (1); Danforth and Wilson, 1925 (34)], degenerative changes of the facet joints [Goldthwait, 1911 (58); Putti, 1927 (98) (Fig. 1.8)], diseases of the sacroiliac joints [Goldthwait and Osgood, 1905 (59)], and lumbar sacralization [Bertolotti, 1917(18)].

Fig. 1.8. *Photograph of Vittorio Putti (1880–1940).*

Forestier (49), based on the researches of Sicard, who had termed the intervertebral foramen "the corridor of pain" (113), understood the relationship between low back pain and sciatica, and identified the cause of the disease in the irritation of the spinal nerve roots in the extrathecal course.

In 1918, Arnone (10) described the criteria for distinguishing true sciatica from simulated sciatic pain. The author listed many clinical maneuvers, some of which he had learnt from oral tradition rather than scientific literature. Reported are the clinical signs or tests described by Dejerine, Leenhart, and Norero (increase in pain with sneezing), Neri (sciatic pain caused by abrupt head flexion), Lasègue and Bonnet (sciatic pain caused by spine flexion), Fajersztajn (pain on the involved side caused by forced flexion of the thigh on the asymptomatic side) and De Sandro (buttock pain on pressure exerted proximally to the popliteal region), and a further clinical test described by Dejerine (decreased perception of diapason vibration in the dorsal aspect of the foot, the external malleolus and the peroneal diaphysis). Arnone also described the conditions which were considered responsible for hyperesthesias, such as vasodilation (Erb), decreased resistance of the medullary grey matter to diffusion of the nervous stimuli (Notnagel) and excitement of the grey matter caused by pain (Hallopean). Furthermore, Arnone mentioned Revault D'Allonnes, who studied, with a forceps he had invented, the degree of pressure on the Achilles tendon, necessary for the appearance of pain. Out of 13 individuals with lumboradicular pain, nine were found to have a marked hyperalgesia in the region of the Achilles tendon, whilst two had hypoalgesia and two others a normal sensitivity. These data were confirmed by Arnone himself, who carried out a similar study.

In the following decade, disc prolapse was mistaken for a benign tumor by many authors. Adson and Ott (2) reported the cases of two patients complaining of sciatica, who recovered after surgical excision of a small benign tumor located behind a lumbar intervertebral disc. Solaro (115) later removed a benign lesion, identified as a fibrochondroma, in a patient who had a several-year history of sciatica and sphincter disorders for a few months. In 1928, Alajouanine and Petit-Dutaillis (3) presented to the Surgical Academy of Paris the case of a patient with unilateral sciatica, who recovered after surgical removal of a tumor originating from a disc (Fig. 1.9). In 1929, Dandy (33) described two cases of paraplegia due to nerve-root compression caused by a tumor of disc origin, as shown by myelography. In the same year, Robineau (99) and Veraguth (125) published a few cases of lumboradicular syndrome due to disc

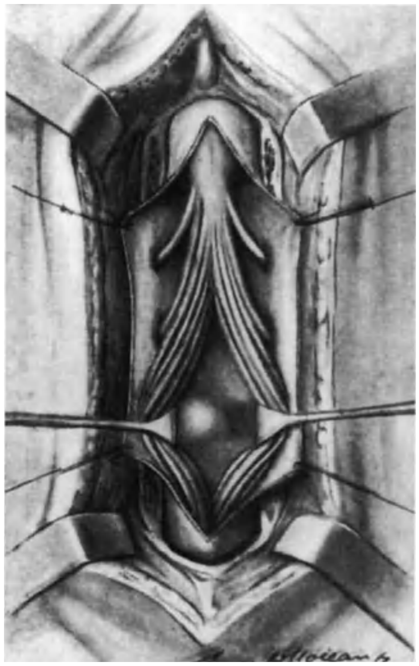

Fig. 1.9 . *Drawing by Alajouanine and Petit-Dutaillis (1928) showing a disc herniation exposed through an intrathecal surgical approach. The herniation was interpreted as a disc tumor.*

fibrochondroma or myxochondroma. In 1930, Bucy (25) reported the surgical finding of a gummy tumor, adherent to disc tissue, within the spinal canal.

In 1925, at the University of Dresda, Schmorl and his collaborators started to examine the pathologic features of the human spine. They studied over 10,000 spines in the course of many years (110). Schmorl described the protrusion of disc tissue into the adjacent vertebral body as well as disc herniation in the spinal canal, however he did not attribute any clinical significance to these findings. Andrae (7), studying 368 spines of Schmorl's collection, found 56 cases of posterior protrusion of fibrocartilaginous nodules originating from the disc. He observed that this pathologic finding was more frequent in females aged over 50 years. However, Andrae attributed no clinical relevance to this finding as well.

In 1930, Alajouanine and Petit-Dutaillis (4) presented another case of sciatica associated with an intraspinal lesion at the Surgical Academy of Paris. The authors, based on the pathologic features described by Schmorl and his collaborators, suggested that what had previously been identified as a tumor actually was herniation of the nucleus pulposus. In the same year, Calvè and Gallant (27) reported on the cases of 24 patients with lumboradicular pain, in whom surgery had revealed a herniated disc. These observations were confirmed by Glorieux a few years later (57).

Meanwhile, in Boston, the neurosurgeon Mixter (Fig. 1.10 A) and the orthopedic surgeon Barr (Fig. 1.10 B) analyzed the histologic features of 16 lesions, previously identified as chondromas, which had been removed from the spinal canal of patients complaining of sciatica, and compared them with the normal disc tissue. The authors concluded that 10 out of the 16 specimens had similar histologic features to the normal disc tissue. The first patient whose preoperative diagnosis was "ruptured intervertebral disc" was operated at the Massachusetts General Hospital on 19th December 1932 (6). The following year, Barr presented the original interpretation of sciatica to the Peter Bent Brigham Alumni Reunion, however he arose little interest (6). In 1934, Mixter and Barr (83) published their observations in the New England Journal of Medicine and correlated disc prolapse with the neurologic disorders associated with this condition, and stressed the therapeutic role of

A

B

Fig. 1.10. (A) *Photograph of the neurosurgeon W. J. Mixter (1880–1958).* (B) *Photograph of the orthopaedic surgeon J. S. Barr (1901–1964).*

Table 1.1. *Historical dates in the invasive treatment of lumbar disc herniations in the last 50 years*

1948	Anterior transperitoneal approach	Lane J. D., Moore E. S.: Transperitoneal approach to the intervertebral disc in the lumbar area. Ann. Surg. 127: 537–551, 1948.
1964	Chemonucleolysis	Smith L.: Enzyme dissolution of nucleus pulposus in humans. JAMA 187: 137–140, 1964.
1975	Manual percutaneous discectomy	Hijikata S., Yamagishi M., Nakayama T. et al.: Percutaneous discectomy: a new treatment method for lumbar disc herniation. J. Todenhops 5: 5–13, 1975.
1977	Microsurgical discectomy	Yarsargil M. G.: Microsurgical operations for herniated lumbar disc. Adv. Neurosurg. 4: 81–82, 1977.
1985	Automated percutaneous discectomy	Onik G., Helmes C. A., Ginsburg L. et al.: Percutaneous lumbar discectomy using a new aspiration probe. AJR 144: 1137–1140, 1985.
1986	Laser discectomy	Choy D. S., Ascher P. N., Soddekini S. et al.: Percutaneous laser disc decompression. Spine 17: 949–956, 1992.

the surgical treatment. These concepts were confirmed and enlarged in 1935 by Mixter and Ayer (82).

Filippi (48), based on studies and critical revisions on disc disease (he quoted: Beneke, 1897; Kahlmeter, 1918; Keyes and Compere, 1932; Putti, 1933; Loeb, 1933), analyzed the changes occurring in the intervertebral disc after removal of the nucleus pulposus in animals, whilst De Sèze (39) stated that the nerve root is affected within the spinal canal before it enters the intervertebral foramen.

In 1938, Love and Walsh (75) reported the clinical results of surgery in 100 patients with disc herniation. In their series, they included, for the first time, a recurrent herniation. In 1940, the cases operated by Love and Walsh became 300 (76).

Over few years, many European and American schools contributed to the increase in knowledge on lumbar disc herniation through scientific articles and monographs, opening the way to the present etiopathogenetic and therapeutic theories.

Some historical dates in the treatment of lumbar disc herniation in the last 50 years are reported in Table 1.1.

Lumbar spinal stenosis

Stenosis of the spinal canal is strictly related to disc herniation not only from the pathologic point of view, since the two conditions often coexist, but also for the historical evolution of the knowledge of the disease.

The first description of narrowing of the vertebral canal is attributed to the French anatomist Portal (96), who in 1803 observed cord compression of stenotic nature and severe muscle wasting in the lower limbs in subjects with a gibbus due to rickets, syphilis or both. However, Portal reports that a pathologic narrowing of the spinal canal had already been described by Lentand, as well as Morgagni in the "De sedibus et causis morborum" (Fig. 1.11). In the same period, other cases of narrowing of the vertebral canal were described by Olliver (86).

Almost a century passed before Sachs and Fraenkel (105) reported the case of a patient suffering from low back pain, weakness and tremors of the lower limbs and difficulty in walking. The patient, who walked with the trunk bent forward and showed absence of the left knee jerk, underwent surgery, since a tumor or an inflammatory spinal disease was suspected, but only an abnormal thickness of the T11 and T12 laminae, and an "enormously thickened lining membrane" were found.

In 1910, Sumita (117) reported the first cases of narrowing of the spinal canal in achondroplasic subjects.

In 1911, Bailey and Casamajor (13), based on the clinical and radiographic evaluation of five patients with symptoms and signs of compression of the spinal cord or cauda equina, thought that the clinical syndrome

JO. BAPTISTÆ
MORGAGNI
P. P. P. P.
DE SEDIBUS, ET CAUSIS
MORBORUM
PER ANATOMEN INDAGATIS
LIBRI QUINQUE.
DISSECTIONES, ET ANIMADVERSIONES, NUNC PRIMUM EDITAS COMPLECTUNTUR PROPEMODUM INNUMERAS, MEDICIS, CHIRURGIS, ANATOMICIS PROFUTURAS.
Multiplex præfixus eſt Index rerum, & nominum accuratiſſimus.
TOMUS PRIMUS
DUOS PRIORES CONTINENS LIBROS.
VENETIIS,
MDCCLXI

Fig. 1.11. *G. B. Morgagni. Title page of "De sedibus et causis morborum", wherein Morgagni describes autoptic findings of pathologic narrowing of the vertebral canal.*

might be attributed to stenosis of the spinal canal or the intervertebral foramina, resulting from degenerative hypertrophy of the articular processes. One of the patients was operated by Elsberg, who found a considerable thickening of the laminae and spinous processes of T12, due to "osteochondritic" vertebral changes and new bone formation, as shown by histologic examination.

In 1925, Parker and Adson (89) reported a series of cases, some of which showed marked hypertrophy of the laminae and spinous processes, and narrowing of the spinal canal. These changes, observed both in the thoracic and lumbar spine, were associated with signs of compression of the spinal cord or cauda equina. In the following years, it was found that stenosis of the spinal canal could also be caused by an abnormal orientation of the articular processes (98) or an excessive thickness of the ligamenta flava (116, 120).

A few years later, Sarpyener (106–107) described a few cases of congenital stenosis of the spinal canal in children or adolescents showing congenital malformations of the spine, such as spina bifida, myelomeningocele or dyastematomyelia.

Van Gelderen, in 1949 (123), reported the cases of two elderly patients, who, after standing or walking a few minutes, presented weakness and paresthesias in the lower limbs. In the sitting position, the symptoms completely disappeared. A spinal disease was suspected, since the arterial pulses in the lower limbs were normal, whilst the osteotendinous reflexes were absent. Furthermore, one of the two patients could ride a bicycle, even for a long distance, keeping the spine bent. At surgery, the author found only marked thickening of the ligamenta flava at L3-L4 level.

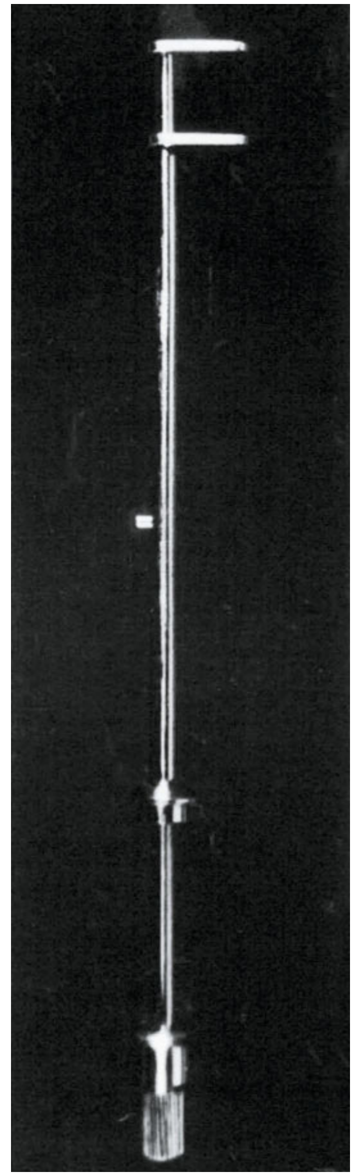

Fig. 1.12. *The stenosimeter used by Verbiest to measure the midsagittal diameters of the vertebral canal during surgery.*

In 1949, Verbiest (126) reported on three cases of abnormal narrowing of the lumbar vertebral canal in the absence of spinal malformations or scoliosis. The author, who first introduced the term stenosis of the spinal canal, believed that the condition was caused by an abnormally short midsagittal diameter of the vertebral canal resulting from a disturbance of vertebral growth of unknown etiology. He used the term "absolute stenosis" to indicate the cases in which the narrowing of the spinal canal was sufficient, in itself, to cause compression of the nervous structures and the term "relative stenosis" for those in which the narrowing could produce nerve-root compression only if associated with additional causes, such as disc protrusion or thickening of the ligamenta flava. Verbiest developed an instrument, the stenosimeter (Fig. 1.12), to measure the midsagittal diameter of the spinal canal at all vertebral levels explored during surgery; by comparing the surgical measurements with those obtained by Huizinga et al. (63) on dry lumbar vertebrae, he believed that 10 mm was the limit between absolute and relative stenosis.

In 1957, Schlesinger (109) published the cases of two patients with nerve-root compression in the lateral recess of the lumbar vertebral canal. This finding was later emphasized by Epstein et al. (44), who, in 1962, reported on a large series of patients with lumbar spinal stenosis, drawing attention to the narrowing of the lateral recess as a cause of nerve-root compression. A decade later, the same authors (45) emphasized that narrowing of the nerve-root canal may be found in patients with a normally-sized midsagittal diameter of the spinal canal.

In the 1970's, many authors, mostly American (9, 42, 67), found the degenerative changes of the facet joints and intervertebral disc to be the most common cause of lumbar stenosis, as opposed to Verbiest, who supported the developmental etiology of the condition.

In the last decades, an important contribution to the knowledge of the morphometry of the vertebral canal has been provided, initially, by transverse axial tomography (55) and, then, by computerized tomography (97, 112) and magnetic resonance imaging. The latter has brought a further important contribution to the knowledge and diagnosis of both disc disease and lumbar stenosis.

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CHAPTER 2

ANATOMY

F. Postacchini, W. Rauschning

Lumbosacral spine

Lumbar vertebrae

Vertebral body

The body of the lumbar vertebrae, like that of the cervical vertebrae, is wider in the transverse than the sagittal diameter. The dimensions of the vertebral body have been measured in skeletal populations of several ethnic groups (8, 30, 64, 96). The mean values obtained in the various studies are comparable, although not equal. This probably depends, to a large extent, on constitutional characteristics related to racial factors. An overall analysis of the results indicates that the transverse and sagittal diameters, as well as the height, as measured on the anterior aspect of the vertebral body, show a regular or only slightly irregular increase from L1 to L5 in all human populations.

The profile of the body of the first four lumbar vertebrae, as viewed from the side, is approximately rectangular. The L5 vertebra, on the other hand, usually is of trapezoid shape, allowing the transition from the lumbar lordosis to the sacral kyphosis. The anterior aspect of the vertebral body shows a slight concavity in the sagittal plane, whereas the lateral aspects are markedly concave in the transverse plane.

The anterior aspect of the body is concave both in the sagittal and horizontal planes. The concavity in the sagittal plane is more pronounced midsagittally than in proximity to the pedicles. The degree of concavity in the midsagittal plane is similar at L1 and L2, increases slightly at L3 and further at L4, and then decreases at L5 (66). The concavity is likely to be due to the hydrostatic pressure of the cerebrospinal fluid (CSF) contained in the thecal sac. The concavity in the lateral sagittal planes, more marked than in the midsagittal plane, increases progressively from L1 to L5. This has been attributed to the pressure exerted by the radicular nerves (66). When evaluated in the horizontal plane, the posterior surface of the vertebral body is concave at L1 to L3, almost flat at L4 and generally concave at L5 (67). The loss of concavity in the lower lumbar vertebrae is probably related to the lower pressure exerted by the thecal sac, which undergoes a progressive thinning in the lower lumbar spine.

Posterior vertebral arch

The *pedicles* originate from the lateral portions of the vertebral body, in close proximity to its posterior aspect. The superior vertebral notch is, thus, less deep than the inferior notch. The narrower portion of the pedicle, located in its middle part, corresponds to the isthmus.

Numerous authors (8, 53, 60, 64, 85, 110, 143) have measured the size of the pedicles and their orientation in the anteroposterior plane on radiographs or CT scans, or on dry vertebrae. The values reported, at times, vary considerably. This may be due to errors related to the method of measurement or to morphometric differences, depending on ethnic factors, between the populations analyzed. The majority of the studies indicate that: the width, at isthmic level, increases progressively from L1 to L5; the height, at isthmic level, decreases from L1 to L4 and then increases at L5; the length decreases progressively from L1 to L5; the angle between the axis of the pedicle and the sagittal plane increases progressively from L1 to L5. The extreme values on which at least two studies agree are, approximately, 7 mm (L1) and 13 mm (L 5) for the width (53, 64), 15 mm (L 1) and 14 mm (L5) for the height (8, 143), and 10°–20° (L1) and 20°–30° (L5) for the orientation (64, 143).

The *articular processes* are orientated obliquely with respect to the sagittal axis of the vertebra. The angle between their sagittal axis and the sagittal axis of the vertebral body varies considerably in different individuals and, occasionally, on the two sides of the same vertebra. The angle formed by the sagittal axis of the articular processes of the two sides is, on average, 74° at L3-L4 level, 96° at L4-L5 and 106° at L5-S1 (129).

Asymmetry of orientation of the articular processes on the two sides in a single vertebra is termed articular tropism. Tropism of varying degree of the articular processes, as seen on lumbosacral radiographs, was found in 23% (39) and 31% (15) of subjects.

The superior articular process contributes to delimit, with its anteromedial border, the lateral portion of the vertebral foramen, whilst the inferior process delimits the inferolateral portion of the foramen.

The superior articular processes of a vertebra and the inferior processes of the vertebra above form the posterior or zygoapophyseal or facet joint. This is a typically diarthrodial joint. The articular surfaces are formed by the articular facets, covered by hyaline cartilage. The joint capsule includes an external layer formed by collagen fibers and an internal stratum consisting mainly of elastic fibers (140). The capsule is covered, in the inner surface, by the synovial membrane and, in the outer aspect, by the ligamentum flavum. Each joint contains one or multiple meniscal-like structures, represented by connective tissue rims, adipose tissue pads and fibroadipose meniscoids (28, 35, 123, 141).

Connective tissue rims are thickenings of the articular capsule, not penetrating the articular cavity, which are located along the ventral and / or dorsal border of the joint. Adipose tissue pads are situated at the proximal and / or distal pole of the joint; they consist of papilliform structures, covered by the synovial membrane, which occupies only the space bounded by the joint capsule and the perimeter of the articular cartilage, or project up to 1 or 2 mm into the joint cavity (35). Fibroadipose meniscoids, also covered by the synovial membrane, are located at the superior and / or inferior pole of the joint. They are tongue-like structures, showing a large base attached to the articular capsule, which penetrates 3 to 4 mm between the articular surfaces (35). The central portion of the meniscoid consists of fatty tissue containing numerous small vessels, whilst the peripheral portion is formed by dense connective tissue. The functional role of these intra-articular structures, particularly the latter two, is probably to protect the articular surfaces during joint movements.

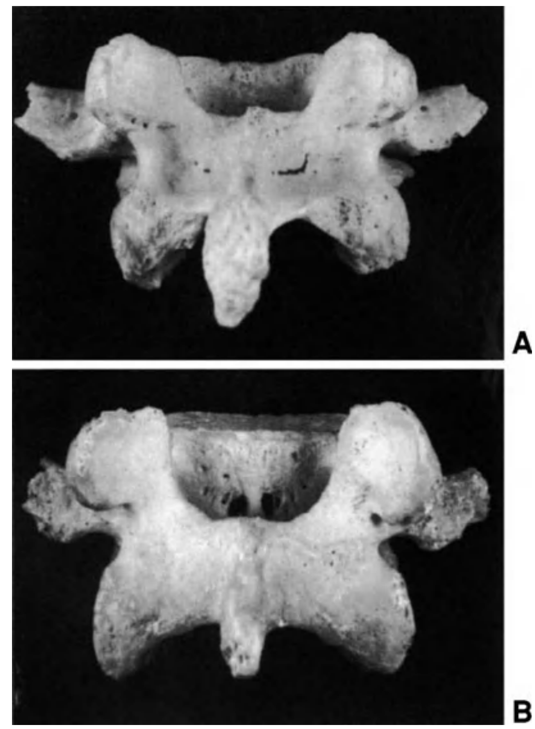


Fig. 2.1. *Different location of the laminae with respect to the vertebral body in two L4 vertebrae.* (A) *The laminae are entirely comprised within the limits of the body.* (B) *The upper border of the laminae is located at the level of the middle portion of the vertebral body. In these cases, the inferior border of the laminar arch is situated caudally to the inferior vertebral end-plate.*

The *laminae* can be contained for their entire height within the limits of the posterior aspect of the vertebral body or their caudal border can extend beyond the inferior vertebral end-plate (Fig. 2.1). In the former instance, the cranial border of the laminae is located in close proximity to the disc above, which is generally situated at the center of the interlaminar space. In the latter, the disc above is located at the level of the proximal portion of the interlaminar space or even of the distal portion of the laminae of the vertebra above. In this event, the disc may be entirely exposed, at surgery, only after removal of the distal half of the proximal lamina.

The sagittal axis of the laminae (from the articular processes to the spinous process) shows a highly variable degree of obliquity with respect to the coronal plane. The mean value of the angle formed by the axis of the laminae of a vertebra is 91° at L3, 99° at L4 and 116° at L5 (129). The laminae of a vertebra may have a different orientation in the presence of articular tropism (Fig. 2.2).

Fig. 2.2. *Asymmetric orientation of the articular processes on the two sides, and different orientation and length of the laminae.*

The vertical axis may lie on the coronal plane or, more often, is directed obliquely downwards and backwards. This holds specifically for the two lower lumbar vertebrae, particularly L5. In these cases, the proximal half of the intervertebral foramen tends to be narrower in the sagittal plane compared with the distal half. On the anterior surface of the laminae, a crest is present, dividing this surface into a cranial smooth portion, in contact with the thecal sac, and a caudal rough portion. The latter portion, which is generally more oblique backwards than the former, gives attachment to the ligamentum flavum.

The *transverse processes* originate from the posterior portion of the pedicles and then run laterally and slightly backwards. Three portions can be identified: the lateral or costiform process, and the mammillary (cranial) and accessory (caudal) tubercles, which are located in close proximity to the articular processes. The lateral process varies in size. Usually the largest, both in height and thickness, is the process of L5, whilst the smallest is that of L3 or L4.

The *spinous process* is large, quadrilateral in shape and directed slightly backwards.

Vertebral foramen

Morphology

The vertebral foramen is the cavity comprised, in the isolated vertebra, between the vertebral body and the posterior arch. The walls of the foramen are formed: anteriorly, by the posterior aspect of the vertebral body; laterally, by the pedicles; and posteriorly, by the articular processes and the partes interarticulares, the laminae, and the base of the spinous process. The vertebral foramen can be roundish, ovoid, triangular or trefoil-shaped. The first two lumbar vertebrae generally have a roundish or ovoid foramen with the major axis lying transversely, whilst the two lower vertebrae usually have a triangular foramen. The shape of the foramen of the third lumbar vertebra is usually somewhat in between the two (Fig. 2.3). The foramen is rarely trefoil-shaped (Fig. 2.4). This occurs usually at L5, rarely at L4, and exceptionally at L3, level (32, 96).

In the triangular and trefoil-shaped foramens, three portions can be identified: the central portion, the lateral corners and the posterior corner.

The central portion corresponds to the roundish area occupied in vivo by the thecal sac. The lateral corners represent the lateral recesses, in which the emerging nerve root runs before entering the intervertebral foramen. The shape of the lateral recesses depends on the degree of prominence of the medial border of the superior articular process and the pars interarticularis into the spinal canal. If these structures do not protrude into the vertebral foramen, the shape of the recesses, like that of the foramen, is approximately triangular, whereas a marked protrusion of these structures into the foramen produces a dome-like configuration of the recesses and a trefoil-shaped vertebral foramen. The posterior corner, or posterior recess, is bounded by the posterior portion of the laminae and the base of the spinous process, and is occupied, in vivo, by a fat pad containing few blood vessels (102).

Dimensions

Eisenstein (30) measured the anteroposterior and transverse dimensions of the vertebral foramen in the lumbar vertebrae of 443 adult skeletons, 113 of Caucasian, and 330 of black South African, subjects. In the Caucasian skeletons, the mean value of the midsagittal diameter of the vertebral foramen, measured in a single point, near the upper border of the posterior arch, was 17 mm, and the limits of normal (mean value ± standard deviation) were 13–21 mm in females and 14–20 mm in males. In South African skeletons, the limits of normal were 12–21 mm in females and 12–20 mm in males. In the whole skeletal population, the mean value of the midsagittal diameter of the vertebral foramen was 16 mm and the lower limit of normal was 13 mm. The lowest mean values were generally found at L3 and L4 and the highest at L1 and L5.

Postacchini et al. (96) examined the lumbar vertebrae of 121 adult skeletons, 63 Italian and 58 Indian. In each vertebra, the midsagittal diameter of the vertebral fora-

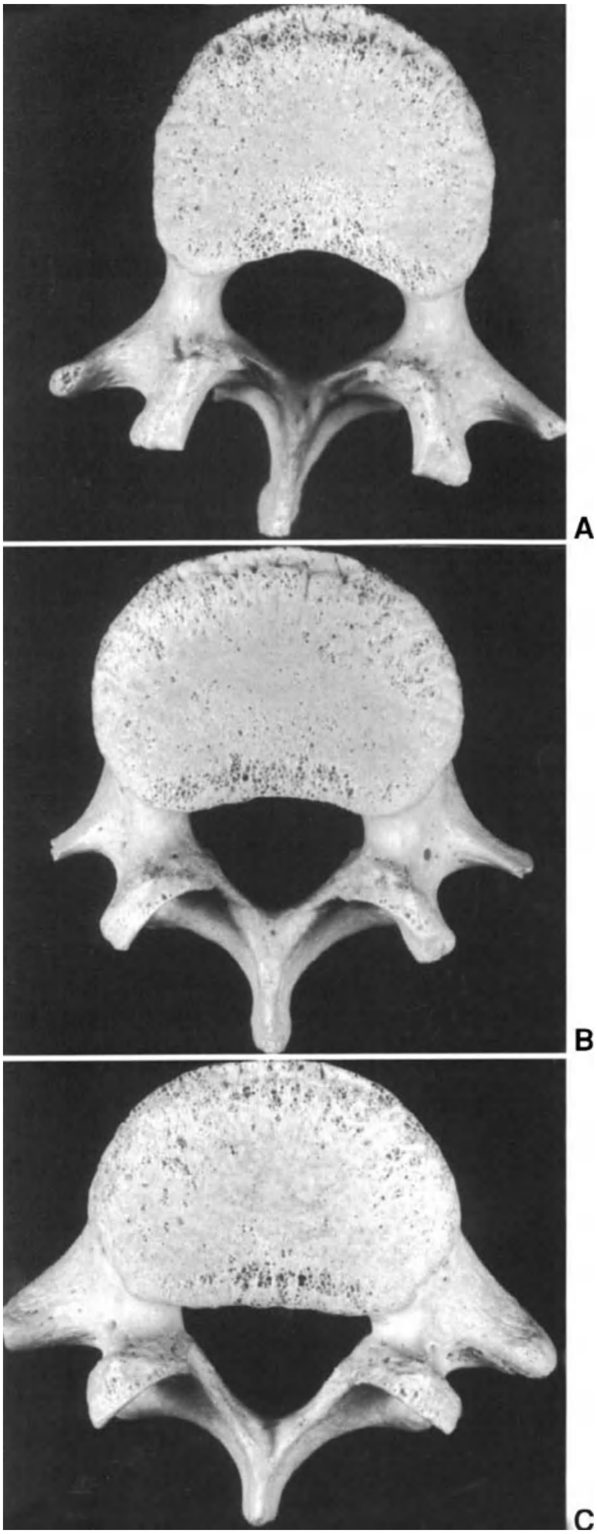


Fig. 2.3. *Morphology of the vertebral foramen at L2* (A), *L4* (B) *and L5* (C) *levels. The shape of the foramen is generally ovoid at L2, tend to be triangular at L4 and is definitely triangular at L5. Note the progressive decrease in length of the pedicles. The lateral recesses of L4 and L5 vertebrae are triangular in shape.*

Fig. 2.4. *L5 vertebra showing a trefoil configuration of the vertebral foramen, due to the prominence of the superior articular processes and the partes interarticulares into the foramen. The dome-shaped lateral corners represent the lateral recesses.*

men was measured cranially and caudally. The cranial diameter was measured between the vertebral body and the cranial border of the posterior arch. The caudal diameter was taken as the shortest distance between the vertebral body and the bony prominence in the anterior aspect of the laminae, where the ligamentum flavum has its proximal insertion.

In both ethnic groups, the highest mean values of the cranial midsagittal diameter of the vertebral foramen were found at L1 and L2 and lowest mean values at L3 and L4. The highest mean value of the caudal midsagittal diameter was at L1 in both skeletal populations, whilst the lowest mean value was at L4 in the Italian, and at L5 in the Indian, skeletons. The mean values of both cranial and caudal midsagittal diameters were significantly higher in the Italian than the Indian skeletons. The lowest limit of normal (mean value minus standard deviation) was 12.5 mm (at L4) in the Italian, and 11.5 mm (at L5) in the Indian, skeletons. All vertebrae with midsagittal dimensions of less than 11 mm were L4 or L5.

The lowest mean values of the interpedicular diameter were found at L1 and the highest at L4 (Italian skeletons) or L5 (Indian skeletons). The mean values of this diameter, as observed for the midasagittal diameters, were significantly greater in the Italian skeletons compared with the Indians at all lumbar levels. The width of the lateral recesses, measured as the sagittal distance between the superior vertebral end-plate (or the vertebral body) and the medial end of the superior articular process, ranged from 5 to 9 mm at L4 and from 4.5 and 8 mm at L5.

The width of the recesses is related, although not strictly, to the sagittal dimensions of the vertebral foramen. It mainly depends on two factors: the width of the pedicles and the shape of the vertebral foramen. A marked shortness of the pedicles and a trefoil configuration of the vertebral foramen, as isolated conditions, have little influence on the width of the lateral recesses. Their association, on the other hand, may cause marked narrowing of the recesses, which may be further narrowed by osteophytes of the superior articular process or the posterior border of the vertebral body.

Sacrum

The sacrum, resulting from the fusion of five vertebrae, is markedly curved and tilted backwards, thus forming a kyphosis, which follows the lumbar lordosis. The lumbosacral transition zone, represented by the fifth lumbar disc and the adjacent portions of the L5 and S1 vertebrae, forms the so-called promontorium or sacrovertebral angle.

On the ventral portion of the superior aspect, or base, the sacrum shows an ovoid surface, with the major axis orientated transversely, representing the upper vertebral end-plate of the S1 vertebral body. Laterally to this surface, there are the lateral masses or alae, that bear the auricular surfaces for articulation with the iliac bones. Medially, the alae are contiguous to the sacral canal and the first sacral foramen, which is directed obliquely downwards and forwards, parallel to the upper aspect of the sacrum. The mean transverse diameter of the sacral alae at the level of the first sacral foramen is 27 mm in males and 29 mm in females; the mean obliquity of the articular surfaces with respect to the horizontal plane is 83° in males and 81° in females (55). The superior articular processes of the first sacral vertebra originate posteromedially to the alae of the sacrum.

The posterior portion of the base of the sacrum shows the proximal, approximately triangular, opening of the sacral canal. The latter, proceeding distally, decreases in size and flattens in the sagittal plane, and then transforms, at S4 and S5 level, into a bony groove corresponding to the sacral hiatus. The posterior portion of the sacral canal is formed, on each side, by an osseous lamina, which is thinner than the lamina of the lumbar vertebrae. The sacral foramens originate from the sacral canal. After a short distance, they divide into an anterior and a posterior foramen, which contain the anterior and posterior branches of the sacral spinal nerves, respectively.

The anterior surface of the sacrum is concave both in the sagittal and horizontal plane. It is segmented by four horizontal osseous ridges, each corresponding to the end-plates of two contiguous vertebrae. Laterally to the ridges, there are the openings of the anterior sacral foramens, which are separated by osseous septa giving attachment to the piriformis muscle. The mean distance between the superior margin of the first sacral foramen and the base of the sacrum is 23 mm (36).

The dorsal aspect is convex both in the sagittal and horizontal plane and shows a markedly rough surface. On the midsagittal line, there is the midsacral crest, which originates from the fusion of the spinous processes of the sacral vertebrae. On each side, laterally to the midsacral crest, there are the posterior sacral foramens, which are smaller than the anterior counterparts. They are situated along the vertical line passing through the superior articular process of the first sacral vertebra. Laterally to the foramens, the prominence of the lateral sacral crest, derived from the original transverse processes of the sacral vertebrae, and the sacral tuberosities give attachment to the dorsal sacroiliac ligaments.

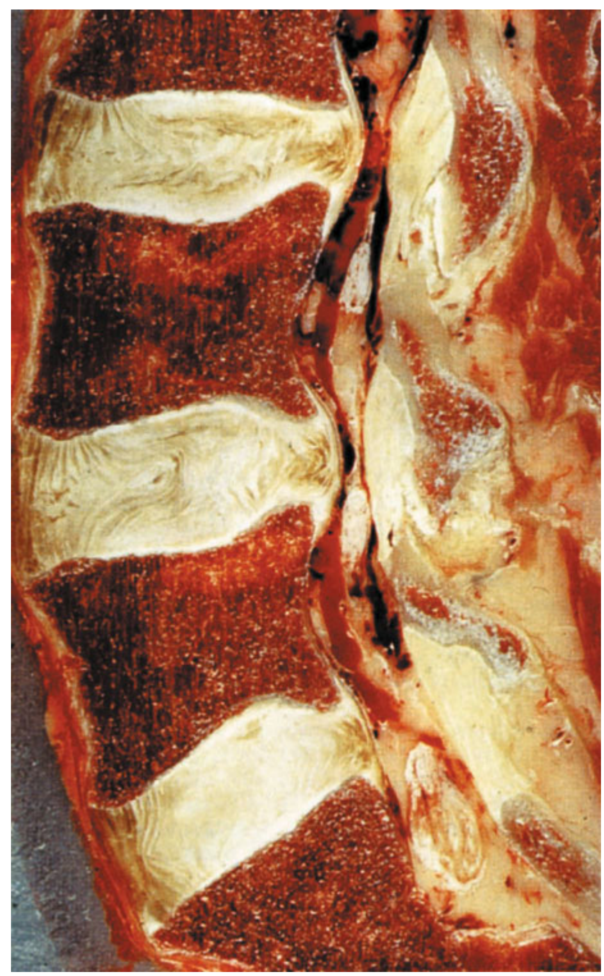


Fig. 2.5. *Paramedian sagittal section of the caudal portion of the lumbar spine. The L4 and L5 vertebrae show a concavity both of the proximal and distal vertebral end-plates. As a result, the L4 disc has the shape of a biconvex lens, whereas the L3 and L5 discs show a pronounced convexity of their caudal and cranial surface, respectively. The posterior aspect of the lumbar vertebral bodies is markedly concave and the L3 and L4 discs show a posterior bulging of the annulus fibrosus.*

Intervertebral disc

Macroscopic morphology

The lumbar discs are the largest on transverse section and the highest of all intervertebral discs. They measure 10–15 mm in height and are higher in the anterior than the posterior portion. This holds particularly for the three lower lumbar discs and, even more, for the fifth. In the lumbar spine, the ratio between the height of the disc and that of the vertebral body is approximately 1 to 3. The lumbar discs, as all intervertebral discs, are shaped like a biconvex lens, fitting the concavity of the end-plates of the adjacent vertebrae (Fig. 2.5). The anterior aspect of the disc is slightly convex, whilst the posterior aspect is flat or slightly concave.

The intervertebral disc consists of the annulus fibrosus and nucleus pulposus. The former is a dense fibrous structure showing a lamellar architecture. On axial section, it is thicker anteriorly than posteriorly. Thus, the nucleus pulposus does not occupy the center of the disc, but it is displaced slightly backwards (Fig. 2.6). The annulus fibrosus shows a lamellar structure with concentric rings in the outer three quarters, whilst it displays an homogeneous texture in the inner part, representing the so-called transition zone (Fig. 2.6). The lamellar zone is thicker in the anterior and lateral portions, than in the posterior portion, of the disc (Fig. 2.6). On sagittal or coronal sections, the outermost lamellae show a uniform outward convexity, whilst the inner lamellae may show a more marked curvature in the equatorial portion of the disc (Fig. 2.7). On the lateral regions of the disc, the annulus fibrosus inserts into the marginal zone of the vertebral end-plate (Fig. 2.7). In the anterior and posterior regions, the outermost annular lamellae extend a few millimeters beyond the vertebral end-plate and insert into the vertebral body, merging with the periosteum and the longitudinal ligaments (Fig. 2.8).

The nucleus pulposus has a gelatinous appearance and, when the disc is sectioned transversely, it protrudes from the plane of section. This is particularly true for young or middle-aged subjects. The intervertebral disc, in fact, undergoes such considerable changes with aging, that analysis of disc morphology, either macroscopic or microscopic, cannot be independent of the age of the subject examined.

Age-related changes

In the early years of life, the annulus fibrosus and nucleus puplosus are sharply distinct and the nucleus occupies more than half of the dimensions of the disc. The nucleus pulposus has a white-lucent color, a turgid appearance and a liquid-gelatinous consistency. It may easily be removed and, in its place, a roundish cavity remains, showing clear-cut limits.

At 20 years, the two components of the disc are still well distinct, although not so sharply as in the early years of life (89). The nucleus pulposus occupies approximately one third of the disc volume. Its appearance is less translucid and its consistency is slightly more solid than at a younger age.

At 30–40 years, the nucleus puplosus is still well distinguishable from the annulus fibrosus, but the bound-

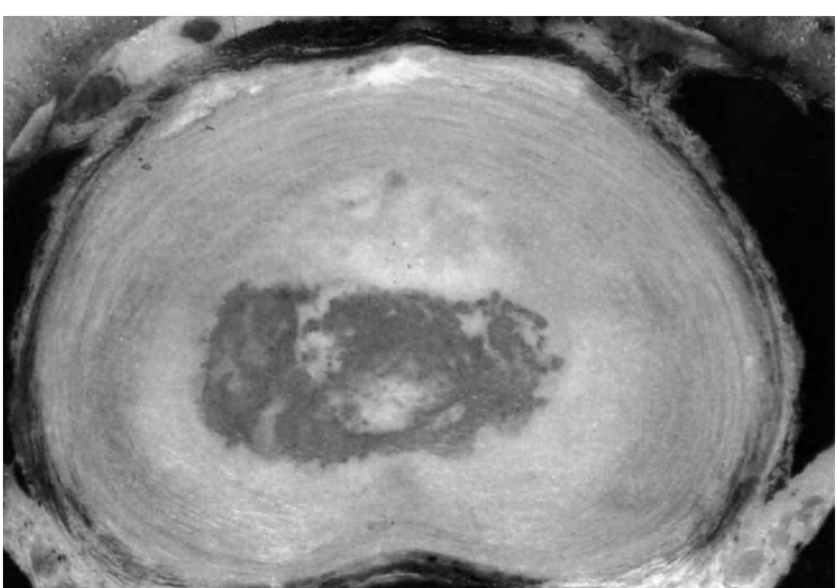


Fig. 2.6. *Lumbar intervertebral disc sectioned transversely in the equatorial plane. The nucleus pulposus, the transition zone and the lamellar zone can be clearly identified. The position of the nucleus pulposus is slightly posterior with respect to the center of the disc. The lamellar zone is thicker in the anterior and lateral portions than in the posterior region. The dorsal border of the disc is slightly concave in the central portion.*

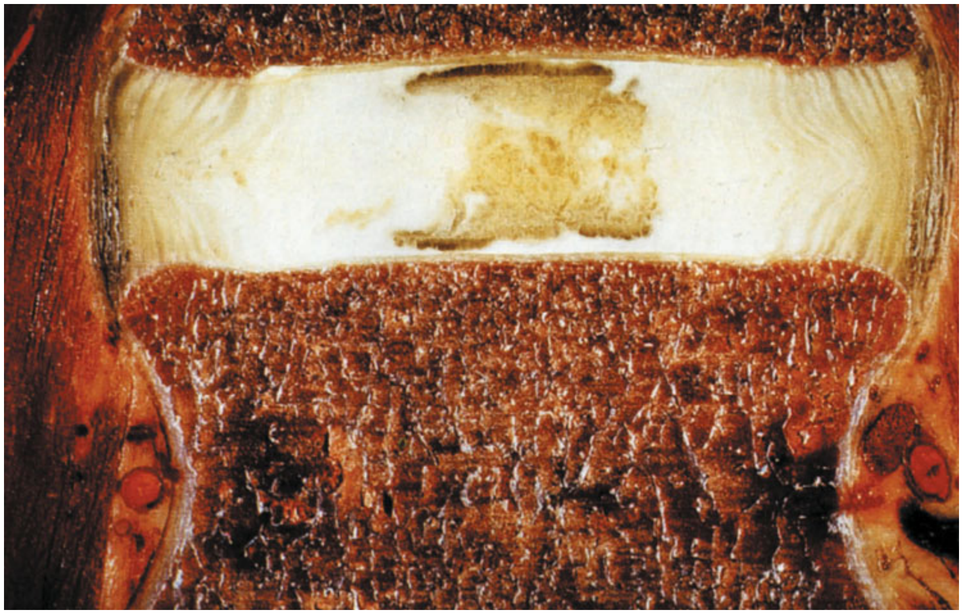


Fig. 2.7. *Coronal section of lumbar intervertebral disc. The transition zone, showing no lamellar structure, is clearly visible. In the lamellar portion, the peripheral layers show an outward convexity, whereas the innermost lamellae display a marked curvature in the equatorial portion of the disc. At the level of the nucleus pulpusus, the transition zone and the innermost part of the lamellar portion of the annulus, the disc is separated from the vertebral body by the cartilage end-plate, lacking in the peripheral portion of the annulus, where the collagen fibers directly insert on the bone surface.*

ary between the two components becomes less and less evident. The annulus fibrosus has a white-ivory color and a distinct lamellar structure. At this age, thin circumferential fissures become apparent between contiguous lamellae (106). The nucleus pulposus is white, but no longer translucid, and is of fibrocartilaginous consistency (89).

At 50–60 years, there is a progressive loss of demarcation between the nucleus pulposus and the annulus fibrosus. The latter slowly acquires a greyish color, whilst the nucleus pulposus is white-opaque in color; occasionally, the disc is brown due to the presence of the so-called semile pigment. The nucleus is of clearly fibrous consistency, and has a turf-like structure, due to the presence of fissures orientated in various directions. If the nucleus pulposus is removed, the residual cavity shows irregular, star-shaped margins (72). The annulus fibrosus has a less distinct lamellar structure than at younger ages; it often shows radial clefts, usually located posterolaterally or posteriorly.

At 70–80 years, the nucleus pulposus is no longer distinguishable from the annulus fibrosus. Numerous clefts are present in both components, particularly in the annulus, where only few lamellae are distinctly identifiable.

This description is a schematization of what occurs in the majority of individuals, in a paradigmatic disc. The changes described above may be more or less marked, depending on various factors, which are analyzed in the description of the degenerative processes of the disc.

Microscopic morphology of the annulus fibrosus

The microscopic morphology of the annulus fibrosus has been investigated in animals and man. In rats, the annulus fibrosus has been studied at various ages at histologic and ultrastructural level (94). In man, it has been investigated sequentially over time only histologically and histochemically.

Rat

Newborn annulus fibrosus. The annulus fibrosus consists of three portions: a thin inner portion, containing ovoid, chondroblast-like cells; a middle portion with roundish or ovoid cells showing long cytoplasmic projections; and an outer portion, containing elongated fibroblast-like cells, which also show cytoplasmic projections (Figs. 2.9 and 2.10). In all three portions, the cells are arranged in concentric rows, corresponding to the interlamellar septa of older animals. In the middle and outer portions, the cells in a row face each other and their cytoplasmic projections cross the lamellae, joining the cells of adjacent rows (Fig. 2.10). The cells in all three portions show an abundant cytoplasm, containing a well developed rough endoplasmic reticulum (Fig. 2.11). The cells are surrounded by a narrow lacunar space containing proteoglycan granules and amorphous or filamentous material.

The lamellae between the cell rows are made up of collagen fibers. In the inner portion, the fibers are ran-

Fig. 2.8. *Lateral sagittal section of the spine at L3-L4 level. Note the attachment of the outermost lamellae of the annulus fibrosus. They run for a short distance behind the vertebral body and insert on the posterior aspect of the latter, where they blend with the fibrous bundles of the periosteum and the posterior longitudinal ligament (thin arrows). In the spinal canal, two nerve roots are visible, together with epidural fat and vessels of the anterointernal plexus (arrowheads). The posterior wall of the canal is delimited by the ligamentum flavum (asterisk) and the lamina. The caudal pole of the posterior joint contains a meniscoid structure (large arrow).*

domly orientated; in the middle and outer portions, the collagen fibers of a lamella are parallel to each other and their orientation differs from that of the fibers in the adjacent lamellae (Fig. 2.12). The collagen fibers are of small diameter (mean, 510 nm). The interfibrillar matrix contains proteoglycan granules similar to those in the pericellular lacunae. The elastic fibers, which are relatively few in number, are in close proximity to the pericellular lacunae (Fig. 2.13). They consists only of bundles of microfibrils (immature elastic fibers) or a peripheral layer of microfibrils and a small central amorphous core (mature elastic fibers).

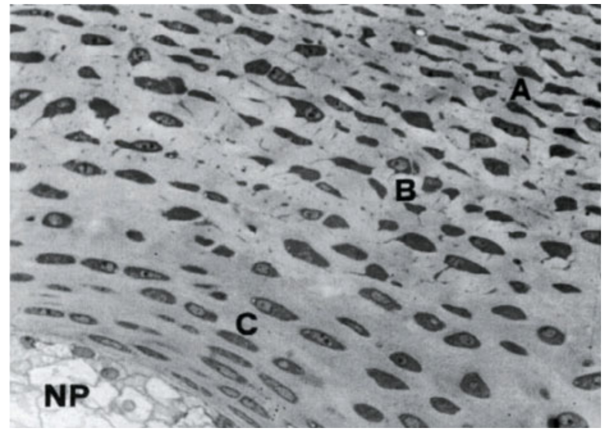


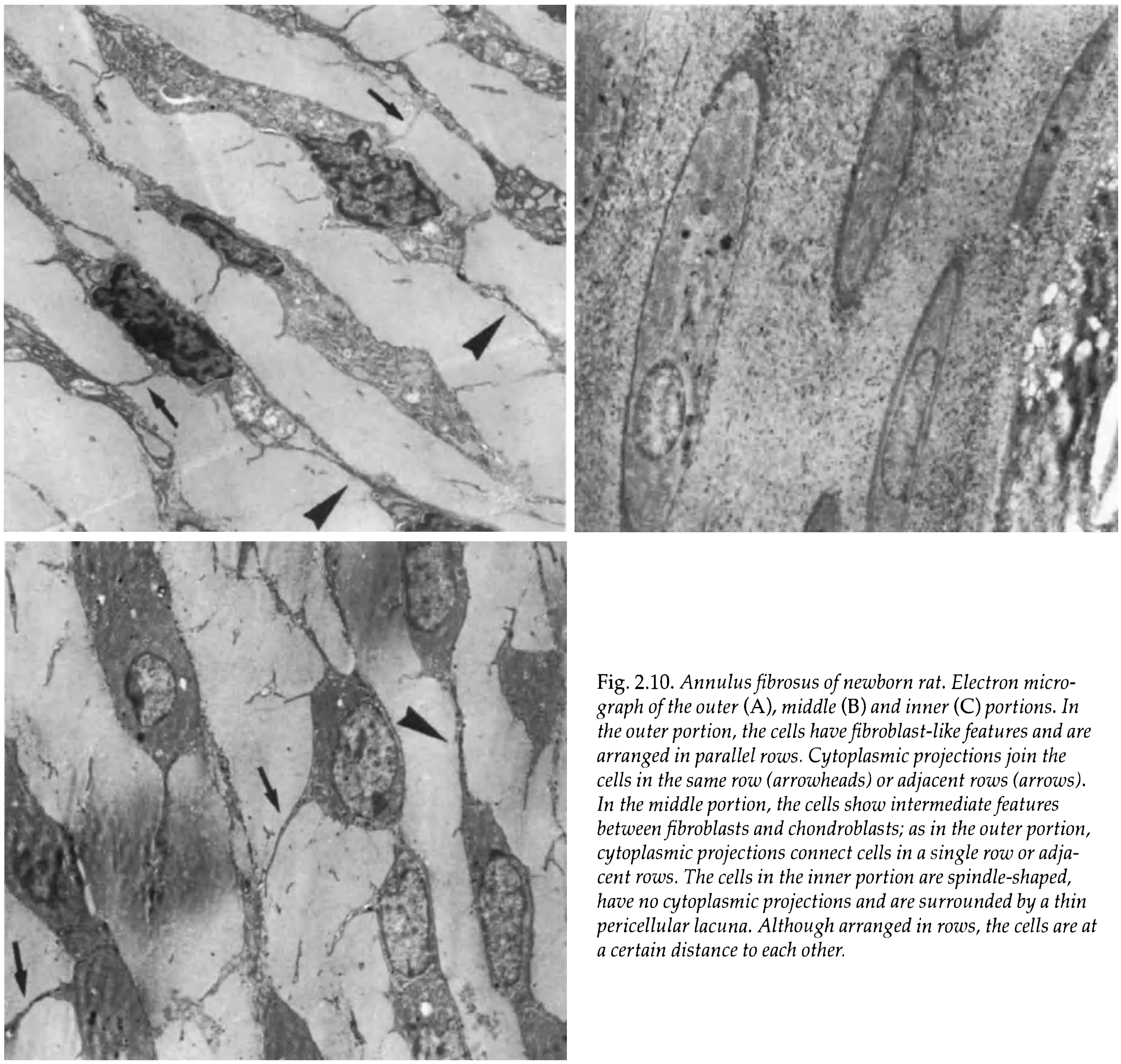
Fig. 2.9. *Light microscopic view of annulus fibrosus of newborn rat. Three portions can be identified: an outer portion* (A) *with elongated fibroblast-like cells, a middle portion* (B) *showing roundish or ovoid cells and an inner portion* (C) *containing ovoid cells, which are adjacent to the nucleus pulposus* (NP).

Young annulus fibrosus. Two portions can be identified: the lamellar zone, forming the outer three quarters, and the transition zone, representing the inner quarter.

The lamellar zone consists of concentric lamellae, and interlamellar septa where the cells are located. In the outer portion, the interlamellar septa are thinner and many cells have fibrocyte-like features (Figs. 2.14 A and 2.15 A). In the middle portion, there is a definite lamellar structure and the cells have similar morphologic characteristics to those of fibrocartilage cells (Figs. 2.14 B and 2.15 B). In the innermost portion, the lamellar architecture is poorly defined and the cells resemble those in the transition zone. The latter is composed of dense fibrillar connective tissue, in which chondrocyte-like cells are scattered (Figs. 2.14 C and 2.15 C).

All types of cells in the lamellar zone are surrounded by a pericellular lacuna containing proteoglycan granules and thin filaments. Outside the pericellular lacunae, the interlamellar septa consist of collagen fibers, mostly thin, numerous proteoglycan granules and small aggregates of electron-dense granular material (Fig. 2.16). Long projections branching off from the septa penetrate the lamellae to reach the adjacent inter-lamellar septa.

The lamellae consist of collagen fibers of varying size and are thicker than in the newborn (mean, 740 nm) (Fig. 2.17). The fibers are surrounded by proteoglycan granules and, occasionally, by small aggregates of electron-dense material. Mature elastic fibers are only occasionally visible in the lamellae in proximity to, or



A B C

Fig. 2.10. *Annulus fibrosus of newborn rat. Electron micrograph of the outer* (A), *middle* (B) *and inner* (C) *portions. In the outer portion, the cells have fibroblast-like features and are arranged in parallel rows. Cytoplasmic projections join the cells in the same row (arrowheads) or adjacent rows (arrows). In the middle portion, the cells show intermediate features between fibroblasts and chondroblasts; as in the outer portion, cytoplasmic projections connect cells in a single row or adjacent rows. The cells in the inner portion are spindle-shaped, have no cytoplasmic projections and are surrounded by a thin pericellular lacuna. Although arranged in rows, the cells are at a certain distance to each other.*

within, the septa. There are no significant morphologic differences between the anterior and the posterior portion of the annulus fibrosus. In the posterior portion, however, the lamellae are thinner and the lamellar structure is less distinct than in the anterior portion.

Old annulus fibrosus. Compared with the young annulus fibrosus, the transition zone is larger and in the rest of the annulus the lamellar structure is less distinct. In the entire annulus fibrosus there are fewer cells per unit of surface. The cell shape is similar to that of the cells in the young annulus, whereas the sizes are slightly smaller. Most cells show a negligible amount of rough endoplasmic reticulum (Fig. 2.18). The pericellular lacunae contain fewer proteoglycan granules compared with the young annulus, whereas the lamellar septa show a larger amount of collagen fibers.

In the lamellae, the collagen fibers are mostly of large diameter (mean, 1340 nm). The proteoglycan granules are less numerous and smaller than in the young (Fig. 2.19). Very few elastic fibers are visible and there are numerous aggregates of electron dense-granular material (Fig. 2.20). The largest aggregates are located in the interlamellar septa and may be as long as 15 μ. In the lamellae and the transition zone, the aggregates often surround one or more collagen fibers, or form a network between them. The aggregates are not digested by hyaluronidase, but disappear after incubation with papain (94). They thus consist of proteins, but not of proteoglycans.

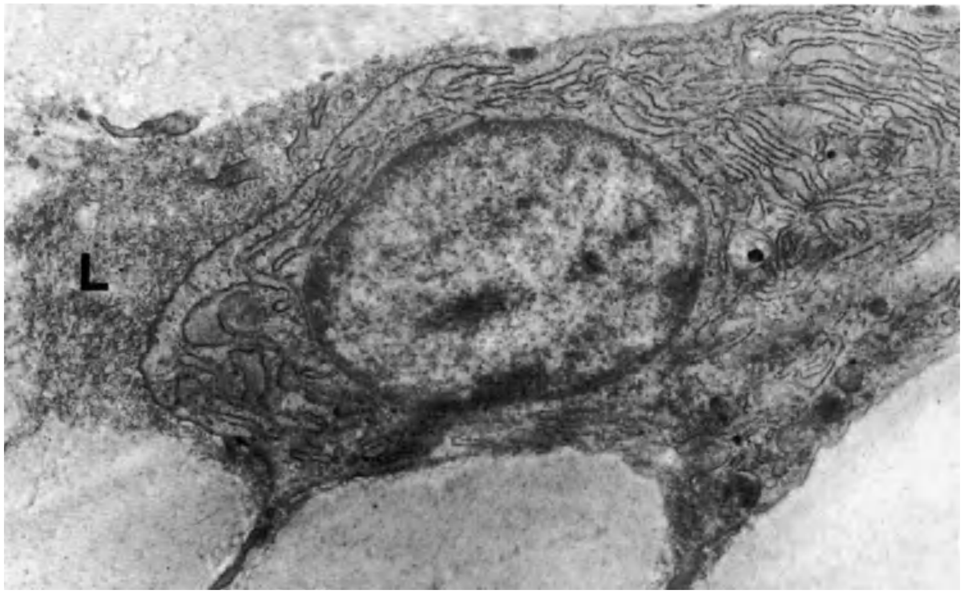


Fig. 2.11. *Annulus fibrosus of newborn rat. A cell of the middle portion showing granular arrangement of the nuclear chromatin and an extremely well developed rough endoplasmic reticulum, filled with secretion material. The cell is surrounded by a pericellular lacuna* (L).

Man

The available studies indicate that the morphologic characteristics of the human annulus fibrosus are very similar to those observed in rat.

Childhood. In the early years of life, the annulus fibrosus shows no lamellar structure at light microscopy (9). However, even at this age a concentric lamellar architecture is present, as indicated by ultrastructural observations in rat (94) and roentgendiffraction studies in man (48).

At this age, the annulus fibrosus appears to consist of closely packed fibrous bundles, separated by thin spaces containing non-fibrillar intercellular matrix. The bundles extend from one vertebra to the next, orientated with their major axis along the longitudinal axis of the spine. In close proximity to the cartilage end-plates, the fibrous bundles bend up and penetrate into the cartilage (72).

Young and middle age. In the young adult, the annulus is made up of fibrous lamellae separated by septa consisting of looser fibrillar connective tissue, which contains the cells. The collagen fibers of a single lamella are closely packed and parallel to each other; they are orientated obliquely with respect to the fibers of the adjacent lamellae. The lamellar structure is clearly evident in the outer half of the annulus fibrosus, whereas in the inner half it becomes less and less distinct, until it disappears completely in the inner one quarter (9), corresponding to the transition zone. In the outermost portion, the cells, as in the rat, show fibrocyte-like morphologic features; in the middle portion, they have fibrocartilaginous characteristics, whereas in the inner portion the cells assume more and more chondrocyte-like features as they approach the nucleus pulposus. The collagen fibers of the inner half of the annulus fibrosus penetrate deeply into the cartilage end-plate, whilst the fibers of the outer lamellae pass through the vertebral end-plate for a short distance (7).

In middle age, spaces and thin clefts, containing an amorphous material, intensely positive to the PAS-reaction, become apparent within the lamellae (7). This material, probably glycoproteic in nature, is likely to correspond to the so-called senile pigment (9) and the electron-dense granular material observed at ultrastructural level in rat in middle and old age (94).

Old age. In early senile age, the spaces and clefts tend to increase progressively in number and size. In proximity to the cartilage end-plate, chondroid areas are visible, in which the cells show typical cartilaginous features.

With increasing age, the annulus fibrosus tends to lose the distinct lamellar structure typical of the young and middle age, and the lamellae contain large spaces and clefts, in which PAS-reaction positive material can be found (7). This material is more abundant in the inner half of the annulus fibrosus. The areas of chondroid tissue increase in number and are visible also at a distance from the cartilage end-plate.

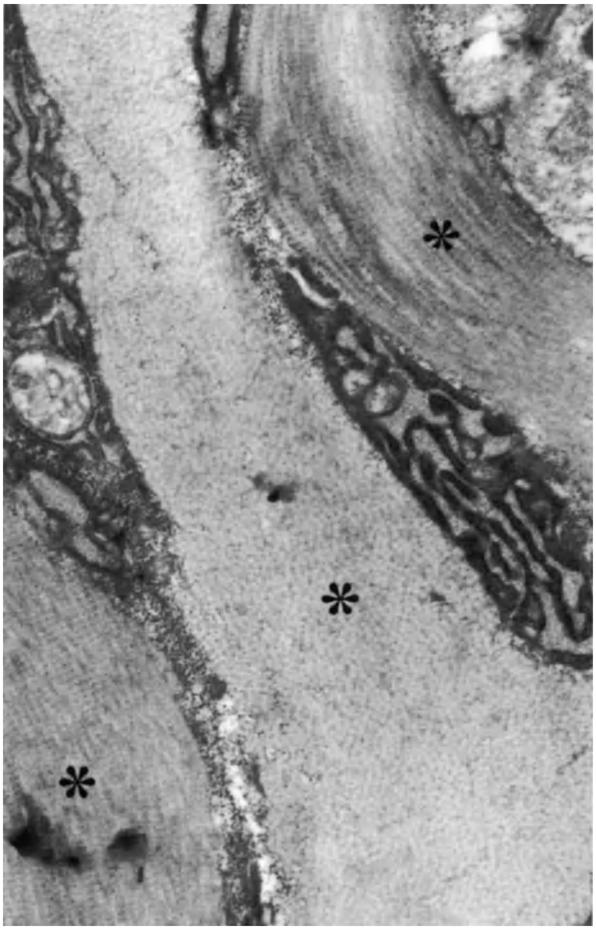


Fig. 2.12. *Annulus fibrosus of newborn rat. Electron micrograph of the middle portion, showing three lamellae (asterisks) separated by cell rows. The collagen fibers of a lamella are orientated parallel and have an oblique direction compared with the fibers of the adjacent lamellae.*

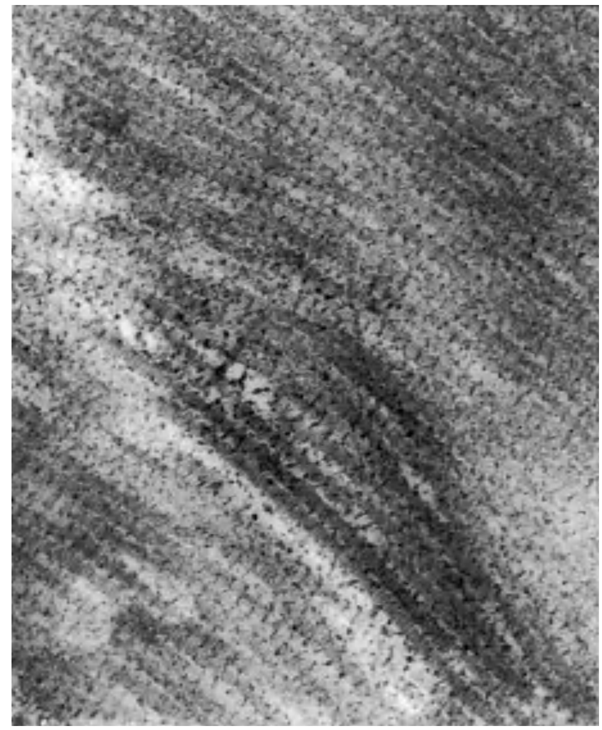


Fig. 2.13. *Annulus fibrosus of newborn rat. High magnification view of a lamella. The interfibrillar matrix contains numerous proteoglycan granules.*

Lamellar architecture

The collagen fibers of a lamella are orientated obliquely to the fibers of the adjacent lamella. In the lamella contiguous to the latter, the fibers have the same direction as the fibers of the first of the three lamellae. This lamellar structure, with fibers showing an alternate direction in successive lamellae, is already present in the fetus. X-ray diffraction studies have shown that, in the human fetus, the angle between the vertical axis of the spine and the direction of the fibers is approximately 65° (48), a comparable value to that obtained, with similar methods, in the annulus fibrosus of adult man (52). However, observations with the stereomicroscope and polarized microscope have demonstrated that the degree of inclination of the fibers is inconstant. It varies depending on the portion (anterior, lateral or posterior) of the annulus fibrosus, within a single portion, and within a single lamella as well (77, 127).

The number of lamellae in the annulus fibrosus in lumbar discs of man ranges from 15 to 25 (77). The number is higher in the lower discs, and in the lateral and anterior portion, compared with the posterior portion, of the annulus. In old age, the number of lamellae decreases by about 20%, compared with the young adult.

The lamellae may be complete or incomplete (interrupted). Two main laminate configurations have been described (77). In one type, three adjacent lamellae become two as a result of the interruption of the middle lamella; in the other type, one lamella splits along its fiber direction to pass on either side of the middle lamella (Fig. 2.21). Approximately half of the lamellae of the annulus fibrosus are incomplete; the lowest rate of incomplete lamellae has been found in the anterior portion (77, 127) and the highest in the posterolateral (77) or posterior (127) portion (Fig. 2.22). The number of incomplete lamellae is higher in the middle, than in the outer, portion of the annulus fibrosus and increases in old age (77, 127).

Thickness of the lamellae increases progressively as they approach the transition zone. In old age, the thickness is more than double (0.44 mm) that in young adults (mean, 0.17 mm) (77). The lamellae are slightly thinner in the posterior, than the anterior, portion.

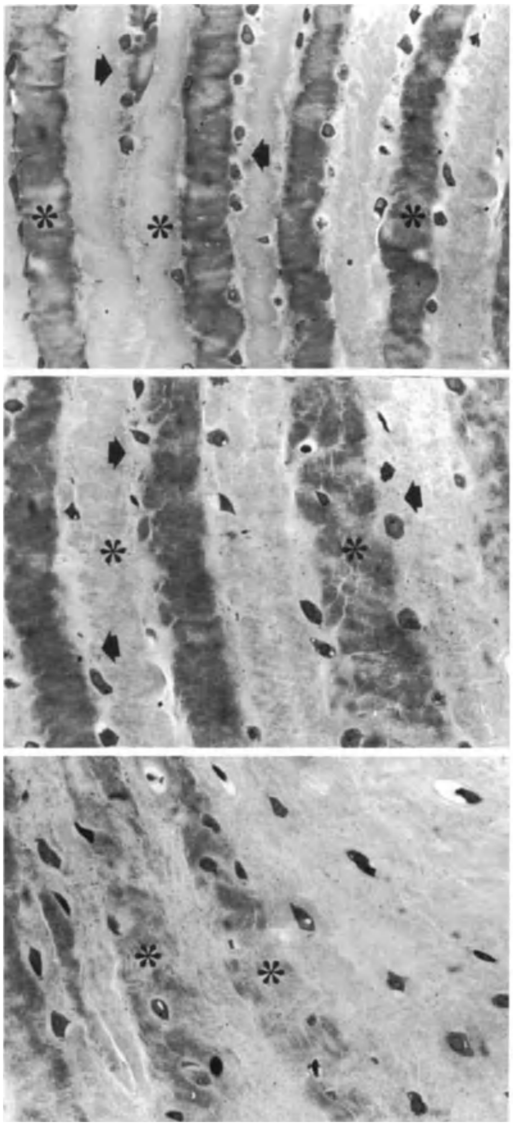


Fig. 2.14. *Annulus fibrosus of young rat. Light microscopic views of the outer* (A) *and middle* (B) *portions of the lamellar zone, and of the transition zone with the nucleus pulposus* (C). *Asterisks: lamellae. Arrows: interlamellar septa.*

In the anterior portion, all lamellae, while running from one vertebra to the next, are curved in regular arcs of circle. In the posterior portion, only the peripheral lamellae are curved in arcs across the vertebrae, whereas the inner lamellae are bent sharply inwards at the end of a nearly flat vertical middle segment, following the horizontal plane of the end-plates (77).

The peripheral lamellae slightly surpass the edge of the vertebral body to end on its faces. The number of lamellae showing this behavior ranges from 4 to 8: the minimum in the posterior, and the maximum in posterolateral, portion (77).

Microscopic morphology of the nucleus pulposus

Newborn

At birth, the nucleus pulposus is made up of notochordal tissue, consisting of syncytial, epithelial-like structures and occasional single cells, surrounded by an abundant, weakly basophilic intercellular matrix. The cells contain numerous large vacuoles located between the perinuclear cytoplasm and the peripheral portion of the cell, as well as large glycogen deposits. The intercellular matrix is made up of amorphous ground substance, proteoglycan granules and few collagen fibers.

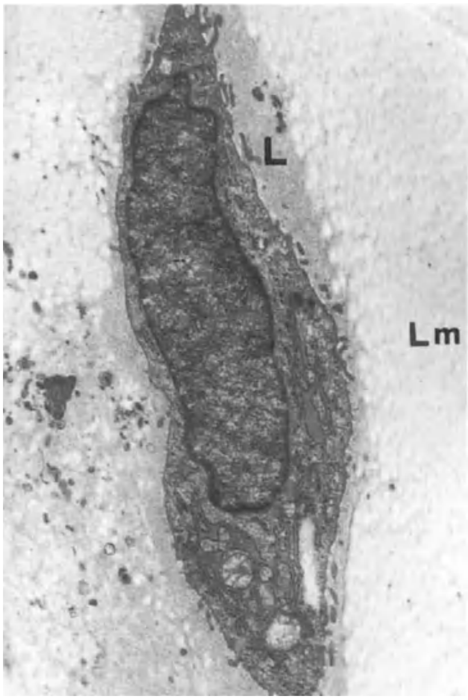
In the early years of life, the notochordal tissue undergoes necrosis and is replaced by cartilage-like tissue. However, also in adulthood, small islands of notochordal tissue may occasionally be observed (79).

Young adult

The nucleus pulposus consists of few cells scattered in an abundant intercellular matrix. Most cells are isolated; a few are arranged in pairs or, less frequently, in clusters containing 3 or 4 elements. Numerous cells are degenerating or necrotic. The viable cells are usually roundish or ovoid, have an often indented nucleus and show short cytoplasmic projections (Fig. 2.23). The rough endoplasmic reticulum is well represented, although never prominent, and the Golgi apparatus is often visible. The cytoplasm contains few mitochondria, lipid droplets, glycogen deposits and vacuoles of varying size. In the cytoplasm of many cells, bundles of filaments measuring about 100 nm in diameter are present, mostly located in the perinuclear cytoplasm. The cells often appear to be surrounded by a pericellular lacuna containing proteoglycan granules, thin filaments and collagen fibrils.

The intercellular matrix is very loose and strongly positive to alcian blue staining. At ultrastructural level, it appears to be largely made up of amorphous ground substance, in which numerous proteoglycan granules, randomly orientated collagen fibrils, and thin collagen fibers are scattered (Fig. 2.24). The collagen fibers are occasionally grouped in small bundles. The fibrillar network is clearly visible following digestion of proteoglycans with papain or hyaluronidase. Matrix vesicles are also visible, particularly in proximity to degenerating cells. These appear as masses of amorphous, or still structured, necrotic material.

At the border with the annulus fibrosus, the cells are often elongated and the pericellular lacuna is more evident, also due to the contrast with the interterritorial matrix. The latter contains a larger amount of collagen



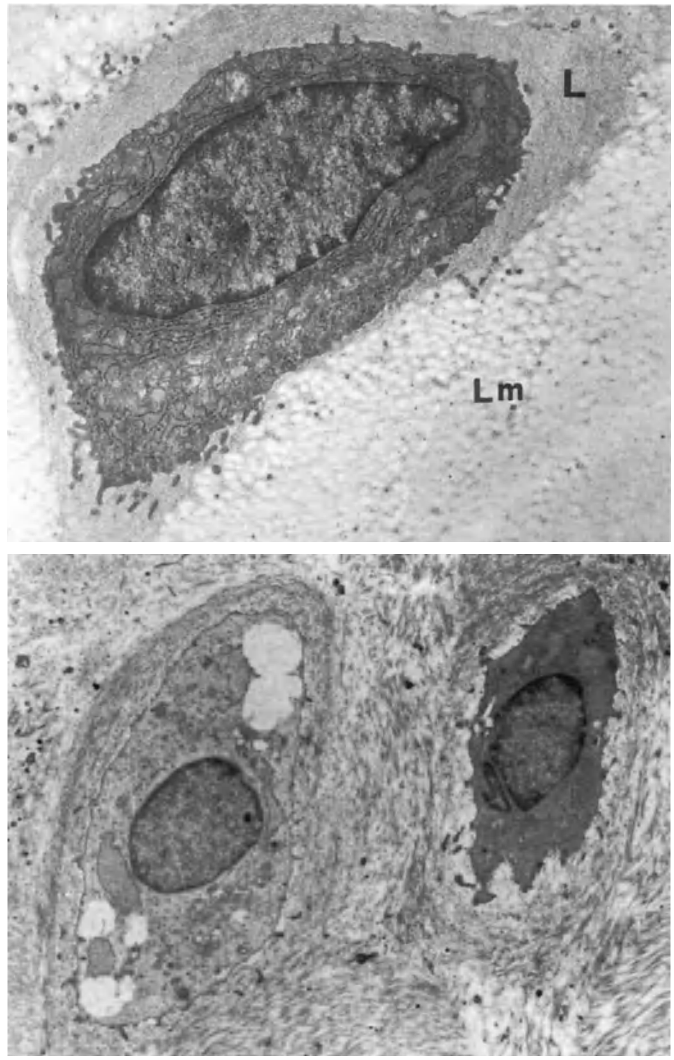


Fig. 2.15. *Annulus fibrosus of young rat.* (A) *A cell in the outer portion of the lamellar zone. The cell, although spindle-shaped as a typical fibroblast, shows short cytoplasmic projections and is surrounded by a pericellular lacuna* (L). (B) *A cell in the middle portion of the lamellar zone showing fibrocartilaginous features. The rough endoplasmic reticulum is well developed and the cytoplasm is surrounded by a large pericellular lacuna* (L). (C) *Transition zone. Two chondrocyte-like cells are visible, lying in a lamellar-like fibrous matrix, which consists of bundles of collagen fibers interwoven with each other. Lm: Fibrous lamella.*

fibers, at times grouped in bundles. The mean thickness of the fibers is greater than in the central portion of the nucleus.

Middle age

The cell morphology shows no significant differences compared with the young age. However, the cells are more often surrounded by a distinct pericellular lacuna or are grouped in small clusters. The interterritorial matrix is looser due to the presence of a denser network of fibrils and collagen fibers. The latter tend to be thicker than in the young adult and are often aggregated in small bundles. Furthermore, the matrix contains small aggregates of electron-dense granular material, which occasionally ensheath single collagen fibers (Fig. 2.25). In the peripheral portion of the nucleus pulposus, the tissue becomes more and more fibrosus as it approaches the annulus fibrosus and many cells show intermediate features between chondrocytes and fibrocytes (Fig. 2.26).

Old age

The viable cells are less numerous than in middle age and the interterritorial matrix contains a large amount of small masses of amorphous material, which is basophilic with the hematoxylin-eosin staining and positive to the PAS reaction. Alcian blue staining of the tissue is markedly weaker than in the young age.

At ultrastructural level, most cells show a small amount of cytoplasm, containing poorly developed organelles (Fig. 2.27). In some cells, a large portion of the cytoplasm is occupied by bundles of filaments. The

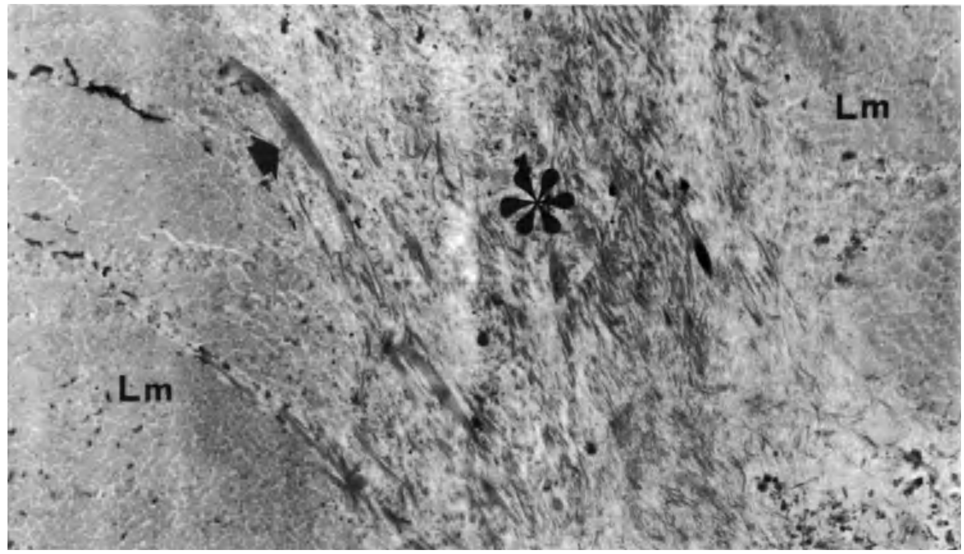


Fig. 2.16. *Annulus fibrosus of young rat. Electron micrograph of an interlamellar septum and the two adjacent lamellae. The septum (asterisk) consists of collagen fibers and fibrils orientated in various directions, elastic fibers (one is indicated by the arrow), proteoglycan granules and few matrix vesicles. In the adjacent lamellae (Lm), the collagen fibers are sectioned transversely (on the left) or obliquely (on the right).*

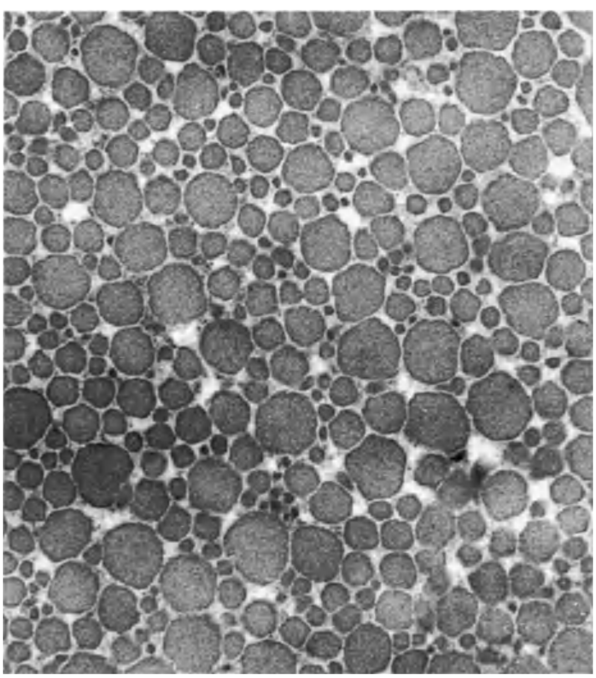


Fig. 2.17. *Annulus fibrosus of young rat. Axial section of collagen fibers of a lamella. The diameters of the fibers are of various dimensions.*

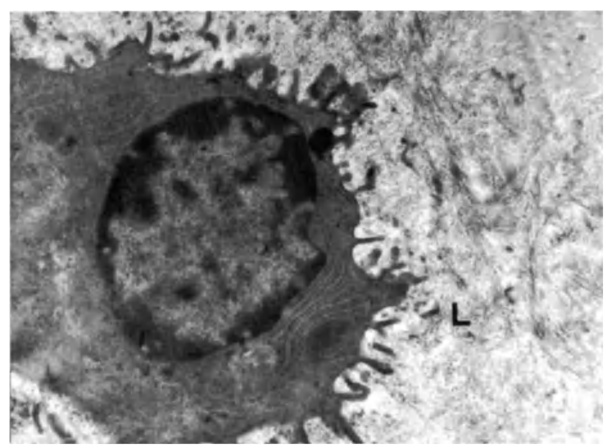


Fig. 2.18. *Annulus fibrosus of old rat. Electron micrograph showing a cell of the lamellar zone in a quiescent functional status. The pericellular lacuna* (L) *is narrow and ill defined, and contains few proteoglycan granules.*

intercellular matrix contains a larger amount of collagen fibers and fewer proteoglycan granules, compared with the middle age. Numerous aggregates of electron-dense granular material, located between the collagen fibers or around them, are also present (16) (Fig. 2.28). This material, similar to that observed in the annulus fibrosus, as well as in the cartilage (81), presumably corresponds to the basophilic and PAS-reaction positive material observed at light microscopy. It probably consists of products of cell degradation.

Cartilage end-plate

The cartilage end-plate has been studied in mouse (49), monkey (38) and man (6). In newborn mouse (49), the

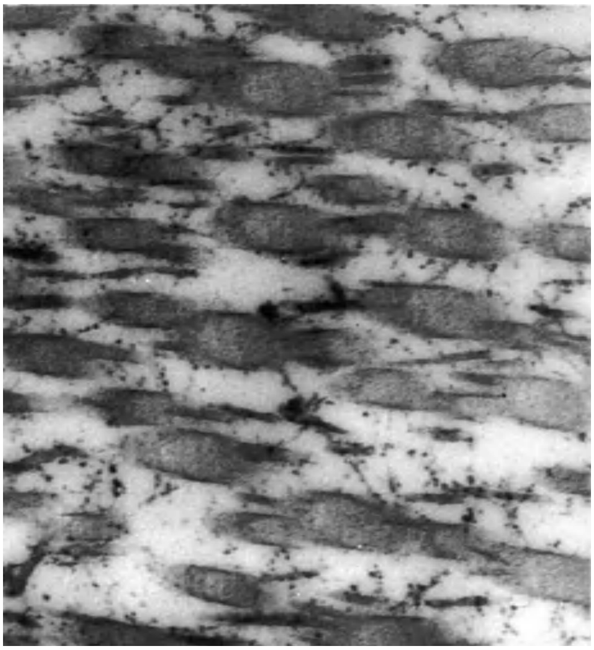


Fig. 2.19. *Annulus fibrosus of old rat. High magnification view of a lamella. Almost all collagen fibers have large diameters and the proteoglycan granules are smaller and fewer than in the young adult.*

end-plate consists of two zones: an outer zone, adjoining the nucleus pulposus, and an inner zone, which is in contact with the vertebral body. The outer zone includes two portions: a superficial portion, adjacent to the disc, and a deep portion. The superficial portion consists of ovoid or spindle-shaped chondrocytes and metachromatic intercellular matrix. The deep portion contains larger chondrocytes randomly distributed throughout the tissue. The inner zone is made up of hypertrophic chondrocytes arranged in columns and, deeply to these, of degenerating chondrocytes surrounded by calcified intercellular matrix and trabecular bone.

After 1 week of life, the deep portion of the superficial zone appears finely calcified. At 2 months, it is invaded by blood vessels and begins to ossify.

At 6 months, the cartilage of the deep portion of the superficial zone is largely replaced by an osseous lamina, separating the outer zone from the inner cartilaginous zone. The latter, with time, becomes progressively thinner, until it is entirely replaced by trabecular bone.

Thus, the morphology and behavior of the complex vertebral body – cartilage end-plate (both in the cranial and caudal portion of the vertebra), is similar to that of a long bone (49). The superficial portion of the outer zone corresponds to the articular cartilage, the calcified and then ossified portion of the outer zone is the equivalent of the epiphyseal ossification center, whereas the inner zone and the vertebral body below correspond, respectively, to the growth plate and the diaphysis of the long bone.

In man (6), the structure and the age-related changes of the cartilage end-plate are similar to those observed in animals. The inner zone, showing the morphologic characteristics of the growth plate, is well developed until the age of 10 years. Subsequently, it becomes thinner and shows a decrease in number of proliferating chondrocytes. Between 17 and 20 years, the deep zone is replaced by trabecular bone. Between 20 and 40 years, the deep portion of the superficial zone becomes calcified and, between 40 and 60 years, it is progressively replaced by bone. These changes, particularly cartilage calcification, might hinder the diffusion of metabolites to the superficial portion of the articular cartilage, with resulting nutritional defect of the cartilage itself and the nucleus pulposus. After 60 years, the cartilage end-plate consists of a thin layer of tissue, represented by the superficial portion of the outer zone. In old age, furthermore, the bone below the articular cartilage shows nutrient canals and medullary spaces, filled with amorphous substance and mostly avascular. The sequence of changes occurring with advancing age is depicted in Fig. 2. 29.

Ligaments

Numerous ligaments are present in the lumbosacral spine. A few play a primary role in vertebral stability and / or pathophysiology of compression of the nervous structures. Others have a secondary role or are not involved in the pathogenesis of lumboradicular syndromes and, therefore, will not be described in detail.

Anterior longitudinal ligament

In the lumbar region, the anterior longitudinal ligament is represented by a fibrous band covering the middle portion of the anterior aspect of the spine. It is formed by three types of bundles. The superficial bundles extend along 4 or 5 vertebrae, the intermediate ones join 2 or 3 vertebrae, and the deep bundles extend from one vertebra to that below. The ligament is intimately attached to the anterior aspect of the vertebral body, until it reaches the vertebral end-plate. At the level of the disc, instead, the ligament is connected to the annulus fibrosus by fairly loose connective tissue. The latter consists of fibrillar connective tissue and little fat, and contains venous vessels and few nerve fibers.

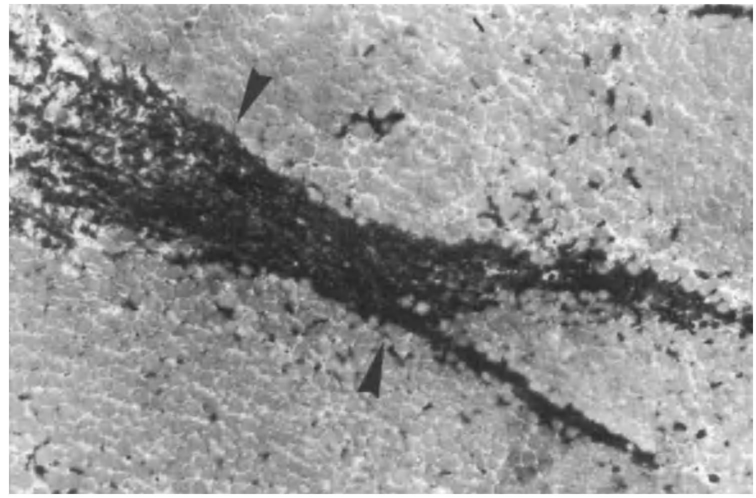


Fig. 2.20. *Annulus fibrosus of old rat. A large aggregate of electron-dense granular material (arrowhead) is visible within a lamella. Numerous small aggregates are also present between the collagen fibers of the lamella.*

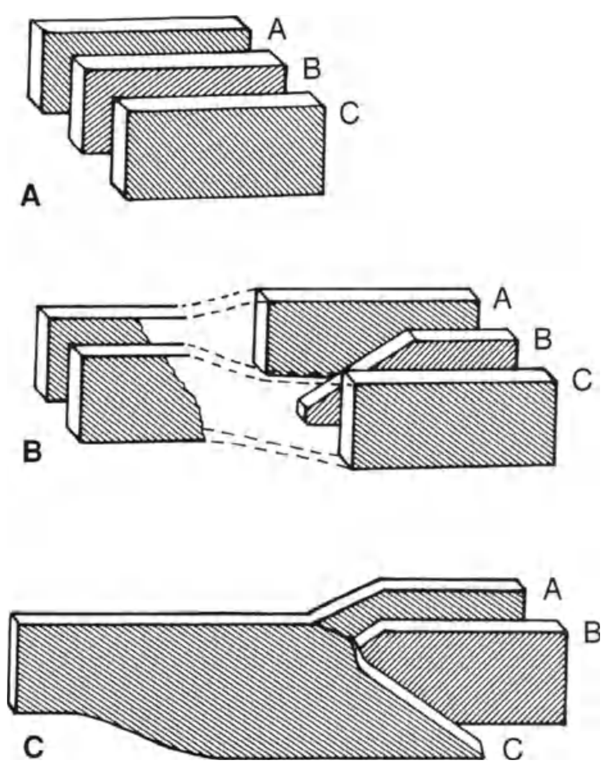


Fig. 2.21. *Various configurations of annular lamellae.* (A) *Three complete lamellae.* (B) *Three lamellae become two, due to the interruption of the middle lamella .* (C) *Three lamellae become only one, since the two lateral lamellae fuse and the middle one interrupts (from Ref. 77).*

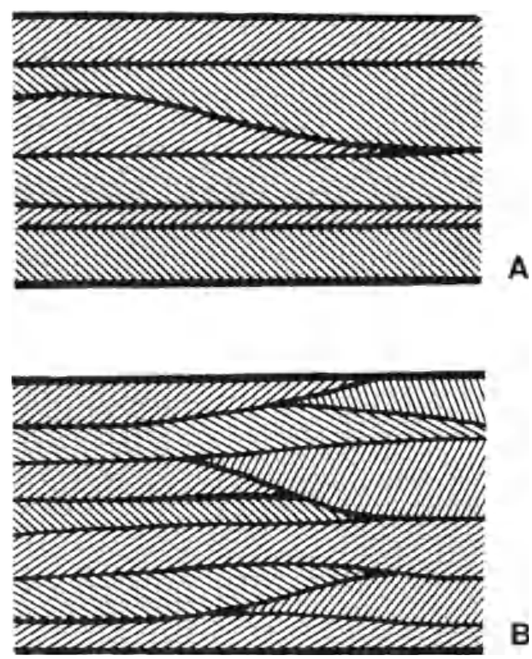


Fig. 2.22. *Schematic drawing of the lamellar structure in the anterior* (A) *and posterior* (B) *annulus fibrosus. The proportion of incomplete lamellae is lower in the anterior portion than in the posterior.*

The anterior longitudinal ligament usually ends at S2 level, where it blends with the periosteum. Occasionally it proceeds further, until the S5 vertebra or the coccyx.

The ligament is made up of bundles of vertically arranged collagen fibers, few elastic fibers, also orientated along the longitudinal axis of the ligament, and cells with the morphologic features of fibroblasts.

Posterior longitudinal ligament

In the lumbar region, the posterior longitudinal ligament consists of a fibrous band, running along the posterior midline, to which two lateral expansions, each triangular in shape with a medial base, are added at the

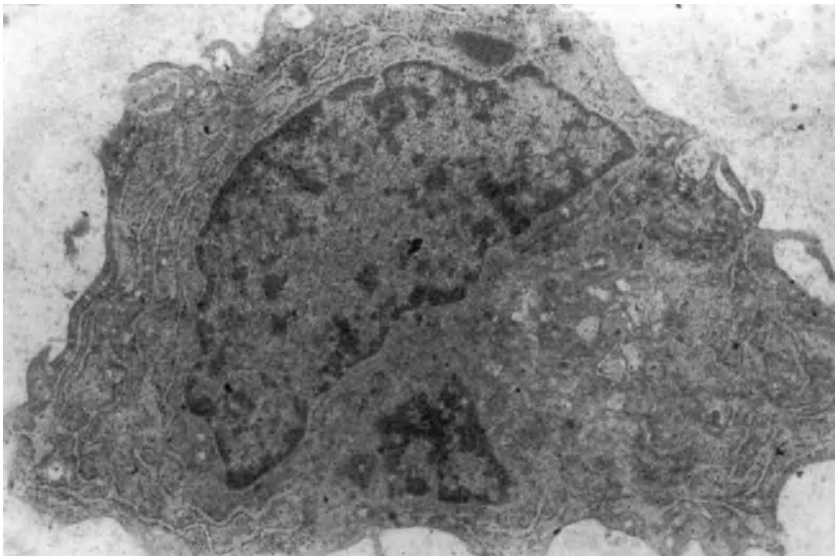


Fig. 2.23. *A cell of the nucleus pulposus in a young adult man. The cell has chondrocyte-like features and shows a fairly well developed rough endoplasmic reticulum.*

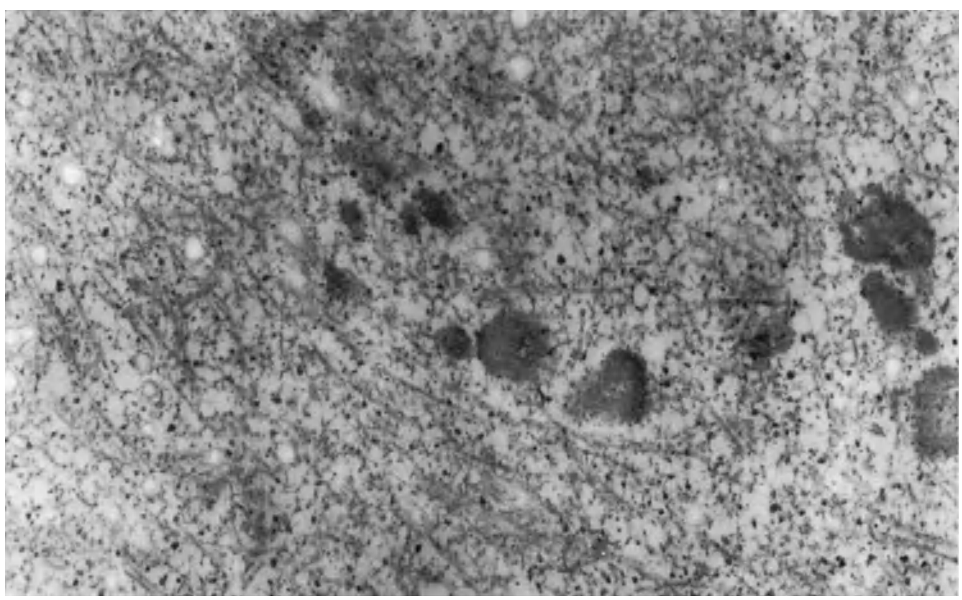


Fig. 2.24. *Intercellular matrix of nucleus pulposus of a young adult man. The matrix contains numerous proteoglycan granules scattered in a network of thin fibrils and collagen fibers, and a few matrix vesicles.*

level of the disc. At intervertebral level, therefore, the ligament displays a characteristic rhomboidal shape. The central portion is firmly attached to the vertebral end-plates, whereas it does not adhere to the posterior aspect of the vertebral bodies. It is bowstrung across the concavity of the vertebral body, thus leaving a thin space occupied by vessels entering the vertebral body or exiting from it (Fig. 2.30). The width of the central portion decreases progressively from L1 (mean, 9 mm) to S1 (mean, 2.8 mm) (83).

In the rhomboidal portion, the central band is more superficial compared with the two lateral expansions, which are located more deeply. This portion is firmly adherent to the disc only at the level of the margins of the rhombus. The central part is very loosely attached to the posterior aspect of the disc, from which it can easily be separated (Fig. 2.31). Also the dimensions of the rhomboidal portion decrease progressively proceeding in the craniocaudal direction. The lowest width decreases from 21 mm at L1-L2 to 11.5 mm at L5-S1; the mean height diminishes from 25 mm to 14 mm (83).

The fibrous bundles of the central portion are prolonged for a few vertebrae, whereas the oblique bundles of the rhomboidal portion extend, at the most,

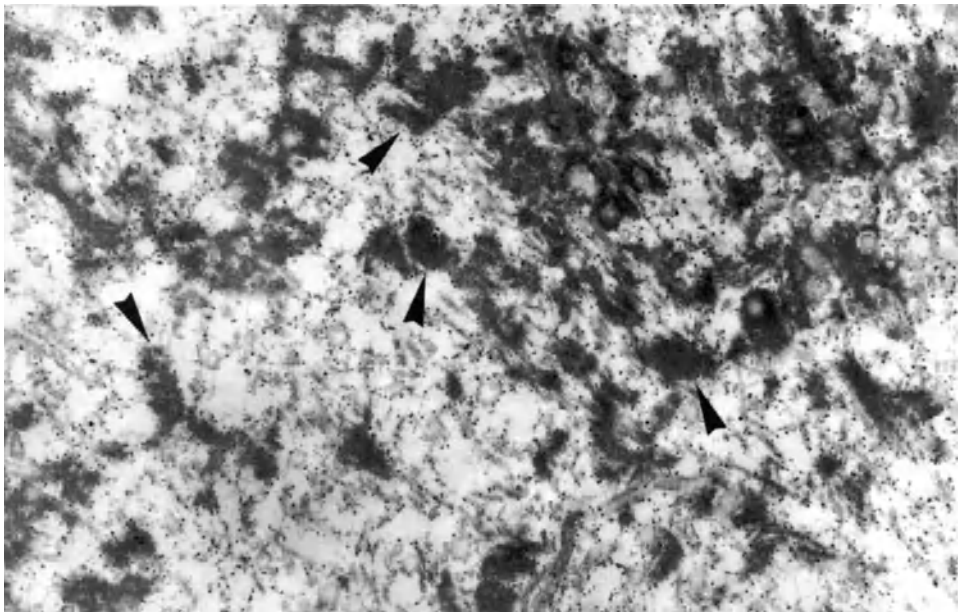


Fig. 2.25. *Electron micrograph of intercellular matrix of nucleus pulposus in a 46-year-old man. The tissue consists of randomly arranged collagen fibers, thin fibrils, proteoglycan granules and numerous aggregates of electron-dense granular material (arrowheads), some of which ensheath single collagen fibers.*

from one disc to that above or below. At histologic level, the posterior longitudinal ligament, like its anterior counterpart, is made up of bundles of collagen fibers, relatively few elastic fibers and typical fibroblasts.

Ligamenta flava

The ligamentum flavum joins two contiguous laminae. It inserts on the proximal border of the distal lamina and on the caudal margin, and caudal half of the deep surface, of the proximal lamina. This type of attachment transforms the deep aspect of the posterior wall of the spinal canal into a uniformly smooth surface. On the posterior midline, the ligaments of the two sides join and blend with the interspinous ligament. Laterally, on both sides, the ligamentum flavum is prolonged ventrally to the capsule of the posterior joint, forming the posterior wall of the intervertebral foramen. Then it proceeds backwards, leaves the intervertebral foramen and blends with the capsule of the posterior joint (99). The dorsal surface of the ligament is separated from the muscle layer by a thin stratum of fat tissue.

Several investigators (46, 92, 142) have measured the dimensions of the ligamenta flava, but have provided even very different data. This is probably due to the fact that the dimensions of the ligament depend on several factors, such as subject's age, presence of vertebral degenerative changes and original size of the spinal canal. The ligamentum flavum is approximately 1.5–2 cm in height and 1–2.5 cm in width. Thickness is 2–6 mm; it reaches the highest values at L4–L5 and the lowest at L5–S1. The thickness of the ligament increases during extension of the trunk and decreases during flexion. Tajima and Kawano (116) found, at L4–L5 level, extreme values of 3.3 mm upon flexion and 4.3–5.9 mm upon extension.

Microscopic features

The superficial portion of the ligamentum flavum is composed of fibrous connective tissue and few elastic fibers. The rest of the ligament consists of numerous, large elastic fibers, which give the ligament the typical yellow color, and thin bundles of collagen fibers (95, 111, 136) (Figs. 2.32 and 2.33). The elastic fibers, 1.1–6.5 μ in thickness, are orientated parallel to the longitudinal axis of the ligament. The cells, which are very few in number, have fibroblast-like features and show little cytoplasm and few, long cytoplasmic projections (Fig. 2.34).

In proximity to the bone attachment, the ligamentous tissue shows fibrocartilaginous features: chondroblast-like cells, and fewer and thinner elastic fibers than in the central portion of the ligament (Fig. 2.35).

In old age (95), the cells decrease in number and show poorly developed cytoplasmic organelles. In a few areas the elastic fibers are less numerous and thinner, whereas the collagen component is more abundant (Fig. 2.36). Chondroblast-like cells are occasionally visible. The fibrocartilaginous zone near the bone attachment slightly increases in thickness. These changes decrease the elasticity of the ligament, which may protrude into the spinal canal on extension of the trunk (95).

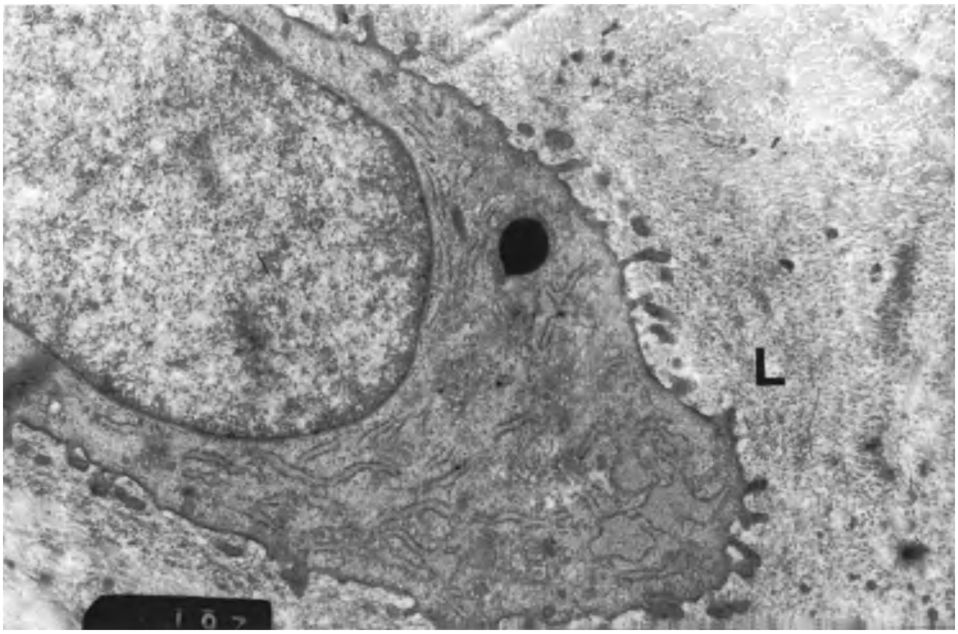


Fig. 2.26. *Peripheral portion of nucleus pulposus near the annulus fibrosus of a middle-aged woman. A cell, showing fibrocartilaginous features and a well developed rough endoplasmic reticulum is visible. A pericellular lacuna* (L) *ensheaths the cell body.*

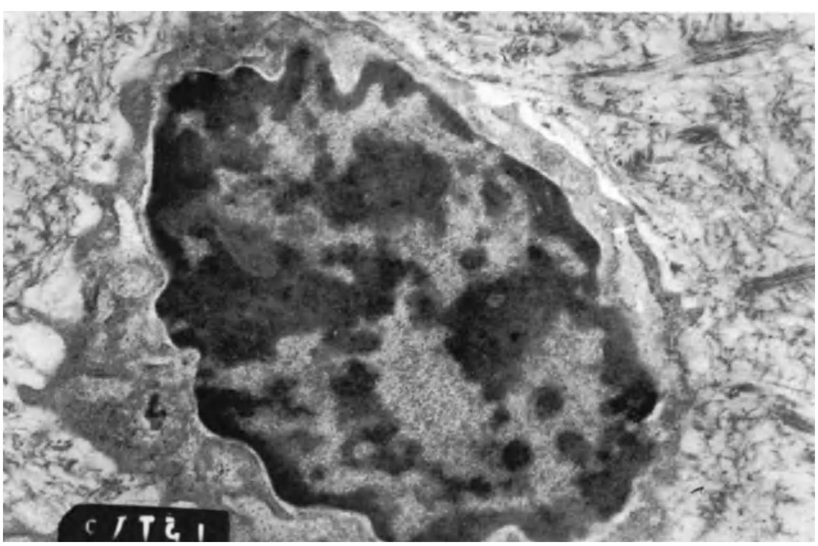


Fig. 2.27. *Nucleus pulposus of a 67-year-old man. Micrograph showing a cell with a very small amount of cytoplasm and poorly developed cytoplasmic organelles. The cell is surrounded by loose fibrillar matrix.*

Supraspinous and interspinous ligaments

The *supraspinous ligament* is a thick fibrous band, which usually reaches the spinous process of L4 or more rarely that of L3 or L5 (105). Distally to its end, it continues with the tendineous rafe of the longissimus dorsi muscle. The ligament consists of three layers. The superficial stratum, showing a variable thickness, is made up of fibrous bundles joining 3 or 4 spinous processes, to each of which they are attached. The middle, usually thin, layer joins 2 or 3 spinous processes. The deep layer, which is the thickest one, joins the tip of two contiguous spinous processes; it is reinforced, to a varying extent, by the tendons of the multifidus muscle.

In the first 2 decades of life, the ligament is entirely composed of tendon-like tissue. Subsequently, the middle and deep layers undergo fibrocartilaginous metaplasia, until the tissue, after the fourth decade of life, becomes entirely made up of fibrocartilage (105). The latter shows areas of calcification and ossification of varying size, particularly at the tip and the margins

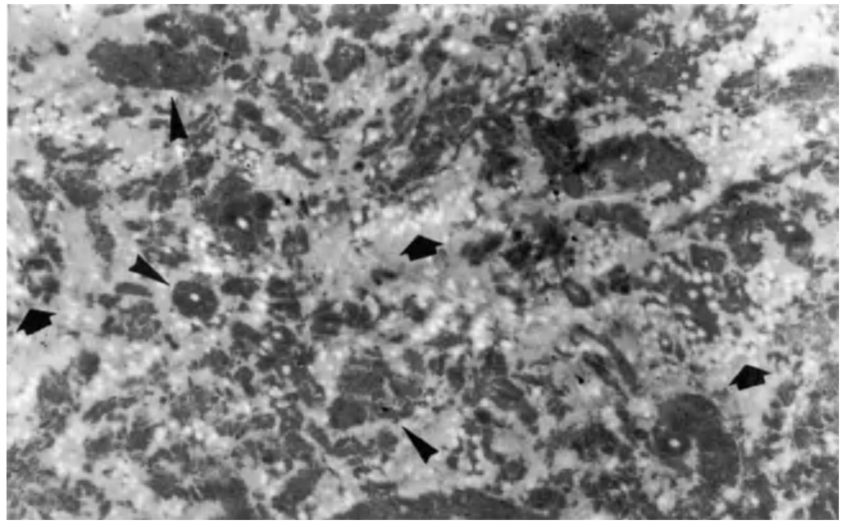


Fig. 2.28. *Nucleus pulposus of an elderly subject. Electron microscope photograph. The tissue contains numerous bundles of collagen fibers arranged in various directions (arrows) and isolated collagen fibers, amorphous material and numerous aggregates of electron-dense granular material (arrowheads).*

of the spinous process. The elastic fibers are few and thin, like in tendons.

The *interspinous ligament* is formed by fibrous bundles running in a posterocranial direction (47, 105). It includes three portions. The ventral portion, consisting of two halves, right and left, represents a posterior expansion of the ligamenta flava. The middle portion, which is the largest component of the ligament, inserts caudally, on the ventral half of the proximal border of the caudal spinous processs and, cranially, on the dorsal half of the distal border of the cranial spinous process. The bundles of the dorsal portion insert on the dorsal half of the proximal margin of the caudal spinous process and, running posterocranially, mingle with the bundles of the supraspinous ligament. The middle portion contains a median cleft, usually occupied by fat (47). The cleft is wider in the last two interspinous ligaments and, with increasing age, may become a cavity a few millimeters wide. In the middle portion, wide spaces may occasionally be visible, which have been interpreted as old ruptures of the ligament (105). However, they are likely to be cavities which have become particularly wide as a result of degenerative changes of the fibrous connective tissue.

The interspinous ligament is essentially made up of bundles of collagen fibers. In the ventral portion, there is a fairly large amount of elastic fibers. In the other portions, the elastic fibers are few and thin.

Meningovertebral ligaments

These ligaments, first described by Trolard (126) and Hofmann (51), are fibrous bands joining the dural sac to

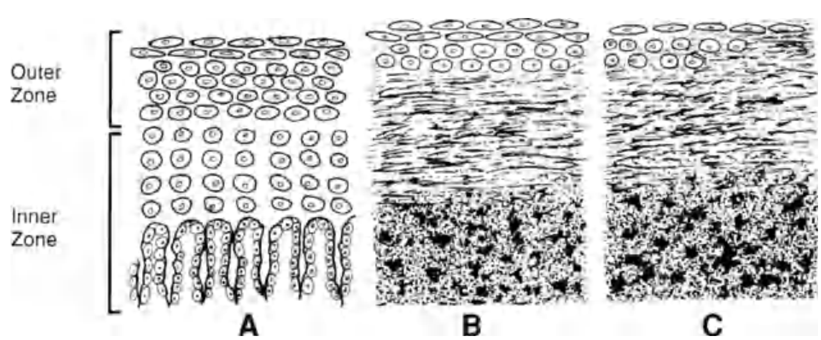


Fig. 2.29. *Morphology of human cartilage end-plate at various ages.* (A) *First years of life. The outer zone, adjacent to the disc, is composed of a superficial portion containing irregularly arranged chondrocytes and a deep portion made up of ovoid or spindle-shaped chondrocytes. The inner zone consists of a portion showing chondrocytes arranged in columns and a portion with degenerated chondrocytes surrounded by calcified matrix.* (B) *20–40 years. The deep portion of the outer zone becomes calcified and is progressively replaced by a bony lamina; the inner zone is substituted by trabecular bone.* (C) *40–60 years. The remaining cartilaginous portion of the outer zone is replaced, to a large extent, by bone tissue.*

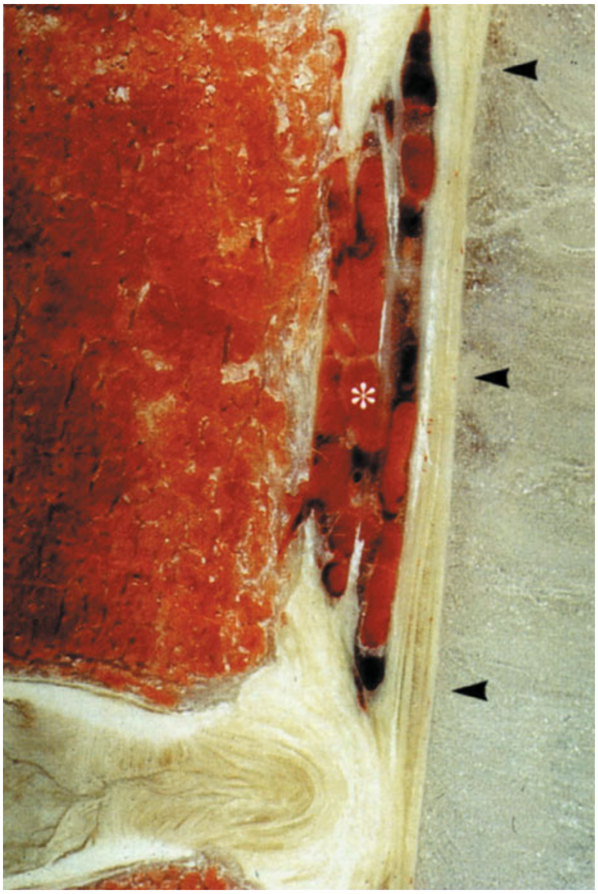


Fig. 2.30. *Midsagittal section of a cadaver spine at the level of L4 vertebra. The posterior longitudinal ligament (arrowheads) is adherent to the adjacent discs, but not to the vertebral body. Between the latter and the ligament, an empty space occupied by vessels of the anterointernal venous plexus (asterisk) is visible.*

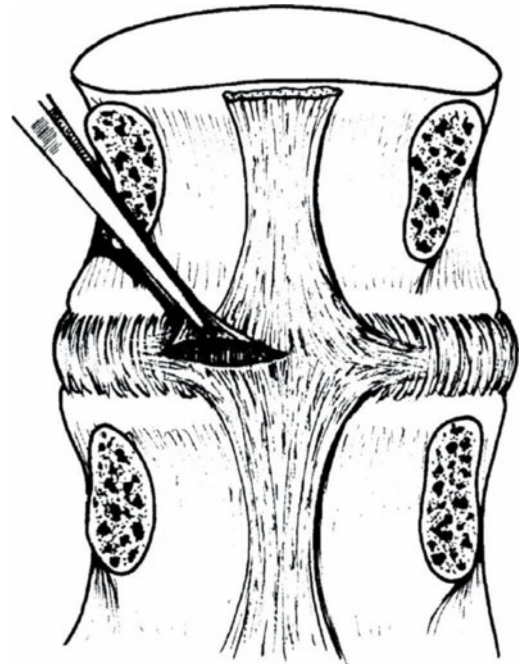


Fig. 2.31. *Schematic drawing of the posterior longitudinal ligament. The rhomboidal portion of the ligament is firmly adherent to the annulus fibrosus only at the level of the borders of the rhombus. The central portion, instead, is loosely attached to the disc.*

the walls of the vertebral canal. The meningovertebral ligaments, particularly well developed in the cervical and lumbosacral regions, include anterior, lateral and posterior ligaments. In the lumbosacral spine, however, only the anterior and lateral ligaments are present. In the lumbar spine, the anterior ligaments, as seen on a transverse section, consist of fibrous septa located in the middle or paramedian plane, single or double, directed from the dura mater to the posterior longitudinal ligament, at the level both of the disc and the vertebral body (101). Their transverse dimensions are 1–1.5 mm, whilst the sagittal dimensions are 3–6 mm (107). When seen on sagittal sections of the spine, they appear as 1 or 2 discontinuous membranes, the fibrous bundles of which are often directed in part caudally and in part cranially. The lateral ligaments are represented by 1 or 2 fibrous discontinuous laminae, thinner than the anterior counterpart, joining the lateral aspect of the dura

Fig. 2.32. *Light microscopic view of lumbar ligamentum flavum of a 43-year-old man. Numerous elastic fibers (arrowheads), separated by fibrous connective tissue, are visible.*

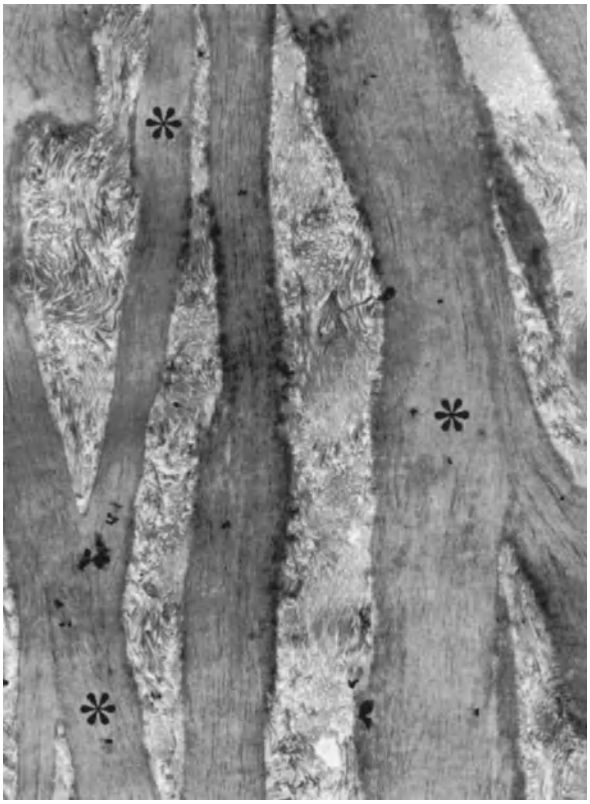


Fig. 2.33. *Electron micrograph of ligamentum flavum of a 36-year-old man, showing elastic fibers (asterisks) separated by thin bundles of collagen fibers.*

mater to the periosteum of the pedicles and the fibrous capsule of the posterior joints (107).

In the sacral canal, these ligaments become more numerous and thicker, and form large fenestrated membranes joining the anterior and posterolateral aspect of the dural cone to the periosteum of the sacrum (Trolard's sacrodural ligament).

The functional role of the meningovertebral ligaments is to anchor the dural sac to the walls of the vertebral canal in order to limit the movements of the sac. Their most important development in the sacrum is related to the greater possibilities of movement that the terminal, thinned portion of the thecal sac could have in the spinal canal.

Iliolumbar ligament

The iliolumbar ligament consists of two distinct bands, one anterior and the other posterior. The anterior band has a transverse direction and inserts on the anterior margin of the iliac crest. The posterior band runs posterolaterally to insert on the posterior margin of the iliac crest. In a few subjects there is also a thinner band, originating from the tip of the transverse process of L4. The iliolumbar ligament is not present at birth. It appears between the second and fourth decade of life as a result of metaplasia of the quadratus lumborum muscle (74). It is likely that the development of this ligament is related to the erect posture of human beings and that it plays an important role in mantaining the stability of the lumbosacral junction.

Lumbosacral ligament

This ligament originates from the transverse process and often also, or only, from the vertebral body of L5 and inserts distally on the anterior surface of the sacrum. It forms, with the L5 vertebra and the sacral ala, an osteofibrous canal, in which the L5 spinal nerve runs before joining the lumbosacral plexus.

Corporotransverse ligament

It is inserted, on the one side, to the base of the transverse process and, on the other side, to the body of the same vertebra and the underlying disc. This ligament divides the exit of the intervertebral foramen into two portions. The radicular nerve leaves the neuroforamen below the corporotransverse ligament, whilst the grey communicans ramus enters the foramen above the ligament (124). It is found almost consistently at L5-S1 level, frequently at L4-L5 and rarely at the levels above.

Suspensory ligaments of the spinal nerves

These ligaments are thin fibrous bands, joining the spinal nerve to the vertebral body above. The number of these ligaments ranges from 1 to 3 for each spinal nerve, however they have not been found at all lumbar levels (124).

Vertebral canal

The vertebral canal results from the sequence of the single vertebral foramens and the interposed non-osseous structures, such as the intervertebral discs and ligamenta flava. In normal conditions, the shape of the spinal canal repeats that of the vertebral foramens or shows a slight narrowing at intervertebral level when the intervertebral disc and/or the ligamentum flavum bulge into the canal.

Three portions can be identified in the spinal canal: pedicular, subpedicular and intervertebral (93). In the

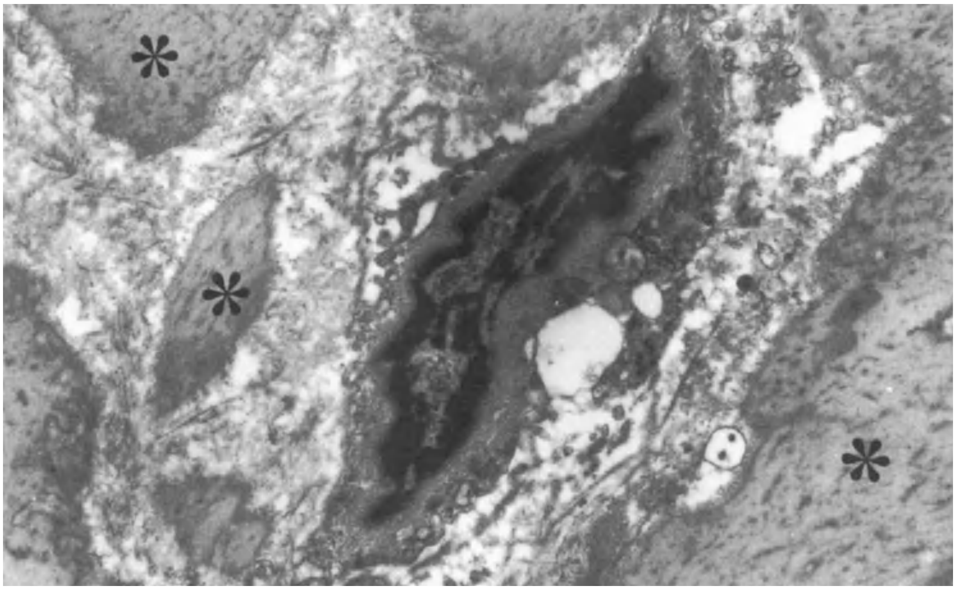


Fig. 2.34. *Lumbar ligamentum flavum. A cell, showing the morphologic characteristics of a fibrocyte, is visible. The cell contains a small amount of cytoplasm, mostly occupied by bundles of filaments, and is surrounded by large elastic fibers sectioned transversely (asterisks).*

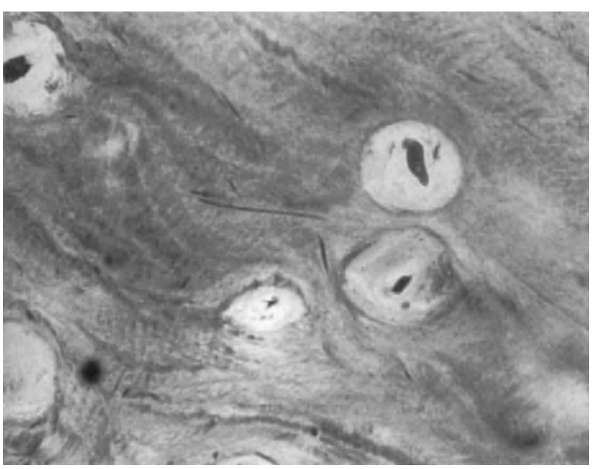


Fig. 2.35. *Light microscopic view of lumbar ligamentum flavum near the laminar attachment. The cells have chondrocyte-like features and few, thin elastic fibers are present in the tissue.*

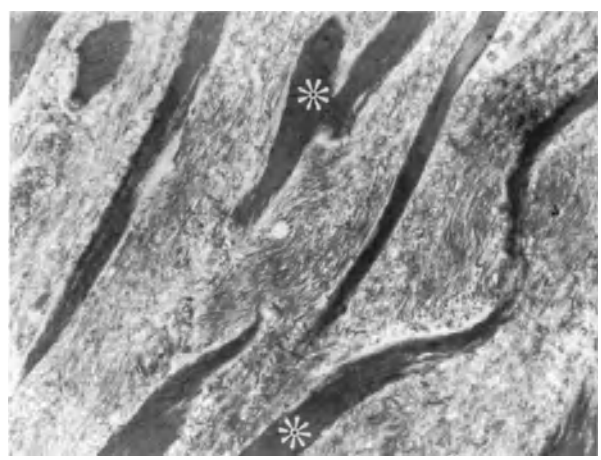


Fig. 2.36. *Electron micrograph of lumbar ligamentum flavum of a 68-year-old man. The elastic fibers (asterisks) are fewer and thinner than in younger age.*

pedicular portion, the canal is entirely bounded by bony structures: anteriorly by the vertebral body, laterally by the pedicles, and posteriorly by the superior articular processes or the partes interarticulares, the laminae and the base of the spinous process. In the subpedicular portion, the vertebral body is separated from the posterior arch by the intervertebral foramen, the sagittal diameter of which reaches the highest values in proximity to the inferior vertebral end-plate. The posterior wall of the canal is formed by the articular processes, the laminae and the base of the spinous process, all covered by the ligamenta flava. In the intervertebral portion, the posterolateral walls of the canal are formed by the articular processes. Posteriorly, depending on the level examined, the spinal canal is delimited by the laminae or the spinous process covered by the ligamenta flava or only by the latter. When seen on a transverse section, the spinal canal can be divided into three portions: the central portion, or central spinal canal; the lateral portion, so-called lateral spinal canal or nerve-root canal; and the posterior portion. The former corresponds to the portion occupied by the thecal sac, the second to that occupied by the spinal nerve root in its extrathecal course and the third to the posterior recess of the vertebral foramen.

The so-called lateral spinal canal has been variably identified. Burton (17) distinguished a central and a foraminal zone. Lee et al. (71) identified: an entrance zone, situated ventrally and medially to the superior articular process; a middle zone located ventrally to the pars interarticularis and inferiorly to the pedicle; and an exit zone, corresponding to the area situated laterally to the pedicle. Van Akkerveeken (128) indicated the three zones as ostium internum, pedicular zone and ostium externum. These authors include the intervertebral foramen in the lateral vertebral canal, probably with the aim at indicating, using a single expression, the entire area through which the radicular nerve runs to exit from the spine. This, however, appears to be incorrect from the anatomic viewpoint, since the vertebral canal is an entity well distinct from the intervertebral foramen. As lateral vertebral canal, therefore, one should indicate only the portion of the spinal canal situated laterally to that occupied by the thecal sac. This portion has also been referred to as nerve-root or radicular canal, expressions which we prefer to that of lateral spinal canal.

Nerve-root canal

This canal, which is more an anatomic concept than a true canal, is the tubular structure in which the spinal nerve root runs from the exit from the thecal sac to the entrance into the intervertebral foramen.

The nerve-root canal includes two portions: a proximal – subarticular or intervertebral – portion; and a distal portion, corresponding to the lateral recess (93). The proximal portion is delimited, anteriorly, by the intervertebral disc and, posterolaterally, by the anterior border of the superior articular process, covered by the ligamentum flavum. The distal portion begins at the level of the superior vertebral end-plate and terminates at the entrance of the intervertebral foramen. In this portion, the nerve-root canal is delimited posteriorly by the base of the superior articular process and the pars interarticularis, and laterally by the pedicle. The nerve-root canal has no true medial wall; this can be identified with the lateral aspect of the thecal sac. Similarly to the lateral recess, the nerve-root canal exists, as a clearly identifiable anatomic structure, only for the L4, L5 and S1 radicular nerves. The more proximal nerves, after they have emerged from the thecal sac, enter almost immediately the intervertebral foramen, the entrance of which is almost in contact with the sac.

Intervertebral foramen

The intervertebral foramen or neuroforamen is an osteofibrous canal, rather than a true foramen. It is formed by two adjacent vertebrae and the intervertebral disc in between.

The anterior wall of the neuroforamen is formed by the subpedicular portion of the body of the proximal vertebra, the disc and the short suprapedicular portion of the body of the distal vertebra. The superior and inferior walls are represented by the pedicles of the two contiguous vertebrae. The posterior wall is formed by: the lateral end of the ligamentum flavum, dorsally to which there is the pars interarticularis; the base of the inferior articular process; the posterior joint capsule; and the superior articular process. The entrance and exit of the foramen correspond to the tangent planes to the medial and lateral aspect, respectively, of the pedicle.

The neuroforamen may be oval, auricular or tear-drop shaped. The configuration depends on various factors, such as the length of the pedicles, the height of the disc, the prominence of the latter into the foramen and the size of the articular processes. Stephens et al. (114) have analyzed, in cadavers, the shape, height and area of the foramen at the various lumbar levels. The mean height ranges from 13 to 16 mm; it increases from the first to the third neuroforamen, whilst decreases in the fourth and, even more, the fifth foramen. The mean area ranges from 83 to 103 mm^2 and shows the lowest values at L1-L2 and the highest at L5-S1. Both the shape and size vary depending on the vertebral level and the state of the disc (normal or abnormal, i.e., degenerated). In the majority of cases, at the upper two lumbar levels the foramen is mostly oval when the disc is normal, and auricularly-shaped when the disc is abnormal; the size is not influenced by the state of the disc. At L3-L4 level, there are similar proportions of auricular and oval foramens when the disc is normal; if the latter is abnormal, the auricular shape prevails and the size decreases. The L4-L5 foramen is mostly auricular when the disc is either normal or abnormal; in the latter instance, however, the prevalence of tear-drop configuration increases; the dimensions are not influenced by the state of the disc. At L5-S1 level, the oval configuration prevails when the disc is normal, whilst the auricular shape is more frequent when the disc is abnormal; in the latter instance the area decreases.

The values of the sagittal dimensions of the foramen at the individual lumbar levels have not been reported. Magnusson (75) reports a mean value of 7 mm and Smith et al. (112) of about 8 mm.

The main structure contained in the neuroforamen is the spinal nerve root (or radicular nerve), which occupies up to 50% of the area of the foramen (115). The spinal nerve root runs in the upper portion of the foramen, which also contains the anterior spinal branch of the lumbar artery, the radicular artery and veins, and the sinuvertebral nerve. The caudal portion of the foramen contains intervertebral veins and fat tissue. The space not occupied by the neurovascular structures is used by the articular processes for their reciprocal movements during spinal flexion-extension. In the sacrum, where there are no intervertebral movements, the foramen is occupied almost entirely by the spinal nerve root.

Neural structures

The neural structures in the lumbar vertebral canal are represented by the caudal portion of the spinal cord, the nerve roots forming the cauda equina and the radicular nerves. The spinal cord and the cauda equina are contained in the thecal sac.

Thecal sac

The thecal sac is formed by the dural sac, lined by the arachnoid membrane. The dural sac consists of parallel rows of fibroblast-like cells and bundles of vertically arranged collagen fibers, occupying the spaces between the cell rows. Interspersed among the collagen fibers are thin, vertically or horizontally orientated elastic fibers, providing elasticity to the dural tissue.

The length of the thecal sac, i.e., the vertebral level where the bottom of the sac reaches, is extremely variable. In the majority of subjects, the thecal sac ends between the S1 and S2 vertebrae or at S2 level. Less frequently, it terminates at the level of the L5-S1 disc or the proximal half of the S1 vertebra, or it reaches the S3 vertebra. Distally to its end, the sac is in continuity with the so-called coccygeal ligament. This is a fibrous tube ensheathing the caudal portion of the filum terminale and reaching the first coccygeal vertebra, on which it inserts. It represents a means of fixation of the thecal sac to the spine.

The arachnoid membrane separates the dura mater from the CSF.

Conus medullaris

This is the terminal, tapered portion of the spinal cord. This structure has no clear-cut limits, since proximally it is in continuity with the lumbar enlargement of the cord and caudally with the filum terminale. Conventionally, as conus medullaris it is generally considered that portion of the spinal cord containing the genitourinary and rectal nervous centers and, thus, the short portion from which the S3-S5 nerve roots and the coccygeal nerve originate.

In most individuals, the conus medullaris is situated at the level of L1 vertebral body or L1-L2 intervertebral disc; more rarely, it is located at the level of the L2 body or D12-L1 disc (73).

The conus continues distally with the filum terminale, which is a thin filament derived from the caudal portion of the neural tube, that, in the embryonal period, did not transform into nervous tissue.The filum runs in the center of the cauda equina and, where the thecal tube ends, it continues with the coccygeal ligament.

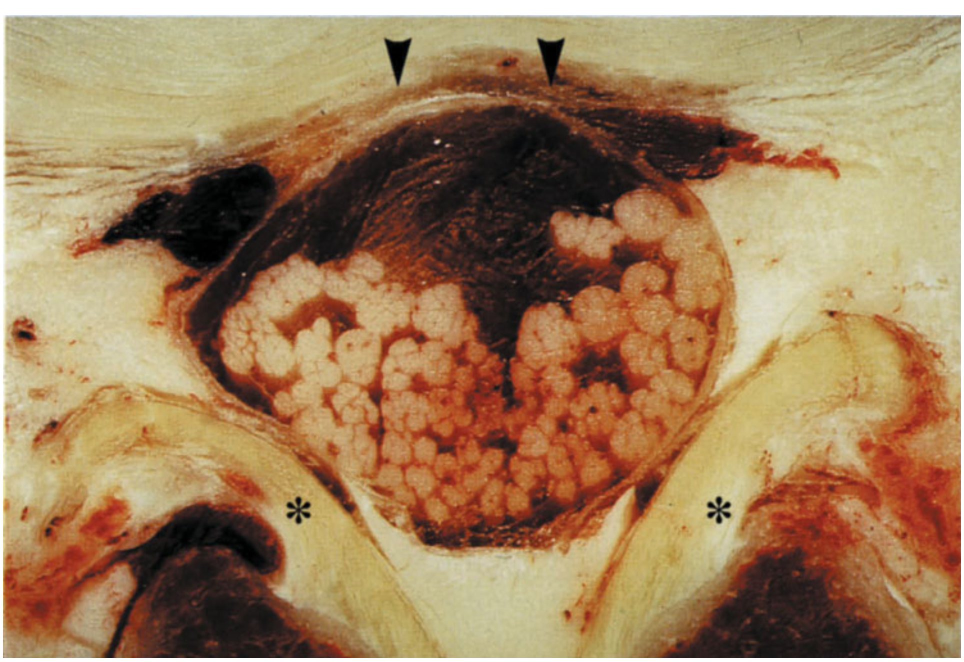


Fig. 2.37. *Axial section at the level of the proximal portion of L4-L5 disc. The spinal canal, delimited posteriorly by the ligamenta flava (asterisks), is almost entirely occupied by the thecal sac, which adheres to the posterior longitudinal ligament (arrowheads). Within the sac, the nerve roots of the cauda equina are visible. They have a posterior location in the sac, since the cadaver was frozen in the supine position.*

Cauda equina

The ventral and dorsal spinal nerve roots emerge, respectively, from the ventrolateral and dorsolateral portion of the spinal cord as thin rootlets. Subsequently, the rootlets originating from each medullary segment join to form the individual roots, within which the original rootlets can be identified, separated from each other by thin fibrous septa. The cauda equina is the bundle of lumbosacral nerve roots contained within the thecal sac in the caudal portion of the thoracic vertebral canal and the lumbosacral canal (Figs. 2.37 and 2.38). Into the sac, the individual roots have a fixed reciprocal position due to the presence of thin arachnoid septa connecting the roots to each other.

The arrangement of the roots of the cauda equina within the thecal sac has been studied by Wall et al. (130, 131) in fresh cadavers after injection of fixative into the sac and subsequent transverse sections at the level of the intervertebral discs.

At D12-L1 level, the terminal portion of the spinal cord is surrounded by the L1-L5 roots, showing a roundish shape on cross section. The ventral roots are closely adjacent to the ventral half, and the dorsal roots to the dorsal half, of the cord. The L1 roots are the most lateral and the L5 the most medial.

At L1-L2 level, the ventral and dorsal L2, L3, L4 and L5 nerve roots on each side appear to be joined to form organized dorsoventral laminae; the sacral roots have a laminar configuration as well, but the ventral and dorsal root remain slightly separated at this level. The S2 and S3 roots are joined in a single lamina. The cranial roots occupy the lateral portion, and the caudal roots the medial portion, of the thecal sac. In each lamina, the ventral portion is formed by the motor rootlets and the dorsal part by the sensory rootlets. At L2-L3 level, the L3 roots are located in the ventrolateral portion, and the S1 roots in the dorsomedial portion, of the thecal tube. The S2-S5 roots on each side form a single bundle situated in the median dorsal portion of the sac.

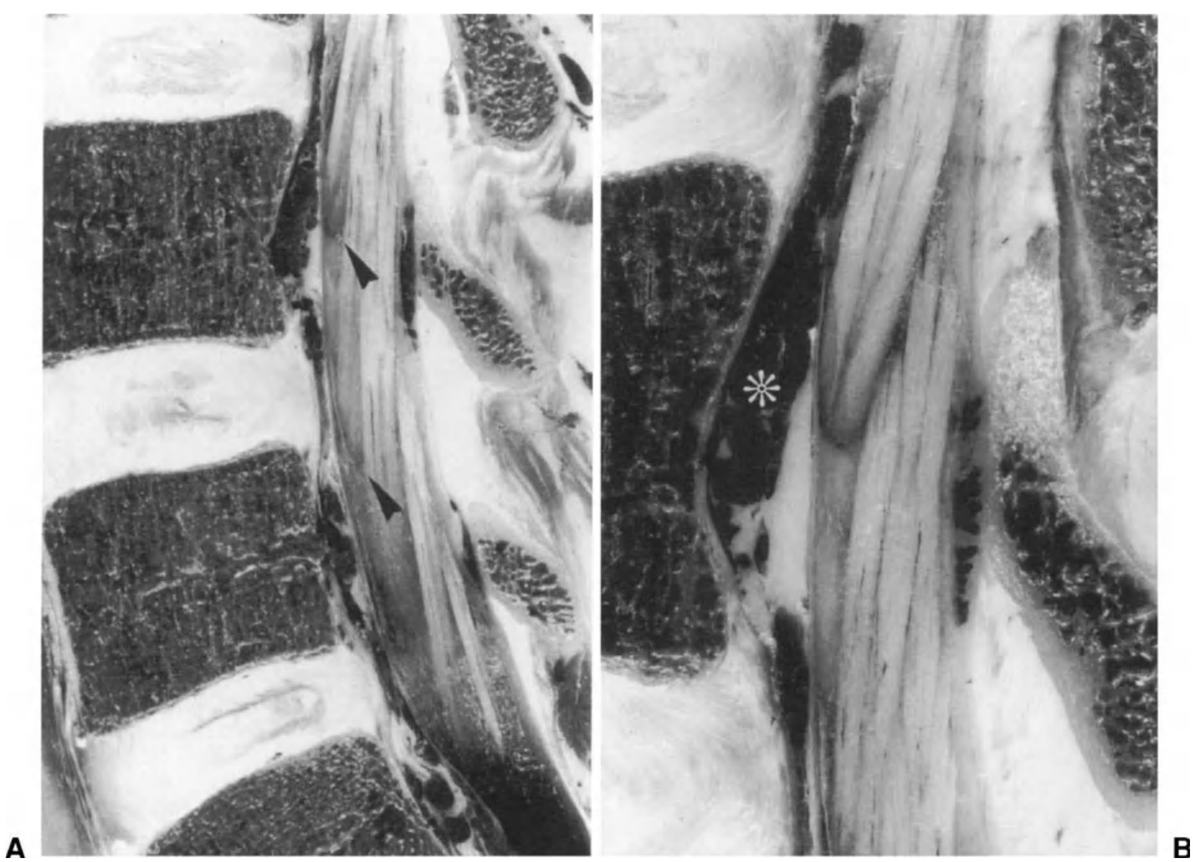


Fig. 2.38. (A) *Lateral sagittal section of the lowermost portion of the lumbar spine, showing the thecal sac and the caudal nerve roots, two of which (arrowheads) have penetrated into the arachnoid and dura mater openings and have emerged in the epidural space.* (B) *Higher magnification view of* (A) *at the level of L4 vertebra. The L4 root is passing, in its extrathecal, not visible portion, below the pedicle of the fourth lumbar vertebra. The posterior concavity of the L4 vertebral body is filled with veins of the anterointernal plexus (asterisk). Note that the root is composed of multiple rootlets in its intrathecal course.*

At L3-L4 level, the arrangement is similar to that at the level above. At L4-L5 level, the ventrolateral portion of the sac is occupied by the L5 roots, medially to which the S1 roots are visible. In each nerve root, the motor rootlets are located ventrally and medially to the sensory rootlets.

At L5-S1 level, the S2 and S3 roots are joined to form a bundle on each side. The S4 roots are separated from the S5 roots, which constitute a single bundle.

Radicular nerve

The radicular nerve – commonly, though improperly, referred to as spinal nerve root – is made up of the two spinal nerve roots, anterior and posterior, emerging off the thecal sac at a given vertebral level. The nerve extends from the thecal sac to the exit from the intervertebral foramen, taking successively the name of spinal nerve. The spinal nerve roots, anterior and posterior, exit from the dural tube through two separated openings, of which the ventral is occupied by the motor root and the dorsal by the sensory root. Once emerged from the thecal sac, the two nerve roots are surrounded by a common fibrous sleeve, within which they are separated by a dividing septum. This dural sleeve is lined, until in proximity to the spinal ganglion, by an extension of the arachnoid, which is separated from the nerve by a thin layer of CSF.

The spinal nerve roots emerge from the thecal sac at a progressively more cranial level, descending from L1 to S5, with respect to the intervertebral foramen where they run. The L1 roots (anterior and posterior) emerge at the level of the center of the L1 vertebral body; the L2 roots, slightly above the center of the L2 vertebral body; the L3 roots, at the level of the proximal one third of the L3 body, and the L4 roots in proximity to the superior vertebral end-plate of the homonymous vertebra. The L5 roots usually emerge at the level of the caudal end of the L4-L5 disc and the S1 roots at the level of the middle portion of the L5-S1 disc. The S2 roots exit from the thecal sac opposite the distal portion of the S1 vertebral body and the S2-S5 roots at the level of the S2 body. However, the site where the spinal roots, particularly the L5 and sacral roots emerge, is strictly dependent on the level of termination of the thecal sac. If the latter ends more cranially than normal, also the roots emerge more cranially, whereas the opposite occurs if the sac terminates more caudally.

The spinal nerve roots emerge from the thecal sac obliquely with respect to the horizontal plane (Fig. 2. 38 B). The angle at which they emerge from the sac is approximately 40° for the L1-L5 roots (131). The S1 roots emerge with a mean angle of 22° and the more caudal roots with progressively more acute angles.

The length of the radicular nerves, and their obliquity with respect to the sagittal plane, increases progressively from L1 to S5. The L1 and L3 radicular nerves run a very short distance in the vertebral canal, with an almost transverse course, before entering the respective intervertebral foramens. The L4 radicular nerve has a slightly longer and oblique course than the upper nerves. These four radicular nerves are in contact with the disc only at the level of the intervertebral foramen. A posterolateral herniation of the three upper discs, therefore, does not impinge on the radicular nerve, but on the corresponding nerve roots in the lateral portion of the thecal sac.

The obliquity of the L5 radicular nerve is 35°–40° and its length is about 2.5 cm (131). Within the vertebral canal, it runs in the L5 nerve-root canal. The anterior wall of this canal is formed by the L4-L5 disc and the body of the L5 vertebra. The posterior wall is represented, up to down, by the L4-L5 ligamentum flavum, the superior articular process of L5 and the pars interarticularis. The medial wall is formed by the thecal sac and the lateral aspect of the pedicle.

The S1 radicular nerve shows, approximately, an obliquity of 25° and a length of 3 cm (131). The anterior wall of the corresponding nerve-root canal is formed by the L5-S1 disc and the S1 vertebral body. The posterior wall is constituted by the L5-S1 ligamentum flavum, and the superior articular process and lamina of the S1 vertebra. The medial wall is represented by the thecal sac. Externally to the S1 radicular nerve, there is the L5-S1 intervertebral foramen, proximally, and the S1 pedicle, distally.

Dorsal root ganglion

The dimensions of the dorsal root ganglion increase progressively from L1 to S1 and then decrease from S2 to S5 (131). The L1 ganglion is, on average, 7 mm long and 5 mm large; that of the S1 root has a mean length of 13 mm and a mean width of 6 mm. The ganglion may be located in the spinal canal (intraspinal), the intervertebral foramen (intraforaminal) or outside the foramen (extraforaminal). The L2 ganglion is consistently intraspinal, whilst the L3 ganglion is intraforaminal in half of the subjects and extraforaminal in the others (45). The L4 and L5 ganglions are intraforaminal in some three quarters of subjects (59). The S1 ganglion is usually intraspinal (45, 59). At the level of the ganglion, the motor nerve root, which is located ventrally to the sensory root, may be divided into two trunks. Likewise, the sensory root may be bifurcated; in this instance, there are two distinct ganglions (59).

The dorsal root ganglion consists of: neurons of varying sizes, showing various morphologic characteristics;

satellite cells, which surround the perikaryon of neurons and prolong along the initial portion of the axons; and fibrillar connective tissue containing capillaries and venules (78, 91, 98).

Spinal nerve

The spinal nerve originates at the lateral end of the dorsal root ganglion, where the anterior and posterior nerve roots join intimately. At this level, the dural sleeve of the radicular nerve continues with the epineurium. The spinal nerve, cylindrical in shape at its origin, flattens slightly and, after a course of approximately 1.5 cm, bifurcates into two terminal branches. The ventral ramus, thicker than the dorsal, proceeds caudolaterally to form the lumbar and sacral plexuses. The dorsal ramus runs dorsally to supply the perivertebral muscles and the articular and ligamentous structures of the posterior vertebral arch.

Furcal nerve

The furcal nerve is an accessory spinal nerve, originating from the cord independently of the other lumbar nerve roots and , like the latter, includes a ventral and a dorsal component. This nerve can be found in all subjects, it is generally single and, in most cases, its roots emerge from the spinal cord and run within the thecal sac beside the L4 roots (58) (Fig. 2.39 A and B). In a small proportion of cases, there are two furcal nerves, L3 and L4 or L4 and L5 (Fig. 2.39 C). Occasionally, only one L5 furcal nerve is present. The dorsal root of the furcal nerve has a ganglion, situated, as for the normal dorsal roots, at the level of the intervertebral foramen. The nerve, once it has left the neuroforamen together with the roots proper of that level, with which it constitutes a single radicular nerve, gives off three branches, contributing to form, respectively, the femoral nerve, the obturator nerve, and the lumbosacral trunk.

The clinical importance of this nerve is that disc herniation, or other pathologic conditions, may impinge both on the radicular nerve proper of that level and the furcal nerve, thus causing atypical biradicular syndromes (58). This may occur, for example, in the presence of an L5 furcal nerve, the branches of which pass into the femoral and / or obturator nerves, as well as the sciatic nerve.

Nervous plexuses

Constitution of the lumbar plexus varies considerably. In most individuals, it is formed by a branch of the anterior ramus of the T12 spinal nerve, by the anterior rami of the L1, L2 and L3 nerves and by two of the three branches of the anterior ramus of the L4 nerve. The third branch of this nerve joins the L5 spinal nerve to form the lumbosacral trunk, which contributes to form the sacral plexus. The most common variants in the constitution of the lumbar plexus are those in which the T12 nerve is entirely included in the plexus (prefixed plexus) and those in which the plexus includes the L5 nerve (postfixed plexus). Less commonly the plexus includes both the T12 and the L5 spinal nerves.

The sacral plexus consists of the lumbosacral trunk, and the anterior rami of the S1, S2 and S3, and a branch of the S4, spinal nerves. In the presence of variations in the constitution of the lumbar plexus, the sacral plexus shows variations as well. When the lumbar plexus is prefixed or postfixed, the sacral plexus is formed, respectively, by the L4-S2 or S1-S5 spinal nerves.

Normally, the second branch of division of the anterior ramus of the S4 spinal nerve joins the anterior ramus of the S5 nerve and the coccygeal nerve to form the coccygeal plexus.

Variations in the constitution of the lumbar and sacral plexuses can be responsible for atypical neurologic syndromes, deviating from the pattern of normal radicular innervation. This is in keeping with the variations observed in the furcal nerve, which are strictly related to those of the nervous plexuses.

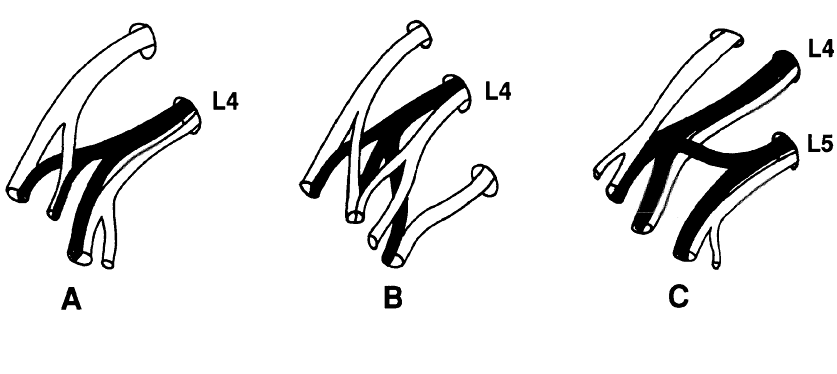


Fig. 2.39. *A few anatomic variants of the furcal nerve.* (A) *The nerve emerges from the thecal sac together with the L4 root and sends a branch to L3 and L4 roots.* (B) *The nerve emerges joined to the L4 root and gives off branches to L3, L4 and L5 roots.* (C) *There are two furcal nerves - L4 and L5 (or L3 and L4) – which send branches to L3, L4 and L5 roots (from Ref. 58, modified).*

Innervation of the spine

With regard to the innervation, the spine can be divided into an anterior portion (intervertebral disc, longitudinal ligaments, ventral epidural tissue, ventral aspect of the dura mater and prevertebral muscles) and a posterior portion (neural arch, ligamenta flava, interspinous and supraspinous ligaments, and perivertebral muscles) (11). The anterior portion is innervated by the sinuvertebral nerve, the ventral ramus of the spinal nerve and the sympathetic chain (Fig. 2.40). The posterior portion is supplied by the dorsal ramus of the spinal nerve.

According to the classic description, the sinuvertebral nerve (or vertebral recurrent, meningeal, or Luschka's nerve) originates from the ventral ramus of the spinal nerve just distal to the dorsal root ganglion and, with a recurrent course, enters the intervertebral foramen and then the spinal canal, after receiving, a few millimeters from the origin, a branch from the ramus communicans of the sympathetic chain. Recent anatomic investigations, however, indicate that the nerve originates only, or to a large extent, from the sympathetic chain (page 136).

In the vertebral canal, the nerve gives off transverse and descending rami, and an ascending ramus. The former supply the posterior longitudinal ligament and the posterior portion of the annulus fibrosus. The ascending ramus contributes to the innervation of the posterior longitudinal ligament and the posterior part of the intervertebral disc above. Other branches of the sinuvertebral nerve distribute to the vessels of the spinal canal and the anterior aspect of the dural sac. In contrast to earlier reports (29), the dura mater of the thecal sac is innervated not only in the anterior, but also in the posterior, aspect. The latter, however, has an extremely limited nerve supply. The nerve fibers are somatosensitive (65) and autonomic (2). The anterior and lateral portion of the disc is innervated by branches of the ventral ramus of the spinal nerve, by the grey ramus communicans or directly by the sympathetic chain (12). (Fig. 2.40). The anterior longitudinal ligament receives branches from the grey ramus communicans or the sympathetic chain.

The posterior ramus of L1-L4 spinal nerves runs dorsally, crosses the distal portion of the intertransverse ligament and divides into three branches: lateral, intermediate and medial (13). The lateral branch supplies the iliocostalis lumborum muscle, the intermediate one the longissimus thoracis and the medial branch the multifidus, the interspinales and the intertrasversarii mediales muscles. The lateral branch also provides cutaneous rami, which innervate the skin of the lateral gluteal region as far as the greater trochanter. The posterior ramus of the L5 spinal nerve gives off only two branches, which have the same distribution of the intermediate and medial branches of the posterior rami of the spinal nerves above. The medial branch of each posterior ramus supplies the structures of the posterior vertebral arch as well (Fig. 2.41). This branch runs around the superior articular process, passes below the mammillo-accessory ligament and, at this level, provides a ramus for the facet joint above. The medial branch then crosses the lamina and sends rami, which, after traversing the transversospinalis muscle, reach the interspinous and supraspinous ligaments, the ligamentum flavum and the underlying facet joint.

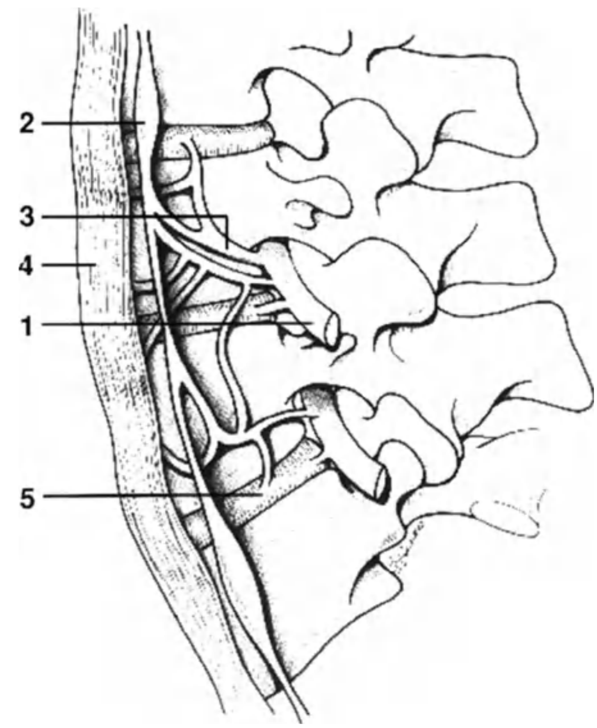


Fig. 2.40. *Schematic drawing of the innervation of the anterior and lateral portion of the spine.* (1) *Ventral ramus of the spinal nerve.* (2) *Sympathetic chain.* (3) *Grey communicans ramus.* (4) *anterior longitudinal ligament.* (5) *Intervertebral disc (from Ref. 11, modified).*

Nerve endings in spinal structures

The presence of nerve endings in the longitudinal ligaments has long since been known; however, conflicting opinions have been advanced in the past concerning the presence of nerve endings in the intervertebral disc. A few authors denied that the disc is innervated (90, 132), whereas others have found nerve endings in the most superficial portion of the disc (50, 54, 57). More recent studies have shown that at least the outer one

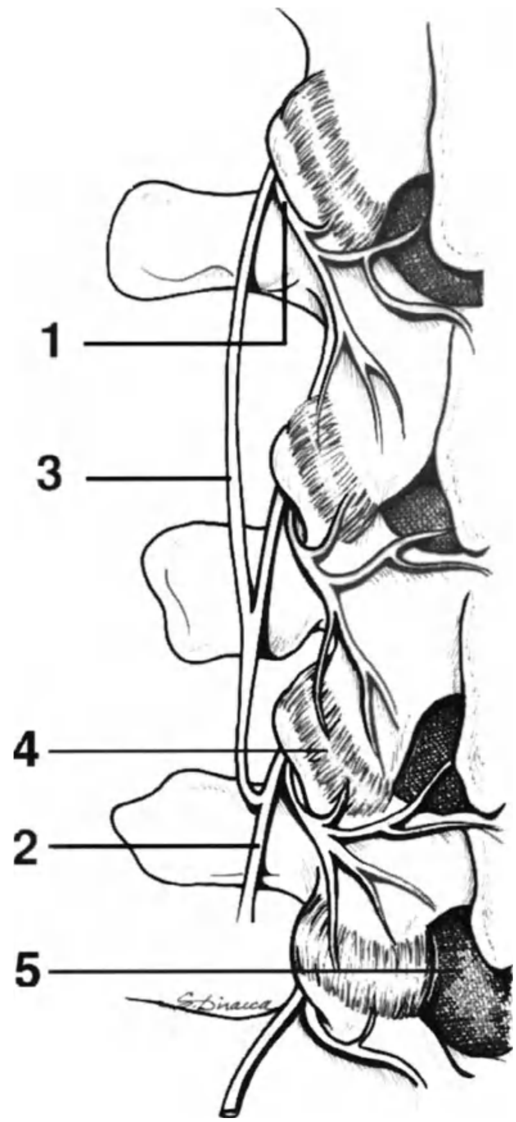


Fig. 2.41. *Schematic drawing of the medial and intermediate branches of the posterior ramus of the spinal nerve.* (1) *Medial branch.* (2) *Intermediate branch.* (3) *Intermediate branch plexus.* (4) *Posterior joint.* (5) *Ligamentum flavum (from Ref. 11, modified).*

third or outer half of the annulus fibrosus is innervated (Fig. 2.42).

The nature of the nerve endings in both the longitudinal ligaments and the annulus fibrosus is still poorly known. Malinski (76) has observed capsulated, and partially capsulated, receptors and several types of free nerve endings. Immunohistochemical studies demonstrated the presence of two neuropeptides – substance P and CGRP (calcitonin-gene-related-peptide) – in the posterior longitudinal ligament and, to a lower extent, in the peripheral portion of the annulus fibrosus (62,

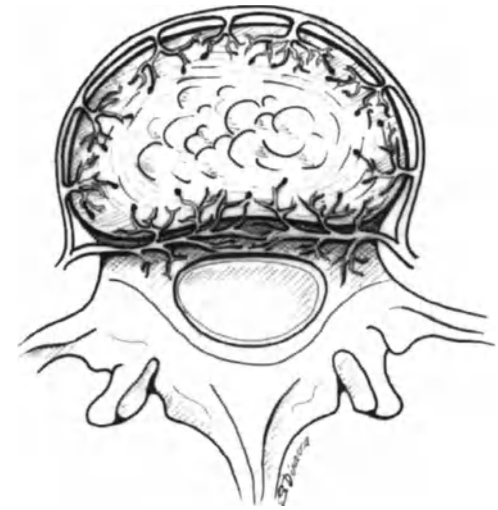


Fig. 2.42. *Drawing showing the innervation of the intervertebral disc. At least the outer one third of the annulus fibrosus is innervated.*

63). They are involved in the transmission of sensory impulses, particularly nociceptive. These observations suggest that the annulus fibrosus, and even more the posterior longitudinal ligament, contain nociceptive nerve endings, which are sensitive to chemical or mechanical stimuli.

In the past, only few free nerve endings had been found in the supraspinous and interspinous ligaments, and the ligamentum flavum (50, 54, 99). Recent studies, however, have shown that the supraspinous and interspinous ligaments have a profuse innervation (56, 104, 137). With the method of gold chloride (137), Pacini and Ruffini's corpuscles and free nerve endings have been observed. With immunofluorescence methods (56), using antibodies for neurofilament proteins, it was found that the ligaments are innervated in all their extension, although the density of neural structures is higher in the peripheral layers. Pacini's corpuscles are irregularly distributed and are mostly located in proximity to the vessels, whereas Ruffini's receptors are situated at the periphery of the ligaments, usually in close association with the bundles of collagen fibers. Nerve fibers may be isolated or grouped in thin or large bundles. Neural elements are more numerous in the loose connective tissue at the periphery of the ligaments; within the latter, they have been observed in the loose connective tissue septa and between, or occasionally within, the bundles of collagen fibers.

It has been suggested that the various neural elements play the role of sensors of the mechanical loads to which the bundles of collagen fibers are submitted during spine movements (56). In a study on ligamenta flava (104), single nerve fibers, mostly located in proximity to the vessels, but no bundles of nerve fibers, were found; furthermore, Pacini or Ruffini's corpuscles were not observed. This study, however, did not reveal these corpuscles even in the supraspinous and interspinous ligaments, where they have later been demonstrated by another study (56). It is thus possible that these bodies are present also in the ligamenta flava.

In the capsule of the posterior joints, capsulated and non-capsulated, and free nerve terminals have been found (50, 54). Immunohistochemical studies have demonstrated nerve terminals containing substance P in the subchondral bone of articular processes (4) and the joint capsule (42), the synovial membrane (42) and the fibroadipose meniscoids (44) of the facet joints. In the synovial membrane and meniscoids, nerve endings containing galanin, another neuropeptide, were also found. The nerve terminals containing these neuropeptides were usually observed in proximity to the vessels. In the posterior joints, these nerve endings are probably involved in local vasoregulation and only marginally in the transmission of sensory impulses (44).

Electrophysiologic studies have shown, in the rabbit, the presence of Group III mechanosensitive units in the anterior surface of the annulus fibrosus (139) and Group II, III and IV units in the capsule of the facet joints (138). These units have a low or high mechanical threshold. The units with a high threshold could play the role of nociceptors and those with a low threshold of proprioceptors.

Vertebral and meningo-radicular dynamics

Intervertebral disc

During flexion of the spine, the vertebral bodies adjacent to a disc move closer ventrally and further apart posteriorly, thus stretching the dorsal lamellae of the annulus fibrosus, which loose entirely, or to a large extent, their posterior curvature. The posterior portion of the disc increases in height and reduces its prominence, when present, into the vertebral canal. The anterior portion of the disc undergoes opposite changes. Upon extension, the height of the anterior portion increases and the anterior annular lamellae loose their curvature, whereas the posterior lamellae, particularly those in the equatorial plane, show an increased posterior convexity (Fig. 2.43). As a result, the posterior surface of the disc bulges into the spinal canal to a varying extent. The nucleus pulposus tends to displace posteriorly during flexion and anteriorly during extension.

Vertebral canal

Upon spinal flexion, the laminae of two adjacent vertebrae move apart and the interlaminar space widens, thus producing lengthening and thinning of the ligamenta flava. These changes and those of the disc lead to an increase in length and sagittal dimensions of the vertebral canal. The opposite occurs upon extension of the spine: the ligamenta flava shorten, become thicker and buckle, to a larger extent than the disc, into the spinal canal, which decreases in length and narrows. Length differences between maximal flexion and maximal extension are 3 mm, on average (73).

The intervertebral foramen shows an increase in the vertical dimensions upon flexion, but narrows by about one quarter both in the vertical and sagittal direction during extension of the spine (116). Narrowing is due to buckling, into the foramen, of the annulus fibrosus and the ligamentum flavum covering ventrally the apophyseal joint, as well as to the associated cranial sliding of the superior articular process.

Thecal sac

Upon flexion of the spine, the thecal sac lengthens and decreases in size both in the sagittal and transverse plane. Upon extension, it shortens, decreases in caliber and, in the cadaver, shows transverse ondulations, particularly at intervertebral level (73). Dimensional variations involve to a larger extent the portions corresponding to the three lower intervertebral spaces, which are the most mobile. Jointly with the portions above, the bottom of the sac moves cranially during flexion and descends during extension. Changes in length of the thecal tube upon flexion-extension are slightly less than those of the vertebral canal.

Nerve roots and radicular nerves

Radicular dynamics is different for the upper lumbar nerve roots, which form the obturator and femoral nerves, compared with the lower lumbar and sacral roots, giving rise to the sciatic nerve. The border between the two groups of roots is represented by the L3 nerve root, which shows no significant dynamic changes (73).

The higher lumbar roots, during flexion of the spine, shorten and acquire an ondulating course; the corresponding radicular nerves move apart from the pedicles and assume a slightly more transverse course. Opposite changes occur during extension: the nerve roots lengthen and become more vertical, whereas the radicular nerves approach the pedicle above.

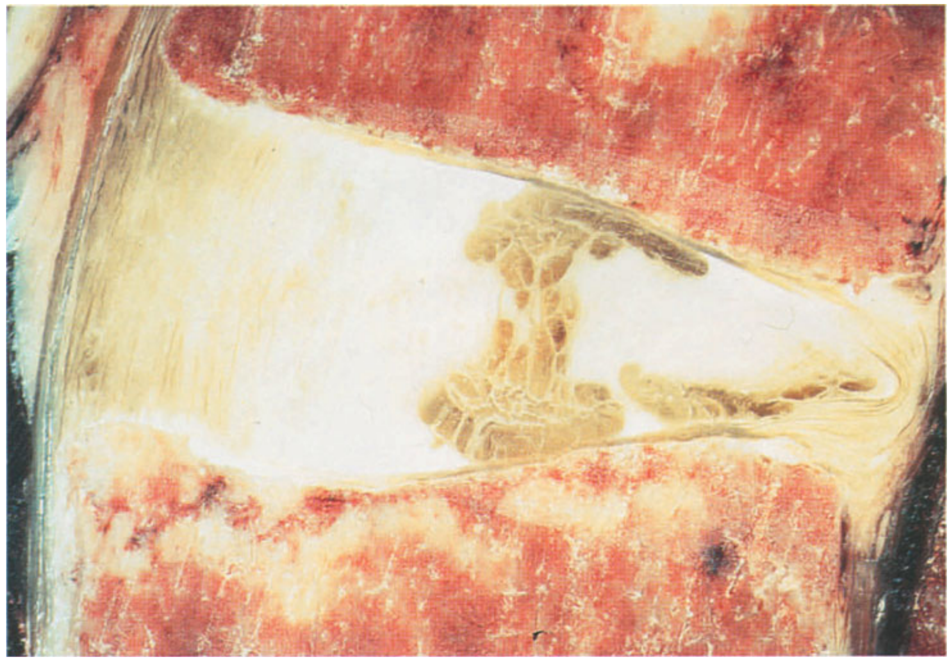


Fig. 2.43. *Midsagittal section of lumbar intervertebral disc of a cadaver frozen with the spine in extension. The anterior portion of the disc is considerably larger than the posterior and the anterior annular lamellae have lost completely their curvature, whereas the posterior lamellae show an increase in their posteriorly convex curvature. A portion of the nucleus pulposus is displaced dorsally with respect to the rest of the nucleus.*

Upon flexion, the lower lumbar and sacral roots increase in length and move cranially by a few millimeters. The radicular nerves are stretched downwards, acquire a more vertical direction, and approach the pedicle and the anterior wall of the vertebral canal. During extension, the nerve roots become winding, whereas the radicular nerves move apart from the pedicles and acquire a more vertical direction with respect to the thecal sac.

In the straight leg raising maneuver, the lower lumbar and sacral radicular nerves on the side of the maneuver move caudally and laterally, and are slightly lengthened (page 184). At the same time, they attract the thecal sac to themselves and downwards. Those on the opposite side are tractioned cranially and attracted towards the side on which the maneuver is carried out. The upper lumbar radicular nerves undergo similar dynamic changes when the knee is flexed with the patient prone.

Blood supply

Vertebral vascular pattern

Arteries

Vascularization of the lumbar spine (26, 100, 133, 134) is provided by the lumbar arteries and the middle sacral artery. The lumbar arteries, arising from the posterior aspect of the aorta, follow a posterolateral course around the middle of the vertebral body. At the level of the intervertebral foramen, they send out three branches: a ventral one (ventral spinal branch), entering the spinal canal anteriorly to the radicular nerve; a middle one (radicular artery), which accompanies the radicular nerve; and a posterior one (dorsal spinal branch), penetrating into the spinal canal dorsally to the radicular nerve. Proceeding posteriorly, the lumbar artery finally sends out a dorsal branch, which supplies the posterior vertebral arch and the regional muscles.

While running along the vertebral body, the lumbar artery sends out primary periosteal arteries, which are directed proximally and distally (Fig. 2.44). Some of them cross the adjacent discs to anastomose with the primary periosteal arteries from the adjacent segmental vessels. In the proximal and distal one third of the vertebral body, there is a horizontal branch (external metaphyseal artery), which anastomoses with the primary periosteal arteries (Fig. 2.44). From these vessels smaller branches are sent out, which represent the secondary periosteal arteries.

Ventrally to the pedicle, the lumbar arteries send a branch, which runs caudally and anastomoses with the branch from the underlying lumbar artery. This trunk (precentral anastomosis) (100) is larger at the level of the L5 vertebra because of the small size of the fifth lumbar artery, arising from the middle sacral artery rather than the aorta.

The ventral spinal branch, once entered the spinal canal, runs distally bordering the pedicle and anastomoses with the underlying artery to form the postcentral anastomosis (100) (Fig. 2.45). The latter gives off

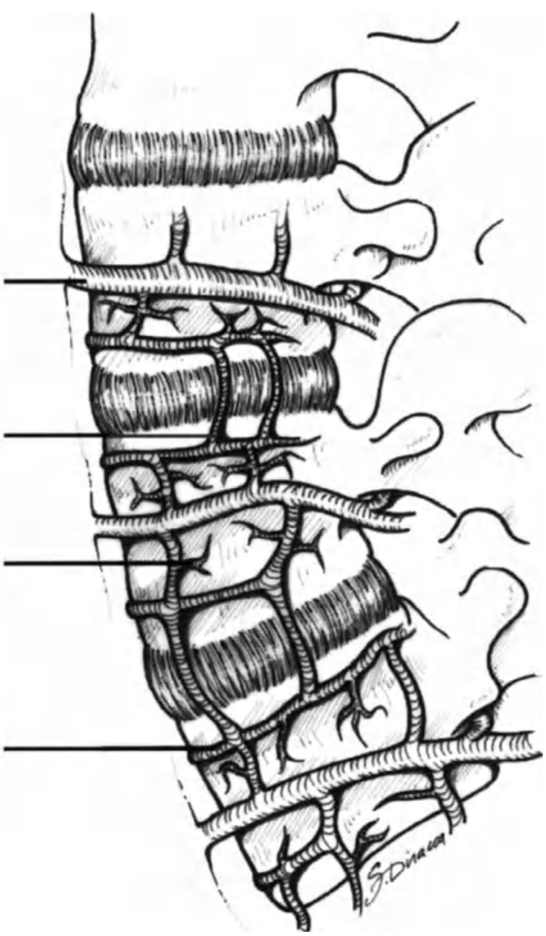


Fig. 2.44. *Schematic drawing of the anteroexternal arterial system of the lumbar spine.* (1) *Lumbar artery.* (2) *Primary periosteal artery.* (3) *External metaphyseal artery.* (4) *Secondary periosteal artery (from Ref. 10, modified).*

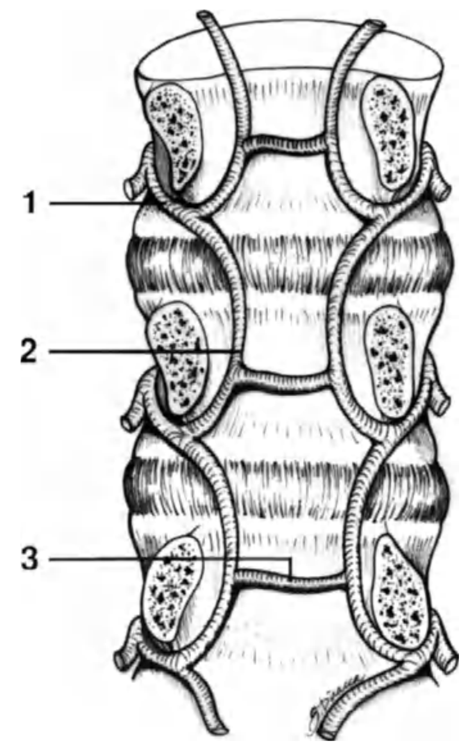


Fig. 2.45. *Arterial system within the spinal canal.* (1) *Anterior spinal artery.* (2) *Postcentral anastomotic trunk.* (3) *Anastomosis joining the trunk of the two sides (from Ref. 10).*

periosteal branches, and transverse branches which anastomose each postcentral channel to its opposite number across the midline. The dorsal spinal branch penetrates into the posterolateral portion of the spinal canal and divides into a proximal and a distal ramus, which form two longitudinal trunks anastomosed by transverse branches. These vessels provide the rami supplying the structures of the posterior arch.

The arterial network of the vertebral body is formed by the equatorial and metaphyseal arteries. The former arise from the postcentral anastomosis (nutrient artery) and the lumbar arteries (radial arteries); they give off proximal and distal branches, supplying that part of the vertebral end-plate which is subjacent to the nucleus pulposus. The latter stem from the external metaphyseal arteries or the periosteal arteries and send out thin branches, directed to the peripheral portion of the vertebral end-plates.

The dorsal branch of the lumbar artery runs posteriorly, surrounds the posterior joint, to which it sends thin rami, and divides into a medial and a posterior branch. The former follows the outer aspect of the laminae and the spinous process, whereas the latter supplies the lumbosacral common mass.

The nucleus pulposus is supplied by the branches of the nutrient artery and by the metaphyseal arteries of the vertebral body. These branches reach the subchondral bone and supply the nucleus pulposus by diffusion of solutes through the cartilage end-plate. In the fetus and newborn, the peripheral portion of the annulus fibrosus is vascularized (80). In adult life, the normal annulus fibrosus contains no vessels. Most of the annulus is supplied by diffusion by the arterial network of the vertebral body, whereas the outer lamellae receive oxygen and nutrients from the periosteal arteries. In the vertebral end-plate, the arteriole and capillary networks show similar density in the area corresponding to the nucleus pulposus and in that facing the annulus fibrosus, however in the former the terminal microvascular coils have more complex convolutions (84).

Veins

The venous architecture of the lumbar spine (3, 22, 24, 27) includes two main systems: the epidural system and that of the vertebral body.

The epidural system is formed, on each side, by an anterointernal and a posterointernal plexus. The anterointernal, or Batson's, plexus consists of a few longitudinal channels, located anteromedially to the pedicles (Fig. 2.46). The posterointernal plexus is a small longitudinal collector running along the lateral portion of the laminae; it is anastomosed with that on the opposite side and the anterointernal plexus by transverse branches. The epidural veins, being devoid of valves, may drain either proximally or distally. Furthermore, an increase in pressure in the vena cava as a result of an increased intra-abdominal pressure is transmitted directly to the epidural venous system.

The anterointernal plexus drains into the two intervertebral veins running in the neuroforamen, which are anastomosed by transverse rami. The intervertebral veins drain into the ascending lumbar vein (Fig. 2.46).

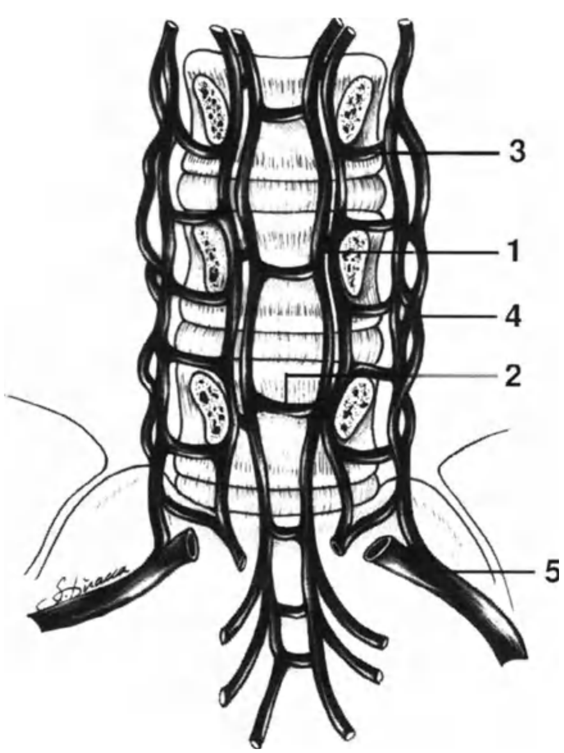


Fig. 2.46. *Anterointernal epidural venous system or Batson's plexus (1) of right and left side, joined by anastomotic branches (2) located behind the vertebral bodies. The anterointernal plexus communicates with the intervertebral veins (3) and, through the latter, with the ascending lumbar venous trunk (4) and this, in turn, with the common iliac vein (5).*

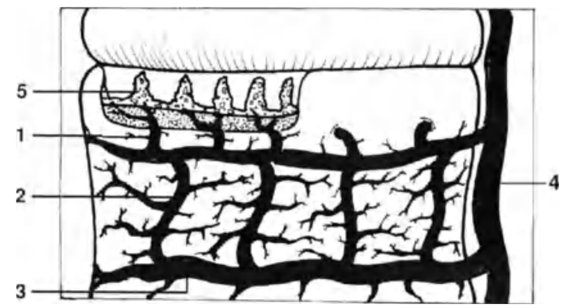


Fig. 2.47. *Venous systems of the vertebral body: epiphyseal system (1), metaphyseal system (2) and basivertebral system (3). (4) Batson's plexus. (5) Subchondral bone.*

This collector, coursing in the corner situated at the junction between the vertebral body and the pedicle, communicates with the common iliac vein caudally, the azygos vein cranially, and the external vertebral venous plexus ventrally.

In the vertebral body, three, horizontally arranged, venous systems have been identified: epiphyseal, metaphyseal and basivertebral (Fig. 2.47). The epiphyseal veins (24, 27) are located in close proximity to the vertebral end-plate, in the area corresponding to the nucleus pulposus. They receive a network of venules coming from the subchondral bone, some of which directly reach the central veins. The epiphyseal veins drain into the Batson's plexus posteriorly and the external venous plexus anteriorly. Below the epiphyseal, there is the metaphyseal, system, which also drain into Batson's plexus, the external vertebral plexus and the

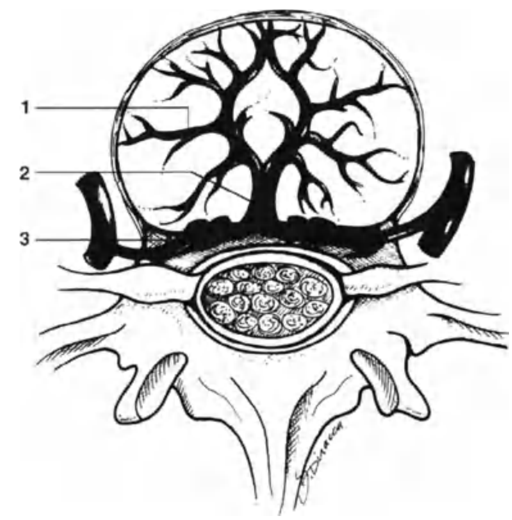


Fig. 2.48. *Basivertebral system as seen on transverse section. The system consists of radially arranged veins (1) flowing into the basivertebral trunk (2), which drains into the anterointernal plexus (3) by means of one or two collectors.*

basivertebral system. The latter is formed by radially arranged veins, running in the central portion of the vertebral body (central veins) (Fig. 2.48). It receives vertical branches from the other two systems and drains into 1 or 2 collectors, which flow into the anterointernal venous plexus. This system is also anastomosed to the external vertebral plexus by means of the radial veins.

Vascular pattern of spinal cord and cauda equina

The thoracolumbar spinal cord derives its arterial blood supply from the radicular arteries, which originate from the segmental arteries (intercostal, lumbar, sacral) and reach the cord following the course of the spinal nerve roots. At the level of the dorsal root ganglion, the radicular artery divides into two branches, anterior and posterior, which follow, respectively, the anterior and posterior nerve root. The anterior branch reaches the anterior median fissure of the spinal cord and divides into an ascending and a descending ramus, which contribute to form the anterior spinal artery. Similarly, the posterior branch reaches the dorsolateral portion of the cord and splits into an ascending and a descending ramus, which contribute to form the posterior spinal arteries. The latter consist, on each side, of two longitudinal channels anastomosed by transverse branches. The anterior spinal artery and the posterior spinal arteries are anastomosed by the vasa corona, forming a perimetral vascular network around the cord.

According to the classic description, the radicular arteries, in the postembryonal life, are less numerous than the spinal roots, since only some roots are accompanied by an artery. For the anterior roots, on each side, there is only one radicular artery every 3 or 4 pairs of roots (120). The arteries of the posterior nerve roots are more numerous – on average, 2 for 3 pairs of roots – but are thinner than the anterior arteries. The distal portion of the thoracic spinal cord and the conus medullaris derive most of their blood supply from an anterior artery – the artery of Adamkiewicz or Lazorthes – which originates at a variable level, generally between T8 and L2 or more rarely at L4 or S1 level, and is generally situated on the left side (1, 68, 69, 73). As for the arteries, not all spinal nerve roots are accompanied by veins; on average, there is one radicular vein every 2 or 3 roots, on each side. Radicular veins drain the blood from the perimedullary venous network.

Parke et al. (87) have described a more complex vascular architecture than the classic one. These authors maintain that all nerve roots, anterior and posterior, are accompanied by at least one artery. These arteries may be of two types: large caliber arteries (medullary arteries) supplying the anterior spinal artery or the posterior spinal arteries; and smaller radicular arteries (true radicular arteries or, simply, radicular arteries), which supply only the nerve roots. In the lumbosacral region, only 1 or 2 anterior roots are accompanied by a medullary artery. One of these often runs together with one of the lower lumbar roots (L3-L5) (69, 87); the caliber of this artery is inversely related to the size of Adamkiewicz's artery. The posterior roots are more frequently associated with arteries classifiable as medullary, although smaller than the anterior vessels. The radicular arteries, in turn, are of two types, distal and proximal. The distal arteries are branches of the lumbar and sacral arteries for the roots not accompanied by medullary vessels; for the roots running with medullary arteries, the distal radicular vessels arise from the medullary artery at the level of the dorsal root ganglion. The distal radicular arteries feed the caudal portion of the root, whereas the cranial portion is supplied by the proximal radicular arteries, which, in the thoracolumbar cord, are branches of anterolateral longitudinal channels, originated from the vasa corona, or of the posterior spinal arteries. The spinal nerve roots, therefore, would be fed by arterial blood coming from the spinal cord network in the proximal part, and directly from the segmental vessels in the distal portion. The venous system would have the same architecture as the arterial one.

According to Crock et al. (25), on the other hand, all nerve roots are accompanied by a radicular artery, which arises from the segmental vessels and reaches, with an uninterrupted course, the perimedullary arterial systems. The radicular arteries are of different caliber in the various roots. Along their course, they send out collateral branches aimed at supplying the nerve root; furthermore, occasionally they send branches which anastomose with the radicular arteries of adjacent roots. The spinal cord would not, therefore, be fed by few large arteries, but by the same number of arteries as the number of anterior and posterior nerve roots. The roots, in addition, would be entirely supplied by branches of the radicular artery. According to this architecture, the venous system is formed by radicular veins, one for each root, draining the blood from the perimedullary venous network, as well as the root itself.

Intrinsic vasculature of the caudal nerve roots

In a single nerve root there are generally 2 or 3 large arterial vessels, deserving the label of main radicular arteries. They usually run at the periphery of the largest nerve-fiber fascicles forming the root (88). In addition, there are smaller vessels, which can be termed collateral radicular arteries. The latter, like the main vessels, have a longitudinal course and are usually located at the periphery of the neural fascicles. From the radicular arteries, and especially the collateral vessels, numerous transverse branches arise, some of which anastomose with the arteries of adjacent fascicles, whilst others enter the fascicles to give off precapillary vessels with a longitudinal course. The capillaries arising from these vessels penetrate between the single nerve fibers, where they have a longitudinal or transverse course.

A peculiar characteristic of the transverse branches is that they show sets of spiraling coils, which are confined to the portion of a branch that is immediately adjacent to its derivation from the parent vessel (88). These coils probably have the role of allowing reciprocal motion of the nerve fascicles during lengthening and shortening of the spinal nerve root, occurring, respectively, in flexion and extension of the spine. A further characteristic differentiating the radicular circulation from that of the peripheral nerve is the presence of numerous arteriovenous shunts. These probably represent a protective mechanism in the presence of circulatory obstruction in a portion of the root.

The radicular veins do not accompany the respective arteries, as occurs in the peripheral nerves, but tend to run, with a spiraling course, within the neural fascicles (88). The smaller-caliber radicular veins end into 2 or 3 major branches, which drain into the segmental veins.

Lumbosacral anomalies

Transitional anomalies

These anomalies consist in the presence of a last lumbar vertebra showing abnormal morphologic characteristics – that is a tendency to, or an actual, partial or complete, fusion with the sacrum – or of a sixth lumbar vertebra with normal morphology.

Castellvi et al. (19) have identified four types of anomalies (Fig. 2.49). Type I, in which the last lumbar vertebra tends to be fused with the sacrum, is characterized by the presence, on one or both sides, of a transverse process, triangular in shape, measuring at least 19 mm in height (113). In Type II, the transverse process of the last lumbar vertebra shows an incomplete fusion with the sacrum, on one or both sides; in type III, the fusion is complete. Type IV is a combination of Type I anomaly on one side and Type III anomaly on the opposite side. Tini et al. (122), who adopted a similar classification, found a transitional anomaly in some 6% of 4000 patients. In the series of Castellvi et al. (19), the prevalence was 30%, but all patients examined had a herniated disc. In both series, the most frequent anomalies were those of Type I or II; furthermore, no distinction was made between sacralized L5 vertebrae and lum-

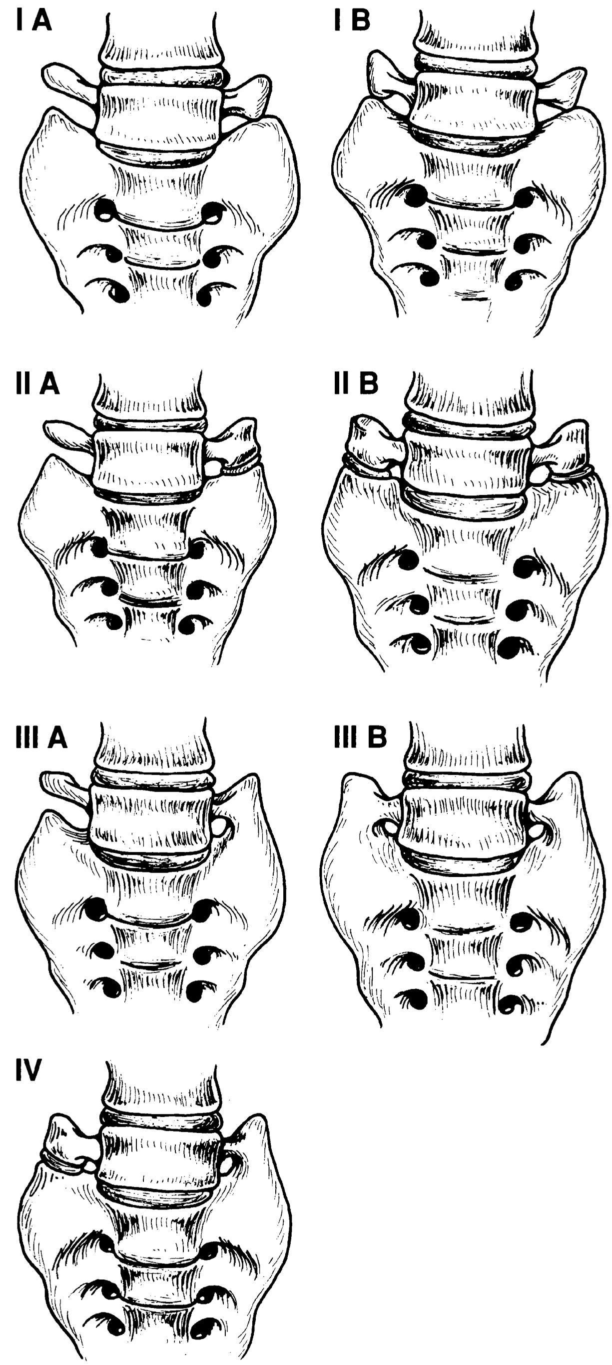


Fig. 2.49. *Schematic drawing of the lumbosacral transitional anomalies according to Castellvi et al. Type I: abnormally large transverse process of L5 on one side* (A) *or both sides* (B). *Type II: transverse process of L5 incompletely fused with the sacrum on one side* (A) *or both sides* (B). *Type III: transverse process of L5 completely fused with the sacrum on one side* (A) *or both sides* (B). *Type IV: combined anomaly, of type II on the right and type III on the left.*

barized S1 vertebrae, because the thoracic vertebrae were not counted. However, there are few subjects who have 12 thoracic and six lumbar vertebrae, of which the lowermost does not show morphologic anomalies of the transverse processes. In our opinion, the latter is a further type – Type V – of transitional anomaly.

The disc below the anomalous vertebra may be normal (in Type I and V anomalies, and rarely in the other types) or be vestigial or absent (Types II–IV). A vestigial disc may have a decreased height, but a normal structure or, more often, it may have a small, or no, nucleus pulposus. In Type I and II, the anomalous transverse process may show mild degenerative changes in the area of contact with the sacral ala or the ilium (34).

The etiology of transitional anomalies may be related to genetic factors, as suggested by reports of families with a high prevalence of the anomaly (122).

Spina bifida occulta

This condition consists in a failure of fusion, on the midline, of the two halves of the posterior vertebral arch. The latter are separated by a space of variable width in the area normally occupied by the spinous process, which is generally absent; the laminae may be shorter than normal or completely absent. Occasionally, in the central portion of the defect, an isolated ossicle is visible, the so-called ossification center of the tip of the spinous process. The dimensions of the vertebral canal, at the levels above the anomaly, tend to be larger than normal (86).

The vertebrae most frequently involved are L5 and S1. Usually, in a single subject, only one vertebra is anomalous. Occasionally, the defect involves all the sacrum and/or two or more lumbar vertebrae. This anomaly has been found in 1.9% of lumbosacral spines in a large South African skeletal population (31). In radiographic studies on living subjects, however, the prevalence ranged from 5% to 15% (61, 109).

The etiology of spina bifida occulta is unknown. An important role is probably played by genetic factors, as indicated by geographic variations in the prevalence of the anomaly (113, 125, 135) and its markedly higher frequency in subjects with spondylolysis (31). However, also acquired factors seem to play a role. It has been shown, in fact, that some substances, such as the valeric and retinoic acids, may cause the anomaly (10, 121) and that this is more frequent in the lower socioeconomic classes (70, 135).

Nerve-root anomalies

Anomalies of the lumbosacral nerve roots have been reported with a frequency of 0.34% to 2.7% (14, 37, 97). Generally, the anomaly is unilateral. The nerve roots most frequently involved are L5 and S1, followed by L4 and L3.

Several classifications of these anomalies have been proposed. Cannon (18) described three types of anomalies: conjoined roots, anastomoses between roots, and transverse course of the root. Bonola and Bedeschi (14) distinguished anomalies of origin, course, length and diameter of the nerve roots. Postacchini et al. (97), based on the analysis of water-soluble lumbar myelograms, have identified five types of anomalies. In Type I, the roots of one or more radicular nerves emerge, in the presence of a thecal sac of normal length, at a more cranial level than normal. In type II, the root emerges at an abormally caudal level and the resulting radicular nerve has a more transverse course than normal (Fig. 2.50). In Type III, the roots of two distinct radicular nerves emerge from the dural sac through closely adjacent openings (Fig. 2.51). In Type IV, the roots of two radicular nerves emerge conjoined in a single trunk (Fig. 2.52); after an extradural course of varying length, the two radicular nerves separate and each runs towards its own neuroforamen, or they remain conjoined and exit from the spine through a single intervertebral foramen. Type V is characterized by the presence of an anastomotic branch, joining two radicular nerves in their extrathecal course. The most common anom-

Fig. 2.50. *Type II nerve-root anomaly. Left oblique myelogram. The left L4 root has an abnormally caudal emergence from the dural sac and the course of the corresponding radicular nerve is more transverse than normal (arrowhead).*

Fig. 2.51. *Type III nerve-root anomaly. Left oblique myelogram. The L5 and S1 roots of the left side (arrow) emerge from the thecal sac through closely adjacent openings.*

alies are Type III and IV. They represent some two thirds of all anomalies. Type V anomaly is extremely rare.

The etiology of lumbosacral radicular anomalies is unknown. The most likely hypothesis, for Type II,III and IV anomalies, is that they occur due to a defect of migration of the nerve roots during embryonal development. Type I anomaly, particularly when bilateral, is probaby due to the abnormal way in which the involved roots emerge from the spinal cord or to an abnormal shortness of the cord (40).

Nerve root anomalies are more frequently observed in subjects showing congenital anomalies of the lumbosacral spine, particularly those with transitional vertebral anomalies. This suggests an etiologic relationship, which, however, is of unknown nature, between the two types of anomalies.

In themselves, nerve root anomalies are asymptomatic. However, the anomalous radicular nerves, particularly in Type III and IV anomalies, are less mobile than normal. In the presence of a compressive agent, such as disc herniation, they have less chances to escape compression compared with normal radicular nerves. They may, therefore, be markedly compressed and cause severe radicular symptoms, even in the presence of a small herniation.

Only rarely may the anomalous radicular nerves be compressed in a radicular canal or neuroforamen that has become moderately stenotic.

Meningeal and perineurial cysts

Three types of cystic lesions may be distinguished: extrathecal cysts and diverticula; perineurial cysts; and intrathecal arachnoid cysts.

The extrathecal meningeal cysts are dilation of the dura mater and arachnoid, developing along the radicular nerve (radicular meningeal cysts) or from the thecal sac (cysts of the thecal sac). These lesions have a more or less narrow collar and contain CSF or a denser yellowish fluid (41). Their wall is formed by fibrous tissue, lined or not by arachnoid (23, 119). On the myelogram, the wider their communication with the

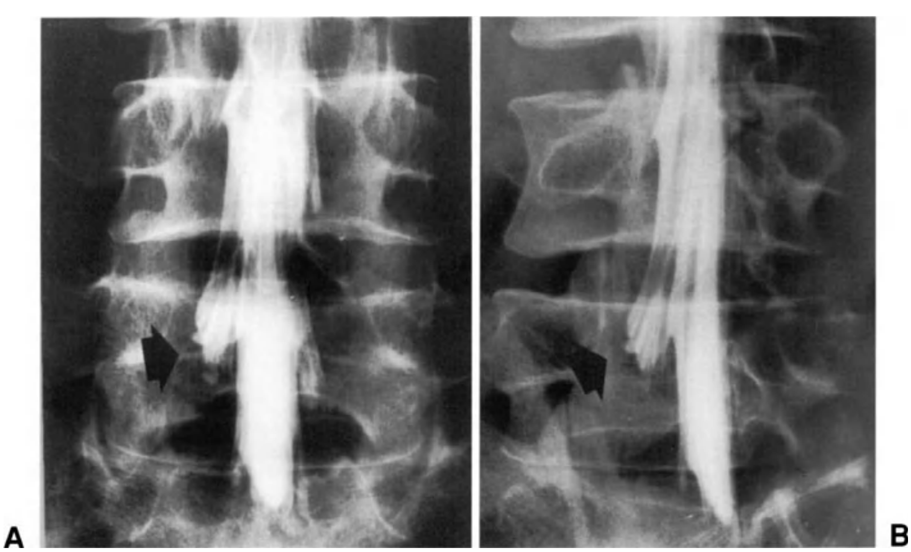


Fig. 2.52. *Type IV nerve-root anomaly. Posteroanterior and right oblique myelograms. The L5 and S1 roots (arrows) emerge from the thecal sac conjoined in a single trunk.*

subarachnoid space, the more rapidly they are filled with contrast medium.

Extrathecal meningeal diverticula are similar for structure and site to the extrathecal meningeal cysts, but they have no true collar.

Radicular meningeal cysts are often multiple (located in multiple radicular nerves) and usually are few millimeters in diameter. Only exceptionally they may become so large as to compress the radicular nerve. The cysts of the thecal sac are much more common in the sacral, than the lumbar, region. They may develop on the ventral or dorsal aspect of the thecal sac and may measure few millimeters to several centimeters. In the latter instance, they may erode the bone structures, where they produce a sort of niche, and may compress the adjacent nervous structures.

It is unclear whether the extrathecal cysts are present at birth or appear later. Elsberg (33) hypothesized that they originate from congenital dural diverticula or herniation of arachnoid through a congenital defect in the dura mater. The cysts of the thecal sac could represent a form of dysraphia, i.e., a congenital failure of fusion in the midline of the mesenchymal structures surrounding the neural tube (108). Interpreted in this sense, they would represent a variety of occult meningocele. The congenital nature of these cysts is supported by their possible familiarity (5) and their observation in neonatal life (82).

The cysts may increase in volume in adult life, but the mechanism by which this occúrs in unknown. To this regard, three hypotheses have been advanced: presence, at the level of the collar, of a valve mechanism allowing inflow of CSF when pressure of the latter increases (upright position, cough, efforts); mechanisms of osmosis through the walls of the cyst; and secretion of CSF by the arachnoid wall (21, 43).

Perineurial cysts , first described by Tarlov (117, 118), are usually located at the level of the dorsal root ganglion. They develop between the endoneurium and perineurium and their wall contains nervous fibers and ganglion cells. Sometimes they may be situated deep to the neural structure (peri-endoneurial cysts) (20). These rare cystic lesions are generally observed in the sacral radicular nerves and often are multiple. They may be few millimeters in diameter and asymptomatic, or may attain a diameter of even a few centimeters and compress the nerve from which they originate. They contain little grey-brownish fluid. Upon myelography, the perineurial cysts are not filled with contrast medium or they are filled only after a few hours. Their pathogenesis is unknown, but they are very likely not to be congenital. Their genesis could be related to hemorrhage of radicular vessels or primary degenerative changes of the neural tissue (119), or to abnormal proliferation of arachnoid elements (103).

Intrathecal arachnoid cysts are rare cystic lesions arising from the leptomeninges within the thecal sac. They may be asymptomatic or may occasionally compress, to a varying extent, the spinal cord or the caudal nerve roots.

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CHAPTER 3

BIOCHEMISTRY, NUTRITION AND METABOLISM

S. Gumina, F. Postacchini

Biochemistry

Normal disc

Collagen

The extracellular matrix of the intervertebral disc is similar, in composition and structure, to hyaline cartilage. It consists mainly of collagen, which accounts for about 50% of the dry weight of the annulus fibrosus and some 20%–30% of that of the nucleus pulposus (151). Collagen fibers, which are flexible and inextensible, offer a high resistance to traction, but not to compressive loads.

Synthesis

Tropocollagen, the macromolecular unit of collagen, is a filamentous protein (Fig. 3.1) with a molecular weight of 300,000 D, which is about 280 nm in length and 1.4 nm in thickness. It consists of three elicoidal polipeptidic chains, termed alpha, which coil around one another to form a right-handed superhelix. The molecular weight of each chain is 100,000 D. The chains are linked by hydrogen and covalent bonds. Tropocollagen has a high content of glycine (about 30%), proline and hydroxyproline (25%) and a more moderate amount of hydroxylysine. Hydroxyproline, which helps stabilize the three chains, is present in very few other protein structures and it is, thus, used as a biochemical marker for collagen. Small chains of carbohydrates are linked to the residues of hydroxylysine, which are mainly formed by galactose. Tropocollagen should be considered as a glycoprotein due to the presence of these chains. The ratio between disaccharides and monosaccharides, linked to the residues of the hydroxylysine of the nucleus pulposus collagen, is about twice that found in cartilage collagen (29, 31). Mono- or disaccharidic units probably form transverse bridges between the chains. The synthesis of each chain and hydroxylation of the proline and lysine occurs within the cell. Hydroxylation and glycoxylation processes take place before the chains coil around to form a spiral. The triple helix (procollagen) is formed in the presence of high concentrations of hydroxyproline. In the extracellular environment, each procollagen chain may lose, due to the action of collagenases, the polypeptidic extensions termed telopeptides, which are located at the extremities (amino-terminal and carboxy-terminal) of the chain. The telopeptides of a few types of collagen are removed by specific peptidases. There are at least one of these peptidases for each terminal and type of collagen. It has been hypothesized that telopeptides prevent the formation of fibers within the cell, co-ordinate the combination between the chains and control both the triple helix formation and extracellular fibrillogenesis.

Tropocollagen molecules, showing a globular head and a tail, drop between them to form longitudinal and parallel lines, being superimposed for one fourth of their length. Microfibrils with a periodicity of 64–70 nm, clearly visible under the electron microscope, are thus formed due to the periodic recurrence of the globular portion of tropocollagen. Lysine and hydroxylysine are converted into aldehydes and their

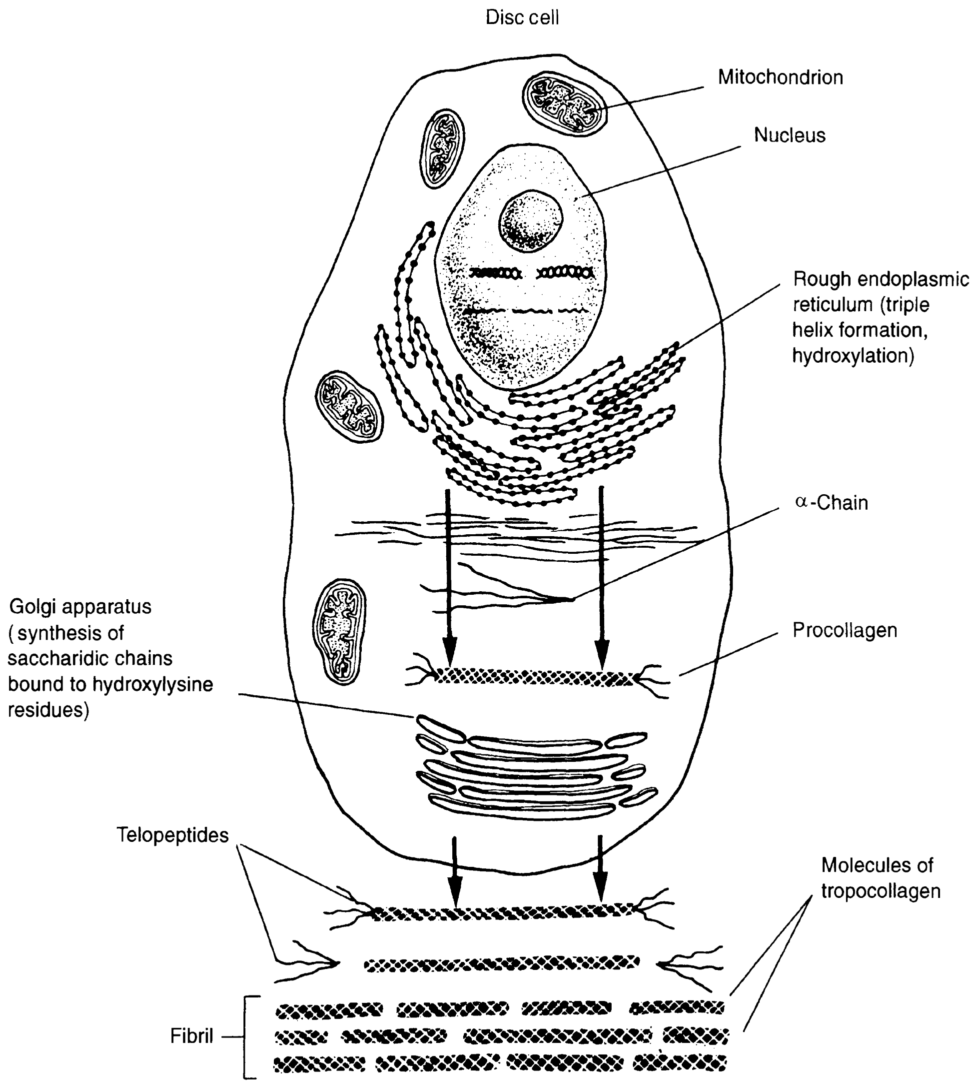

Fig. 3.1. *Schematic drawing showing synthesis, secretion and extracellular aggregation of tropocollagen molecules.*

reactions produce covalent and crossed links which bind the microfibrils to each other.

Collagen fibers can be decomposed, depending on the resolution of the different means of investigation, into 40-nm thick microfibrils, 0.2- to 0.3-μ fibrils or 1 to 12-μ fibers.

The amount of collagen present in the normal adult annulus fibrosus increases from L2-L3 to L5-S1 disc (3).

Collagen types

Fourteen types of collagen have been recognized (104, 159), which differ from one another in the amino acid sequence of the tropocollagen chains. Type I, II, III, V, IX, and XI collagens have been isolated from the normal intervertebral disc by immunohistochemical methods. However, types I and II account for 80% of the collagen in the intervertebral disc.

Type I collagen is present in all layers of the annulus fibrosus and in the transitional zone (14, 129). It is particularly concentrated in the outermost layer of the annulus (80%), decreases in the inner annular layer and is absent in the nucleus pulposus (14). Since the synthesis of this type of collagen depends on two structural genes, the triple helix consists of two different alpha chains $[\alpha 1(I)]_2\alpha 2(I)$. Type I collagen shows a low content of simple or glycosylate hydroxylysine and forms thick fibers with a clearly visible periodicity. By contrast, type II collagen has a high content in hydroxylysine and the fibers that it forms are thin and have very few visible periodic bands. Type II collagen is produced by a single gene and is usually indicated with the formula $[\alpha 1(II)]_3$. This collagen type is particularly concentrated in the nucleus pulposus, but it is present, even if in decreasing amounts, in the transitional zone and in the inner and outer layers of the annulus fibrosus (14, 129). In type II collagen fibers, the interfibrillar spaces are wider, and the water content is thus higher than in type I collagen fibers. Therefore, type II collagen fibers have a greater ability to undergo deformation and to withstand compressive load (90). Bailey et al. (6), studying the different forms of bonds linking the tropocollagen chains, observed that the proportion of cross-links OH-LNH and HHMD (histidinohydroxy-merodesmosine), which are more typical of type I, than type II, collagen, appeared to be greater in the lower, than the upper, spine. This suggests that type II collagen is more abundant in these discs, which are those submitted to the greatest mechanical load.

Type III collagen $[\alpha 1(III)]_3$ has a low content of simple and glycosylate hydroxylysine, and a high rate of hydroxyproline. Its chains are linked by numerous disulphide bonds. The carboxylic terminal of type III collagen maintains the telopeptides, which might have the role of hindering the formation of thicker fibers. In a study on the disc tissue and cartilage end-plate of man, rat and calf using immunolocalization techniques, it was observed that antiserum to type III collagen produces a concentric pericellular staining, which is often irregular in shape (129). In this study, type III collagen was found in the pericellular and territorial matrix and, occasionally, in the pericellular capsule of the chondron. The latter is formed by a cartilaginous cell surrounded by pericellular matrix (lacuna), pericellular capsule and territorial matrix. In human intervertebral disc, the rate of type III collagen is higher than in the bovine disc. This type of collagen, as well as type VI collagen, are found in proximity to calcium pyrophosphate crystals in three normal discs of a human subject.

In the annulus fibrosus, type V collagen, which presents a high content of simple and glycosylate hydroxylysine, was found to be associated with type I collagen. It represents 3% of the entire collagen in the annulus fibrosus (30, 151).

Type VI collagen was found in the capsule and pericellular matrix of the chondron (129). Molecular lateral aggregates of type VI collagen lead to the formation of a band with a periodicity of 100–110 nm, as observed in cultures of skin and tendon fibroblasts (12, 13). Fibers with this periodicity have at times been observed in the nucleus pulposus (16, 20). Aldehyde-mediated cross-linking residues have not been found on direct analysis in type VI collagen, whilst they have been observed in other types of collagen (165). In the bovine intervertebral disc, type VI collagen is unusually abundant; in the calf, it accounts for 20% and 5% of total collagen in the nucleus pulposus and annulus fibrosus, respectively.

Type IX collagen has a pericellular distribution and it has been observed both in the nucleus and annulus and, in the latter, particularly in the inner layer (30, 129). This type, which represents 1%–2% of disc collagen, was found to be closely associated with type II collagen (160, 164). Roberts et al. (129) extracted type IX collagen from rat and bovine, but not from normal human, intervertebral disc. This could be due to the fact that, in the human disc, it is masked by other macromolecules not removed by digestion with hyaluronidase. It was also hypothesized that type IX collagen occurs in different forms in the intervertebral disc and cartilage end-plate, as occurs in chick cartilage and cornea, due to a variation in transcription start sites on a same gene (129).

Type XI collagen was found in the nucleus pulposus associated to type II collagen (30). It represents about 3% of disc collagen (30).

Disc collagen fibers have many functions: they bear compressive loads and are submitted to tensile strengths; they form a network, in the meshes of which the proteoglycans are located; and they stabilize the gelatinous tissue of the nucleus pulposus and anchor the disc to the cartilage end-plate. These functions are mainly carried out by type I and II collagens. The higher percentage of type II collagen in human intervertebral disc with respect to the bovine disc might be due to the greater compressive load to which the human spine is submitted (30). Little is known, instead, concerning the function of the other types of collagen. Since type III and VI collagens are present in the pericellular and intercellular matrix and the pericellular capsule of the chondron, it has been hypothesized that they might act as strain sensors within the tissue, enabling the cell to respond metabolically to a mechanical stimulus (11, 129). Staining of the chondronic capsule, in fact, is more intense in the nucleus pulposus and the middle and deep zones of the articular cartilage, which are submitted to compressive load, than in the annulus fibrosus and superficial zone of cartilage, where tensile stresses prevail. Type III and VI collagens of the chondronic capsule might have the role of maintaining a constant microenvironment around the cell, by selectively retaining some molecules. Thus, these types of collagen might retain pericellular proteoglycans in order to control osmotic pressure around the cell and, thus, the vitality of the latter (106).

The role of type V collagen remains to be elucidated. However, the fact that it is closely associated with type I collagen suggests that type V collagen might play a role in regulating the spatial orientation and dimensions of type I collagen. Type IX collagen might have a similar role to that of type II collagen.

Little is known concerning the role of type XI collagen.

Proteoglycans

Structure and distribution

Proteoglycans, or protein-mucopolysaccharidic complexes, are polymers with a molecular weight of 50,000 to 10 milion D. They are formed by a 100–150 nm long protein core, with a molecular weight of 200,000 D, to which lateral sulphorate glycosaminoglycan chains (molecular weight about 20,000 D), at a distance of 3–5 nm from one another, are covalently bound (151). Synthesis of the protein component occurs in rough endoplasmic reticulum, while formation, conjugation and sulphatation of the glycidic component is performed in the Golgi apparatus. Disc proteoglycans have a greater amount of proteins than cartilage proteoglycans. In fact, the dry weight of proteoglycan proteins extracted from the human nucleus pulposus is 14% of the entire weight (58), whilst the dry weight of the protein component in larynx and nasal septum proteoglycans is only 7% (55, 149). From childhood to adult-senile age, the protein component increases from 25% to 59% in the proteoglycans of nucleus pulposus and from 35% to 51% in those of annulus fibrosus (44).

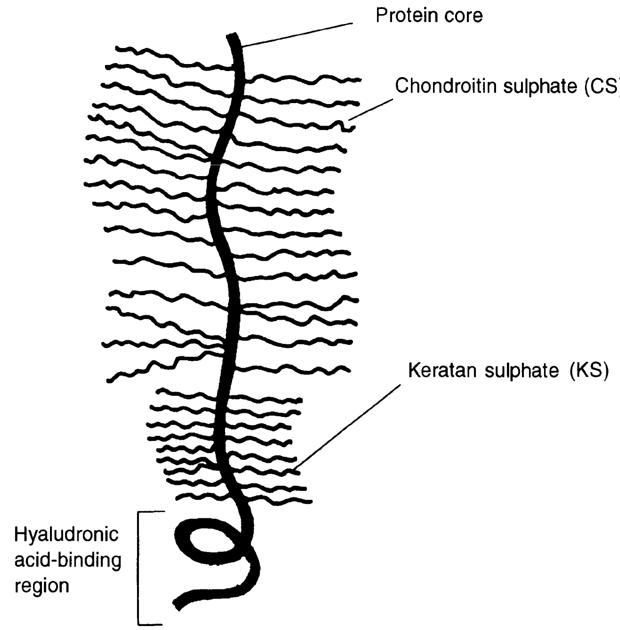

Fig. 3.3. *Schematic drawing of a proteoglycan. It is formed by a protein core to which sulforate glycosaminoglycan chains are covalently bound. One of the two free extremities of the protein core may be linked to a molecule of hyaluronic acid.*

Glycosaminoglycans are represented by chondroitin sulphate (CS), keratan sulphate (KS) and, in elderly subjects, by dermatan sulphate (22, 96) (Fig. 3.2). CS and KS occupy different regions in the molecule (Fig. 3.3). The CS chains are linked to an extremity of the protein core (CS-rich region), always in proximity to a serine residue (130). CS includes chondroitin-4-sulphate (C-4-SO4) and chondroitin-6-sulphate (C-6-SO4). In the intervertebral disc and articular cartilage, their ratio varies with age. In the intervertebral disc, the ratio between C-4-SO4 and C-6-SO4 is about 2:1 at 1 to 4 years (17), whilst C-4-SO4 prevails at 60 to 80 years (17, 103). However, the age-related changes in the ratio between the two chondroitins in nucleus pulposus and annulus fibrosus remain to be fully elucidated. KS occupies the intermediate region of the protein core (keratan sulphate-rich region); it seems to be linked to serine and threonine residues by N-acetylgalactosamine (9). The other end of the protein core, showing no glycosaminoglycan chains, is termed the hyaluronic acid-binding region. In fact, proteoglycans may be either in the form of monomers (protein core and mucopolysaccharidic lateral chains) or as large macromolecular aggregates represented by monomers not covalently bound to a long hyaluronic acid molecule (53, 54, 84, 147, 148) (Fig. 3.4). The link is stabilized by protein complexes (link proteins) (35, 49), which make the aggregate more resistant to pH changes, rise in temperature or an increase in urea concentration (49).

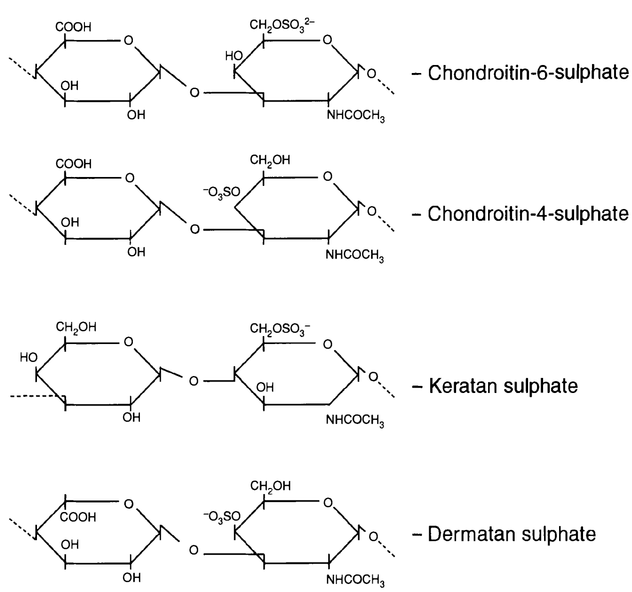

Fig. 3.2. *Disaccharidic units of glycosaminoglycans of disc proteoglycans.*

Disc link proteins (LP) were first observed by Tengblad et al. (146) in moderately degenerated intervertebral discs of elderly subjects (grade 2 of Lewin's classification). These authors found that the LP in the disc have less ability to aggregate proteoglycan monomers to hyaluronic acid than those in the articular cartilage, probably because, in vitro, the biophysic

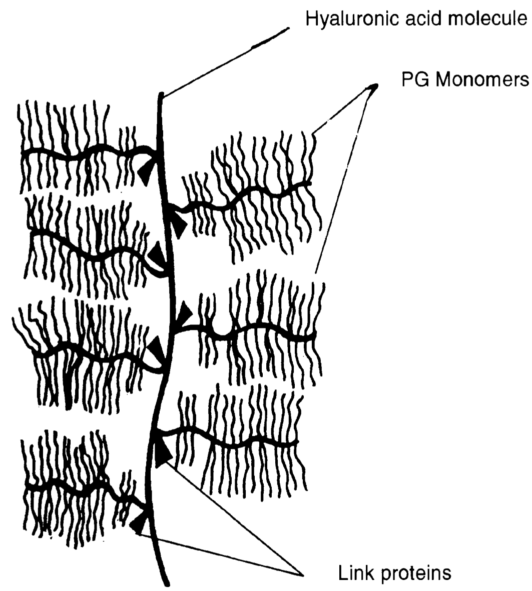

Fig. 3.4. *Model of aggregated proteoglycans. They consist of monomers bound to a hyaluronic acid molecule. The link is stabilized by protein complexes (link proteins).*

conditions differ from those normally present in the disc in vivo. In neonatal cartilage, three subpopulations of LP–LP1, LP2 and LP3 – have been found. They are glycosylated to various extent, in particular LP1 > LP2 > LP3. In situ enzymatic digestion of LP1 and LP2 produces LP3 (111). The study on LP from cadaver discs of postnatal and young adult subjects has shown that LP1 prevails in postnatal tissue, whereas LP3 predominates in the young adult disc (27). This finding is not in keeping with observations in the articular cartilage of subjects aged 50–70 years, in whom LP1 and LP3 have comparable concentrations. The proportion of LP1 is as high as 63% in neonatal disc, whilst it is 26.5% and 45%, respectively, in young adult disc and elderly human articular cartilage. By contrast, LP3 is the minor component in postnatal disc tissue (11%), however, not in young adult disc (59.7%) and elderly human articular cartilage (37%). These data suggest that LP of human intervertebral disc undergo degradation with aging. This hypothesis is supported by the presence of peptide fragments originating from degradation of LP and proteoglycans in young adult, but not in postnatal, disc tissue. In adults, accumulation of catabolic products might prevent the chondrocytes from responding to feedback signals which stimulate synthesis of proteoglycans and LP and this might affect the ability of disc tissue to respond to biomechanical stress.

The ratio of monomer to aggregate proteoglycans changes not only with advancing age, but also in different areas of the disc; the amount of monomers, in fact, is higher in the nucleus pulposus (2, 5, 93, 126). With aging, proteoglycans lose, or undergo a decrease in, their aggregating ability. This may be due to: the inability of the newly-synthesized proteoglycans to interact with hyaluronate; the physiologic decrease in hyaluronic acid in the disc; or the reduced ability of proteoglycans to interact with hyaluronic acid (3). As a result, monomers could be degraded by enzymes released in the matrix by necrotic cells. Neutral and acid proteases might attack the protein core (116) or the LP that stabilize the complex (45). Melrose et al. (108) found that lysozyme may affect, in vitro, the shape and aggregating ability of proteoglycans.

The functional significance of the ratio of monomer to aggregate proteoglycans is not yet understood. It has been suggested that aggregation keeps the proteoglycans in the tissue, since there is no evidence that strong bonds exist between proteoglycans and other matrix components (151). However, according to Eyre (29), KS rich regions are able to firmly bind to the surface of collagen fibers or to glycoproteins which are linked to them. CS-rich regions, on the other hand, might have the role of maintaining collagen fibers separated from each other, thus increasing the elastic properties of the tissue.

With advancing age, proteoglycans decrease in size, possibly due to degeneration of the CS-rich region and the loss of hyaluronic acid-binding region (57, 59). The resulting molecule is reach in KS, is of smaller size and has a higher ratio of glucosamine to galactosamine.

In the articular cartilage, hyaluronic acid accounts for less than 1% of total uronic acid (51, 53); therefore, the molar ratio glucosamine/galactosamine essentially reflects that between KS and CS in the proteoglycans (3).

KS-rich proteoglycans have been found in the annulus fibrosus of discs from elderly subjects, probably due to increased synthesis of proteoglycans rich in KS; greater resistance to enzyme degradation with aging; or selective diffusion of the smaller CS-rich species out of the tissue (19). The two former hypotheses are more likely, since, in the human intervertebral disc, the KS-rich region of the proteoglycan protein core displays a greater resistance to proteolysis than the CS-rich region. Davidson and Small (21) reported that, in the rabbit nucleus pulposus, KS has a slower turnover than CS. Lohmander et al. (92), however, found the half-life both of KS and CS to be 30 days.

The amount of KS in the human adult disc depends on disc level. Adams and Muir (3), in fact, have found a lower concentration of KS in the lowermost lumbar discs.

The monomers are smaller and more polydispersed in the intervertebral disc than in the articular cartilage (29, 151) and, compared with the latter, present a short-

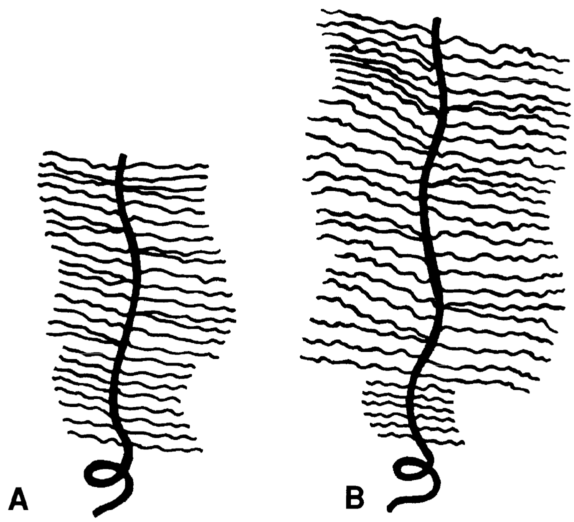

Fig. 3.5. *Proteoglycan monomers of the intervertebral disc* (A) *are smaller than those of the articular cartilage* (B). *Furthermore, the protein core and the CS chains are shorter, whilst the KS chains are longer.*

er protein core and CS chains, and longer KS chains (74) (Fig. 3.5).

The amount of proteoglycans increases from the outer layer of the annulus to the nucleus pulposus (50, 142). In fetal and newborn nucleus, the proteoglycan rate is two- to three-fold compared with that in the annulus fibrosus (7). The latter, when immature, synthesizes five times more proteoglycans than the adult annulus. In micro-autoradiography studies on immature rabbit discs using labeled sulphate, the highest incorporation of radioisotope was observed in the peripheral portions of the nucleus and the inner two thirds of the annulus fibrosus (137). Histologic studies have shown that in the immature annulus fibrosus the most active cells are those located in the inner annular layers (7). On the other hand, in human annulus fibrosus, the cells producing the greatest amount of proteoglycans are those located between the outer and inner layer. However, the high level of biosynthetic activity in this area does not appear to be related to the number of tissue cells, the degree of hydration or the amount of proteoglycans already present (155). Furthermore, proteoglycans in the nucleus pulposus differ from those in the annulus fibrosus. The KS/CS ratio is higher in the nucleus, whereas the amount of monomers able to form aggregates is higher in the annulus fibrosus (3). In the adult, 40% of the proteoglycans in the annulus fibrosus may aggregate, compared with only 15% in the nucleus pulposus (151). In the young disc, the respective percentages rise to 60% and 25%. Instead, in the articular cartilage of the hip joint, 80% of proteoglycans are able to aggregate (78).

Proteoglycan turnover is relatively faster in the young, than the elderly, disc. Studies on the discs of rabbit and guinea pig aged a few weeks have shown that the CS half life time is less than 30 days (92), whilst in adult rabbit and dog the half life time is 120 days and 2–4 years, respectively. In the annulus fibrosus of human adult disc, the mean proteoglycan turnover is over 2 years (151). This findings suggest that there are structural differences between proteoglycans from different species and organs. For instance, LT proteoglycans, which have the ability to bind to type IX collagen of the chondron capsule by a disulphide bridge, have never been isolated from the normal human disc, but have been isolated from chick embryo cartilage (119).

Chromatographic and electrophoretic studies

Di Fabio et al. (24) submitted the proteoglycans extracted from nucleus pulposus and annulus fibrosus of three subjects aged 64, 67 and 72 years to chromatography (Sepharose CL-2B) and obtained six and three pools from nucleus pulposus and annulus fibrosus, respectively. The six pools from the nucleus correspond to: aggregate proteoglycans (pool 0); a mixture of aggregate and non-aggregate proteoglycans (pool 1); and non-aggregate proteoglycans (pools 2, 3, 4, 5) containing equimolar amounts of hexuronate, however, with decreasing hydrodynamic volume. The fractions corresponding to pools 2–5, obtained by the chromatographic analysis of the annular proteoglycans, showing a greater proportion of aggregating proteoglycans, were grouped in a single pool. Subsequently, each proteoglycan pool was submitted to electrophoretic analysis, which showed two or more distinct bands. Previous electrophoretic studies on baboon (140) and human (105) discs had revealed only three bands. For human discs, two bands were attributed to aggregate, and one to non-aggregate, proteoglycans. Instead, Di Fabio et al. (24) have found three bands for non-aggregate proteoglycans. According to these authors, bands I and II correspond to the two distinct subpopulations of aggregate proteoglycans demonstrated by McDevitt et al. (105) and refer to 0 and 1 pools. Band III was found in pools 3–5, band IV in pools 4–5, and band V only in pool 5. Pool 2 had an intermediate mobility between bands II and III. KS is the most abundant glycosaminoglycan present in band III proteoglycans, whilst CS is scarcely. By contrast, band IV proteoglycans contain primarily CS and only little KS. Band V contains CS alone and differs from the corresponding proteoglycanic pool due to the low protein content (60). The composition of the protein core in band III differs from that in band IV. No differences have been observed between nucleus pulposus and annulus fibrosus as far as concerns these two bands, except for the larger amount of KS in band III from the annulus. Band III contains more threonine and proline than band IV, whereas the latter, which is rich in CS, contains more serine and glycine compared with band III. The latter might be a fragment arising from a proteoglycanic region near the hyaluronate-binding region, and this might account for the high content in KS; band IV might represent a fragment from a portion of the molecule remote from the hyaluronate-binding region, since it is rich in CS; and band V might be a short portion of the protein core.

Jahnke and McDevitt (77), in an electrophoretic study of proteoglycans extracted from discs of human subjects aged 17, 20 and 21 years, found that non-aggregate proteoglycans migrate as a single band. This finding, observed in younger discs than those analyzed by Di Fabio et al. (24), led to the hypothesis that disc aging is associated with changes in the catabolic and/or synthetic mechanisms that give rise to a different set of non-aggregate proteoglycans. With aging, in fact, a decrease in proteoglycans has been observed (19), which precedes degeneration of the nucleus pulposus (124).

Function

Glycosaminoglycan chains have a negative charge, and are, thus, able to bind organic and inorganic cations and proteins. CS and KS contain the negative charges in the sulphate and carboxyl groups. CS has two charges per disaccharide, whereas KS averages one (151). Therefore, the amount of negative charges in the matrix–fixed charge density (FCD) – depends not only on the concentration of proteoglycans in the tissue, but also on the CS/KS ratio. The negatively charged components of the matrix affect both the distribution of the solutes with a positive or negative charge (100) and the osmotic pressure and, thus, the fluid contents of the disc. Ions and other solutes are distributed as to form an equilibrium (Gibbs-Donnan equation) between the plasma and the disc matrix; therefore, due to the definitely negative electric charge of the disc tissue, the total number of ions in the disc is consistently higher than in the plasma (156, 157). Since osmotic pressure depends on the difference between the number of particles dissolved in the plasma and those contained in the disc, the large number of ions in the disc endows the latter with a high osmotic pressure (156). The latter also depends, although to a lesser extent, on the morphologic characteristics of the proteoglycans, which, in turn, are affected by the electric charge of the electrolytes bound to the acid mucopolysaccharides. In fact, proteoglycans can be transformed from the elongated, to the entangled, shape by changing the solution viscosity. When entangled, they form a tridimensional network, which occupies a considerably larger volume termed "dominion" or "excluded volume", since all the other molecules are excluded from it. Thus, disc resistance to compression depends on the dominion occupied by proteoglycans, as well as on the collagen fibers.

The FCD of the nucleus pulposus in the adult lies between 0.2 and 0.4 mEq/ml and osmotic pressure ranges from 0.1 to 0.3 mPa (1 to 3 atm) (158). Osmotic pressure is lower in the annulus fibrosus than the nucleus pulposus, but is considerably higher compared with that in non-weight-bearing tissues.

In the intervertebral disc, cation concentration is higher than in the plasma. Sodium can reach values of 300 to 400 mM. Its distribution varies in different disc areas, with aging and with the degree of hydration of the disc (85, 86). Divalent cations, such as magnesium and calcium, are even more sensitive to proteoglycan content and may reach concentrations as high as 10 times that in the plasma (101). By contrast, anions are affected by FCD and reach, as in the case of chloride, concentrations less than half of that in the plasma.

Macromolecule solute distribution depends both on the proteoglycan charge and the "partition coefficient", i.e., the concentration on a molal basis in the disc matrix, relative to the concentration in the surrounding fluid or plasma. For instance, glucose, which has a molecular weight of 200, is partially excluded from the disc, since its partition coefficient is only 0.7 to 0.8 in the nucleus pulposus (153). On the other hand, solutes of larger size, such as serum albumin (molecular weight 60,000–70,000), may have lower partition coefficients (0.01–0.001) (151).

FCD also influences the disc response to mechanical loads, since the disc resists pressure exerted on it and packing of the tissue with the repulsion force which develops between the negative charges of glycosaminoglycans (151).

Water

Water is the major component of the intervertebral disc. Due to the few cells in the disc tissue, most of the water is extracellular and is associated with collagen and proteoglycans (66).

In the young, 85%–90% of nucleus pulposus and 78% of annulus fibrosus consist of water (90). The water content of the disc decreases with age: in senile age, water represents 70% of the nucleus pulposus and annulus fibrosus (29, 44, 90).

Much of the information on the biochemical and mechanical properties provided to the disc by its water content, stems from studies performed primarily on fragments of intervertebral discs obtained at surgery or autopsy. However, it must be borne in mind that discs removed 12–36 hours after death usually have a greater fluid content in the nucleus pulposus and a lower content in the annulus fibrosus compared with disc tissue excised at surgery (79). After death, in fact, the exchanges of fluids between the cartilage end-plate and intervertebral disc are interrupted (63, 120) and, thus, the water balance occurs only as a result of intradiscal redistribution and diffusion from and to the tissues surrounding the annulus fibrosus. Furthermore, a prolonged immobilization of the patient in bed, before death, may affect the water content of the disc. Disc hydration, in fact, depends on reciprocal perfusion between disc tissue and cartilage end-plate, and is partially influenced by the external pressure exerted on the disc by body weight, spatial position of the spine and muscle action (86, 112, 163). The disc expells water when submitted to loading and draws it from the adjacent vertebral bodies when the load is removed. This may explain why nocturnal bed rest, and the resulting intradiscal water imbibition, can lead to recovery of even a few centimeters in body height, which, in turn, are lost in the daytime, when discs are submitted to loading.

Disc hydration depends on the difference between the hydrostatic and osmotic pressure. The latter is influenced by the proteoglycan rate in the matrix. However, in vitro, intervertebral disc cells are able to synthesize large amounts of proteoglycans only if they are submitted to a hydric equilibrium comparable to that present in vivo (8). Therefore, water content of the disc depends on proteoglycan concentration, but, in turn, regulates the synthesis of the latter.

The proteoglycan-collagen complex, compared to collagen alone, is able to withhold much larger amounts of water (25, 90).

Noncollagenous proteins

Noncollagenous proteins (NCP) of the disc are those proteins not involved in the formation of collagen fibers. Thus, NCP also include elastin and enzymes, which, however, we have analyzed separately.

NCP have been observed in the nucleus pulposus and annulus fibrosus at all ages and in both genders (144). They have been found, in varying amounts, in adjacent discs and in different areas of the same disc (42, 144). In the nucleus pulposus, NPC were found to be more abundant than in the annulus fibrosus (23).

Fricke (36) and Fricke and Hadding (37) have isolated albumin, α1-glycoprotein, γ-globulin and transferrin from the nucleus pulposus of human intervertebral discs; the same proteins, except for α1-glycoprotein, have been extracted from annulus fibrosus. In effect, some of these NCP are glycoproteins. They are particularly abundant in the nucleus pulposus of elderly patients and contain large amounts of sialic acid (43) and mannose (125). Ghosh et al. (40) maintain that some of these glycoproteins are the so-called "link proteins", which are involved in the aggregated proteoglycan formation; other NCP, in particular some glycoproteins, might form a sort of primary framework for the subsequent deposition of correctly orientated collagen fibers. At roentgendiffraction, NCP are poorly crystalline, however crystallinity varies in different areas of the same disc (144). It is still unclear whether the dyshomogeneous crystallinity is the result of different mechanical loads to which the disc is submitted in different areas or whether disc mechanical properties depend also on the amount and quality of NCP dyshomogeneously distributed in the disc. The latter hypothesis appears to be more feasible, since a different crystallinity of NCP has been found in the matrix of other cartilaginous tissues submitted to high load, such as the menisci (145).

Elastin

Elastin forms elastic fibers, which, in the disc, are few in number and irregularly distributed (15, 109, 128). Probably, the function of the elastic fibers is to permit disc shape recovery once the deformation produced by a mechanical agent ceases (29).

Elastin amounts to 1.7% ± 0.2% of the dry weight of the human intervertebral disc (109). This percentage is markedly lower than that found in human ligamenta flava (46.7% ± 0.9%) (109), where the elastic fibers are 10 times as thick as those in the disc. Quantitative analysis of elastin from 59 discs of subjects aged 10–71 years (average 43 years) showed no significant differences between the annulus fibrosus and nucleus pulposus, whilst ultrastructural studies have revealed that the elastic fibers in the nucleus and annulus are different both in shape and orientation (15, 20). Furthermore, the elastin content is comparable in both sexes and does not change significantly with age.

Disc elastin has a different amino acid composition compared with that from other human tissues, such as aorta wall, achilles tendon, joint capsule, ligamentum nuchae and ligamenta flava (109, 135). It has both a higher concentration of diamino-monocarboxylic amino acids (histidine, lysine, arginine), the aminic extragroups of which enhance ionic bond formation, and threonine and serine, the oxydrilic groups of which take part in hydrogen bond formation (99). Disc elastin has a lower concentration of alanine, valine and leucine than elastin in the ligamenta flava; this may be due to the fact that these amino acids, rich in lateral hydrophobic chains, are poorly represented in proteins of highly hydrated matrixes which are very rich in water, such as disc matrix. Proline, glycine and alanine are the most common amino acids in the elastin of disc and ligamenta flava (109).

Enzymes

Collagenolytic enzymes, which are known to be produced, in different amounts, by connective tissue cells, are the most common enzymes in human intervertebral disc (134). Little information is available on the role played by this family of enzymes in the normal disc. Harris et al. (52), in a study on collagenases produced by fibroblasts or leucocytes of non-discal tissues, found the two enzymes to have a higher activity towards type III and type I collagen, respectively. Instead, both collagenases were poorly active towards type II collagen. The level of activity of disc collagenase against different collagen types or the characteristics of the collagenolytic enzymes produced by the different types of disc cells are still unknown.

Disc collagenase displays the greatest activity against type II collagen, whilst the activity towards type I collagen is low (117). The mean value of activity of nucleus pulposus collagenase towards type I collagen is similar to that found for annulus fibrosus and transitional zone collagenase (117). No significant differences in collagenase activity have been found between the various lumbar discs (117). Gelatinase, which belongs to the metalloproteinase family (MMPs) as collagenase, further breaks down the products of collagenase digestion.

Disc proteinases have similar characteristics, such as the greatest activity at pH 7.4–7.6, the property to be inactivated by class-specific inhibitors and an activity dependence on tissue NaCl, lysine and calcium concentrations (107). Some proteinases exert a breakdown effect on the bonds between proteoglycans and hyaluronic acid chains, whilst others, such as stromelysin (MMP-3), act on the proteoglycan protein core. In the normal disc, a perfect equilibrium exists between neutral proteinases and endogenous inhibitors. The possible excess of inhibitor activity decreases the proteoglycan amount and leads to disc degeneration. It has been hypothesized that proteinases are activated by cell membrane-bound activators (107). This suggests that disc cells are able to form a microenvironment, which might regulate the exchange of solutes and catabolites with the pericellular matrix, thus creating ideal osmotic and electric conditions.

Lysozime, which is a basic protein with a low molecular weight (14,000 D), normally present in chondrocyte lacunae and close to the intracellular lysosomes of non-cartilaginous tissues, has been found in the human intervertebral disc and in the disc of immature dog (28, 136). The level of intradiscal lysozime and its degree of activity increases with age (108). The enzyme displays a bacteriolytic action (33), which is enhanced by complement proteins, which succeed in entering the disc through the cartilage end-plate only when the latter has undergone bacterial damage. In this case, complement proteins, together with lysozime, form a potent bacteriolytic complex, which makes the tissue sterile. This could explain why the tissue obtained from discs in an advanced stage of infection may be sterile (108). Lysozime acts as an antagonist in the formation of bonds between proteoglycans, hyaluronic acid and link proteins; in this way, it might control the amount of aggregated proteoglycan in the disc tissue (108).

Degenerated disc

Our knowledge of the biochemical characteristics of the degenerated disc is based on studies usually carried out on a limited number of discs, often obtained at autopsy and with an undefined degree of degeneration. Furthermore, it is unclear which biochemical process takes place first. For example, solute diffusion, which is indispensable for disc nutrition and cell viability, depends on a mutual relationship between collagen, proteoglycans and water content; however, this relation is preserved only if a reasonably cellular function persists, typical of non-degenerated tissue. The enzymatic mechanisms responsible for the calcification process remain to be elucidated. In fact, it is unclear whether micro- or macrocalcification, which are often present in the matrix of the degenerated disc, result from an initial biochemical change or whether they themselves contribute to disc tissue degeneration by hindering normal solute diffusion.

However, it is difficult to establish the boundaries between physiologic tissue aging and degeneration.

Collagen

The amount of collagen in the intervertebral disc increases progressively with increasing age. This structural change in the disc has been known for many decades (22, 48, 110) and may offer an explanation for some of the macroscopic changes related to aging, such as loss of the gelatineous appearance of the nucleus pulposus and the decrease in the clear-cut distinction between nucleus and annulus fibrosus.

Discovery of new types of disc collagen and the introduction of new techniques, able to locate and calculate the amount of each collagen type, have allowed us to advance new hypotheses on the etiopathogenesis of disc degeneration. With aging, type I collagen considerably increases, particularly in those areas of the disc and cartilage end-plate showing the most severe degenerative changes (31, 129). Electrophoretic studies have shown an increase also in type II collagen (29). However, immunohistochemical investigations have demonstrated that, in the degenerated disc, the amount and distribution of type II collagen are comparable to those in the normal disc (129).

In the interterritorial matrix of degenerated discs (grade III–V according to Galante's classification), type III collagen was found to be much more abundant than in the normal disc (129). Antisera to type III collagen occasionally form irregular concentric rings around the cells. This suggests that the cells in the degenerated tissue produce type III collagen in a periodical way and in response to various mechanical stimuli (129). Chromatographic studies carried out on degenerated discs of an elderly subject have shown type III collagen in the outer portion of the anterior annulus fibrosus, however not in the control disc of a young subject (1).

Type IV collagen was found only in the degenerated disc, in particular in the walls of the blood vessels which are often present in the outer annulus fibrosus (162, 167).

Antiserum to type VI collagen, as well as that to type III collagen, forms irregular concentric rings around the cells. Furthermore, type VI collagen is also located around the intradiscal blood vessels present in the degenerated annulus fibrosus. The presence of type IV and VI collagens in, or close to, the walls of blood vessels is probably due to an attempt to occlude their lumen. In the interterritorial matrix, type VI collagen was often found in smaller amounts than in the normal disc (129).

Type IX collagen has been observed in few specimens, always in proximity to cells or a Schmorl's node (129).

No significant information is available on the possible qualitative and quantitative changes in the other types of disc collagen.

Proteoglycans

In degenerated discs, proteoglycan concentration considerably decreases with respect to that in control discs of similar age (48, 64, 110, 115, 158) and the reduction is directly related to the degree of degeneration (124).

Bayliss et al. (8) have shown that, in vitro, the rate of proteoglycan synthesis changes as a function of disc tissue hydration. This phenomenon is more evident in the nucleus pulposus. However, these authors do not clarify whether in the degenerated disc the reduced proteoglycan amount is the result or the cause of disc dehydration. In fact, proteoglycan amount and shape affect osmotic pressure, FCD, viscosity and water content of the disc. In the degenerated disc, proteoglycan amount and shape considerably change. Electric charge is also modified, due to the greater CS concentration of the newly-synthesized proteoglycans (66). Furthermore, the ability of the newly-formed proteoglycans to form aggregates is higher than that of proteoglycans already present in the degenerated disc, since some enzymes, normally present in the disc, have not yet removed or altered the hyaluronic acid-binding region of the proteoglycan protein core (3, 18, 95). The larger dimensions of the proteoglycans in the degenerated disc might be due to: a more rapid proteoglycan turnover with a faster synthesis of new large aggregating proteoglycans (98); or the difficulty for large aggregating proteoglycans to diffuse out of the disc (151). However, it is possible that the greater size of proteoglycans is only apparent; in fact, the low number of small lateral chains of glycosaminoglycans makes proteoglycans appear larger in size (66).

Newly-formed proteoglycans are similar, as far as concerns composition and shape, to those in non-degenerated young discs. Thus, a few authors (18, 43, 95) believe that the changes in proteoglycan structure result from a faster turnover of these molecules is an attempt at tissue repair.

In intervertebral discs of mice with hereditary kyphoscoliosis, a higher proteoglycan synthesis was observed in degenerated vertebral segments and in the areas showing a low number of cells (161). This suggests that a larger amount of proteoglycans is synthesized by the remaining cells, probably as a result of the abnormal mechanical stress to which the disc is submitted. Increase in proteoglycan synthesis was also observed in rabbit (91) and human (95) degenerated discs.

Ghosh et al. (41) maintain that the decrease in proteoglycans and increase in collagen in the degenerated disc are due to a change in biomechanical condition, inducing the cells to synthesize a cartilage-like matrix more suitable for supporting compressive loads. Thus, the decrease in proteoglycan content would not be the result of an accelerated process of aging, but an attempt at tissue remodeling.

Water

The decrease in water content is one of the most typical features of disc degeneration. Due to the mutual control between water and proteoglycan contents, it is still unclear whether the decrease in water occurs primarily or is the result of the reduction in proteoglycan con-

Table 3.1. *Scheme of the biochemical changes in herniated disc tissue*

Increase in concentration or activity	* Collagen * Proteoglycans (DS) * Noncollagenous proteins IgG, IgM Cytokine: * IL-1 → bFGF (basic fibroblast growth factor) → Vascular neogenesis Cytokine: * IL-1 → NO (nitric oxyde) → Vessel dilation Enzymes Collagenolytic: type I collagen Gelatinase Elastase * Metalloproteinases (MMP-1; MMP-3) * Peroxidase → * Lipofuscin ? → * Amyloid Phospholipase A2 (132) → Arachidonic acid Cyclo-oxygenases | Lipoxygenases Prostaglandins G2; H2 / Leukotrienes — Chemical mediators of inflammation
?	Elastin
Decrease in concentration or activity	* Proteoglycans (CS; KS) * Water Collagenolytic enzymes: type II collagen * TIMP-1 (tissue inhibitor of MMP-3)

*Changes present also in degenerated non-herniated disc. DS : dermatan sulphate; CS : chondroitin sulphate; KS : keratan sulphate.

centration, which is typical of the degeneration process. It has been hypothesized that the decreased water content alters the intradiscal hydrostatic pressure; this would lead to considerable mechanical and hydrostatic changes, able to favor the formation of annular tears. Furthermore, the decrease in water negatively affects the process of diffusion of solutes throughout the intercellular matrix, which is already altered due to the decreased peridiscal blood supply related to aging. The result is a low intradiscal oxygen tension, which is responsible for an increased lactate production by the cells and accumulation of it in the extracellular matrix. This leads to a reduction in pH level in the tissue, which causes first metabolic and biosynthetic cellular changes and then cell death (14).

Grynpas et al. (47) maintain that, in the degenerated disc, water is located, to a large extent, between the collagen fibers and is, thus, unable to interact with proteoglycans or other molecules.

Noncollagenous proteins

NCP, like collagen, increase in amount with aging, to a larger extent in the nucleus pulposus than in the annulus fibrosus (23, 40, 110, 144, 145). According to Dickson et al. (23), the increase in NCP, which occurs particularly between the fourth and sixth decade of life, involves several protein classes, containing different proportions of tyrosine. Since disc degeneration increases with aging, the increase in the amount in NCP is likely to be related to tissue degeneration. Taylor and Akeson (144) have calculated the age-related changes in the collagen/noncollagenous protein ratio in the human intervertebral disc: the ratio increases linearly and considerably in the nucleus pulposus, and to a lesser extent and irregularly in the transitional zone and annulus fibrosus. Furthermore, wide-angle x-ray fiber diffraction studies have shown that NCP undergo an increase in crystallinity with advancing age (144). However, it is unclear whether the increased crystallinity affects the mechanical properties of the disc.

Elastin

The process of disc degeneration is unlikely to cause qualitative and quantitative changes in the little elastin contained in the disc. In fact, analysis of amino acid composition of elastin in discs of subjects aged 11–71 years, revealed no significant differences between subjects older than 50 years and those younger (109).

Furthermore, no data are available on the percentage of elastin with respect to dry weight of the tissue.

Enzymes

Ng et al. (117) have observed that in disc tissue specimens of elderly subjects with degenerative changes of varying degree, collagenase, elastase and gelatinase activity show no significant changes with respect to those found in normal discs. It would seem, therefore, that collagenolytic enzymes are not responsible for those biochemical and structural changes which are able to predispose to disc herniation. On the other hand, others have observed, in degenerated discs, a high activity of collagenases and other matrix metalloproteinases (MMPs) (82), particularly stromelysin (MMP-3) (81), which can degrade the proteoglycan protein core. Furthermore, it has been found that MMP-3 activity is not related to disc age, but increases parallelly to the degree of disc degeneration (81). Of the 15 specimens of degenerated disc tissue studied by Kanemoto et al. (81), 14 did not contain TIMP-1 glycoprotein, which is an antagonist and tissue inhibitor of stromelysin. Thus, it has been hypothesized that degeneration of disc tissue depends on disturbances in the equilibrium between MMP-3 and its inhibitor.

Synthesis of metalloproteinases by disc cells would be enhanced by some cytokines, particularly interleukin-1 (IL-1) and tumor necrosis factor-α (TNF-α) (81, 82). However, it is still unclear why the cells of the degenerated disc produce chemical mediators of inflammation, such as cytokines, during the early phases of degeneration, when the annulus fibrosus is devoid of blood vessels and inflammatory cells.

Degenerated disc tissue (Lewin's grade 3B) was found to contain up to eight-fold more lysozyme than normal disc (Lewin's grade 0) (108). The amount of lysozyme also tends to increase with aging, regardless of the degree of disc degeneration. High concentrations of lysozyme were found in close proximity to osteocartilaginous junctions (133). Since lysozyme reduces the concentration of aggregate proteoglycans, which inhibit the deposition of calcium phosphate in vitro, it has been hypothesized that this enzyme might play a role in enchondral ossification (87, 127). The deposition of calcium salts which often occurs in the degenerated disc might be correlated with the high tissue concentrations of the enzyme (108).

Yasuma et al. (166) observed small lipofuscin granules in the cells of the nucleus pulposus and inner and middle layers of the annulus fibrosus of degenerated intervertebral discs. These pigments have never been seen in normal discs of subjects younger than 50 years. Since lipofuscin originates from oxidation of lipids or lipoproteins, some activated lipid peroxides might be involved in the mechanism of intervertebral disc degeneration (166). This hypothesis is supported by the fact that the areas with the highest lipofuscin concentration are those showing the most severe degenerative changes at histologic level (166).

Amyloids have often been observed in postmortem discs, particularly in the outer layer of the annulus fibrosus (166). These substances were found only in specimens from subjects over 40 years of age at death and tended to show an increase with increasing age (88, 143). Probably, disc amyloid does not reach the disc via the blood vessels, often present in degenerated annulus fibrosus, but is produced in the intervertebral disc. It has been suggested that amyloids may originate from changes in enzymatic processes, which, however, are still unknown (166).

Herniated tissue

Collagen

In herniated disc tissue, the amount of collagen is considerably higher than in non-herniated (normal or degenerated) coeval discs (22, 110). Furthermore, the collagen of herniated tissue increases with patient's age and duration of symptomatology; this led to the belief that both disc degeneration and herniation may result from changes in collagen metabolism (110). Since, age being equal, the prolapsed tissue presents a greater concentration of collagen compared with the degenerated disc, it is possible either that there is a collagen content limit beyond which a further collagen increase causes considerable changes in the mechanical properties of the disc matrix, predisposing the latter to herniation, or that the process of fibrosis in the nucleus pulposus continues after herniation has occurred. This would support the hypothesis that disc herniation is the result of an early and rapid aging of disc tissue.

Adam and Deyl (1) have hypothesized that type III collagen, which is more abundant in degenerated than normal disc, forms a more extensible network than that normally present in the interterritorial matrix, thus predisposing the nucleus pulposus to herniate.

Proteoglycans

Proteoglycans of the herniated tissue differ quantitatively and qualitatively from those in the normal disc. Two studies have analyzed the hexosamine content in discs of subjects with no pathologic vertebral conditions and in specimens of herniated tissue removed at surgery (22, 110). In both studies, control groups showed a decrease in proteoglycan content with aging. However, in one of the two studies, proteoglycan concentration showed a slight increase between 30 and 50 years. A similar observation has been made for proteoglycans of rib cartilage (56). Regardless of age, the exosamine content in herniated tissue was found to be lower than in normal control specimens. In one of the two studies (22), hexosamine percentage was found to be decreased up to one fifth. This finding has led to the hypothesis that the polysaccharide content in the disc should decrease below a critical level before pathologic changes able to predispose to disc herniation can occur (110). Furthermore, it has been observed that the hexosamine content in the herniated tissue decreases with increasing duration of clinical symptoms (110).

The decrease in polysaccharide content is not due to a diffuse tissue autolysis, since the percentages of nitrogen (which is an indicator of noncollagenous proteins) and collagen are increased. However, mucopolysaccharide degradation might produce a molecular substratum, able to stimulate collagen synthesis (75, 76, 110).

Lyons et al. (96, 97) isolated a purified protein-polysaccharide complex from herniated disc tissue and normal human intervertebral discs. Two fractions were separated by ultracentrifugation from the purified complex: PP-L (protein-polysaccharide light fraction) and PP-H (protein-polysaccharide heavy fraction), as had previously been done for bovine nasal cartilage (38). In the PP-L fraction of the normal disc, a gradual decrease in polysaccharide content was observed with aging. This was also found for the fractions extracted from the herniated tissue of subjects of different ages, whose symptoms, however, were of unknown duration. Comparison of PP-L fractions from healthy subjects and from patients with disc herniation showed that the decrease in proteoglycan content in patients with disc herniation is comparatively more marked in young subjects. Furthermore, the percentage of hexosamine in the PP-H fraction of the herniated tissue was found to vary from patient to patient and to be considerably lower compared with controls. However, Szirmai (142) noted that if nucleus pulposus samples of the herniated tissue were minutely separated from the annulus fibrosus and cartilage end-plate, the hexosamine content was markedly higher than that found in previous studies. This indicates that to correctly interpret the results of the biochemical analysis, it is necessary to have available both macroscopic and histologic data of the tissue under examination. The herniated tissue, in fact, may contain different proportions of inflammatory and scar tissue (144), in addition to normal disc components.

The decrease in proteoglycan content concerns not only the herniated disc but also the thoracolumbar fascia (62). However, this observation is of little importance, since it is well known that immobilization due to pain causes a reduction in mucopolysaccharide content in the periarticular connective tissue (4).

In the herniated tissue, a more marked CS decrease with respect to KS was found (22). This involves an increase in the glucosamine/galactosamine ratio. Davidson and Woodhall (22) have also extracted small fractions of dermatan sulfate (chondroitin sulfate B) from herniated tissue. Dermatan sulfate is easily identified with infrared spectra, as well as enzymatic studies, since it is resistent to testicular hyaluronidase. Dermatan sulfate, normally present in the matrix of fibrocartilaginous tissues, such as that of menisci (29), has only been found in the normal disc of subjects over 60 years of age (144).

The decrease in proteoglycan concentration, the changes in the ratio between the different glycosaminoglycan chains and the presence of dermatan sulfate are characteristic features of the herniated tissue, however, also of senile disc tissue. This has led to the belief that disc herniation is the result of a similar degenerative process to that occurring during aging, albeit markedly accelerated (22, 97). It has also been suggested that disc herniation might be the result of changes in polysaccharide metabolism, particularly of an accelerated catabolism (62). However, Pearce and Grimmer (123) hold that the biochemical changes observed in herniated tissue would develop after, rather than before, disc herniation occurs.

Water

A decrease in the intradiscal fluid content, as occurs in the degenerated disc, can affect the biomechanical properties of the disc (110). The decreased hydration favors the formation of clefts in the annulus fibrosus and reduces the diffusion of solutes throughout the intercellular matrix, thus negatively affecting disc nutrition. The fissures, on the other hand, represent the prerequisite for herniation of the nucleus pulposus. This hypothesis is supported by the observation that the herniated nucleus pulposus presents a marked decrease in water content, also in young patients (22, 97).

Noncollagenous proteins

The amount of NCP in the herniated tissue is considerably greater than in the normal disc (96, 110, 144, 145). Colorimetric studies have shown that the NCP content in the herniated disc tissue of patients aged 20–30 years is higher than in non-herniated discs of subjects aged 50–60 years (110). These studies have also shown that, in young patients, the NCP content of the herniated tissue tends to be higher than in elderly patients.

Cristallinity of noncollagenous proteins of herniated tissue is comparable to that of proteins in the nonherniated disc of elderly subjects (144). This observation might also justify the hypothesis that disc herniation is the result of fast and rapid aging of the disc tissue. It has been hypothesized that the increase in NCP of herniated tissue is due to a nutritional disturbance (96). This would negatively affect cell function, thus leading to changes both in the quality and amount of intercellular matrix.

Immunoglobulins (IgG and IgM) were also found in herniated tissue specimens; their presence would appear to be related to the inflammatory process which occurs close to the compressed nerve root (138).

Elastin

No studies have focused on the possible biochemical changes of elastin in the herniated disc tissue. Mikawa et al. (109) studied the amino acid composition of elastin in disc samples obtained from subjects of different age groups during surgery for cervical spondylosis, spinal cord tumor, scoliosis, stenosis of the vertebral canal or intervertebral disc herniation. In this study, the amount of histidine, hydroxyproline, methionine and arginine in disc elastin was found to be three or four times higher between 35 and 54 years – the age period with the highest prevalence of disc herniation – than at other ages. However, the samples of disc tissue were not classified according to the patient's pathologic condition.

Enzymes

Collagenolytic activity towards type I collagen, as well as gelatinase and elastase activity, were found to be considerably increased in fragments of herniated tissue, compared with normal disc (117). Conversely, collagenase activity towards type II collagen was two thirds less. The increase in collagenolytic activity towards type I collagen and elastin might weaken the outer annulus fibrosus, thus predisposing the disc to herniate. It is, therefore, possible that disc cells may dedifferentiate and lose their phenotypic expression, thus modifyng the amount of collagenolytic enzymes produced (89). However, it is also possible that these changes are due to the herniation process.

Immunohistochemical studies (81) have shown an increase not only in collagenase (MMP-1), but also in stromelysin (MMP-3), another metalloproteinase, in herniated disc tissue. TIMP-1, a glycoprotein which is able to inhibit MMP-3, was found only in 8.5% of herniated tissue samples. Disc cells were found to be positive to antihuman MMP-3 monoclonal antibodies in 38.3% of extruded or sequestered disc herniations, but only in 19.8% of contained herniations. Moreover, the ratio between MMP-1 and MMP-3 and their respective inhibitor glycoproteins were constantly higher in herniated tissue than in bulging disc (80). It has therefore been hypothesized that cytokines produced by infiltrating inflammatory cells, often present in extruded and sequestered disc materials, induce metalloproteinase synthesis, which may play a primary role in the resorption of extruded disc material when not inhibited by TIMP-1 (80).

Of the cytokines in the herniated tissue, IL-1 stimulates the synthesis of bFGF (basic fibroblast growth factor) (26) and nitric oxide (NO) (82), which are able to induce vascular neogenesis and vessel dilation, respectively. bFGF and NO concentration was found to be higher in extruded or sequestered, than in protruded, disc. However, it should be taken into consideration that chemical mediators of inflammation are considerably widespread and might, thus, be produced by tissues adjacent to disc herniation (152). Moreover, disc tissue used in control studies is usually obtained from the anterior area of the annulus fibrosus, where metalloproteinase activity is higher than in the nucleus pulposus (152).

Intracellular lipofuscin pigments and amyloid deposits have often been observed in herniated disc samples, also from young subjects (166). These were produced after activation, respectively, of peroxidase and other little known enzymatic processes. Both lipofuscin and amyloid were often found in degenerated discs, and, in these cases, always in specimens of individuals over 40 years of age (166). Their presence in the herniated tissue of young patients (88, 166) indicates that the discs in these subjects are severely degenerated, possibly due to early activation of some enzymatic systems.

Biochemical studies have demonstrated high phospholipase A2 levels in herniated disc tissue (132). The mean value of phospholipase A2 activity was 10,000 times higher than in the plasma of control subjects. Phospholipase A2, once activated by calcium, interacts with membrane phospholipids and leads to the release of arachidonic acid. The latter is an important family precursor of chemical mediators of inflammation produced by further action of two enzyme classes: cyclo-oxygenases and lipoxygenases. Cyclo-oxygenases convert the arachidonic acid into two endoperoxides: prostaglandin G2 and H2. The former is a vasodilator, which increases vascular permeability and pain sensitivity, concentrations having been found to be higher in the herniated tissue than in normal disc (82). Lipoxygenase action on arachidonic acid, on the other hand, induces the synthesis of leukotrienes, which are chemotactic substances and powerful mediators of inflammation. High phospholipase A2 concentrations were also found in the synovial fluid of arthritic joints (32), where the enzyme activity appears to be regulated by the equilibrium between inhibitors and activators of phospholipase. It has been hypothesized that the change in this equilibrium in the disc may induce phospholipase A2 activation, which might play a role in the genesis of disc degeneration (34, 132). However, this hypothesis is not in keeping with the findings of Gronblad et al. (46), who evaluated phospholipase activity both in macroscopically normal and degenerated discs, with no significant differences emerging between the two, both showing a low enzymatic activity.

Detection of enzymes and other chemical mediators of inflammation in the herniated tissue has opened the way to new etiopathogenetic concepts on disc herniation and radicular pain, and has led to a reappraisal of the role of compression of the nerve root by the herniation in the genesis of radiated pain. In fact, the nucleus pulposus, which, on account of its avascular nature, is considered as alien from the immune system (39), may cause inflammatory reactions leading to vein congestion and edema within the nerve root (94, 141).

Nutrition

The intercellular matrix of the disc consists of a tight network of collagen fibers and a gel formed by water, NCP and proteoglycans. The protein component is synthesized by the cells and regulates, directly or indirectly, the hydric condition, electrical charge, viscosity and osmotic pressure of the intervertebral disc. Thus, the mechanical properties of the disc depend on cell function, which is guaranteed only by an adequate nutritional supply. Nutritional deficiencies and inadequate removal of the products of cell catabolism lead to a reduction in the already low cell density of the disc, changes in tissue pH and modification in water content of the matrix (67, 69, 70, 72, 113, 114, 121, 153).

The mechanisms by which nutritional substances are transported into, and catabolites are removed from, the disc are unknown to a large extent. Since the normal disc is avascular, nutrient supply depends on the blood vessels of the vertebral body and epidural space. It has been suggested that the decrease in number of the capillaries in the vertebral body and peridiscal tissue due to aging impairs disc nutrition and favors degeneration of disc tissue (67).

It has been shown, using fluorescent substances, that solutes enter the rabbit intervertebral disc through the outer layer of the annulus fibrosus and, to a lesser extent, the cartilage end-plate (10). Solute diffusion occurs only in one third of the central region of post-mortem human cartilage end-plate and only in one tenth of the peripheral portion of the cartilage end-plate (102). The entire outer portion of the annulus fibrosus, on the other hand, is permeable to solutes (Fig. 3.6).

The transport of molecules necessary for cell metabolism occurs almost entirely (80%) by a diffusion process across the cartilage end-plate and outer layer of the annulus fibrosus (67, 73, 83, 102, 114). A role, however, may also be played by other physico-chemical transport mechanisms, such as flow of lymph/fluid, mechanical fluid pump – dependent on mechanical stimuli – and, probably, active transport mechanisms.

Solute transport

Diffusion

Diffusion is the solute motion that occurs when a membrane separates fluids which have the same hydrostatic pressure, but different solute concentration (concentration gradient). When the solutes are freely diffusible, an

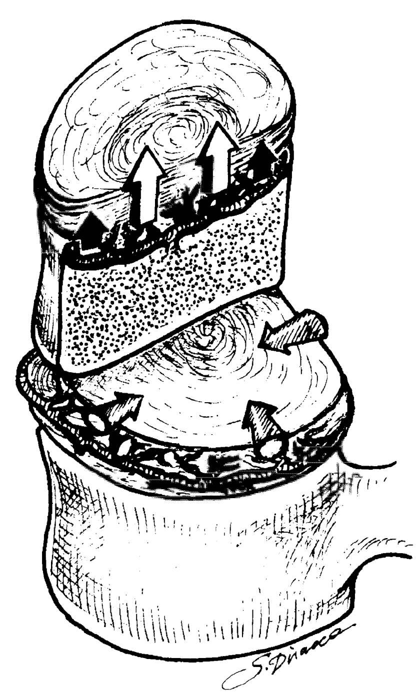

Fig. 3.6. *Nutrient supply to the intervertebral disc depends on the blood vessels of epidural space and vertebral bodies. Solute diffusion occurs to a larger extent through the central region (white arrows) than the outer portion (black arrows) of the cartilage end-plate. The outer portion of the annulus fibrosus, instead, is entirely permeable (conic arrows).*

equilibrium is rapidly reached on either side of the membrane. Instead, if some solutes, as in the disc, are unable to diffuse on account of their dimensions or electric charge, the division becomes unequal even between freely diffusible solutes (Gibbs-Donnan equilibrium). In dilute solutions, where the solute concentration is low and the interactions between solutes are minimal, the speed of molecular diffusion, based on the concentration gradient, is regulated by the Fick equation:

$$dv/dt = J = -DA\,(dc/dx)$$

where: 1) dv/dt is the diffusion speed, mols/sec; 2) dc/dx is the concentration gradient through which diffusion occurs, expressed in mols/cm^{-3}/cm^{-1} (the minus sign indicates that diffusion occurs in the direction in which the lowest concentration is present); 3) A is the solution plane area described by the lines of molecular diffusion; 4) D is the diffusion coefficient (the number of molecules which diffuse in one second, the concentration gradient being 1 mole/cm^{-3}/cm^{-1} and the plane area 1 cm^2).

If electrolytes have to diffuse through an electrically charged matrix, as in the disc, the chemical potential depends both on the matrix and the solute concentration. When the electric potential is of equal intensity and of an opposite sign to the chemical potential, the electric and osmotic works are equal. The corresponding potential is the so-called equilibrium potential, which can be calculated by the Nerst equation:

$$E_{ions} = 61 \text{ mv} \log C1/C0 \text{ at } 37° \text{ C}$$

where C1/C0 is the ratio of ion concentration inside and outside the membrane. However, this equation does not take into consideration the interactions that occur in the disc either between different solutes or solvent and solute, which alter the electric gradient of the matrix.

The diffusion coefficient of a solute in the disc matrix is different from the coefficient that the solute would have in a free solution. The difference is due to the presence, in the disc, of other components (proteins, carbohydrates, lipids) which occupy space, thus reducing the area of diffusion, and cause friction phenomena with the moving molecules (61).

In the disc, small solutes which are, or not, electrically charged, have a diffusion coefficient (depending on the molecule size and solution viscosity) no greater than 40%–60% of that which they would have in a free solution (122, 154).

Compared with the nucleus pulposus, the diffusion coefficients of solutes in the annulus fibrosus are lower due to the lower hydration (150). Therefore, in the degenerated disc, the matrix of which is less hydrated, the diffusion process is reduced compared with the normal disc (131).

Osmotic pressure

The cartilage end-plate and the outer portion of the annulus fibrosus are similar to a semipermeable membrane, which allows solute inflow into the disc matrix depending on solute dimensions and the difference in concentration and electric potential between the disc and peridiscal tissues. For instance, cations are attracted into the disc by the negative charge of glycosaminoglycans, whereas anion flow is obstructed. Even water molecules are able to move out of, or into, the disc matrix depending on the water concentration gradient and permeability coefficient of the matrix. However, the flow of water molecules may also occur due to a water chemical potential which may result, for example, from an increase in intradiscal hydrostatic pressure or a different concentration in electrically charged solutes (Fig. 3.7). In the matrix, cations and glycosaminoglycans tend to reach an electric equilibrium, and thus they do not diffuse outside the disc. In diluted solutions, the concentration of water molecules is lower than in pure water. In fact, if a solute is added to one of two pure water containers separated by a semipermeable membrane, the concentration of water molecules in the resulting solution is lower than that on the side where pure water is present. Therefore, in the disc, a chemical potential for water is established, which

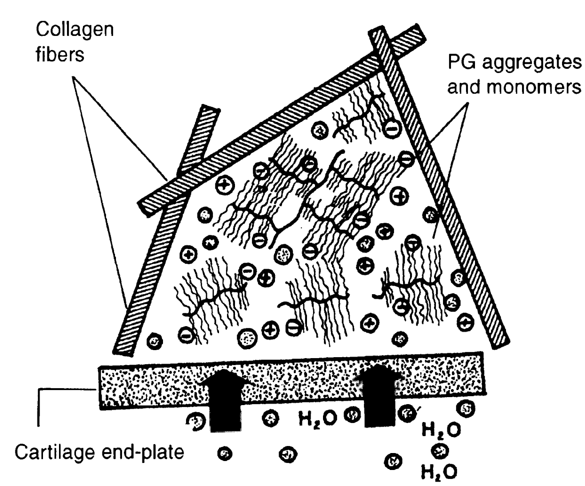

Fig. 3.7. *Flow of water molecules to the vertebra, and from the latter to the disc matrix, is regulated by the concentration gradient and permeability coefficient of the water and by a chemical potential which develops due to the different concentration in electrically charged solutes or an increase in intradiscal hydrostatic pressure.*

causes water flow into the matrix (osmosis) until an intradiscal hydrostatic pressure, able to oppose further flow, is reached. Disc osmotic pressure is produced by the increase in hydrostatic pressure which should be applied to the disc itself to prevent water inflow.

Only proteoglycans permanently contribute to create a water chemical potential, since the other electrically charged solutes are distributed between the two fases, also due to Gibbs-Donnan's equilibrium. Osmotic pressure of any solution depends on the number of particles present in the solution, rather than their shape or weight. Thus, each ion, originating from the intradiscal dissociation of a molecule, has the same osmotic effect as a non-dissociated molecule.

Water flowing into the disc due to the osmotic effect penetrates into the tridimensional network formed by the collagen fibers (where proteoglycans are located), causing a sort of swelling of the meshes.

Fluid flow

In vivo, an intervertebral disc submitted to an external load becomes deformed if compression is slight and temporary; furthermore, it expels water if the load is considerable and persistent. However, the amount of fluid expelled under loading is recovered by the disc when compression ends. Therefore, the continuous water movement from and towards the disc helps the flow of molecules and removal of cell catabolites.

Active transport

No studies have so far been performed on the possible use, by the disc, of this facilitated transport route. For this route to be used, the solute should be bound to a "carrier" with a particular affinity for the solute so that the diffusion process can occur even against concentration gradients. An enzymatic reaction would then break the bond between the solute and the carrier. The latter, after separation from the solute, would be available for transporting another molecule.

However, active transport is unlikely to occur in the disc, since it implies a high waste of energy.

Nutrition disturbances

Holm and Nachemson (68) found a reduced concentration of some solutes (sulphate-glucose-oxygen) in a surgically fused motion segment and an increase in metabolic activity in the adjacent segments. It has been suggested that the decrease in concentration of nutritive substances is due to a reduced blood supply to the vertebrae of the fused motion segment (67). By contrast, increased movement and mechanical loading (as occurs in the discs adjacent to the fused segment) led, in experimental disc models, to a greater uptake of the labeled nutritive substances by the disc tissue (68, 69).

A decrease in blood flow in the peripheral area of the disc may also occur due to vibrations (72), vasoconstrictive activity of nicotine (71) or atherosclerosis caused by some pathologic conditions, such as diabetes (65). In these cases, the reduced supply of proteins, amino acids, carbohydrates and other solutes to the disc tissue produces a chronic nutritive defect, which may lead to disc degeneration.

Metabolism

A large amount of oxygen enters the intervertebral disc by means of the diffusion mechanism. This process is inversely proportional to disc thickness (67, 139). Thus, disc cells, particularly those in the nucleus pulposus, where the oxygen tension is only about 2 to 5 mm Hg (67), follow the anaerobic breakdown of glucose to produce ATP, i.e., energy (131). The metabolic process is called Embden-Meyerhof's cycle. The latter starts with glucose phosphorylation, which leads to the formation of phosphoric esters. These are degraded into two triose molecules that are then transformed into pyruvic acid. In the cycle, some coenzymes able to bind hydrogen are involved, such as diphosphopyridine nucleotide (NAD), which is reduced to NADH. The piruvic acid, after a NADH molecule action, is reduced to lactic acid.

In the disc, degradation of the piruvic acid, amino acids and fatty acids into carbon dioxide and water through Krebs' cycle, is scarcely feasible due to the low tension of intradiscal oxygen. Hydrogen ions and electrons originating, during Krebs' cycle, from reduced nucleotides (NAD+, NADP, FAD) are linked to oxygen and contribute, although to a minimal extent, to increase the water content in the disc.

The entire anaerobic metabolic process leads to the formation of four ATP molecules, starting from two. The anaerobic breakdown of glucose is, thus, less efficient than the aerobic pathway, which produces 34 ATP molecules in addition to the two produced by the anaerobic glycolysis.

No studies appear to have analyzed the ability of the disc to use, as a metabolic pathway, direct oxidation of glucose, i.e., the hexosemonophosphate shunt. This pathway would lead to oxidation of the glucose-6-phosphate molecules and their conversion into phosphorylate pentose, which may be catabolized until carbon dioxide and water are formed. Ribose-5-phosphate produced through the hexosemonophosphate shunt can be used to synthesize nucleotides and nucleic acids, as well as reduced NADP. The latter represents a reserve of reduction equivalents, which are indispensable in many synthesis reactions.

Oxygen consumption in the intervertebral disc is only about one twentieth of that in the liver or kidney. Holm et al. (67) demonstrated that oxygen consumption per cell significantly differs in the various regions of the disc; however, since cell density differs in the different areas, the oxygen consumed by one gram of nuclear tissue is much lower than that consumed by the same amount of annular tissue.

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CHAPTER 4

BIOMECHANICS

G. Cinotti, F. Postacchini

Intervertebral disc

Biomechanical properties

Vertebrae, discs and ligaments form a column of vertebral motion segments, called functional spinal units. Each functional spinal unit includes a disc, the two adjacent vertebrae and the connecting ligaments; it represents the smallest segment of the spine showing biomechanical properties similar to those of the whole spine and, hence, is the anatomic unit of reference in biomechanical studies (81). Due to the presence of discs and ligaments, the whole spine acts as a flexible column, straight in the frontal plane and curved in the sagittal plane. The curved alignment of the spine in the sagittal plane increases spinal flexibility and the ability to withstand mechanical forces, whilst maintaining the stability of the spine (81).

The intervertebral discs, along with the facet joints, carry the complex loading acting on the spine and transmit mechanical stresses to the adjacent vertebrae. Under unloading conditions, the disc shows a positive intradiscal pressure, or preload, due to the hydrostatic pressure generated by the nucleus pulposus. This is caused by the tensile forces applied by the annular fibers, ligaments and muscles running between two adjacent vertebrae (31, 81). As the disc is under loading conditions, an increase in intradiscal pressure occurs, which is related to the amount of the applied load (59). The increase in intradiscal pressure under loading enhances the tensile stresses on annular fibers and, as a result, the stiffness of the disc (68). Therefore, disc stiffness is affected by the magnitude of the applied load; it increases as the applied load increases and vice versa. The functional spinal unit, thus, exhibits greater stability under large loads compared with small loads.

Under loading conditions, the intervertebral disc behaves as a viscoelastic material; when a constant load is applied, the disc suddenly undergoes a time-dependent deformation. This phenomenon, named creep, is related to the magnitude of the applied load. As the load is applied, the disc deforms immediately due to changes in the spatial arrangement of the collagen network (25). It has been shown that this process may cause a decrease in disc height which is about 25% of the whole deformation provoked by the applied load (10). If the loading condition is mantained, the disc further deforms due to the outflow of fluids through the vertebral end-plates (Fig. 4.1). The fluid loss leads to an increase in proteoglycan content and, hence, in the osmotic pressure of the nucleus. When the swelling pressure of the disc is increased to such an extent as to balance that generated by the applied load, a steady state is reached (osmotic equilibrium) and the fluid loss from the disc stops (28, 31, 77, 78). Disc deformation is recovered entirely or partially once the applied load is removed (23).

The fatigue strength of the disc is affected by several factors, including the biomechanical properties of annular fibers and the integrity of disc tissue. The annular fibers exhibit different biomechanical characteristics, depending on the region of the disc analyzed and the degree of tissue hydration (16, 26, 48, 72). The annular fibers located anteriorly and in the outermost part of the annulus fibrosus show greater tensile strength compared with the fibers located in the posterior and innermost annulus. Type I collagen fibers, which are prevalent in the outermost annulus, are likely to have a greater tensile strength compared with type II collagen fibers, which are predominant in the inner annulus (72).

The biomechanical properties of the disc are also influenced by the content of biochemical components

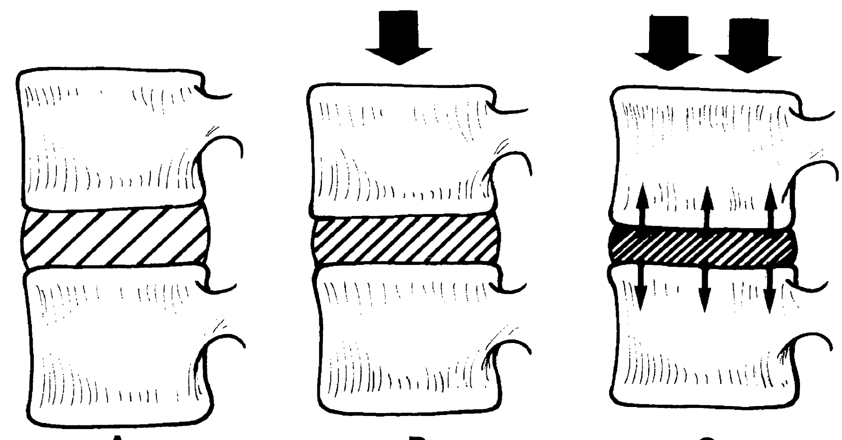

Fig. 4.1. *Disc deformation under axial compression loading.* (A) *Unloaded disc. As a load is applied* (B), *the initial deformation of the disc is due to changes in the spatial arrangement of the collagen fibers. If the applied load is maintained* (C), *the disc further deforms as a result of outflow of fluids through the vertebral end-plates.*

of the disc matrix (7, 26, 47, 48). In particular, the water and proteoglycan content of the tissue is related to its hydraulic permeability and compressive modulus, respectively (38). Thus, water and proteoglycan content affects the rate of creeping of the disc under loading. Moreover, since collagen fibers are more abundant in the outer portion of the annulus compared with the inner portion, which is rich in water and proteoglycans (12, 15, 79), the biomechanical properties of the disc differ depending on the region of the tissue analyzed (7). This marked specialization of disc tissue may be essential to provide an adequate mechanical strength under different loading conditions.

In conclusion, the viscoelastic properties of the disc are responsible for the biphasic behavior of the functional spinal unit under loading; this is highly flexible at low loads, but becomes more rigid as the applied load increases (52). The viscoelastic characteristics of the disc are due to the intrinsic properties of the tissue and, mainly, to the flow of fluid from the disc (7). The proteoglycan content guides the fluid flow from the disc and regulates the osmotic pressure of the tissue. As a load is applied, disc deformation results until a steady state is reached; this occurs when the swelling pressure of the disc balances the external pressure generated by the applied load. Disc tissue shows a dishomogeneous biomechanical behavior, reflecting the unequal content of its biochemical components in the different regions (7).

Disc under compression, flexion and axial torque

Upon daily activities the intervertebral discs are submitted to various mechanical stresses, which, in most cases, occur simultaneously. For instance, during lifting, the disc is likely to undergo both flexion-compression and axial rotation forces. When various loads act simultaneously, the disc is subjected to complex loading.

Compression

Under axial compression the nucleus pulposus expands horizontally, thus inducing increased tensile stresses in the annular fibers. The magnitude of tensile stresses is maximum in the inner annulus and decreases progressively towards the external annulus (33, 68, 71) (Fig. 4.2). Vertebral end-plates undergo compression stresses, mainly in the area adjacent to the nucleus pulposus (37).

Axial compression causes circumferential disc bulging in the horizontal plane, which is largest in the posterior annulus (68). The degree of disc bulging is inversely related to the tensile status of the annular fibers and the intradiscal pressure. When the latter is within normal values, compression load increases tensile stresses in the annular fibers; this allows the annulus to withstand the nuclear expansion and disc bulging is mild. However, when the intradiscal pressure decreases, annular fibers are subjected to low tensile stresses and this reduces their ability to resist the nuclear expansion and to limit disc bulging under load (9).

When an axial compression load exceeding the physiologic limits is applied to the functional spinal unit, vertebral end-plates are the first structures to fail. They fracture or deform under the compression forces generated by the nucleus (27, 61, 68). On the other hand, mechanical stresses caused by axial compres-

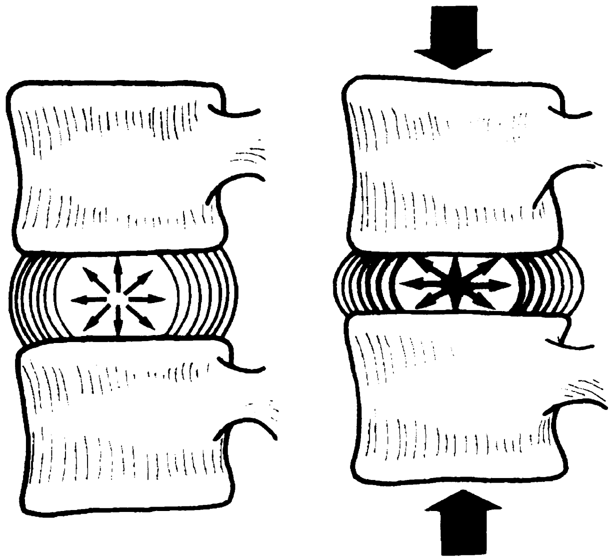

Fig. 4.2. *Mechanical stresses in the annular fibers under axial compression loading.* (A) *Unloaded disc.* (B) *The compression load increases the hydrostatic pressure in the nucleus which, in turn, increases tensile stresses in the inner annular fibers.*

sion are not sufficient to provoke failure of the annulus fibrosus.

Flexion (flexion, extension, lateral bending)

Under flexion loading, the annulus is submitted to compressive stresses in the region where the compressive force is applied and to tensile stresses in the opposite zone. Thus, anterior-flexion loading causes compressive stresses in the anterior part of the disc and tensile stresses in the posterior part, whereas the opposite occurs under extension loading (81) (Fig. 4.3). On lateral bending, compressive stresses take place on the concave side of the spinal curve and tensile stresses on the convex side.

Upon flexion-extension loading, the nucleus pulposus moves away from the zone of the disc submitted to compression forces, i.e., it moves posteriorly during flexion and anteriorly during extension (34, 46). Possibly, this shifting of the nucleus provides a better distribution of the load across the disc during vertebral motion (34) (Fig. 4.3).

Upon flexion loading, the disc bulges anteriorly during anterior-flexion, posteriorly during extension and on the convex side of the spinal curve during lateral bending (11, 60, 61, 81); thus, disc bulging occurs in the zone of the disc submitted to compressive stresses (Fig. 4.3).

Axial torque

The mechanical stresses caused by torsion vary depending on the region of the disc analyzed. In the anterior and lateral regions, the annular fibers oriented along the direction of the axial torque undergo tensile stresses, whereas annular fibers with the opposite orientation are submitted to no mechanical stress. Conversely, in the posterior region of the disc, all annular fibers are subjected to tensile stresses under axial torque, independently of their orientation (69).

Under torsion, mechanical stresses are greater in the anterior and lateral regions of the disc compared with the posterior annulus. However, as a compression load is associated with axial torque, mechanical stresses are greatest in the posterior annulus (69).

Torsion causes an increase in intradiscal pressure, which has been found to be higher compared with the increase occurring in extension, but lower than that induced by flexion (69). Likewise, it has been shown that axial torque causes larger mechanical stresses in the annulus fibers than during extension, but lower than those induced by flexion. Torsion, in itself, does not appear to cause failure of the annulus lamellae; however, as a compressive load is combined with axial torque, annular tears may occur in the posterior and posterolateral regions of the disc (69). Under torsion, disc bulging takes place in the posterior and posterolateral zones of the disc (69).

Intradiscal pressure

Intradiscal pressure plays a major role in disc biomechanics, since it affects the degree of tension of the annular fibers and, thus, the stiffness of the disc and entity of annular bulging (9, 68). Intradiscal pressure has been assessed both in vivo upon different body postures and using finite element models (3, 44, 49, 58, 59). It has been shown that in vivo intradiscal pressure reaches peak levels with sitting, decreases with standing and is lowest while lying down. Moreover, in the different body postures, intradiscal pressure increases with the anterior flexion of the trunk (43, 44). With these in vivo measurements, it is also possible to assess the loads carried by the disc during various postures and exercises, as well as to evaluating the effects of muscle tone on the intradiscal pressure. It has been found that, under general anesthesia, intradiscal pressure decreases by about 1/3 compared with normal values due to muscle relaxing (44).

The severity of disc degeneration affects intradiscal pressure. As disc degeneration advances, there is a decrease both in the intradiscal pressure under unloading conditions and in the maximum pressure borne by the disc (49).

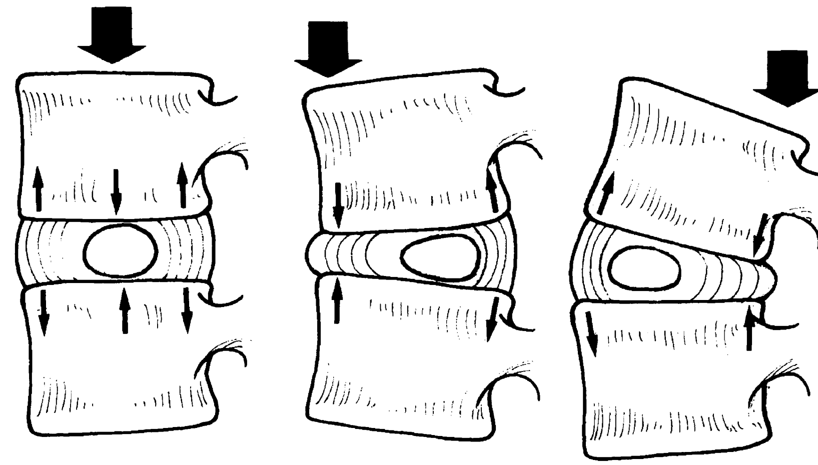

Fig. 4.3. *Mechanical stresses in the annular fibers during axial compression and flexion-axial compression loading. Under pure axial compression* (A), *the nucleus pulposus and annular fibers are submitted to compressive stresses and tensile stresses, respectively. When a flexion-axial compression load is applied* (B), *the anterior annular fibers are subjected to compressive stresses and the posterior fibers to tensile stresses; moreover, the disc bulges anteriorly and the nucleus moves posteriorly. The opposite occurs when axial compression is combined with extension loading* (C).

Kinematics of lumbar spine

Centers of motion

Vertebral motion occurs along three axes of rotation and exhibits six degrees of freedom since, upon each axis of rotation, combined translation and rotation motions occur. As a result, during vertebral motion, the center of rotation moves, at every instant, in each plane of motion. The centers of rotation, which may be identified during vertebral motion, are called instantaneous axes of rotation, and the locus joining consecutive instantaneous centers of rotation during a complete range of motion has been defined as centrode (17). The locus of centrode was found, at L5-S1 level, to be in the posterior half of the disc space and, at L4-L5 level, just below the vertebral end-plate in the posterior half of the L5 vertebral body (17, 46) (Fig. 4.9). The displacement of the center of rotation during vertebral motion is due to the presence of associated motions, or coupled motions, occurring along different axes of rotation compared with the main motion. For instance, during lateral bending, lateral rotation in the frontal plane (main motion) is associated with axial rotation in the horizontal plane, anterior rotation in the sagittal plane and lateral translation in the frontal plane (coupled motions) (52). Coupled motions are reduced in entity compared with main motions; however, they may be as important as main motions in the kinematics of the spine.

Vertebral motion

During vertebral motion, the spine shows a nonlinear and biphasic behavior, since vertebral displacement does not increase proportionally to the magnitude of the applied load. In particular, the functional spinal unit exhibits marked displacement under low loads and relatively less displacement under larger loads. As a light load is applied, in fact, the functional spinal unit is highly flexible and resistances to vertebral displacement are reduced. This phase, referred to as the "neutral zone", is the phase of high flexibility or laxity of the range of motion. Beyond the neutral zone, much higher resistances need to be overcome to further increase vertebral displacement; this phase, defined as the "elastic zone", is the phase of marked stiffness of the range of motion (50). Within the physiologic range of motion, the percentages of the neutral zone and the elastic zone vary depending on the segment of the spine analyzed. In the cervical spine, the neutral zone was found to account for about 60% of the entire range of motion, while in the lumbar spine it accounted for 20% of the entire range of motion (Fig. 4.4) (50). It has been shown that in the presence of disc degeneration, or after injuries impairing spinal stability, the percentage of the neutral zone markedly increases compared with intact specimens. Moreover, the increase in the neutral zone was found to be larger than the overall increase in the range of motion (50). In keeping with these findings, the assessment of the neutral zone could be a useful tool to detect spinal instability.

Vertebral motion has been analyzed in vivo and in vitro. Both investigations show several shortcomings. Quantitative evaluation of vertebral motion on flexion-extension radiographs was found to be rather inaccurate due to errors regarding the radiographic measurements. Only when angular motion or sagittal translation are markedly increased, may flexion-extension radiographs be useful in diagnosing vertebral hypermobility (65). Moreover, on radiographs, coupled

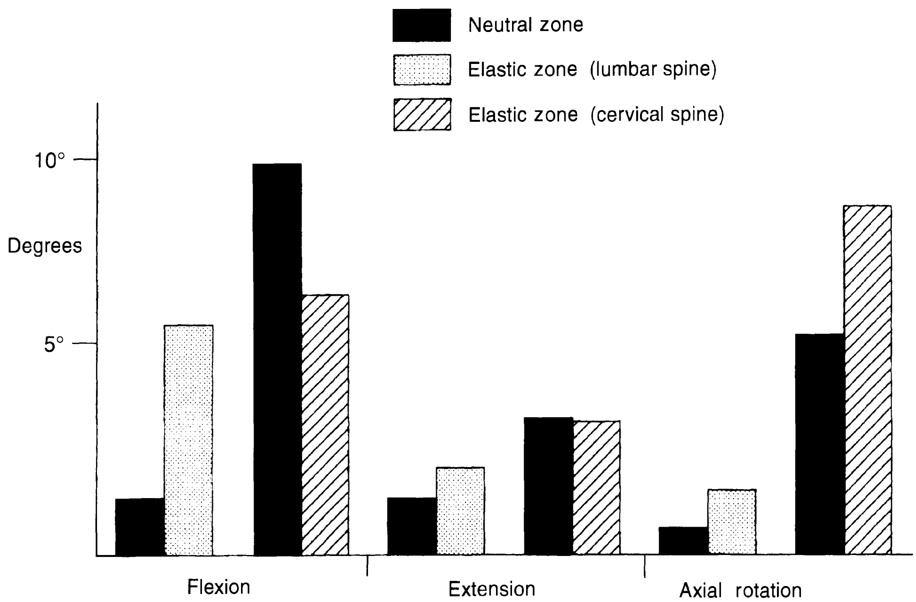

Fig. 4.4. *Relationship between neutral zone and elastic zone of range of motion in the lumbar and cervical spine, during flexion (anterior), extension and lateral bending (from Ref. 50).*

motions may be difficult to assess. Numerous studies have analyzed vertebral motion on cadaveric specimens (2,6, 18, 40, 41, 63, 75). A major limitation of these studies is that the effects of spinal muscles on the stability of the functional spinal unit are not taken into account. However, in vitro studies may be more accurate than in vivo investigations, since they analyze vertebral motion under defined loading conditions and evaluate both main and coupled motions.

Panjabi et al. (52) have evaluated, tridimensionally, main and coupled motions on in vitro specimens of the lumbar spine. They found that during flexion-extension, the main motion is anterior-posterior rotation and the more relevant coupled motion is translation in the sagittal plane. The latter occurs, during flexion, anteriorly and cranially and, during extension, posteriorly and caudally (52). The largest angular motion was found at L4-L5 (17° to 20°) and L5-S1 (15° to 25°) levels (52, 56), and the largest sagittal translation at L2-L3 level (3.3 mm) (52).

Upon lateral bending, lateral rotation is the main motion and anterior rotation, axial rotation and lateral translation are the associated coupled motions. Axial rotation occurs on the opposite side compared with the direction of the applied load, whereas lateral translation occurs on the same side. The main motion, i.e., lateral rotation, was found to be largest at L2-L3 level and averaged 5° on each side (52).

During torsion, the main motion is axial rotation and the coupled motions are anterior rotation and lateral rotation. The latter occurs on the same side as the direction of the applied load at the two lowest lumbar levels and, on the opposite side, at the two upper lumbar levels. Thus, axial rotation, on the right side, causes an associated lateral rotation on the right, at L4-L5 and L5-S1 levels, and an associated lateral rotation on the left, at L1-L2 and L2-L3 levels. The largest axial rotation was found at L2-L3 level, the maximum value being 2° on each side (52).

Vertebral motion resulted on in vitro and in vivo studies is reported in Figs. 4.5 to 4.7.

Disc degeneration

Biomechanics of degenerated disc

The biomechanical behavior of the degenerated disc has been assessed in vitro and with the use of finite element models. In vitro studies have shown that in degenerated discs the intradiscal pressure is decreased (49), thus leading to a reduction in tensile stresses in annular fibers and a decrease in stiffness of the disc (32). Degenerated discs show a reduced elastic modulus and, as a constant load is applied, creeping occurs to a larger extent and more rapidly compared with healthy discs (32, 45, 76). Moreover, once the applied load has been removed, creep is recovered slowly and, unlike in the healthy disc, the recovery curve varies depending on the amount of the applied load (76). The effects of disc degeneration may be even more severe in vivo, since in vitro studies do not take into account physiologic conditions, namely blood perfusion and breathing, which have been found to increase disc flexibility (28, 31).

Different mathematic models have been used to simulate disc degeneration. Kulak et al. (36), compared the

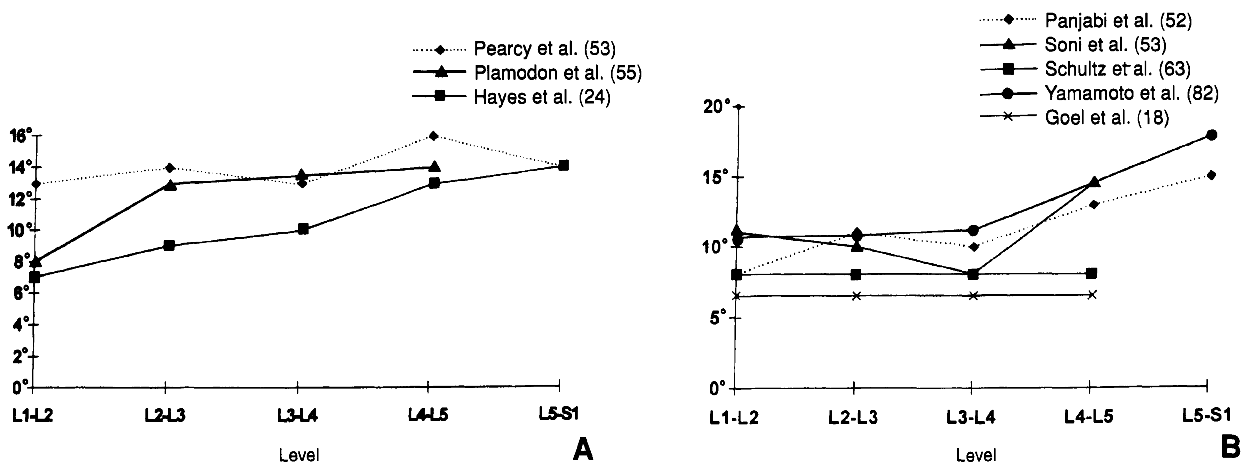

Fig. 4.5. *Flexion-extension motion in vivo* (A) *and in vitro* (B).

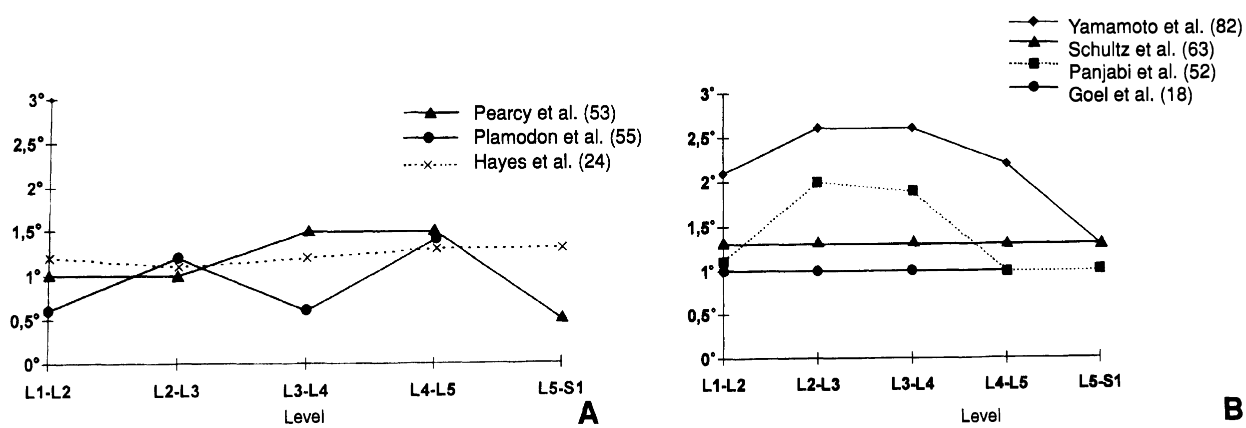

Fig. 4.6. *Axial rotation in vivo* (A) *and in vitro* (B).

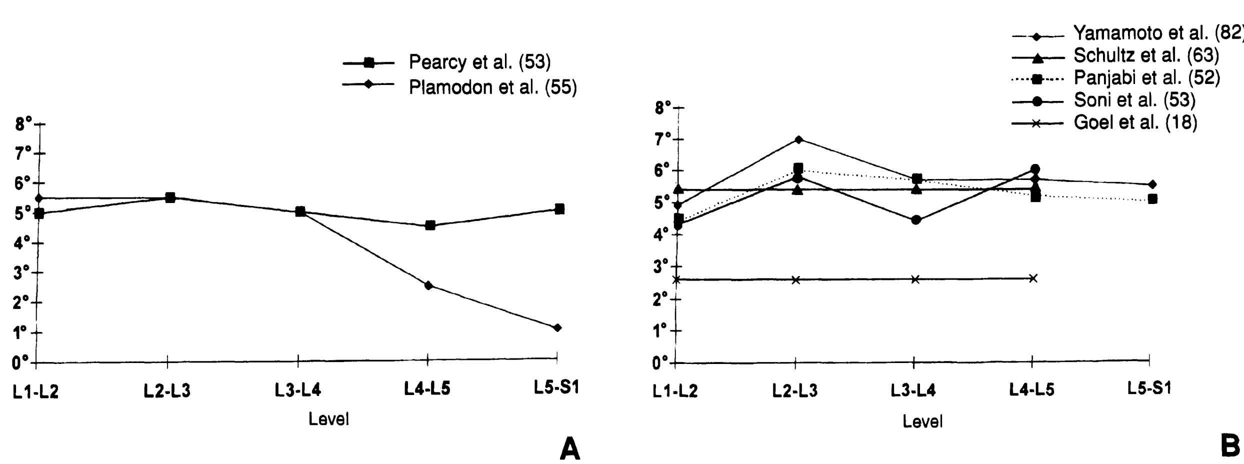

Fig. 4.7. *Lateral bending in vivo* (A) *and in vitro* (B).

biomechanical behavior of a disc devoid of the nucleus, but with intact annulus, to that of a disc with intact nucleus and radial annular tears. They found that the denucleated disc was less stiff whereas annular tears, in themselves, did not lead to significant changes in disc biomechanics. Other authors simulated disc degeneration by removing the nucleus (68), decreasing the intradiscal pressure by 60% (69) or reducing the fluid content of the nucleus by 12% compared to its original volume (70). These conditions were found to decrease tensile stresses in annular fibers and to increase compressive stresses (5, 68, 70); hence, the annular lamellae become lax, bulge inward or outward depending on whether they are located in the inner or outer annulus, respectively. Annular lamellae also tend to carry the compressive loads individually and this may predispose to annular failure (70). Disc bulging increases mainly in the anterior and posterolateral regions (40, 60, 68, 69).

Degenerative changes increase the flexibility of the disc under axial torque and enhance mechanical stresses on the posterior joints. Moreover, unlike in the healthy disc, a combined axial rotation and compression load induces tensile radial strain in the annulus fibrosus, which may eventually cause annular tears (68, 69).

Under normal conditions, compressive stresses are transmitted from the disc to the vertebral bodies in the region adjacent to the nucleus pulposus. However, as disc degeneration occurs, transmission of the compressive forces shifts from the nucleus to the outermost annulus (37) (Fig. 4.8). The increased compressive stresses on the peripheral portions of the vertebral end-plates may explain the formation of vertebral osteophytes often associated with disc degeneration.

Kinematics of lumbar spine

Centers of rotation

Disc degeneration affects vertebral motion both quantitatively (main motions) and qualitatively (coupled motions). The locus of the centrode in the sagittal plane varies in its position and length depending on the degree of disc degeneration (64). In mildly degenerated discs, the locus of the centrode is lengthened, since flexion-extension on the sagittal plane takes place along more distant axes of rotations compared with healthy discs. In moderately degenerated discs, the locus of the centrode moves from the interspace to the superior part of the vertebral body below and, in markedly degenerated discs, the length of the centrode is decreased (64) (Fig. 4.9). Assessment of the centrode on flexion-extension radiographs could be useful to detect abnormalities in the quality of vertebral motion in the early stages of disc degeneration (17). However, the diagnostic value of this technique may be limited by the low accuracy of the radiographic measurement (54).

Upon torsion, the instantaneous axis of rotation is located in the spinal canal, anteriorly to the facet joints and in the midline (22). However, after an injury to the disc or facet joints, the axis of rotation has been found to move posteriorly or anteriorly, respectively (22). Thus, following a spinal injury, the axis of rotation in the horizontal plane moves towards the remaining intact structures.

Vertebral motion

Degenerative changes decrease the stiffness of the disc and its ability to maintain the stability of the functional spinal unit under loading. Thus, disc degeneration, in itself, increases the flexibility of the functional spinal unit. However, as degeneration advances, a marked decrease in disc height restricting the angular motion may occur. Spinal motion may also be restricted by the presence of vertebral ostheophytes which, by increasing the end-plate cross-sectional area, further limit vertebral motion (42).

An in vitro investigation has shown that, in the presence of a moderately degenerated disc, only lateral bending is significantly decreased, possibly because it is the type of motion most influenced by disc height

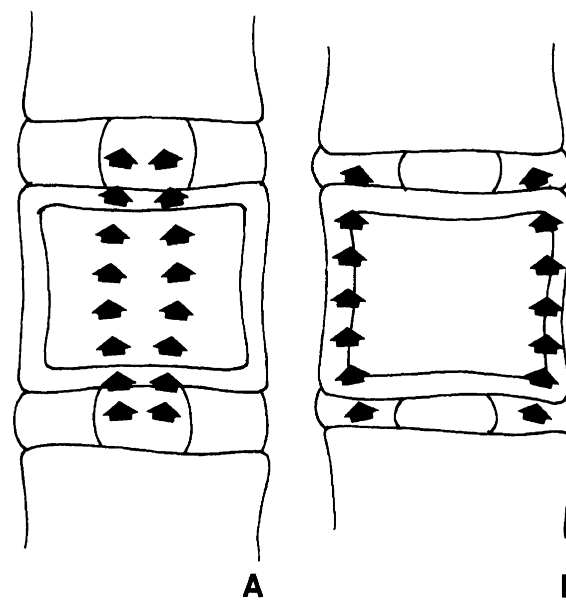

Fig. 4.8. *Effects of disc degeneration on the transmission of mechanical stresses from the disc to the adjacent vertebral bodies. In healthy discs* (A), *mechanical stresses are transmitted to the vertebral bodies through the area adjacent to the nucleus pulposus. In degenerated discs* (B), *mechanical stresses are transmitted to the vertebral bodies through the peripheral portion of the vertebral end-plates (from Ref. 37).*

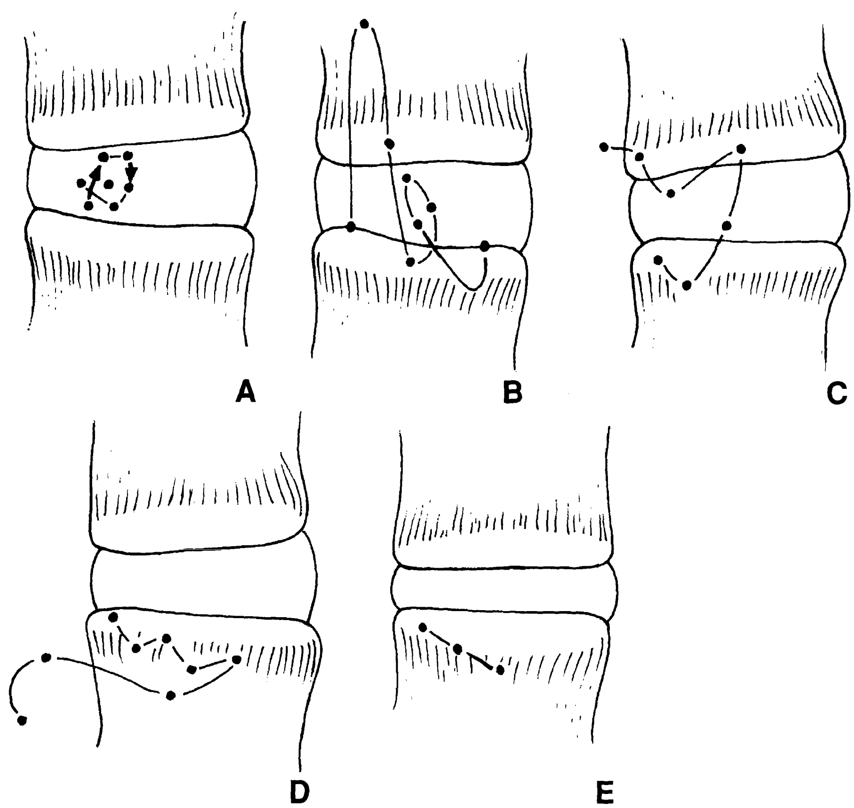

Fig. 4.9. *Instantaneous axes of rotation in the sagittal plane during flexion-extension motion in healthy disc and in the presence of disc degeneration of different severity.* (A) *Healthy disc;* (B) *and* (C) *mildly degenerated discs;* (D) *moderately and markedly* (E) *degenerated discs (from Ref. 17).*

(42). Flexion-extension was not significantly decreased and axial rotation, which is not influenced by disc height, tended to increase due to the increased laxity of annular fibers. Only marked disc degeneration led to a significant reduction of vertebral mobility in the three planes of motion (42).

In conclusion, disc degeneration may cause quantitative or qualitative changes in vertebral motion compared with healthy discs. The magnitude of vertebral motion may be biased by disc height and the cross-sectional area of the vertebral end-plates and, hence, its assessment may be of little value in diagnosing spinal instability due to disc degeneration. Coupled motions should be further investigated, because they might be more useful to detect abnormal vertebral motion.

Effects of disc excision

Surgical discectomy

The biomechanical behavior of the disc following surgical discectomy has been analyzed in vitro, in animals and by means of mathematic models (9, 18, 19, 29, 30, 51). In the evaluation of the effects of discectomy on disc biomechanics, it should be taken into account: 1) the type of anulotomy performed, 2) the site in the disc where anulotomy is carried out, and 3) the amount of disc tissue excised.

The biomechanical effects of a 5 × 5 mm rectangular anulotomy, compared with the effects of a transverse slit, have been investigated in animals. Both types of anulotomies caused significant changes in the intradiscal pressure and the flexibility of the functional spinal unit (4). However, these changes were significantly less pronounced following a transversal slit than a window anulotomy. The increased flexibility induced by these types of anulotomies was found to be maximum 4 weeks after surgery, but recovered to normal values after 6 weeks (4).

A nucleotomy performed in vitro through a square window of 5 × 5 mm on the right lateral side of the annulus, causes a significant increase in the flexibility of the functional spinal unit under flexion and left lateral bending as well as under anterior and right shear loads (51). It, thus, increases the flexibility of the disc when the injured site is submitted to tensile stresses (51). Moreover, this type of nucleotomy was found to increase coupled motions and creep deformation and to cause asymmetric lateral bending. It should be noted, however, that these findings resulted from a nucleotomy performed on the lateral annulus and they might reproduce the effects of a discectomy carried out through an extravertebral approach to remove an extraforaminal disc herniation.

Goel et al. have shown that total nucleotomy carried out through a posterolateral disc incision, i.e. the usual site of discectomy, causes an increase in flexibility under lateral bending both on the injured site and the contralateral site (18). Moreover, total nucleotomy induces an increased flexibility under flexion, extension and axial rotation and also increases translation motion during anterior flexion and lateral bending. Conversely, partial nucleotomy was found to increase vertebral motion under anterior flexion (18, 19), lateral bending (18) and axial rotation on the side of the nucleotomy (19); it, thus, affects spinal stability to a less extent compared with total nucleotomy.

Brinckmann and Grootenboer (9) analyzed the changes in disc height, intradiscal pressure and radial disc bulging, after in vitro removal of 1, 2 and 3 g of disc tissue. Discectomy was performed through a posterolateral anulotomy. Specimens submitted to the test came from donors aged 20 to 40 years and showed grade I or II disc degeneration. The authors found that disc height decreased, on average, 0.8 mm and disc bulging increased 0.2 mm, for each gram of tissue removed. As a compressive load was applied, disc bulging increased by 0.5 mm in the discectomized disc and 0.15 mm in the intact specimen. After removal of 3 g of disc tissue, intradiscal pressure was found to be, on average, 39% of the initial value. However, when discectomy was performed on discs coming from elderly subjects, with grade III or IV disc degeneration, intradiscal pressure fell to zero. This finding indicates that the effects of discectomy are markedly influenced by the severity of disc degeneration; therefore, in vitro studies carried out on specimens coming from elderly subjects may accentuate the effects of discectomy on disc biomechanics.

Chemonucleolysis

Intradiscal injection of chymopapain, the proteolytic enzyme most commonly used in chemonucleolysis, leads to a decrease in the nuclear and annular volume (21) and in the intradiscal pressure (35), a finding that may explain the relief of radicular pain occurring after treatment.

The biomechanical behavior of the disc treated with chymopapain is significantly modified during the first few months after enzyme injection. Two to six weeks after chemonucleolysis, the flexibility of the disc increases under axial compression, anterior flexion and lateral bending, as well as under axial rotation and shear stresses (29, 74, 80); the creep rate also increases (30, 80). The most striking effect of chymopapain injection is the marked decrease in disc stiffness under torsion and anterior flexion; the flexibility of the functional spinal unit was, in fact, found to increase up to 50% and to 100% under torsion and anterior flexion, respectively (29, 74). The marked increase in flexibility under anterior flexion would suggest a more intense enzymatic activity of chymopapain on the posterior region of the disc, possibly due to the different biochemical composition of the posterior annulus compared with other regions of the disc (74).

After 3 to 6 weeks of chemonucleolysis, the height and stiffness of the injected disc, as well as the creep rate, were found to return to normal values (29, 74, 80). Wakano et al. (80) showed that, 3 months after chemonucleolysis, the stiffness of the disc under axial compression tends to recover and, under torsion, is even larger than that of untreated discs. Moreover, during torsion or compression loads, there is no significant difference in the creep rate between treated and untreated discs. Spencer et al. (74) found that flexibility under lateral bending had returned to control values 3 months after chemonucleolysis, whereas flexion and torsion flexibilities remained substantially unchanged. However, 6 months after treatment, also the torsion flexibility had returned to control values. In keeping with these results, Kahanovitz et al. (29) observed that disc stiffness returned to normal values 5 months after chymopapain injection, though the flexibility under lateral bending was found to be increased by 30%.

In conclusion, in keeping with histological studies showing regeneration of disc tissue after chymopapain injection (8), biomechanical properties of the disc injected with chymopapain appear to return to normal values 3 to 6 months after treatment. Although these results seem to be extremely encouraging, it should be noted that surgical discectomy perfomed in animals provides comparable outcomes (29, 30). However, with respect to surgical discectomy, chemonucleolysis causes a marked flexibility of the functional spinal unit under flexion and torsion loads in the first few weeks after treatment. This may explain the greater back pain reported by patients treated with chymopapain, compared with those submitted to surgery, during the first weeks after treatment.

Automated percutaneous nucleotomy

The effects of automatic percutaneous nucleotomy on disc biomechanics have been analyzed by Castro et al. (13). Nucleotomy was performed on healthy discs for 45 min and an average of 4.6 g of disc tissue was removed. The height of the treated discs was found to be decreased by a mean of 0.7 mm after 15 min and 1.4 mm after 45 min. Intradiscal pressure was significantly decreased after 45 min (5.7 bar) and disc bulging was increased by 0.23 mm and 0.45 mm after 15 and 45 min, respectively. In contrast with these findings, Shea et al. (67) found that the reduction in disc height and intradiscal pressure occur within 10 min of the beginning of the nucleotomy and do not change significantly with time. Moreover, the introduction of a trocar into the annulus without removal of any disc tissue, led to a reduction in intradiscal pressure comparable to that produced by automated nucleotomy (67). These findings suggest that automated nucleotomy may relieve radicular pain by decreasing disc height and, hence, by reducing the tension of the nerve root caused by the herniated disc (67).

Laser discectomy

This technique has been proposed on the hypothesis that in a sealed space, such as the intervertebral disc, a small variation in volume of its content would result in a marked reduction of intradiscal pressure (14). In keeping with this hypothesis, the intradiscal pressure measured during discectomy, performed with a 3 mm cylindrical laser tract, was found to increase within the first minute, but then decreased by 44% and 56% after a mean of 9 min and 23 min, respectively. When a non-operative cylindrical laser tract of equal diameter was inserted into the disc, as a control experiment, the intradiscal pressure decreased by 6% (14).

Laser discectomy causes disc ablation by means of vaporization and charring of disc tissue. The entity of laser ablation was found to be related to the total amount of energy used (57) and the laser wavelength (39). By imparting a total energy of 1200 J and 3000 J, the disc tissue ablation was found to be, on average, 2.7 cm^3 and 4.3 cm^3, respectively (39). Holmium (Ho :YAG) and CO_2 lasers seem to induce a larger ablation compared with other lasers, possibly because their energy is largely absorbed by the water of the nucleus pulposus rather than transferred to the surrounding tissue (39).

Effects of laminoarthrectomy

Standard discectomy and microdiscectomy are usually accomplished through partial removal of laminae and facet joints. However, in a few conditions, such as in the presence of intra- or extraforaminal disc herniations, total facetectomy may be carried out deliberately or inadvertently. This may occur particularly at the upper lumbar levels, where the size of the spinal canal is often narrower with respect to the nervous structures contained. Furthermore, when disc herniation occurs within a stenotic spinal canal, bilateral laminotomy or central laminectomy may be needed.

The influence of spinal structures on the stability of the functional spinal unit have been analyzed in vitro. Posner et al. (56) found that during anterior flexion loading, complete failure of the functional spinal unit occurs when the supraspinous and interpinous ligaments, facet joints, posterior annulus and posterior longitudinal ligament have been resected. Goel et al. (20) evaluated the mobility of the functional spinal unit (L4-L5) in the three planes of motion after resection of the posterior ligaments associated with partial laminoarthrectomy performed bilaterally. This procedure was found to cause a significant increase in angular motion, under flexion-extension loads, and of axial rotation, under torsion.

Abumi et al. (1) analyzed vertebral motion after unilateral or bilateral graded facetectomy, with or without excision of the supraspinous and interspinous ligaments. They showed that partial arthrectomy carried out on one or both sides does not change the flexibility of the functional spinal unit. However, partial arthrectomy, when associated with the division of the posterior ligaments, causes a significant increase in spinal flexibility under anterior flexion. On the other hand, total arthrectomy, unilateral or bilateral, significantly increases spinal flexibility under anterior flexion and torsion, even when the posterior ligaments are left intact (Tables 4.1 and 4.2)

In conclusion, total arthrectomy affects spinal flexibility independently of the surgical procedure carried

Table 4.1. *Increase in vertebral motion after partial or total arthrectomy, unilateral or bilateral, with intact posterior ligaments*

	Type of arthrectomy			
Vertebral motion	Partial unilateral	Partial bilateral	Total unilateral	Total bilateral
Flexion	(–)	(–)	(++)	(++++)
Extension	(–)	(–)	(–)	(–)
Left axial rotation	(–)	(–)	(–)	(++++)
Right axial rotation	(–)	(–)	(+)	(+++)
Lateral bending	(–)	(–)	(–)	(–)

(–): Non-significant increase compared with intact specimen.
(+): p = 0.05; (++): p = 0.02; (+++): p = 0.01; (++++): p = 0.001.

Table 4.2. *Increase in vertebral motion after partial or total arthrectomy, unilateral or bilateral, after division of the posterior ligaments.*

	Type of arthrectomy			
Vertebral motion	Partial unilateral	Partial bilateral	Total unilateral	Total bilateral
Flexion	(+)	(++)	(+++)	(++++)
Extension	(–)	(–)	(–)	(–)
Left axial rotation	(–)	(–)	(–)	(++++)
Right axial rotation	(–)	(–)	(++)	(+++)
Lateral bending	(–)	(–)	(–)	(–)

(–): Non-significant increase compared with intact specimen.
(+): p = 0.05; (++): p = 0.02; (+++): p = 0.01; (++++): p = 0.001.

out to decompress the nervous structures, whereas partial arthrectomy does not increase spinal flexibility, provided the posterior ligaments are not transected.

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·Chapter 5·

Pathomorphology

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Disc degeneration

Stages of disc degeneration

Pathomorphologic studies on lumbar discs in individuals of varying ages have led to the identification of various stages of disc degeneration. The grading proposed by Friberg and Hirsch (27), and later adopted by Nachemson (57), identifies four types of disc morphology, whilst that of Thompson et al. (81) distinguishes five types. Adams et al. (2), based on pathomorphologic and discographic studies, have identified five types of disc: cottonball, lobular, irregular, fissured and ruptured (Fig. 5.1).

In the cottonball disc (Type 1), the nucleus pulposus is a white, gelatinous mass devoid of fissures or fibrotic areas.

In the lobular disc (Type 2), the nucleus pulposus consists of fibrous lumps separated by softer areas, which are found particularly at the border with the annulus fibrosus and cartilage end-plates. The nucleus shows thin fissures, whereas the annulus displays a distinct lamellar structure and no fissures.

The irregular disc (Type 3) has an entirely fibrotic nucleus pulposus, that can hardly be differentiated from the annulus. Both the nucleus and the inner portion of the annulus fibrosus show clefts, that in the annulus usually display circumferential patterns.

In the fissured disc (Type 4), the nucleus pulposus is clearly fibrotic, has an opaque appearance and is greyish or yellowish in color. The annulus fibrosus shows radial clefts, generally located in the posterior or posterolateral portion. The clefts extend up to close the periphery of the disc, but do not cross the outermost annular lamellae. The disc is often narrowed.

The disc is defined as ruptured (Type 5) when it shows a complete radial cleft, which crosses the entire annulus fibrosus, allowing communication between the inside of the disc and the deep aspect of the posterior longitudinal ligament or the epidural space.

In our opinion, two further types should be added to these five: disorganized and resorbed disc (Fig. 5.1).

In the disorganized disc (Type 6), there is no distinction between nucleus pulposus and annulus fibrosus. The disc tissue is considerably dehydrated and friable in consistency, and often yellowish or brownish in color. There are numerous complete or incomplete circumferential and radial clefts, as well as cavities of varying size, either empty or filled with debris (fibrous or necrotic). The disc is usually markedly reduced in height. The resorbed disc (Type 7) is extremely narrowed and its internal portion is completely empty or occupied by debris. Occasionally, it contains gas collections, responsible for the so-called vacuum phenomenon (45). The annulus fibrosus is very thin, particularly in the posterior and posterolateral portions, and shows large clefts running in various directions.

These types represent successive stages in the natural history of disc degeneration. However, a complete cleft in the annulus fibrosus (stage 5) may be present also in non-degenerated (stage 1) or slightly degenerated (stage 2) discs; in these cases the cleft is likely to be traumatic in origin (3).

Characteristics of disc fissures

The fissures in the nucleus pulposus may be located both at the periphery and in the center of the nucleus pulposus and have no definite orientation. Very often, however, they run parallel to the vertebral end-plates.

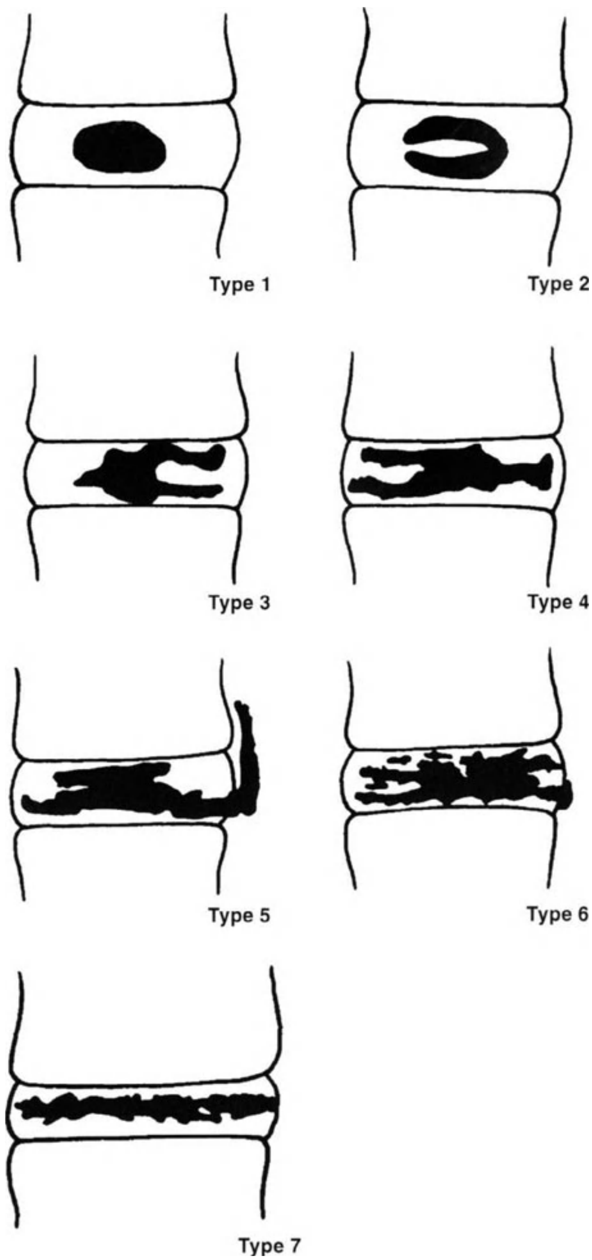


Fig. 5.1. *Normal disc* (Type 1) *and various types of disc degeneration* (Types 2–7) *as they appear at discography.*

The fissures in the annulus fibrosus may have a circumferential or radial arrangement. The circumferential clefts result from disaggregation of contiguous lamellae and, on transverse sections of the disc, appear to run along the circumference of the annulus fibrosus (Fig. 5.2). They extend for a few millimeters to one fifth or one fourth of the circumference of the disc. In the latter instance, they originate from coalescence, over time, of multiple clefts arranged along the same arc of circle. In the presence of concentric clefts, the interposed tissue may appear as sequestered from the rest of the disc.

A peculiar type of horizontal fissure has been described by Yasuma et al. (92). It is due to myxomatous degeneration of the annulus fibrosus, leading to separation of the middle annular lamellae and reversed orientation of the inner lamellae, which become convex towards the center of the disc.

The radial clefts are mostly located in the posterior half of the disc. On sagittal sections, the clefts are equidistant from the adjacent vertebral end-plates or are situated in proximity to the latter (Figs. 5.3 and 5.4). On transvere sections, the clefts have a sagittal (in the middle or paramedian plane) or oblique orientation. The oblique clefts are directed towards the postero-

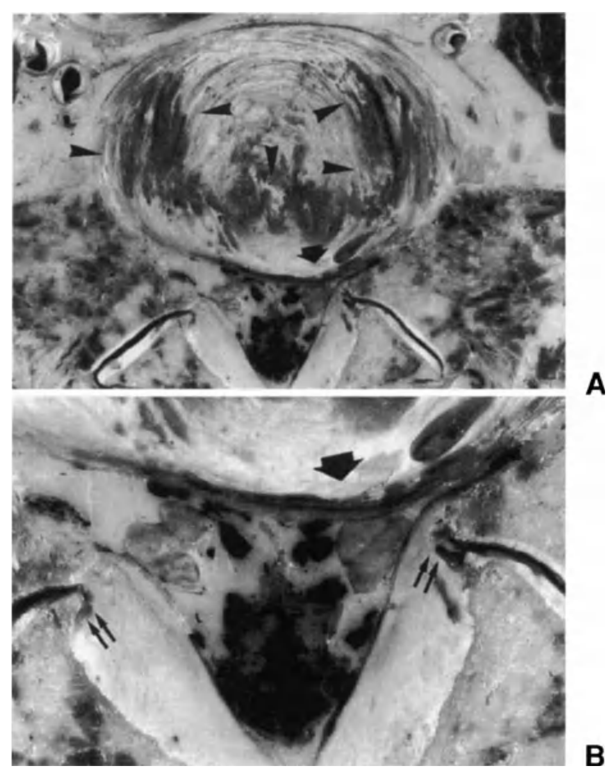


Fig. 5.2. *Axial section of intervertebral disc and vertebral canal in an elderly subject.* (A) *Circumferential fissures are visible in the lateral portions of the disc and a few incomplete radial fissures are present in the central posterior portion (arrowheads); the fissures contain brownish material, probably consisting of the so-called senile pigment. The disc shows, on the left, a mild posterolateral protrusion, which is in contact with the nerve root (arrow).* (B) *High magnification of* (A). *The posterolateral protrusion of the disc is clearly visible (large arrow). The facet joints show short anteromedial osteophytes (thin arrows) and the left joint narrows the corresponding nerve-root canal. Both joints, particularly the left, display a narrow articular space and thinning of the articular cartilage.*

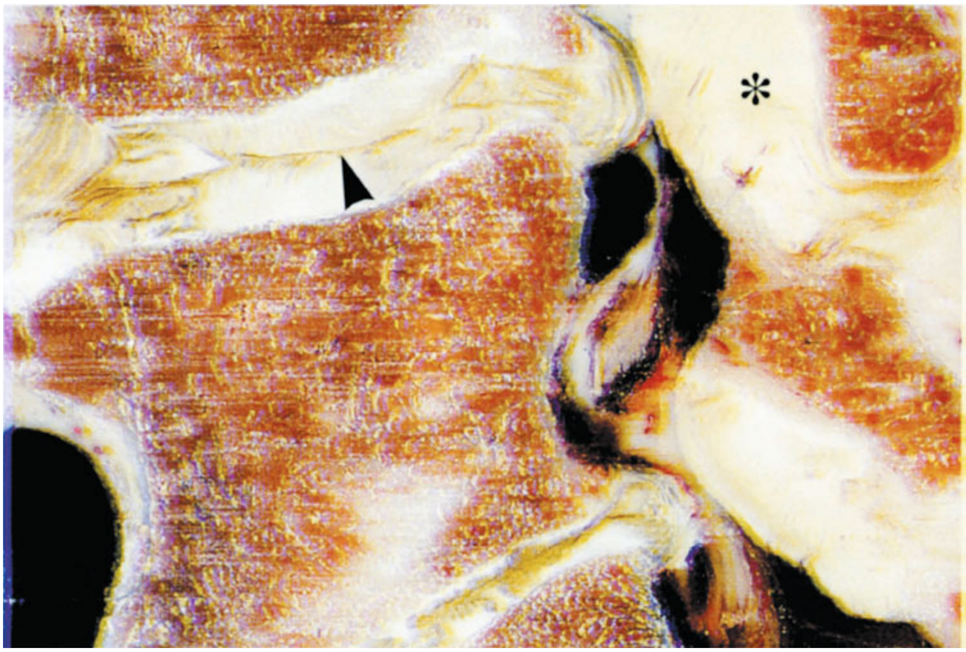


Fig. 5.3. *Paramedian sagittal section of L5 vertebra and lower two lumbar discs in an elderly subject. The L4-L5 disc is decreased in height and a long radial cleft is visible, equidistant from the adjacent vertebral bodies (arrowhead); a large part of the latter are no longer covered by cartilage end-plates; the posterior annulus fibrosus bulges into the vertebral canal and is in contact with the ligamentum flavum (asterisk). The L5-S1 disc, which is almost completely resorbed, shows a radial fissure and contains brownish material; the annulus fibrosus of this disc also bulges into the nerve-root canal.*

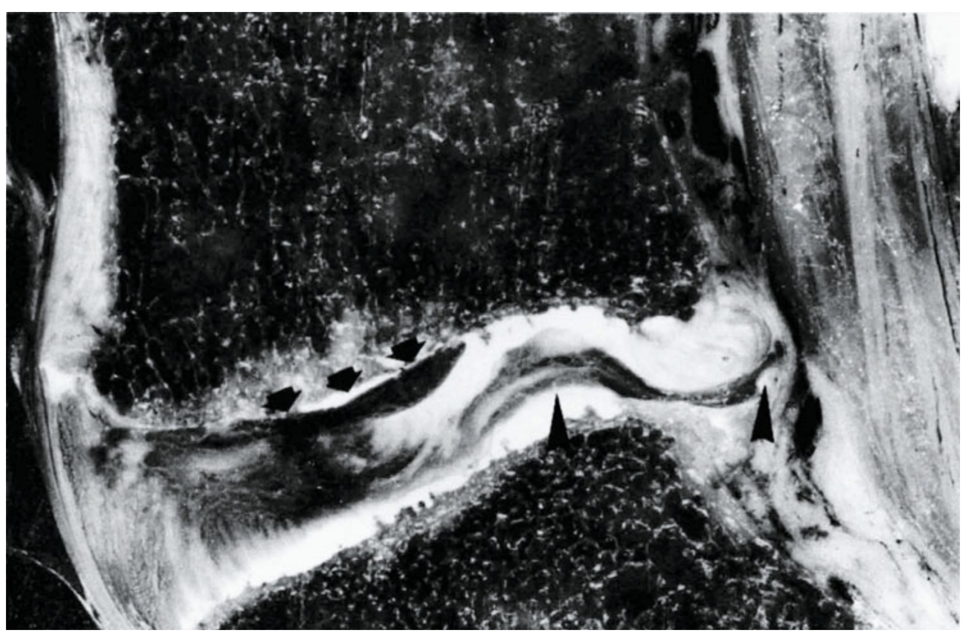


Fig. 5.4. *Midsagittal section of the L5-S1 disc and adjacent vertebrae of a middle-aged subject. In the posterior half of the disc, a large radial cleft (arrowhead) is visible, reaching the posterior longitudinal ligament. Another radial cleft is visible in proximity to the L5 vertebral end-plate (arrows).*

lateral portion of the disc and may be unilateral or bilateral, the latter being symmetrical or asymmetrical; the presence of two symmetrical fissures may lead to a kind of sequestration of the posterior portion of the annulus fibrosus. The incomplete clefts extend for varying distances from the central part to the periphery of the disc. The complete clefts reach the posterior longitudinal ligament (Fig. 5.4). In the anterior portion of the disc, fissures orientated at a right angle with respect to the direction of the collagen bundles may be observed in proximity to the attachment of the annulus fibrosus to the vertebral body (rim lesions).

Nuclear or annular clefts may be empty or contain mucoid material or necrotic debris. When the disc is resorbed, the disc tissue is often replaced, to a large extent, by a single or multiple empty clefts (Fig. 5.5).

Within the rim lesions, fibrovascular or fibrocartilaginous tissue has often been observed, which probably results from attempts to repair the fissure (33).

Fibrovascular invasion of disc

In the case of a complete radial tear in the annulus fibrosus, the inside of the disc, which is normally avascular in the adult, is then in communication with vascularized structures, such as the posterior longitudinal ligament and the epidural tissue. This may allow penetration of vascular buds and fibroblasts within the disc. Vessel ingrowth is presumably aimed at repairing the annular lesion, and it is probable that the repair often occurs, at least in the peripheral portion of the disc. Ingrowth of fibrovascular tissue usually occurs in the posterior portion of the disc and can extend to the nucleus pulposus (Fig. 5.6).

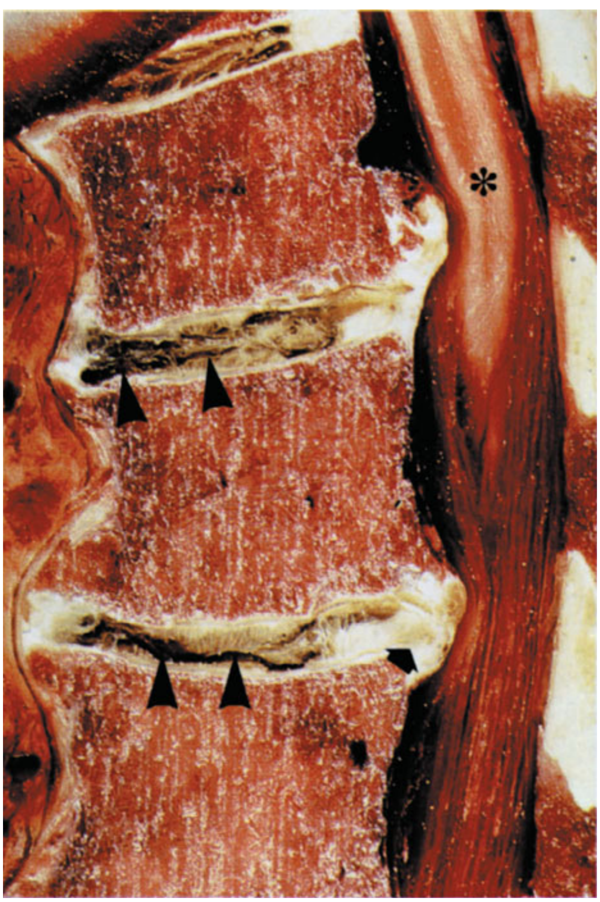


Fig. 5.5. *Midsagittal section of the cranial portion of the lumbar spine in an elderly subject. Two almost completely resorbed discs can be seen. Disc tissue is largely replaced by large clefts (arrowheads). The lowermost disc shows posterior bulging of the annulus fibrosus (arrow). The ventral aspect of the conus medullaris (asterisk) is indented by a large posterior osteophyte of the vertebral body.*

Fibrovascular tissue may invade the disc also through defects in the cartilage end-plate resulting from degenerative or necrotic changes in the cartilage, or from Schmorl's nodes (73, 84, 91). The latter mechanism, probably less common than the former, may lead to widespread vascular invasion of the disc.

Vascular invasion of the disc has been observed (91) only in subjects over 40 years of age and with a progressively higher frequency with advancing age (from 48% in the fifth decade to 60% in the ninth decade).

Correlation with age and vertebral level

The various grades of degeneration of lumbar discs are strictly related to the subject's age and the vertebral level (2, 55, 57, 81).

Subjects younger than 30 years usually have Type 1 or 2 discs. However, even adolescents may have discs showing a Type 3 or 4 morphology. Between 30 and 50 years, there is a progressive decrease in number of Type 1 and 2 discs and an increase in Types 3 to 5. Between 50 and 70 years, it is extremely uncommon to find Type 1 discs, whilst Type 2 become less numerous; at this age, most lumbar discs are Types 3 to 5, but also Types 6 or 7 are frequently found. After 70 years, the vast majority of the discs are Type 4 to 7.

The upper two lumbar discs rarely show morphologic features of Types 4 to 7, even in old age. The morphology of L3 disc is usually of Types 2 to 4; it is rarely of Types 5 to 7. The most marked degenerative changes are observed in the two lower lumbar discs. However, while in one study (55) the L4 disc showed the greatest tendency to degenerative changes, in another study, the more advanced stages of degeneration were most frequently found at L5 level. These findings suggest that disc degeneration is related to the amount of functional stress to which the individual discs are subjected. This may explain, at least partly, the greater tendency of males to undergo disc degeneration (55). However, a role might also be played by other factors, such as the amount of lumbar lordosis (i.e., the inclination of the disc with respect to the horizontal plane), the shape of the disc and the symmetry of the articular processes (26).

Physiologic and pathologic degeneration

With advancing age, all connective tissues undergo regressive changes, which tend to be more and more marked with the amount of the functional stress to which the structure is submitted. This holds also for the intervertebral disc. Disc degeneration, therefore, is a physiologic process, which begins already during the course of the second decade of life (68). In the majority

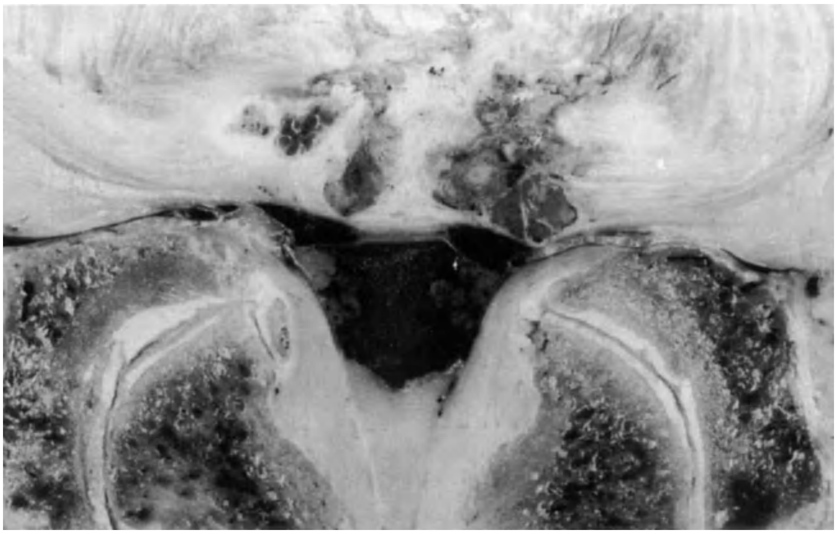


Fig. 5.6. *Axial section through the proximal portion of the L4-L5 disc. The posterior portion of the annulus fibrosus shows radial fissures partially occupied by fibrovascular tissue. Hypertrophied articular processes and thickened ligamenta flava cause a moderate narrowing of the spinal canal.*

of subjects, the disc at a given level shows physiologic changes ranging from mild to relatively severe. Furthermore, these changes appear only at certain stages of aging. For instance, in most subjects the L3 disc is Type 1 or 2 in the third decade of life, Type 3 in the fourth to fifth decade and Type 4 or 5 in the sixth to seventh decade. Transition from one type to the next is, therefore, very slow and occurs harmoniously in the two components of the disc.

The degenerative process should be considered pathologic when: 1) at a given level, and at a given age, degenerative changes are abnormally marked compared with those found in the majority of subjects of the same age; 2) degenerative changes involve a component of the disc to a much larger extent than the other. The result is that the mechanical stress on the disc is exceedingly high compared with its structural characteristics at that age; or that the most impaired component is not able to play the function normally required to it, when the other component is normal or only slightly impaired. From the morphologic viewpoint, however, the changes in the two components, considered individually, are similar to those occurring in the process of physiologic degeneration.

Degenerative changes of cartilage end-plate

Degenerative changes of the disc are often associated with similar changes in the cartilage end-plate.

With aging, the end-plate undergoes structural changes, characterized initially by calcification and then ossification of the deep portion of the superficial zone. True degenerative alterations may also be present. The alterations consist of degenerative or necrotic changes (73), vertical fissures and avulsions of portions of cartilage from the bone surface. Tanaka et al. (79) have identified two types of pathologic avulsion. In one type, the cartilage is separated from the bone surface by a layer of fibrous tissue, whilst in the second, the cartilage fragment is completely detached from the vertebral body and is free in the disc tissue. Avulsions of the cartilage end-plate have been observed in senile and pre-senile age, being more and more frequent with greater disc degeneration. Since the cartilage end-plate plays an important role in the nutrition of the disc, the avulsion, and, more generally, the degenerative changes of the cartilage end-plate, possibly tend to enhance disc degeneration.

In both cartilage end-plates, the zone most often showing avulsions is that in the center, followed by the posterior zone. This may explain the possibility both of avulsions of fragments of cartilage end-plate by the annulus fibrosus and extrusion of islets of cartilage together with disc tissue.

Degenerative changes of adjacent vertebrae

Degenerative changes of the disc, particularly when severe, are often associated with degenerative changes of the two adjacent vertebrae, namely osteophytosis and subchondral sclerosis of the vertebral body, and arthrotic changes of the facet joints. The narrower the disc, the more severe tend to be the changes. However, it is not yet known whether disc degeneration may represent the only cause of degenerative changes of the vertebrae or whether, in the etiology of the latter, a relevant role is played by constitutional, mechanical or traumatic factors; or whether degenerative changes of the facet joints may cause alterations of the other components of the motion segment. According to Kirkaldy-Willis and Yong-Hing (44, 94), alterations in any component of the motion segment lead to a series of events linked together, in turn triggering changes in the other components.

Osteophytes of vertebral body

These may be anterior, lateral or, less frequently, posterior. Three hypotheses have been advanced to explain the development of somatic osteophytes.

Schmorl believed that they result from fissures in the peripheral portion of the annulus fibrosus, which detaches from the vertebral body, thus loosing the ability to stabilize the adjacent vertebrae (73). This role is then played by the anterior longitudinal ligament, the attachment of which to the vertebral body is submitted to eccessive mechanical stress, giving rise to reactive bone growth. The stress can be further enhanced by displacement of disc tissue behind the ligament and subsequent detachment of the latter from the bone surface. This pathogenetic hypothesis, however, has been advanced specifically for osteophytes of spondylosis deformans. Schmorl, in fact, maintained that disc degeneration does not involve formation of osteophytes.

Other authors (17, 84) have hypothesized that the initial event in development of somatic osteophytes is a decrease in disc height. This involves an anterior tilting of the adjacent vertebrae, which increases pressure on the ventral portion of the disc and causes anterior protrusion of disc tissue. The disc bulging, laterally to the anterior longitudinal ligament, results in detachment of the periosteum, thus stimulating the formation of subperiosteal reactive bone. The latter then fuses with the bone of the vertebra, forming an osteophyte, This mechanism may also be associated with that proposed by Schmorl (Fig. 5.7).

Milgram (54) advanced a third hypothesis, which may explain the formation of osteophytes in markedly degenerated spines. In this instance, the disc shows large clefts, allowing abnormal micromovements of the adjacent vertebrae. The abnormal motion may stimulate the formation of chondroid tissue in the cartilage end-plates, the peripheral disc tissue and the subchondral bone. Calcification and ossification of the chondroid tissue in the peripheral portion of the disc is responsible for the formation of marginal osteophytes. This mechanism could explain the development of marginal posterior, as well as anterolateral, osteophytes.

Sclerosis of subchondral bone

The subchondral bone in the vertebrae of a motion segment often displays sclerosis in the presence of severe degenerative changes of the disc, particularly when the latter is markedly decreased in height. Sclerosis is likely to be due to eccessive mechanical stress on the vertebrae, which may be responsible for the transformation into compact bone of the trabecular bone underlying the cartilage end-plate and the ring apophysis. Alternatively, mesenchymal cells of bone marrow in the trabecular bone may undergo cartilaginous metaplasia; ossification of the newly-formed cartilage may then lead to transformation of the trabecular bone into compact bone (54).

Arthrotic changes of facet joints

These are similar to those found in all diarthrodial joints and would be consistently present when the disc is considerably degenerated (35). Changes consist in erosions of articular cartilage, formation of marginal osteophytes and a synovial inflammatory reaction.

Articular cartilage, when moderately degenerated, presents depressions and fissures in the superficial layer, which may be replaced by fibrous tissue. Chondrocytes in the middle layer are isolated or arranged in clones, and often appear degenerated. In the deep layer, there is an increase in number of cell clusters.

The cartilage of the facet joints rarely shows severe arthrotic changes. When this is the case, the thickness of the cartilage is decreased and its surface is considerably irregular due to the presence of erosions and large clefts. In some zones, the subchondral bone is covered only by a thin layer of cartilage showing cells mostly arranged in clones. The interterritorial matrix contains a large proportion of large-diameter collagen fibers.

Development of marginal osteophytes may be relatively independent of alterations of the articular cartilage. Large osteophytes may, thus, be present also when the cartilage shows only mild changes. Osteophytes result from ossification of the articular cartilage, the joint capsule and / or the ligamenta flava where they are attached to bone.

The articular capsule may become abnormally lax due to thinning of cartilage, fragmentation of meniscoids and joint effusion caused by a synovial inflammatory reaction (94). Laxity may cause or favor subluxation of articular processes, which tends to enhance the arthrotic changes.

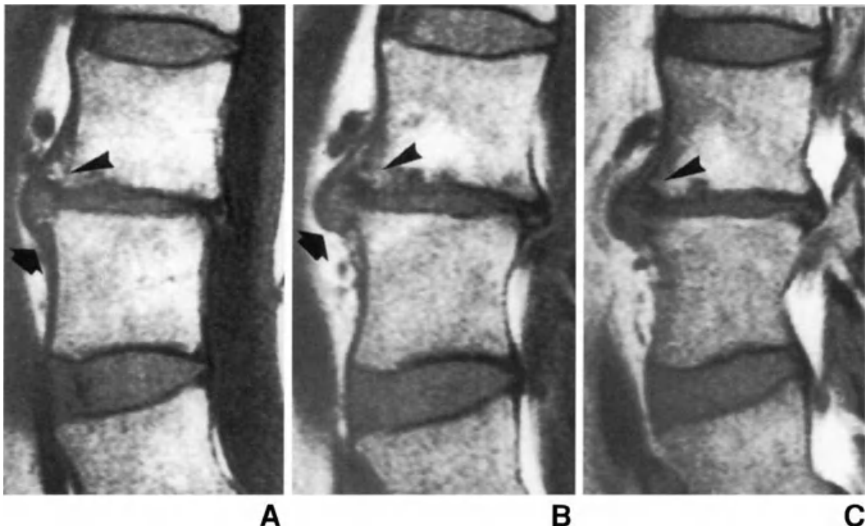


Fig. 5.7. *Sagittal T1-weighted MR images [(A) paramedian; (B) and (C) lateral] of the lumbar spine. The L4-L5 disc is markedly decreased in height. At this level, the anterior longitudinal ligament and periosteum appear to be detached from the vertebral bodies by a portion of disc tissue displaced ventrally (arrows). At the level of the caudal rim of the proximal vertebral body, subperiosteal reactive bone tissue and, in the lateral sections, a short osteophyte (arrowhead) can be seen.*

Effects on adjacent motion segments

Degenerative changes of the disc lead to an increase or, more often, a decrease in mobility of the motion segment. Both conditions produce abnormal or excessive mechanical stress on the healthy adjacent discs (76). In vivo radiographic studies have demonstrated that the disc above a degenerated disc shows increased mobility on combined movements of lateral flexion and axial rotation (82). Biomechanical investigations on cadaver motion segments have demonstrated that the disc underlying a disc that has been made hypomobile, thus simulating a degenerative condition, shows, as a result of compression loading, an increase in intradiscal pressure and a more marked bulging of the annulus fibrosus. These findings suggest that degeneration of a disc tends to produce degenerative changes in the adjacent healthy discs, particularly in the underlying one, due to functional overloading. This is consistent with the clinical and pathologic observations indicating that subjects showing disc degeneration tend to present this condition in multiple contiguous discs.

Bulging of annulus fibrosus

In this condition, the annulus fibrosus bulges beyond the tangent plane to the posterior edge of the adjacent vertebrae. Bulging of the annulus fibrosus must be distinguished from disc herniation. In the former condition, in fact, the bulging is relatively mild and affects a large portion of the disc and, in a normally-sized spinal canal, does not cause compression of the nervous structures. On the other hand, the two conditions are strictly related. Annular bulging, in fact, generally results from degenerative changes of the disc similar to those responsible for a herniation and may occasionally evolve into a typical disc herniation.

Annular bulging may involve the anterior, lateral or posterior portion of the disc. However, only bulging of the two latter portions may be of clinical relevance. Furthermore, annular bulging may be normal or pathologic.

Normal bulging

The posterior aspect of the lumbar intervertebral discs may be flat or concave, or may even be slightly convex. In some subjects, the posterior aspect of one or more discs displays a moderate convexity and protrudes into the vertebral canal. This occurs particularly in subjects, such as achondroplastic dwarfs, presenting a marked concavity of the vertebral bodies in the sagittal plane.

In this condition, the disc displays the degenerative changes normally related to aging. Disc bulging, therefore, although contributing to narrowing of the spinal canal, does not represent, in itself, a pathologic condition.

Pathologic bulging

Annular bulging is pathologic when it is the result of pathologic degenerative changes of the disc.

In an anatomo-radiologic study of discs showing posterior annular bulging, Kambin et al. (40) consistently found moderate or marked disc changes, consisting in circumferential and radial tears of the annulus fibrosus and migration of fragments of fibrotic nucleus pulposus between the fissured annular lamellae. All the discs, furthermore, were decreased in height by at least one third, which presumably favored the posterior protrusion of the outermost annular lamellae. Annular bulging, however, is not necessarily associated with a decrease in disc height and advanced degenerative changes of both disc components. Two conditions may, in fact, be identified:

1. The two components of the disc show changes of similar severity. The nucleus penetrates into incomplete radial fissures and/or circumferential fissures of the annulus fibrosus, but does not cross the outermost, non-fissured, lamellae. These resist, but bulge under the pressure of the nucleus pulposus. Bulging of this type can involve the entire posterior and/or lateral portion of the annulus fibrosus, or a more circumscribed portion of it. This is usually the mid-posterior part, in which the resistance of the annulus fibrosus is increased by the central strand of the posterior longitudinal ligament. The disc usually shows a mild to marked decrease in height, which contributes to the etiology of bulging.

2. The nucleus pulposus shows moderate degenerative changes, whereas the annulus fibrosus is comparatively more impaired and/or abnormally thin (4, 46), and thus unable to withstand the pressure exerted by the nucleus pulposus. In these conditions, which are less common than the former, the disc height is mostly normal or slightly decreased. This type of bulging is typical of young subjects and usually involves the entire posterior or lateral portion of the disc.

The amount of annular bulging may vary considerably. When it is marked, it may be difficult to differentiate the condition of bulging from that of true herniation of the annulus fibrosus (Fig. 5.8). On occasion, in the same disc showing a large annular bulging, there may be a narrow zone with a herniation-like prominence.

Bulging of the annulus fibrosus tends to increase on extension of the trunk, since in this position the adjacent vertebral bodies get closer dorsally and the curvature of the outermost annular lamellae increases. Annular bulging, in the presence of a narrow or stenotic spinal canal, can contribute to compression of the neural structures.

Types of herniation

Classification

The classifications commonly adopted distinguish between 3 or 4 types of posterior or lateral herniation of the disc.

One classification (6) identifies: disc protrusions, extruded herniations and sequestered herniations. Extruded herniations are those conditions in which the herniated material entirely perforates the annulus fibrosus, but remains in part within the limits of the disc. In sequestered herniations, the herniated material is found completely outside the disc, loosing any relationship with it and becoming a free fragment of tissue. The fragment may remain in close proximity to the disc or migrate at a distance.

Another classification (53) distinguishes between: contained herniations, which are equivalent to the disc protrusions of the former classification; and non-contained herniations, which include extruded – subligamentous or retroligamentous – herniations, and sequestered herniations. The subligamentous and sequestered herniations may be migrated or non-migrated.

The drawback of the former classification is that it reduces to only three, the possible types of disc herniation. The second classification uses different terms to indicate conditions that are anatomically similar: a subligamentous herniation that has migrated at a distance from the disc is usually a sequestered herniation; however, the term sequestration is used for only retroligamentous disc fragments free in the vertebral canal, which may or may not be migrated. Some authors (69), on the other hand, use this picturesque, but hardly anatomic, term to indicate exclusively free fragments migrated at a distance from the disc. These discrepancies lead to confusion in the description and interpretation of pathologic findings.

We identify lumbar disc herniation as: contained, extruded or migrated. The extruded herniations are subligamentous, transligamentous or retroligamentous, but not migrated. This terminology has the advantage of not using the term sequestration; of using a specific term for each type of pathologic condition; and of distinguishing between pathologic conditions implying different therapeutic indications. The term retroligamentous indicates that the herniated disc fragment is located in front of the disc, but is free, or substantially free, and cannot thus be removed with percutaneous intradiscal procedures. The term migrated herniation indicates that the only, or essential, pathologic condition is at a distance from the disc, which may be a secondary element in terms of surgical treatment.

Contained herniation

This is the most typical form of lumbar disc herniation.

The pathogenetic mechanism is related to the presence, in the annulus fibrosus, of large circumferential fissures extending also to the most peripheral lamellae or of radial fissures reaching to close proximity of the

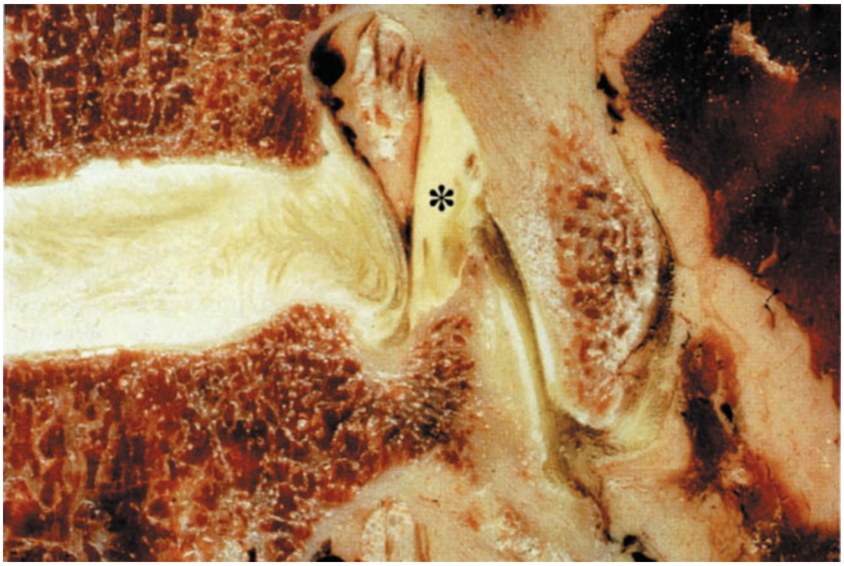


Fig. 5.8. *Lateral sagittal section of a cadaver spine at L4-L5 level. The intervertebral disc, of normal height, shows fissures in the posterior annulus fibrosus reaching in proximity to the outermost lamellae. The annulus bulges into the vertebral canal and, in its caudal portion, the prominence has the appearance of a true herniation. Asterisk: ligamentum flavum located ventrally to the facet joint.*

disc surface. The nucleus pulposus shows degenerative changes of varying severity. The herniated tissue enters the fissures of the annulus fibrosus and comes into contact with the outermost lamellae, but does not actually perforate them (Figs. 5.9 and 5.10). Alternatively, it is the peripheral portion of the annulus fibrosus that protrudes under the posterior longitudinal ligament, in a limited zone of the disc, even in the absence of displacement of the nucleus pulposus (page 114).

The herniation, considered the mechanism of formation, is generally located in a narrow area of the circumference of the disc, in most instances the posterolateral one. When the outermost lamellae of the annulus fibrosus are incised, the herniated portion of the nucleus pulposus is often seen to emerge from the disc, even spontaneously. Usually the nucleus is moderately fibrotic. A still pulpy and elastic nuclear tissue, in fact, can more easily enter and proceed into the annulus fibrosus than a highly fibrous tissue. For this reason, the amount of nucleus pulposus that can be excised from inside the disc is often abundant.

The posterior and lateral portions of the annulus fibrosus not involved by the herniation can be of hard-fibrous consistency or even relatively friable. This depends on the degree of degeneration of the disc, which is related, to a large extent, to the subject's age.

Fig. 5.9. *Schematic drawing of contained herniation. The peripheral portion of the annulus fibrosus and the posterior longitudinal ligament are intact.*

Extruded herniation

An extruded herniation is the condition in which the herniated tissue exits partially or completely from the limits of the disc, but does not migrate at a distance from the vertebral border. This condition occurs when the fissures in the annulus fibrosus extend to the outermost annular lamellae. An extruded herniation of the posterior portion of the disc, covered by the posterior longitudinal ligament, can be: subligamentous, transligamentous or retroligamentous.

In subligamentous herniations, a portion of the nucleus pulposus exits from the disc, but does not perforate the posterior longitudinal ligament and, thus, does not penetrate into the vertebral canal (Fig. 5.11). When the ligament is incised, a disc fragment can be

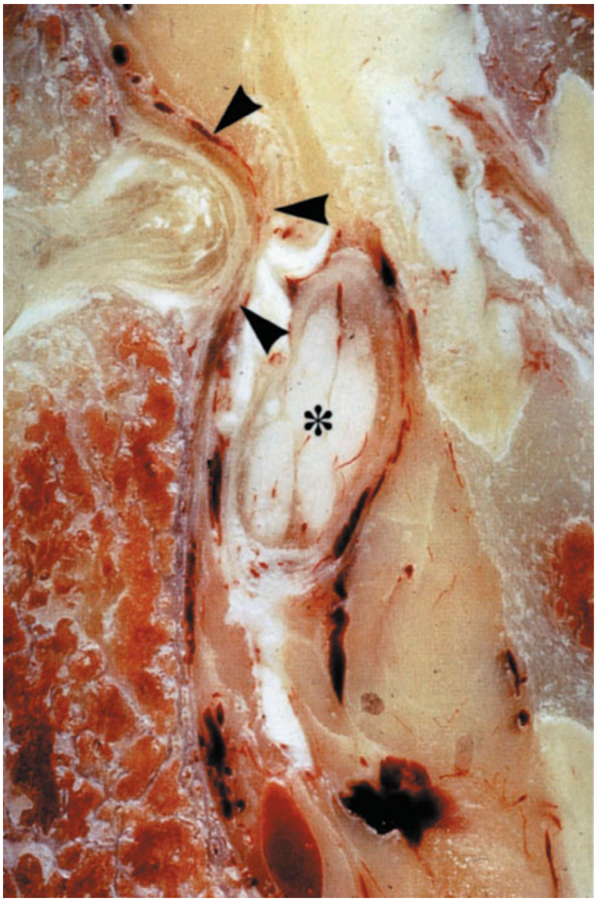


Fig. 5.10. *Paramedian sagittal anatomic section showing a contained herniation. The outermost lamellae of the annulus fibrosus and the posterior longitudinal ligament (arrowhead) are intact. Asterisk: nerve root that is penetrating the intervertebral foramen.*

seen, completely extruded from the disc or still partly contained within the annulus fibrosus. The herniated fragment may be located behind the cranial or caudal rim of the vertebral body, rather than opposite the disc (Fig. 5.12). In these cases, the annular cleft is in close proximity to one of the rims of the vertebral body. Occasionally, the herniated tissue does not perforate the outermost annular lamellae, but detaches them from the posterior rim of the vertebral body and the adjacent portion of the body (Fig. 5.13). These herniations are often pedunculated, i.e., the completely extruded fragment is in continuity with the disc through a short pedicle of tissue.

The herniation is defined as transligamentous when the herniated tissue perforates the posterior longitudinal ligament and a part penetrates into the vertebral canal, while the residual portion remains subligamentous (Fig. 5.14). This portion can be in continuity with the contents of the disc or be completely extruded. This condition is probably rare and difficult, with the imaging techniques or at surgery, to differentiate from the other types of extruded herniation.

A retroligamentous herniation is the condition in which the herniated disc fragment perforates the posterior longitudinal ligament and remains free in the vertebral canal without migrating at a distance from the disc (Fig. 5.15).

The fragment escaping from the disc can be single or there can be multiple extruded fragments. In the case of a single fragment, this is mostly of large dimensions; with multiple fragments, there is one large fragment and other smaller pieces, or occasionally several small fragments. The extruded disc material is generally of a hard-fibrous consistency, since it includes both a nuclear component and portions of annulus fibrosus detached in the process of herniation.

An extruded transligamentous or retroligamentous fragment may be free in the vertebral canal or be covered by a thin fibrous sheath, which is usually the case when the process of extrusion has occurred more than 2–3 weeks previously.

In the presence of a completely extruded fragment, no hole is visible in the annulus fibrosus and the posterior longitudinal ligament (where this is present). Usually, the annulus fibrosus appears to be intact and often does not bulge, or only moderately protrudes, into the spinal canal. The absence of an evident hole in the annulus fibrosus could be due to a door mechanism: the outermost annular lamellae (together with the posterior longitudinal ligament, where this is present) are elevated and displaced dorsally by the extruding

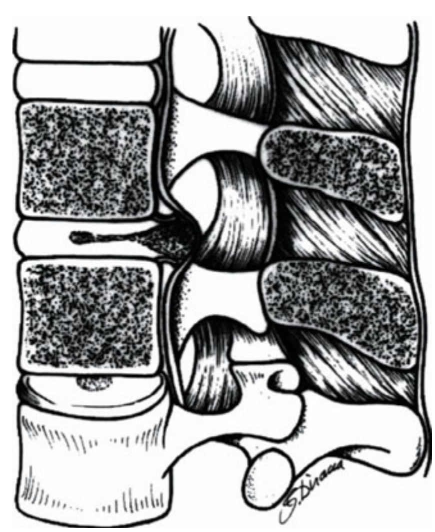


Fig. 5.11. *Schematic drawing of subligamentous extruded herniation. The annulus fibrosus is perforated, whilst the posterior longitudinal ligament is intact.*

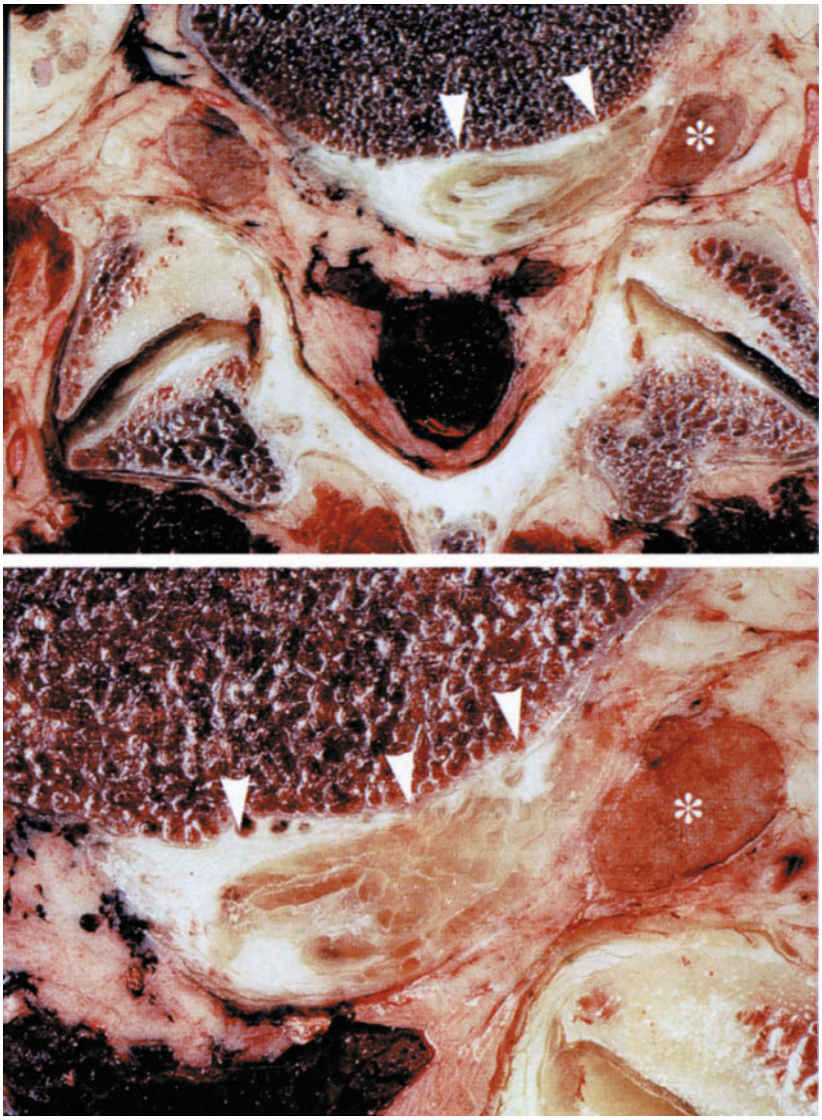


Fig. 5.12. *Axial section of a cadaver spine immediately cranial to the L4-L5 disc.* Top: *Disc herniation extruded cranially in the posterolateral region and partially in the left intervertebral foramen (arrowhead). In this section, the herniation encroaches on the spinal canal, but appears to compress only the root running in the intervertebral foramen (asterisk).* Bottom: *Higher magnification.*

fragment, and immediately return to their position, thus obliterating the annular hole. A concomitant or alternative factor may be represented by periannular scar phenomena, rapidly occluding the tear through which the fragment passed. In spite of the distinguishing features, however, it may at times be difficult, based on CT or MRI findings, or even operative findings, to determine whether the herniation is extruded or migrated.

The contents of the disc may range from very abundant to extremely meager. This depends upon various factors, such as the size of the extruded fragment, the height of the disc and the degree of disc degenerartion. Frequently the contents are meager, particularly when the extruded fragment is of large dimensions.

Migrated herniation

This is the condition in which the extruded fragment migrates at a distance from the disc (Fig. 5.16). The fragment may remain subligamentous or be free in the spinal canal behind the posterior longitudinal ligament. A subligamentous extruded herniation may become a migrated herniation, since the posterior longitudinal ligament does not adhere to the middle portion of the posterior aspect of the vertebral body: if the fragment dissects the ligament at the level of its attachment to the posterior rim of the vertebral body, it may subsequently migrate behind the middle portion of the ligament or may invade the vertebral canal and become retroligamentous. Usually the migrated

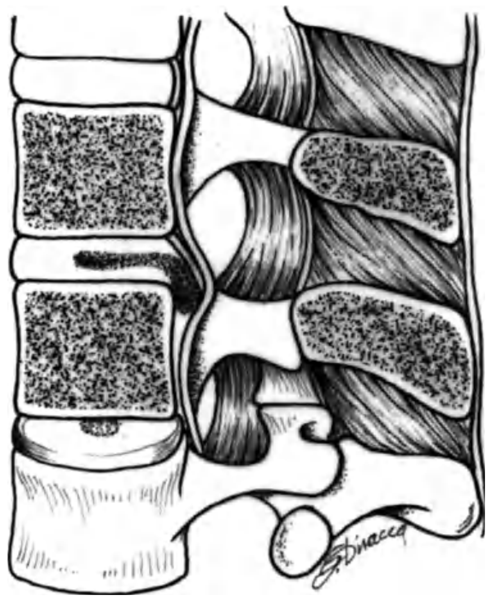


Fig. 5.13. *Pedunculated extruded disc herniation. The herniated tissue has detached the annulus fibrosus from the vertebral body and is displaced dorsally to the latter.*

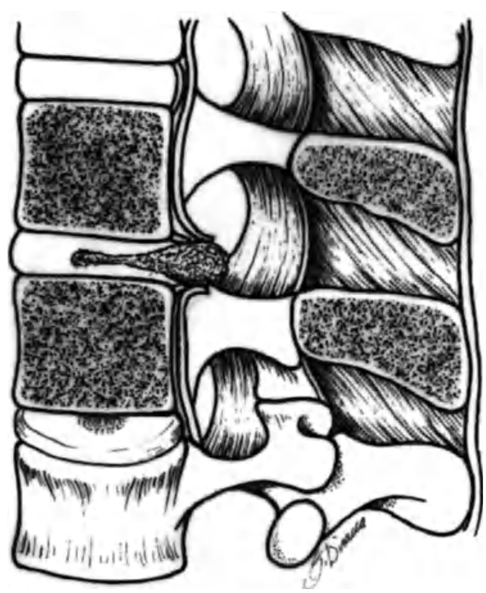


Fig. 5.14. *Schematic drawing of transligamentous herniation.*

fragment has lost all relationships with the disc. A subligamentous fragment is rarely in continuity with the parent disc through a long pedicle. This condition can simulate a subligamentous extruded herniation. The distinguishing factor is the distance of the fragment from the disc. When the fragment has migrated beyond the rim of the vertebral body, the condition should be identified as a migrated herniation, since surgical

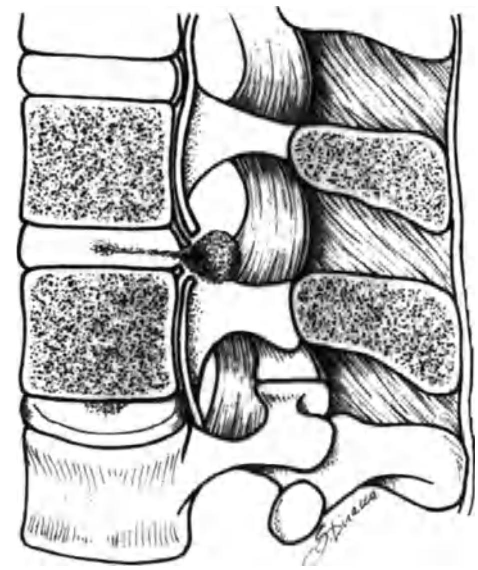


Fig. 5.15. *Retroligamentous extruded disc herniation. The herniated disc fragment (nucleus pulposus and/or annulus fibrosus) perforates the posterior longitudinal ligament and migrates behind the latter, but not at a distance from the disc in the longitudinal direction.*

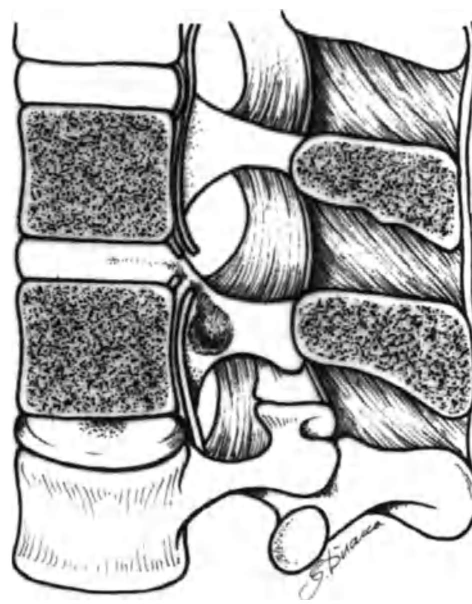


Fig. 5.16. *Migrated herniation. The disc fragment has perforated the annulus fibrosus and the posterior longitudinal ligament and has migrated at a distance from the disc, thus losing any relationship with the latter.*

exploration limited to the disc space does not allow identification and removal of the fragment.

Migration may occur, in order of decreasing frequency, in the caudal, intraforaminal or cranial direction, and within, or dorsally to, the thecal sac.

Caudal migration

This may occur towards the midline or laterally. Midline migration is fairly rare, since extrusion of disc tissue is more likely to occur posterolaterally than in the midline. In these cases, the extruded fragment is mostly large and is located ventrally to the thecal sac. When migration occurs in the posterolateral direction, the fragment is located laterally, ventrally or medially to the emerging nerve root. In the latter instance, it is generally situated in the axilla of the root (Fig. 5.17).

Intraforaminal migration

The fragment migrates proximally, in the concavity of the posterolateral portion of the vertebral body, medially or ventrally to the root running in the intervertebral foramen.

Cranial migration

This is fairly rare and may occur in a midline or centrolateral direction. In the former instance, the herniation is subligamentous or retroligamentous, and often of large dimensions. In the latter, the fragment, usually small in size, is located between the dural sac and the root emerging at the level above (Fig. 5.17).

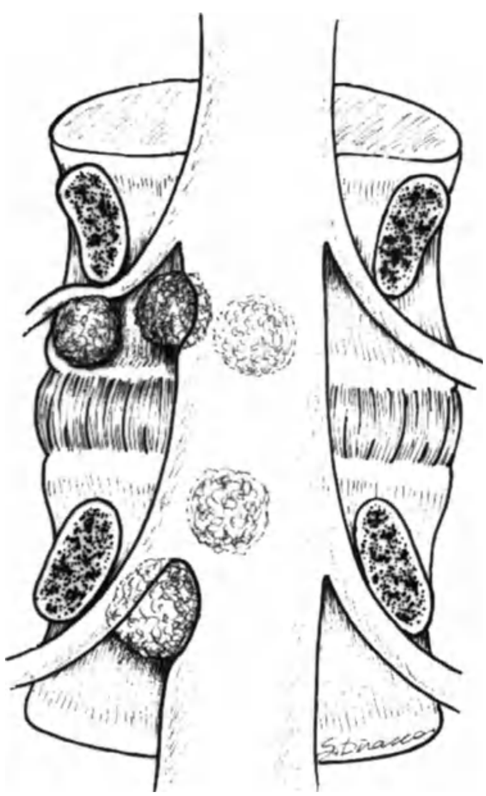


Fig. 5.17. *Most frequent sites of migration of a disc fragment. Transparent effect shows the herniations migrated ventrally to the thecal sac, proximally, or caudally to the disc.*

Intradural migration

The incidence of intradural herniations ranges, in large series, from 0.04% (49) to 0.27% (14, 61); in a few small series, however, the incidence exceeds 1% (43, 59). Intradural migration predominates in males (76%) and in the fourth to sixth decade of life; the discs most frequently involved are the fourth (50.8%) and third (20.6%) (43). Perforation of the dural tube may occur abruptly, due to the high energy with which the fragment is extruded from the disc (20) or, more probably, results from a mechanism of slow and continuous pressure on the dura mater (51, 74, 75). One predisposing factor to the intradural migration of the herniated fragment may be the presence of adhesions between the posterior longitudinal ligament and the dural sac. This hypothesis is supported by the anatomical study of Blikra (11) who, in 40 cadavers of asymptomatic subjects, found adhesions between the ligament and the dura mater at L4-L5 level being very tenacious in one fifth of cases. In patients with an intradural herniation, adhesions may be the result of inflammatory phenomena of traumatic origin, caused by herniation or previous surgery (16, 43, 61, 80), or they may be due to a congenital fusion between the ligament and the dura mater (11). The fragment can penetrate entirely or only partly into the thecal sac. The latter usually shows a hole of varying size on its ventral aspect at the level of the disc. Occasionally, the subarachnoid space is in direct communication with the inside of the disc (39). Only exceptionally may a disc fragment penetrate into the dural sheath of the nerve root in its extrathecal course (9, 83).

Usually, there is only one migrated disc fragment. At times, the migrated tissue consists of several parts connected by fibrous bands or, occasionally, separated from each other. The tissue is generally of hard-fibrous consistency. This is probably due either to the presence of annular portions of the disc or the initially inflammatory and then cicatritial reaction developing around the migrated fragment and within its peripheral portion.

Retrothecal migration

Very rarely a disc fragment migrates dorsally to the nervous structures (10, 34, 48). It probably passes through the axilla of the emerging nerve root or laterally to the latter, then becoming positioned posteriorly to the root and / or the thecal sac.

Site of herniation

Midline herniation

Midline, or central, herniation occurs in the midportion of the disc (Fig. 5.18); that is, at the level of the central strand and the most medial portion of the lateral expansions of the posterior longitudinal ligament. Herniations in this site are rare at the high lumbar levels and, at any vertebral level, are usually represented by bulging of annulus fibrosus; this holds particularly for the high lumbar levels, where the central strand of the ligament is wider. Extruded herniations, furthermore, are mostly subligamentous, since in the middle portion of the disc the ligament is thicker and, therefore, more difficult for the extruded disc tissue to perforate.

The extruded fragment tends to remain in close proximity to the disc, due to the tenacious adhesion of the posterior longitudinal ligament to the posterior rim of the vertebral body. Less frequently the extruded tissue is directed towards the right or left side, between the longitudinal ligament and the annulus fibrosus, due to the poor adherence between the two structures over a large part of the rhomboidal portion of the ligament. Often, part of the extruded tissue displaces towards one side, whereas the residual portion remains in the subligamentous midline region.

The extruded fragment that succeeds in perforating the posterior longitudinal ligament is generally of large dimensions and, remaining in the midline, can impinge on the nerve roots of both sides in their intrathecal course. The fragment may migrate in various directions and, more easily than fragments extruded from other portions of the disc, can perforate the dural sac and become intrathecal.

Paramedian herniation

This herniation is that occurring in the centrolateral portion of the disc (Fig. 5.19). This portion corresponds to the zone occupied by the base of the lateral expansions of the posterior longitudinal ligament. The anatomic limits of this zone, however, are not well defined. Therefore, a herniation is often considered paramedian because it is a large herniation extending towards either the midline or the lateral portion of the disc. In the centrolateral zone of the disc, the posterior longitudinal ligament offers lower resistance than in the portion occupied by the median strap, but greater than in the posterolateral portion. For this reason, paramedian herniations are often contained, and extruded herniations are more often subligamentous than transligamentous or retroligamentous.

An extruded subligamentous fragment of disc tends to easily detach the posterior longitudinal ligament and slide behind the subjacent, or more rarely suprajacent, vertebra. If the ligament is completely detached in the caudal direction, or is perforated, the disc fragment tends to migrate medially to the emerging nerve root and subsequently in the axilla of the latter. In both cases, it can impinge on both the emerging root and the most lateral of the roots running within the thecal sac. When detachment occurs in the cranial direction, the fragment migrates towards the axilla of the nerve root emerging from the thecal sac at the level above.

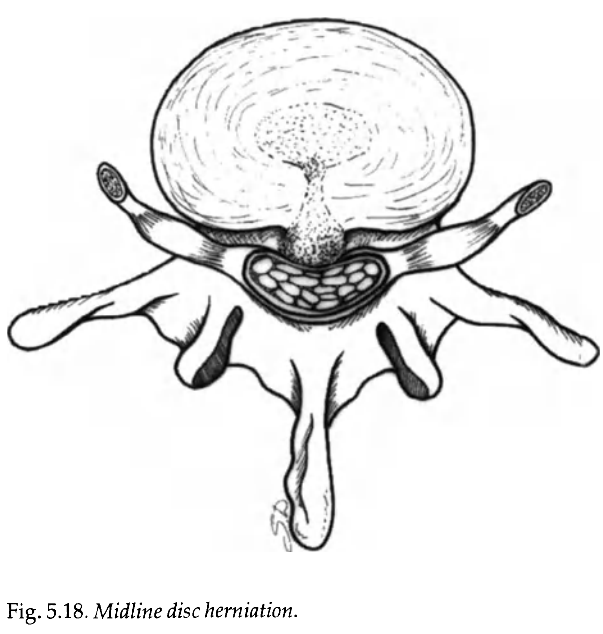


Fig. 5.18. *Midline disc herniation.*

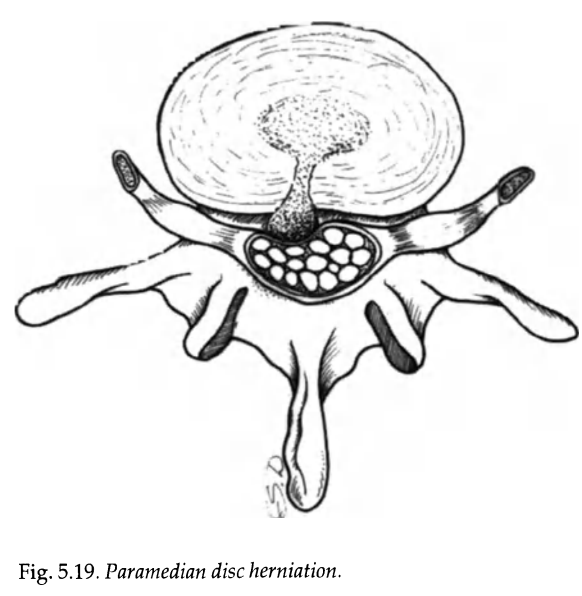


Fig. 5.19. *Paramedian disc herniation.*

Posterolateral herniation

This develops in the zone comprised between the base of the lateral expansion of the posterior longitudinal ligament and the entrance of the intervertebral foramen (Fig. 5.20). In this zone, facing the nerve-root canal, the disc is covered by the middle portion of the lateral expansions of the posterior longitudinal ligament. The lateral expansions are not only loosely adherent to the disc, but in the middle portion cover only part of the annulus fibrosus and this part progressively narrows from the first to the fifth lumbar disc. These anatomic characteristics may explain why posterolateral extruded herniations are more frequently transligamentous or retroligamentous compared with midline or paramedian herniations and why they are mostly located at the level of the two lower lumbar discs (58). These herniations, developing in the nerve-root canal, electively impinge on the emerging root and, thus, tend to produce more severe radicular signs and symptoms than midline or paramedian herniations.

Intraforaminal herniation

This herniation has been referred to with various terms: lateral (28, 30, 69), extreme lateral (1, 7, 60), far lateral (23, 29, 38), and foraminal (37). We prefer the term intraforaminal and distinguish this from the extraforaminal herniation; we use the term lateral as comprehensive of both types. Intraforaminal herniations are those located within the limits of the intervertebral foramen (Fig. 5.21). Often the herniation is partly intra- and partly extraforaminal. In this instance, the herniation takes the name of the site in which it is prevalently located; that is, a herniation located in the foramen for more than half of its axial dimensions is referred to as intraforaminal, whereas that located outside the foramen for more than half of its size is indicated as extraforaminal. Similarly, the herniation is termed posterolateral when less than half of its extension is situated in the foramen and the remaining portion, medially to the foramen.

Intraforaminal herniations can be contained, extruded or migrated. Within the foramen, the disc is not covered by the posterior longitudinal ligament and, thus, the extruded herniations cannot be classified as sub-, trans- or retroligamentous, like those of the posterior wall of the disc. Extruded herniations can be of two types: a) the herniated fragment escapes partially or completely from the disc, but remains in close proximity to the disc itself; b) the herniated tissue detaches the annulus fibrosus from the body of the vertebra above and locates just proximally to the caudal rim of the proximal vertebral body (Fig. 5.22). The latter condition is more frequent than the former. A contained herniation impinges on the nerve root emerging from the thecal sac at the intervertebral level above the herniated disc. The herniation, when it extends medially to the foramen, may also compress the root emerging from the sac at the level of the herniated disc.

Migrated herniations are characterized by the presence of a free fragment of disc tissue in the intervertebral foramen, at a distance from the disc. The fragment can originate both from the intraforaminal and the posterolateral zone, or even the paramedian portion, of the disc.

Intraforaminal migrated fragments locate ventrally and/or inferomedially to the nerve root running in the intervertebral foramen, i.e., behind the inferolateral

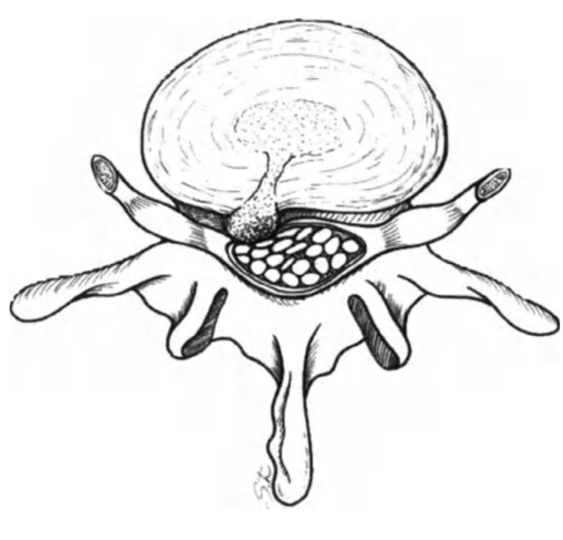


Fig. 5.20. *Posterolateral disc herniation.*

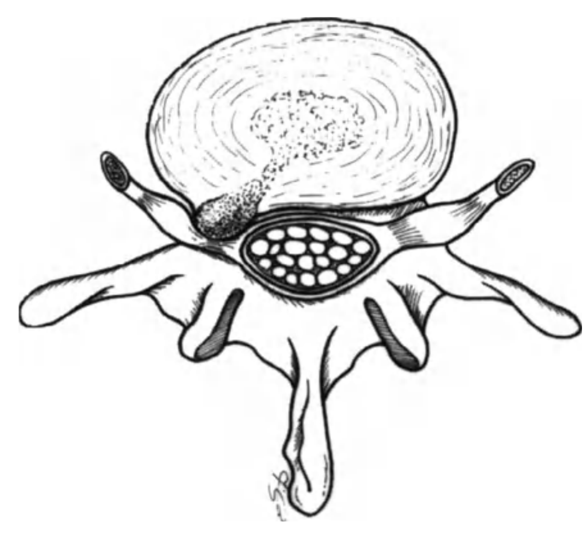


Fig. 5.21. *Intraforaminal disc herniation.*

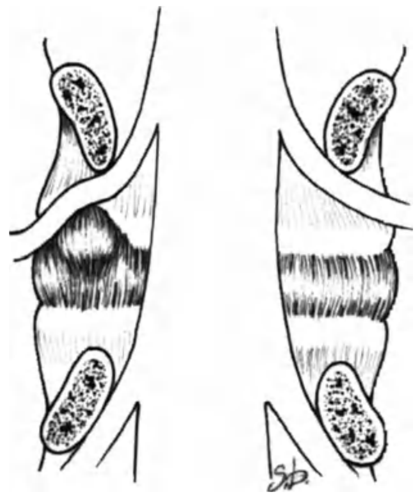


Fig. 5.22. *Migrated intraforaminal disc herniation located behind and just proximally to the caudal rim of the vertebral body above.*

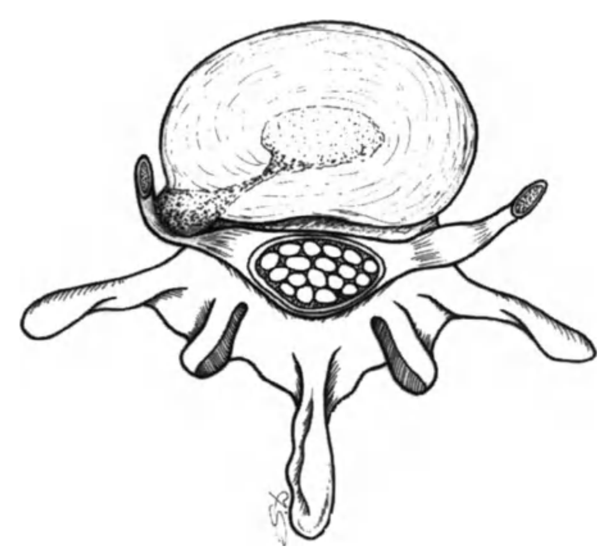


Fig. 5.23. *Extraforaminal disc herniation.*

portion of the vertebral body above the herniated disc. Very occasionally they have a branch, which prolongs downwards and outwards, in the extraforaminal region. The size of the fragments rarely exceeds 1 centimeter and, in most cases, there is only one fragment.

Extraforaminal herniation

This herniation is situated entirely, or at least for a large part of its transverse dimensions, outside the neuroforamen (Fig. 5.23). It is much less frequent than the intraforaminal herniation. Extraforaminal herniations are generally contained or, at the most, extruded. Migrated herniations are exceedingly rare, if they exist as clinically symptomatic conditions. This holds particularly for those herniations which are entirely, or to a large extent, extraforaminal. A migrated fragment originating from a herniation in this site has, in fact, few chances of impinging on the spinal nerves whether it ascends proximally or descends caudally to the disc.

Extraforaminal contained herniations are often large in size. Compared with intraforaminal herniations, however, they tend to produce less severe compression on the nerve root, probably because it is easier for the root to escape compression.

Bilateral herniation

In this condition, there are two disc herniations at a single level, each on one side. This is a rare occurrence. Compression of both roots emerging at one level is

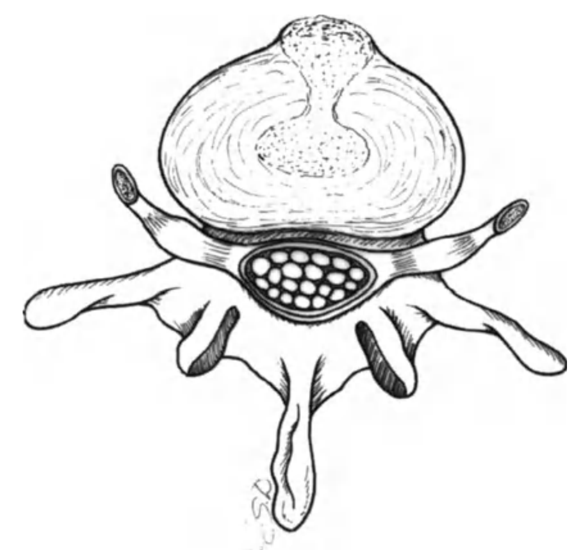


Fig. 5.24. *Anterior disc herniation.*

generally due to a central herniation expanding towards the sides or to bulging of the whole posterior aspect of the annulus fibrosus. True bilateral disc herniations usually occur when the portion of the annulus fibrosus reinforced by the central strand of the posterior longitudinal ligament resists the pressure by the nucleus pulposus, which thus simultaneously proceeds towards the two lateral expansions. Alternatively, these herniations occur in the presence of bilateral radial clefts in the annulus fibrosus, allowing penetration of nuclear tissue at the sides of the middle zone. Bilateral lateral herniations are exceedingly rare. Less rarely, a

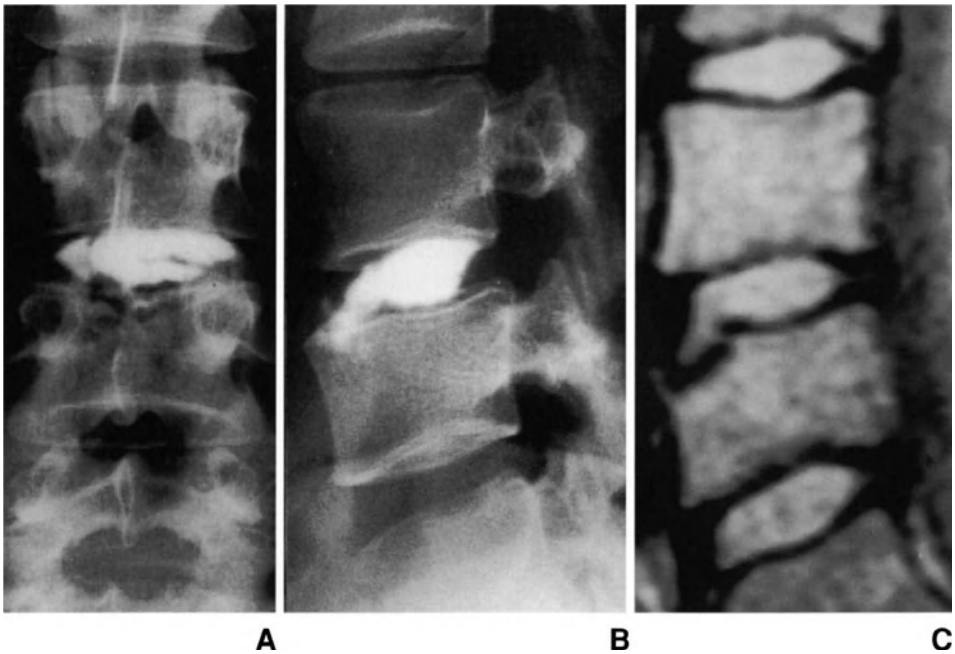


Fig. 5.25. *Anteroposterior* (A) *and lateral* (B) *discograms, and T2-weighted MR image* (C) *of 17-year-old patient with an anterior marginal intravertebral herniation of L4 disc. The patient first complained of low back pain after vertebral trauma in flexion-compression. Penetration of contrast medium and of nucleus pulposus into the anterior portion of the vertebral body of L4 is visible on the lateral discogram and MR image, respectively.*

posterolateral herniation on one side may be asssociated with a foraminal bulging of the annulus fibrosus on the other side.

Generally, bilateral disc herniations are contained or one herniation is contained and the other extruded.

Anterior herniation

The nucleus pulposus may wedge itself into the anterior portion of the annulus fibrosus and cause bulging of the latter or a true disc herniation (Fig. 5.24). This occurrence is not as rare as commonly believed, but nor as frequent as a posterior or lateral herniation. This is due to the considerable thickness of the anterolateral annulus fibrosus, the resistance of which is further increased by the thick anterior longitudinal ligament. On the other hand, anterior herniations are of less clinical relevance than posterior herniations, since, at the most, they can cause only back pain, and, maybe for this reason, they are rarely diagnosed during life.

The most marked anterior bulgings of annulus fibrosus are usually observed at L5-S1 level. Disc herniations may occur anteriorly or, more often, anterolaterally, where the disc is not covered by the anterior longitudinal ligament. The herniation can be contained or extruded; migrated herniations, on the other hand, have never been described. The extruded disc tissue may detach the periosteum from the vertebral body and thus stimulate the formation of subperiosteal bone (17, 84).

Intravertebral herniation (Schmorl's node)

Schmorl's node is a herniation of the nucleus pulposus into the vertebral body through a fracture of the vertebral end-plate and subchondral bone. In the very large amount of autopsy material studied by Schmorl (73), the prevalence of these nodes was 38%, with slightly higher values in males (39.9%) than females (34.3%). The frequency with which the nodes were visible on radiographs, however, was only 13.5%. A possible explanation for this discrepancy is that most of the nodes, particularly in the initial stage, are too small to be revealed by plain radiographs.

The formation of a Schmorl's node may be favored by the presence of areas of decreased resistance in the cartilage end-plate. According to Schmorl, these are represented by: 1) areas of thinning of the cartilage, located in the zone where the vertebral end-plate shows, in many subjects, a depression resulting from incomplete obliteration of the dorsal cord; 2) "vascular scars", i.e., areas of fibrous tissue situated in the zones of cartilage which, during fetal life, are crossed by blood vessels; 3) "ossification holes" represented by degenerative or necrotic areas, with unknown etiology (73). An important role may also be played by acquired factors, such as senile degenerative changes of the cartilage end-plate and vertebral osteoporosis responsible for a decreased mechanical resistance of the subchondral bone.

Herniation into the vertebral body may occur spontaneously or as a result of repeated microtraumas or traumas in flexion or compression. Trauma can provoke a fissure in a structurally abnormal cartilage endplate, but also in a normal end-plate. Trauma is the most feasible etiology for most Schmorl's nodes, at least in subjects showing no evidence of Scheuermann's disease (84).

Once the defect in the cartilage end-plate has occurred, a part of the nucleus pulposus penetrates into the vertebral body, causing a fracture of the bone trabeculae and necrosis of bone marrow. The bone niche subsequently becomes enlarged, either rapidly or slowly, under the pressure of the herniated tissue. The size stops increasing once the forces causing further herniation decrease as a result of dehydration or senile degenerative changes of the nucleus pulposus, or when the surrounding bone acts as a barrier against the pressure of the herniating tissue. The bone undergoes reactive phenomena leading to the formation of a cartilage cap, probably due to metaplasia of the bone marrow cells. The shell, however, can even be formed by sclerotic bone. This may show numerous microfractures, resulting from repeated traumatic stress exerted on the bone trabeculae (85). On occasion, the herniated disc tissue is invaded by vessels and may undergo calcification or ossification. The herniated intervertebral disc is usually narrowed as a result of the herniation or degenerative changes of the disc tissue.

The herniation described by Schmorl occurs in the central portion of the vertebral end-plate, corresponding to the nucleus pulposus. In addition to this central type, a marginal type has been described, that develops in the anterior part of the vertebra at the level of the inner portion of the annulus fibrosus (5, 52) (Fig. 5.25). Marginal Schmorl's node, the highest prevalence being at L1 level, would generally result from a fracture of the vertebral end-plate due to traumas in flexion or flexion-compression.

Cartilaginous and osteocartilaginous avulsion fractures of vertebral end-plate

Two categories of lesions can be identified: avulsions in young or middle age, and avulsions in pre-senile or senile age. These conditions, though showing similarities, should be considered separately on account of the different pathologic characteristics and, probably, different pathogenetic mechanism.

Avulsion fractures in young and middle age

These lesions consist in a separation of the posterior rim of the vertebral body, associated or not with an avulsion fracture of part of the remaining portion of the body. At least 90 cases of these lesions have been reported (25, 72, 78, 88). However, they are likely to be less rare than generally believed, considering that Takata et al. (78) observed 29 cases in a period of 3 years.

These authors have described three types of lesion (Fig. 5.26). Type I is a simple separation of the entire posterior margin of the cartilage end-plate. This lesion occurs in teenagers in whom there is still the epiphyseal ring apophysis, that becomes completely ossified between 18 and 25 years. The detached fragment is entirely cartilaginous and, on axial sections, has an arcuate shape. Type II is an avulsion fracture of the posterior rim of the vertebral body, including the overlying annulus fibrosus. Type II fragment is not arcuate and is thicker than Type I. This lesion occurs in adolescents or young adults. Type III is a small fracture of the posterior border of the vertebral body. It occurs in the second to fourth decade of life and, depending on age, the fragment can be cartilaginous, osteocartilaginous or osseous.

To these types, Epstein et al. (25) have added a fourth one, characterized by a fracture of the posterior rim of the vertebral body extending along the entire posterior aspect of the body (Fig. 5.26). This lesion has been observed only in adults.

The vertebral levels most frequently involved are L4-L5 and L5-S1 (caudal part of L5). A disc herniation is often associated with the lesion, particularly in adolescents.

In Type I and II lesions, the avulsed fragment, with the attached annulus fibrosus, largely encroaches on the spinal canal. In Type III lesion, the usual aspect is that of a herniation of varying size showing a bone or cartilage fragment included in the herniated tissue. In Type IV lesion, there may be a mild to massive invasion of the vertebral canal. In long-standing lesions, the space between the detached fragment and the vertebral body is occupied by fibrous tissue or bone. In the latter instance, the vertebral body may present a posterior prominence of one of the rims.

Avulsion fractures in pre-senile and senile age

These fractures, which occur in subjects in pre-senile or senile age (32), consist in separation of a fragment of the posterior portion of the cartilage end-plate, which is pulled out by the annulus fibrosus and extruded from the disc together with an annular fragment. These lesions are likely to occur more easily, or only, when the cartilage end-plate shows degenerative changes, which are responsible for detachment, at least partial, of a portion of the cartilage from the bone surface (79). The inner one third of the annulus fibrosus is strongly

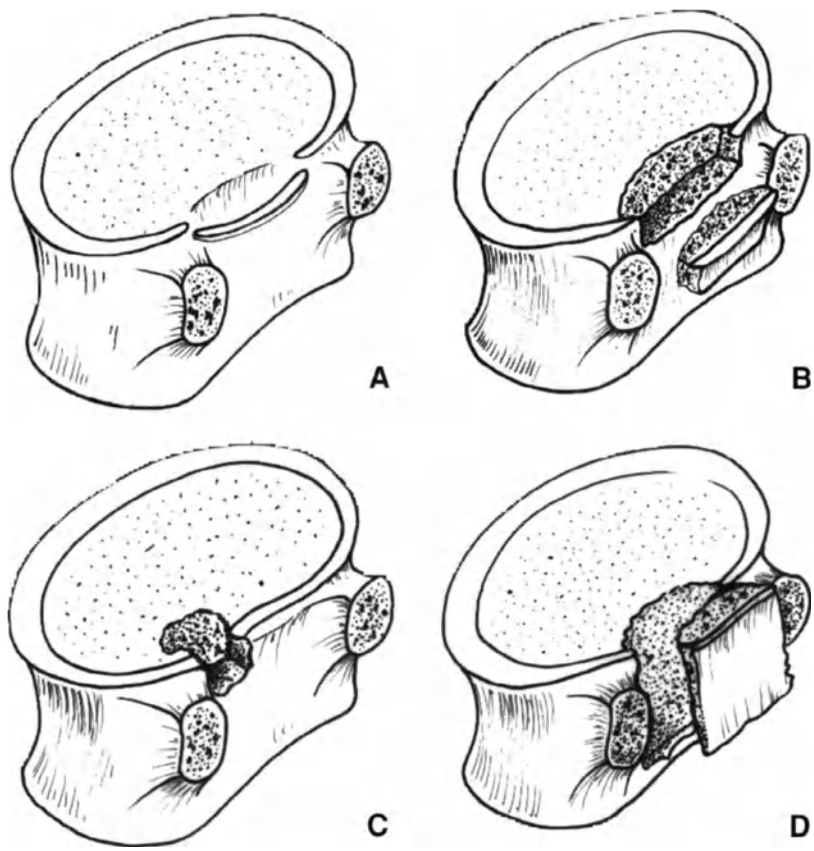


Fig. 5.26. *Drawing of the various types of osteochondral fracture avulsion of the vertebral body.* (A) *Type I. Separation of the posterior portion of the cartilage end-plate in the adolescent.* (B) *Type II. Fracture avulsion of the posterior portion of the vertebral ring apophysis.* (C) *Type III. Small fracture of the posterior margin of the vertebral body.* (D) *Type IV. Posterior marginal fracture of the vertebral body extending along the posterior aspect of the latter.*

anchored to the cartilage end-plate. If the latter becomes separated from the bone surface, the annulus fibrosus, in a process of herniation, may drag with itself the cartilaginous fragment after having detached it completely.

Processes of herniation of the disc

Experimental herniations

Adams and Hutton (3, 4) have produced a disc herniation in motion segments submitted to compression loading applied on the proximal vertebra positioned in flexion compared with the distal vertebra. Two types of herniation have been obtained: gradual and sudden. The former occurred slowly, in subsequent stages, following cyclic compression; the latter occurred in less than 1 second after a single application of compression loading.

A gradual herniation has been obtained only in discs with a soft, pulpy nucleus pulposus and a posterior annulus fibrosus much thinner than the anterior. These discs mostly belonged to adolescents or young adults. Structural changes of the disc were represented, in progression, by distorsion (increase in curvature and packing) of the posterolateral annular lamellae, formation of a radial cleft, bulging of the outermost annular lamellae and extrusion of nuclear material. A sudden herniation has been obtained in moderately degenerated discs of subjects in the fourth to sixth decade of life. In these cases, the nucleus pulposus is probably wedged in pre-existing radial clefts of the annulus fibrosus and produces a contained herniation when the cleft is incomplete, or an extruded herniation when the cleft is complete or becomes complete under the pressure of nuclear tissue.

In vivo herniation

Stages of herniation of nucleus pulposus

In the process of herniation in life several stages can be identified, which are similar to those observed in gradual experimental herniations.

Stage I. The prerequisite for herniation of the nucleus pulposus is the occurrence of a radial fissure in the annulus fibrosus. The fissure may form slowly, only as a result of degenerative changes in the disc, or may occur suddenly, due to an abrupt mechanical stress in flexion or torsion.

Stage II. The nucleus pulposus penetrates into the annular fissure and may increase the length and width of the latter. This occurs more easily if the nucleus is only slightly fibrotic and still highly hydrophile.

Stage III. The nucleus pulposus penetrates the radial fissure without perforating the outermost annular lamellae, thus producing a contained herniation. In the passage through the annulus fibrosus, part of the nuclear material may insinuate into the circumferential fissures originating from the radial cleft and subsequently produce a new radial fissure at a distance from the original one. In this instance, part of the annulus fibrosus is surrounded and sequestered by the nucleus pulposus.

Stage IV. The outermost annular lamellae are also perforated and the nuclear material comes into contact with the posterior longitudinal ligament or, where the latter is lacking, protrudes into the spinal canal.

Stage V. The nucleus pulposus perforates the posterior longitudinal ligament and migrates into the spinal canal together with sequestered fragments of annulus fibrosus. The surge to the tissue fragment that is abruptly extruded from the disc, may be such that it makes it migrate even at a considerable distance.

The herniation process may occur through all these stages or from an intermediate stage it may suddenly reach the final one, for instance from Stage II directly to Stage V. Missing one or more stages usually occurs as a result of mechanical stress producing abrupt compression of the disc. Based on studies on experimental herniations, it is presumable that the process tends to occur slowly, with a gradual passage from one stage to the next, in the disc showing mild degenerative changes, and more rapidly, possibly missing the intermediate stages, in the presence of more severe degeneration. In the latter instance, in fact, structural changes are still present, which make it easier for a contained herniation, or extrusion of nuclear material, to occur.

Herniation of annulus fibrosus

The mechanism of herniation of the annulus fibrosus has been analyzed by Yasuma et al. (92, 93) based on macroscopic studies on the intervertbral discs and histologic observations indicating that, in patients with a herniated disc, the extruded or migrated fragments often consist only of portions of annulus. This type of herniation would result from myxomatous degeneration of the annulus fibrosus and consequent separation of annular lamellae. The midlle and/or inner lamellae become convex towards the center of the disc, i.e., undergo a reversal in their orientation. This involves, in the presence of a degenerated nucleus pulposus, an increase in pressure on the peripheral annular lamellae, which protrude out of the disc. If a cleft forms in the outermost lamellae, a portion of annulus fibrosus, of various dimensions, can be extruded from the disc. This type of herniation is observed particularly in the elderly.

Another mechanism of herniation of annulus fibrosus, possibly more frequent than the latter, is related to the presence of annular fissures converging towards the center of the disc. The portion of the annulus fibrosus comprised between the fissures can be sequestered from the rest of the annulus, and can protrude or be extruded in the spinal canal following a sudden mechanical stress in extension or torsion on the motion segment (page 163).

Degenerative changes of herniated disc

Degenerative changes of the disc have been the subject of numerous pathomorphologic studies, none of which, however, have analyzed the degenerative changes in discs with a posterior or lateral herniation. This is conceivable considering the benign nature of the condition. On the other hand, with time, the herniated tissue undergoes considerable changes and, thus, information that can be obtained from autopsy of previously herniated discs is of little value.

The information available on the structural changes of a herniated disc derive from discography and MR images, as well as from surgical findings. Schematically three conditions can be identified.

Mildly degenerated disc

Usually, the disc height is markedly decreased. Discography shows a cottonball or lobular nucleus pulposus, with an appendix crossing the annulus fibrosus. On MR images, the nucleus displays normal or slightly decreased hydration.

At surgery, the annulus fibrosus appears brilliant-white, has a hard-elastic consistency and is strongly attached to the adjacent vertebrae. It can be excised with some difficulty, in small fragments, with surgical instruments. The nucleus pulposus has a turgid appearance and a jelly-like consistency. However, little nuclear material can be removed.

This condition is found, in the most typical form, in adolescents or young adults with a herniation of recent onset. This is generally contained or extruded behind the posterior longitudinal ligament, and, in most cases, is located posterolaterally.

Moderately degenerated disc

Degenerative changes of the disc can be physiologic or pathologic. The disc height may be normal or decreased; in the latter instance, the decrease is mostly mild. Discography shows a lobular or, more often, an irregularly-shaped, disc; the contrast medium may leak from the disc, but rarely to a large extent. On MR images, the disc tissue usually appears dehydrated, on occasion severely.

The annulus fibrosus, at surgical exploration, has a white-opaque color and a lower consistency and elasticity than in the previously described condition. On pressure, the annulus may be ruptured with difficulty, but it is not tenaciously adherent to the adjacent vertebrae. The nucleus pulposus has a fibrous consistency and can be easily removed with surgical instruments. The nuclear material is often abundant and is removed in lumps of varying size. Together with the nuclear material, small fragments of cartilage, which have detached from the cartilage end-plate, are occasionally excised. This condition is the most frequently found, particularly in middle-aged subjects. The herniation may be of any type and dimensions. When it is migrated, the nuclear material still within the disc may be very scarce.

Markedly degenerated disc

Disc height is almost always decreased, often considerably. At discography, the disc appears to be irregularly shaped and largely fissured. It frequently accepts a large volume of contrast medium, that easily leaks into the vertebral canal. MRI shows marked dehydration of the disc tissue.

At surgery, the annulus fibrosus appears white-opaque or yellowish, and friable. It is easily excised, mostly in small fragments, at times mixed with portions of cartilage end-plate.

This condition is relatively rare, since a severely degenerated disc rarely undergoes herniation. These structural characteristics are typical of elderly subjects, but can easily be observed also in midlle-aged individuals with long-standing disc degeneration. The disc herniation is usually of small size and generally extruded. A migrated fragment is rarely found.

Microscopic characteristics of herniated tissue

Histology

The herniated tissue consists of cartilage-like cells and an abundant intercellular matrix. The cells may be isolated or grouped in clones, generally formed by few elements (Fig. 5.27). In a few areas the cell population consists, to a large extent, of clones, or giant clones are present, containing up to 30 or more cells (Fig. 5.28). The isolated cells are generally surrounded by a pericellular lacuna, which is more basophile than the interterritorial matrix; furthermore, a large lacuna is almost always present around the cell clones. Necrotic cells or empty pericellular lacunae are frequently visible. The frequency with which necrotic cells are observed is not related to the type of herniation (contained, extruded or migrated) or the patient's age. The density of cell clones in the tissue has no relationship with the type of herniation, but giant clones are more often observed in extruded or migrated, than contained, herniations. In a few areas, spindle-shaped cells resembling fibroblasts can be seen.

Four types of interterritorial matrix can be identified. In Type I, the matrix may have a homogeneous, carti-

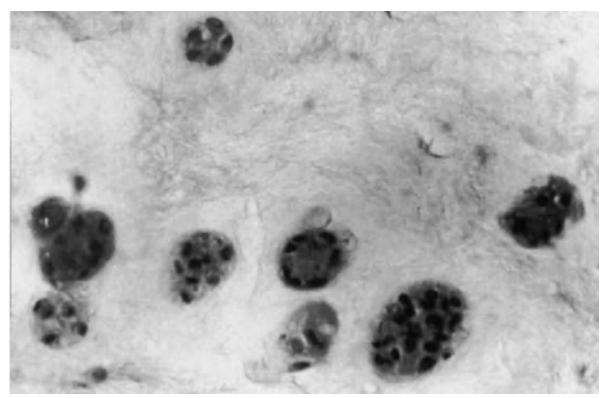


Fig. 5.27. *Area of herniated disc tissue in which the cell population is made up only of cell clones.*

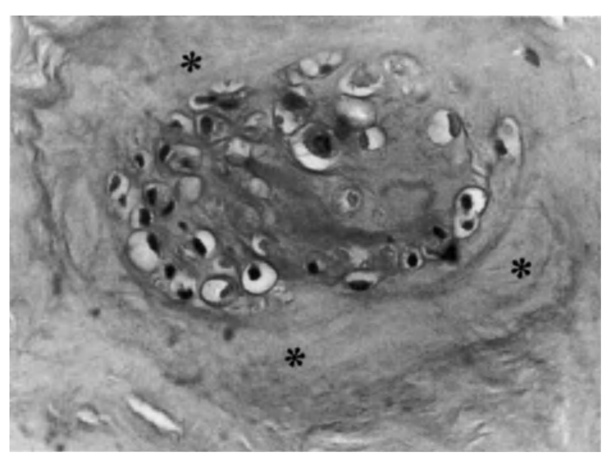


Fig. 5.28. *Giant cell clone in which more than 30 cells are visible. The clone is surrounded by a large area of territorial matrix (asterisks).*

lage-like appearance, may be formed by a network of fibrous bundles in the meshes of which a cartilage-like matrix is contained, or may consist of thin bundles of collagen fibers orientated in various directions and separated by an amorphous matrix; these features are typical of nuclear tissue (Fig. 5.29 A). In Type II, the matrix is mainly or exclusively formed, as the annulus fibrosus, by lamellae consisting of fibrous bundles orientated in the same direction (Fig. 5.29 B); two adjacent lamellae can be tightly packed to each other or be separated by a narrow area of homogeneous or finely fibrillar matrix. In Type III, there is a mixture of areas showing, alternately, the features of nucleus pulposus and those of annulus fibrosus; the two types of tissue are present in almost equal proportions. In Type IV, the matrix does not show the typical characteristics of either the nucleus pulposus or the annulus fibrosus; in most cases, it has the appearance of common fibrous connective tissue showing no lamellar structure. Two or more of the four types of matrix may coexist in a herniation, or a single type forms the whole herniated tissue. The morphologic characteristics of the cell population show no significant differences depending on the type of tissue. However, in the areas showing the morphologic features of nucleus pulposus, the cells have an irregular arrangement, whereas in those displaying clear-cut annular characteristics they often tend to be arranged in rows and occasionally fibroblast-like cells can be observed throughout the tissue. In elderly patients, the interterritorial matrix often has a more homogeneous appearance than in young or middle-aged subjects.

Small calcified areas are rarely visible in the sections stained with hematoxylin-eosin. Fragments or hyaline cartilage may be intermingled with disc tissue (Fig. 5.30). Generally, the cartilage adheres to portions of the annulus fibrosus or to a tissue showing the characteristics partly of annulus and partly of nucleus pulposus. Also the dimensions of the cartilaginous fragments vary considerably, ranging from a few hundred microns to several millimeters. Fragments of cartilage may be present in all types of herniations, but particularly in those extruded or migrated.

Areas of granulation tissue, consisting of thin vessels delimited by a single layer of endothelial cells and of mononuclear cells, are often visible (Fig. 5.31). Some of the cells are macrophages, others have the morphologic characteristics of lymphocytes or fibroblasts, but the majority cannot be identified as cells of a specific type. The areas showing granulation tissue are generally located in the peripheral areas of the herniated material. Usually, in a single herniation, only few (1 to 5) of these areas are visible, each formed by a limited number of vessels (1 to 20). In rare cases the whole peri-

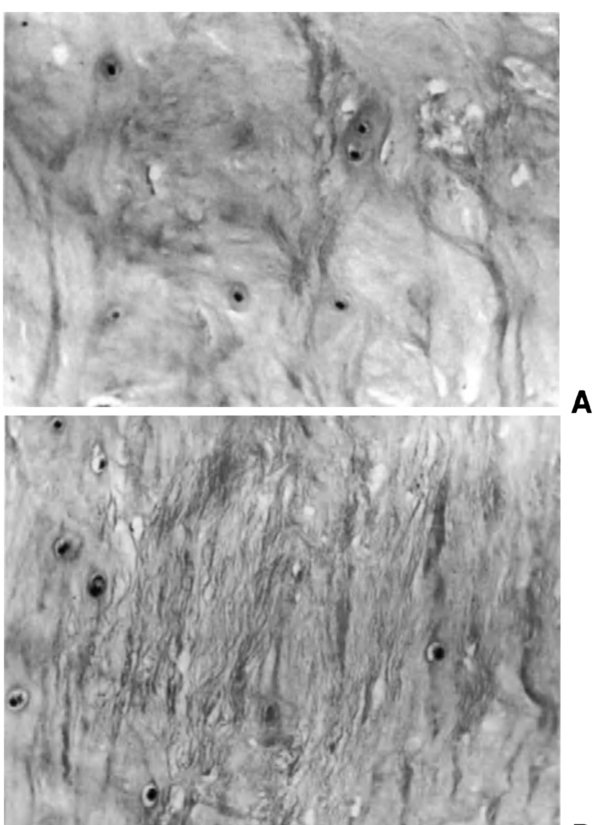


Fig. 5.29. *Different types of interterritorial matrix in herniated disc tissue.* (A) *Network of fibrous bundles, the meshes of which contain intercellular matrix showing a homogeneous appearance; the cells are irregularly scattered throughout the tissue.* (B) *Lamellar appearance of the tissue, which consists of fibrous bundles with a parallel arrangement; the cells tend to be arranged in rows.*

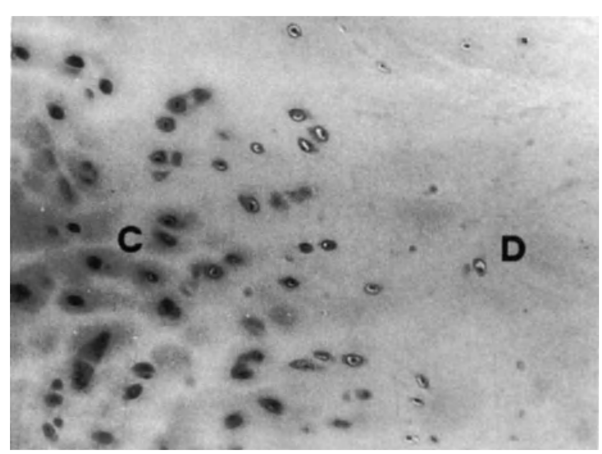
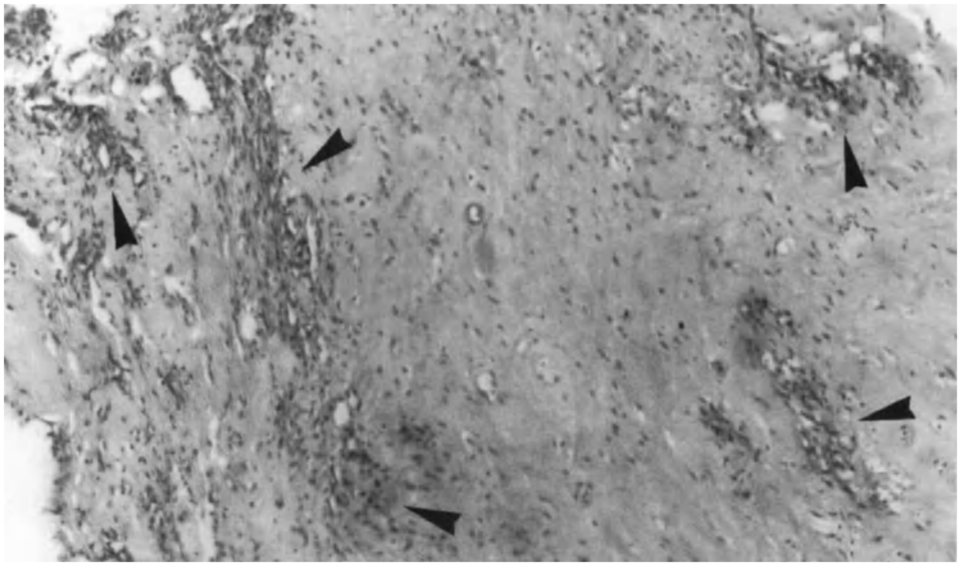
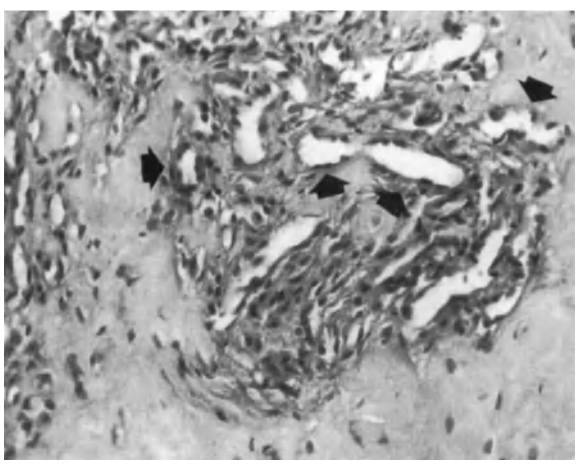


Fig. 5.30. *Extruded disc herniation. Fragment of cartilage end-plate* (C) *in continuity with disc tissue* (D).



A



B

Fig. 5.31. *Fragment of migrated herniation in a patient complaining of radicular symptoms of 25-day duration.* (A) *A few areas of granulation tissue invading the disc tissue are visible (arrowhead).* (B) *Higher magnification of an area of granulation tissue. This consists of small vessels delimited by a single layer of endothelial cells (arrows) and mononuclear cells with roundish or spindle-shaped nucleus.*

pheral portion of the disc fragment is invaded by granulation tissue. Occasionally, in the peripheral area or in the center of the tissue, there are: vessels not surrounded by cell infiltrates; small groups of mononuclear cells not associated with blood vessels; or areas where the cell population consists of typical fibroblasts (Fig. 5.32). The areas of granulation tissue are seen in migrated or extruded, and very rarely in contained, herniations. Generally, granulation tissue is present when the herniation has appeared at least 2 to 4 weeks previously. Chitkata (15) found that the incidence increased progressively from 12% in the patients who had symptoms less than 1 month at the time of surgery to 82% in the patients in whom the herniation had appeared more than 6 months previously.

Histochemistry and immunohistochemistry

Alcian blue staining at low pH, that selectively demonstrates chondroitinsulphate and keratansulphate, is strongly positive in the entire herniated tissue and, to a larger extent, in the pericellular lacunae (Fig. 5.33). In the portions with the appearance of nucleus pulposus, staining of the interterritorial matrix tends to be greater than in those consisting of annulus fibrosus, which are often only weakly stained. No significant differences in the intensity of tissue staining can generally be appreciated between young and elderly subjects.

The PAS reaction, which is specific for glycoproteins, is usually strongly positive (Fig. 5.34 A). As for alcian blue, the positivity of the reaction is frequently greater

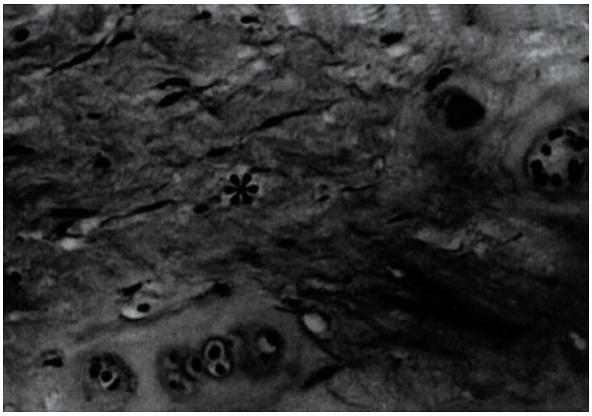


Fig. 5.32. *Area of herniated disc tissue containing typical fibroblasts (asterisk), adjacent to zones showing chondroid features in which cell clones are visible.*

in the areas consisting of nucleus pulposus. Areas consisting entirely of intensely PAS positive granular material (Fig. 5.34 A), or areas of tissue containing small lumps of material interspersed among the bundles of collagen fibers (Fig. 5.34 B), are often visible. This material has been identified with the so-called senile pigment (18) and presumably corresponds to the electron-dense granular material visible at ultrastructural level. In the zones invaded by granulation tissue, the positivity of PAS reaction, like the alcian blue staining, is generally weaker than in the rest of the tissue.

With the Sudan black staining, the aggregates of senile pigment acquire a black color. With the same staining method, numerous small black globules are visible throughout the tissue, particularly in proximity to the cell clones (18). With the Congo red, aggregates of amyloid can be seen in the zones consisting of annulus fibrosus, but not in those showing the typical features of nucleus pulposus (90).

With Von Kossa's method, calcium deposits are visible in about 20% of herniations. Generally, the calcified areas are small in size and are often shaped like striae of varying length and thickness (Fig. 5.35). In a single herniation, calcified areas are mostly multiple, but rarely numerous. Usually, the calcium deposits are scattered throughout the tissue; on occasion, they tend to be concentrated, and larger and denser, in the peripheral areas of the excised fragments.

In recent years, immunohistochemical methods have contributed to determine the morphofunctional characteristics of some of the cells in the granulation tissue often present in extruded or migrated herniations. Many cells in the granulation tissue are immunoreactive to monoclonal antibodies to macrophages (Fig. 5.36); and occasionally cells surrounding newly-formed vessels are immunoreactive to monoclonal antibodies to lymphocytes T and B (31, 36). The use of anti-metalloproteinase-1 (collagenase) and metalloproteinase-3 (stromelysin) antibodies has demonstrated that the cells in the granulation tissue, as also the chondrocytes,

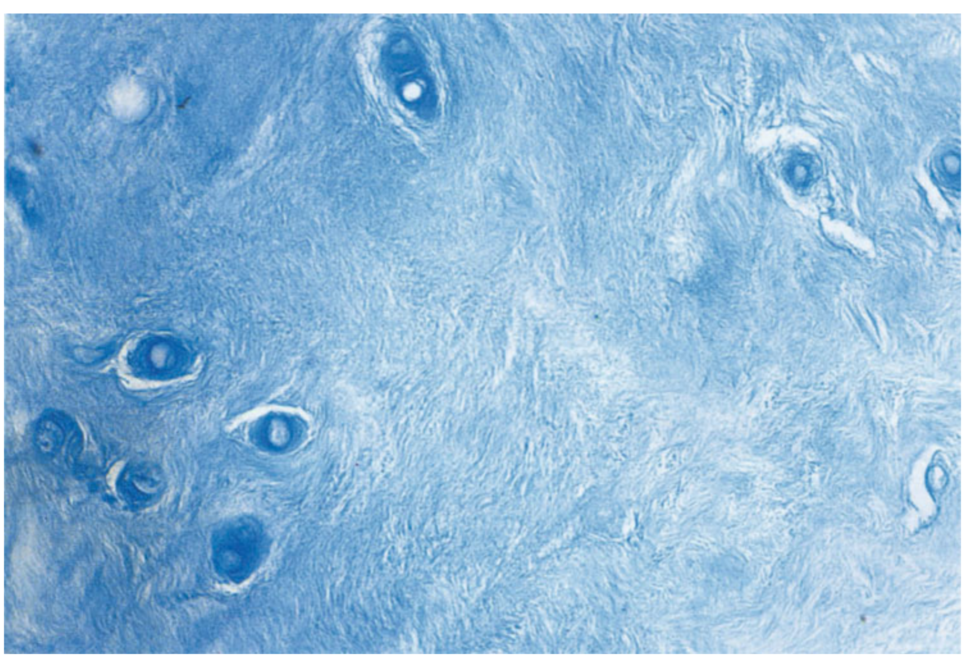


Fig. 5.33. *Alcian blue staining, pH 2.5. Fragment of extruded disc tissue. Intense staining of the pericellular lacunae. Staining of the interterritorial matrix is intense, but dyshomogeneous. The less stained portion appears to have a more fibrous texture.*

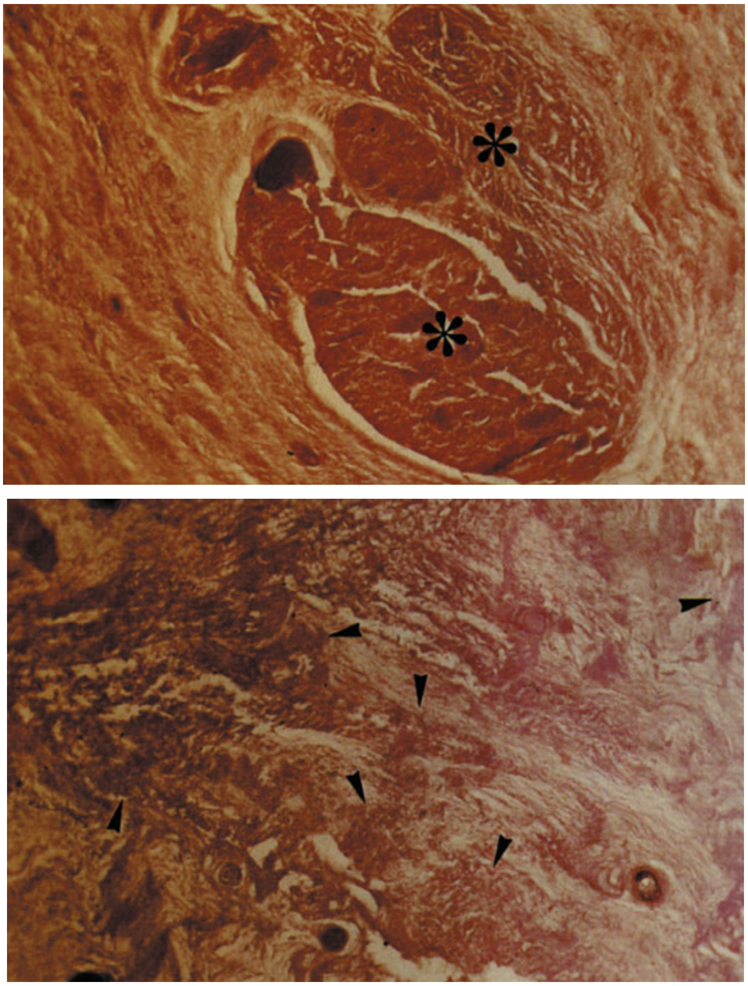
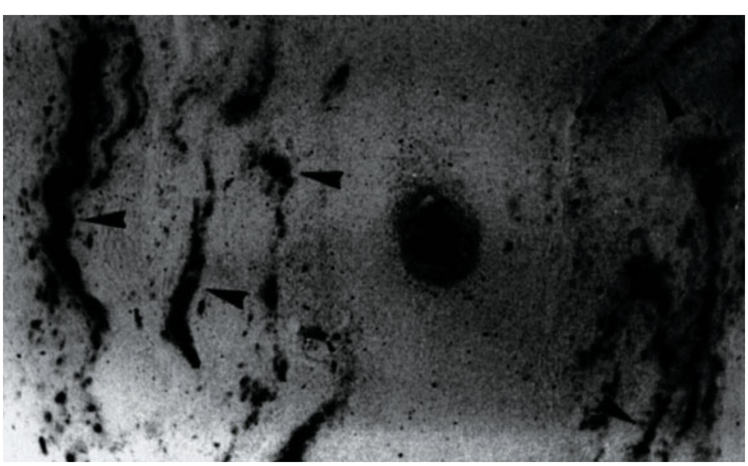


Fig. 5.34. *PAS reaction. Contained disc herniation in a 58-year-old patient.* (A) *The tissue is positive to PAS reaction. A few roundish or ovoid areas (asterisks), showing intense positivity to PAS reaction are visible.* (B) *Area of tissue containing numerous lumps with intense PAS reaction (arrowheads).*



produce these substances (41, 42). Immunohistochemical methods, furthermore, have shown that the chondrocytes and/or the cells in the granulation tissue produce inhibitors of tissue metalloproteinase-1 and -3, as well as various interleukins and other chemical mediators of inflammation (22, 41, 42, 77).

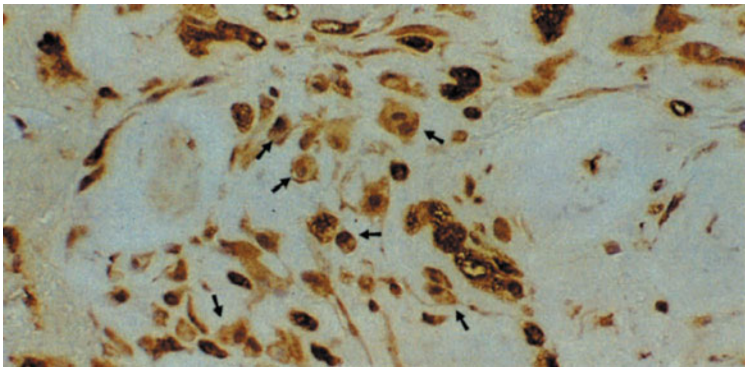


Fig. 5.36. *Fragment of migrated disc herniation incubated with monoclonal anti-macrophage antibodies. Portion of herniation containing granulation tissue. Many cells of the tissue are immunoreactive (arrows).*

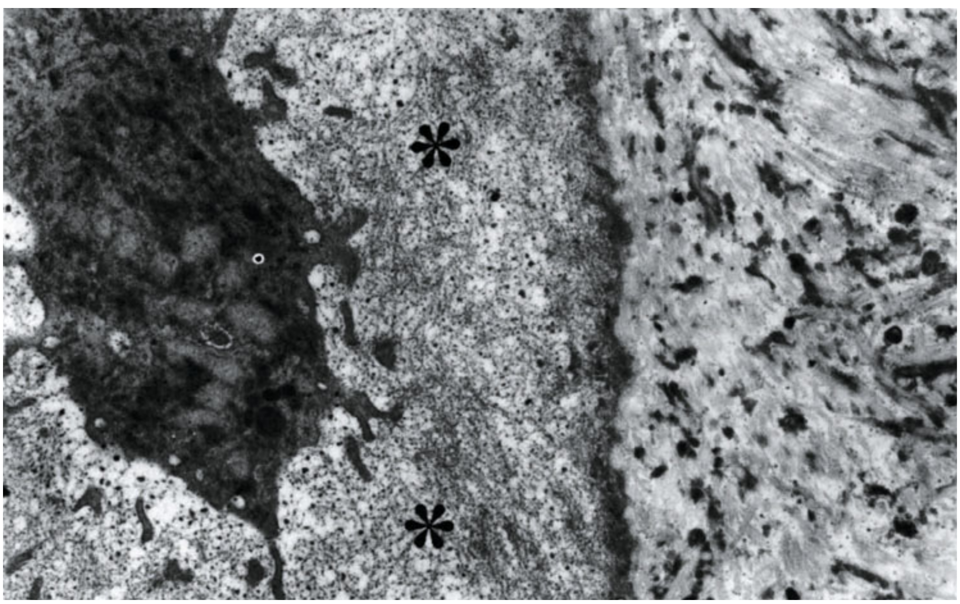


Fig. 5.37. *Contained disc herniation in a 64-year-old patient. Electron micrograph showing a cell with cartilaginous features, surrounded by a large pericellular lacuna (asterisks) containing thin fibrils and proteoglycan granules. A sharp limit is visible between the lacuna and the extraterritorial matrix, which is formed by a dense network of collagen fibers and contains matrix vesicles.*

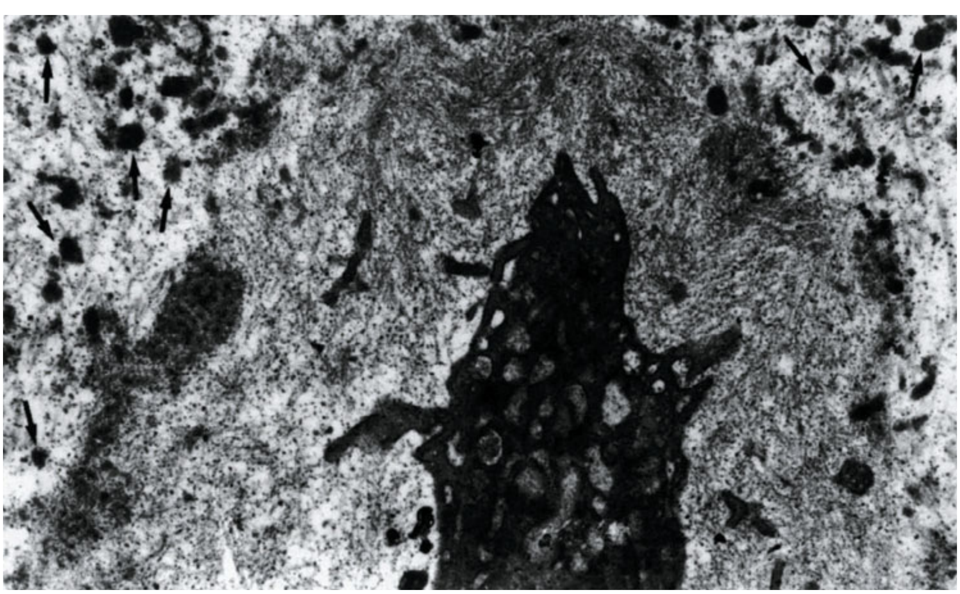


Fig. 5.38. *Contained disc herniation in a 32-year-old patient. A cell with cartilaginous features, surrounded by a pericellular lacuna showing no sharp boundary with the interterritorial matrix. The latter is formed by collagen fibers, abundant amorphous ground substance, proteoglycan granules and numerous matrix vesicles (arrows).*

Ultrastructure

At ultrastructural level, the cells have the features of chondrocytes or show intermediate characteristics between chondrocytes and fibrocytes. The chondrocyte cytoplasm is surrounded by a large pericellular lacuna containing thin fibrils and numerous proteoglycan granules (Fig. 5.37). The lacuna may have clear-cut borders (Fig. 5.37) or there may be a gradual transition from the lacuna to the extraterritorial matrix (Fig. 5.38). Fibrochondrocytes are surrounded by a narrower lacuna, poorly delimited with respect to the extraterritorial matrix. In some cells, particularly fibrochondrocytes, a large part of the cytoplasm is occupied by filaments 100 nm in thickness. Degenerating cells or remnants of necrotic cells are very frequently observed (Fig. 5.39). A consistent characteristic is the presence, in the extraterritorial matrix, of roundish or ovoid structures featuring matrix vesicles. These are scattered throughout all the tissue, but are usually more numerous in proximity to the cells. Even at a distance from the cells, however, aggregates formed by numerous vesicles can often be seen (Fig. 5.40).

In the areas that at histologic level show the morphologic features of nucleus pulposus, the interterritorial matrix is formed by irregularly-arranged collagen fibrils, and fibers of varying thickness, separated by spaces containing amorphous ground substance and

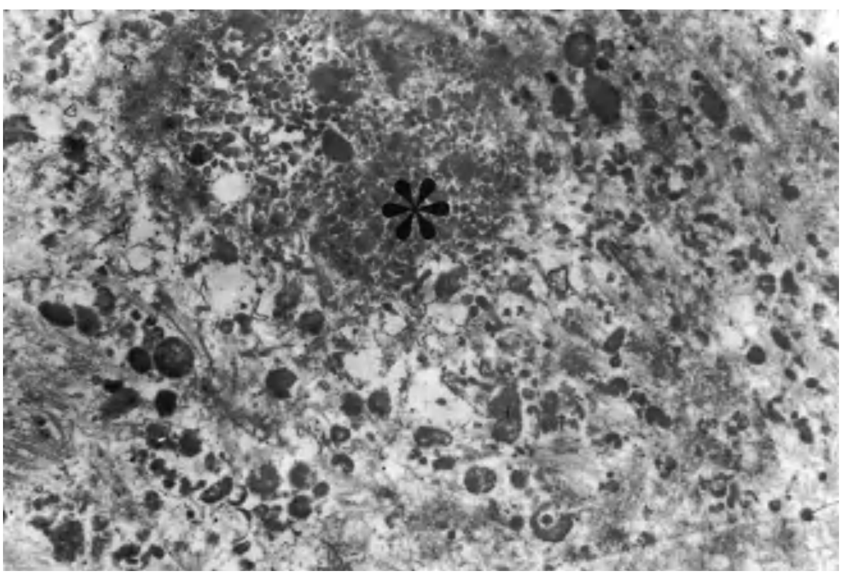


Fig. 5.39. *Extruded disc herniation. Electron micrograph showing a disintegrating necrotic cell (asterisk).*

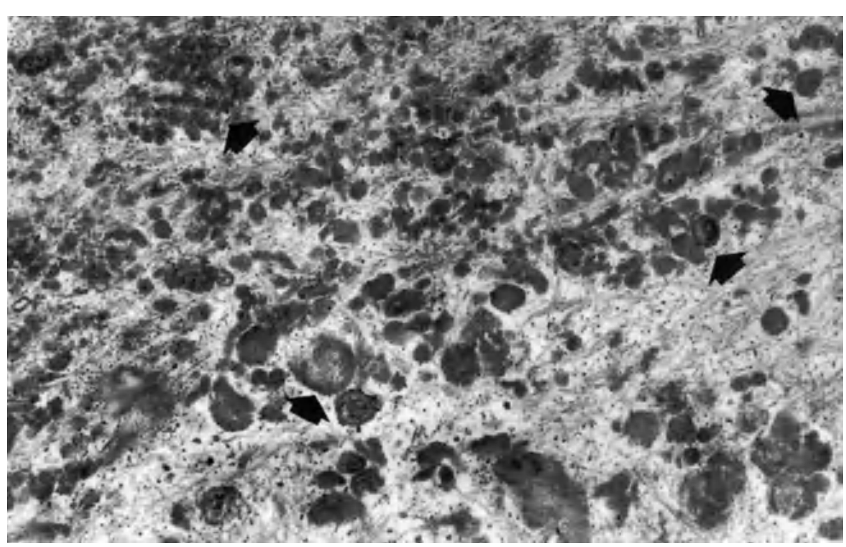


Fig. 5.40. *Extruded disc herniation. Electron micrograph showing an area of interterritorial matrix containing numerous matrix vesicles (arrows), as well as a network of thin collagen fibers and proteoglycan granules.*

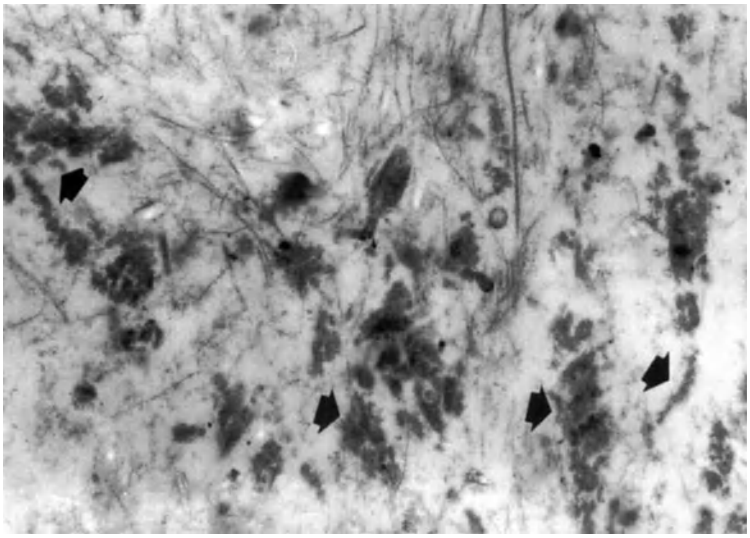


Fig. 5.41. *Contained disc herniation of a 36-year-old patient. Electron micrograph showing an area with the features of nucleus pulposus at light microscopy. The intercellular matrix consists of fibrils and thin collagen fibers separated by abundant amorphous ground substance and small aggregates of electron-dense granular material (arrows).*

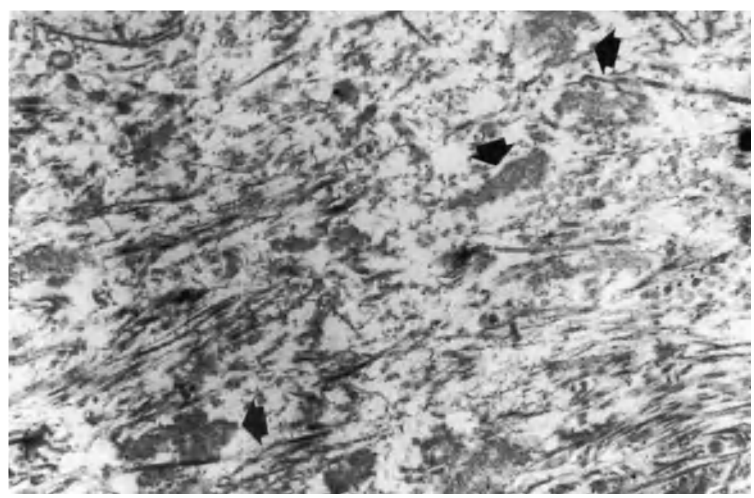


Fig. 5.42. *Intercellular area of herniated nucleus pulposus consisting of thin collagen fibers, some of which packed in small bundles, amorphous ground substance and rare aggregates of electron-dense granular material (arrows).*

proteoglycan granules. Usually, areas consisting of collagen fibrils and fibers scattered in an abundant amorphous ground substance (Figs. 5.41 and 5.42) alternate with areas showing a high density of medium- or large-thickness collagen fibers. Aggregates of electron-dense granular material, probably consisting of degradation products of cell or extracellular matrix, are consistently present in the tissue. In some cases the aggregates are few in number and small in size, whilst in other cases large and numerous masses of the material can be seen (Fig. 5.43). At times, the material occupies up to one third of the interterritorial matrix. Both the compactness of the tissue (density and thickness of the collagen fibers), and the number and size of the aggregates tend to increase with advancing age.

In the zones showing the morphologic features of annulus fibrosus, the interterritorial matrix is formed by collagen fibers with a parallel arrangement, either separated by narrow spaces or closely packed (Fig. 5.44). In these zones, the cells often present fibrochondrocyte features and the matrix vesicles tend to be fewer in number. The aggregates of electron-dense granular material are also less abundant than in the areas with the features of nucleus pulposus. The material may form a sort of network between the collagen fibers (Fig. 5.45) or large masses may entirely replace the fibrillar component of the tissue (Fig. 5.46).

In the zones with no definite annular or nuclear characteristics, there are areas where the collagen fibers tend to form lamella-like structures (fibers with parallel orientation, but separated by wide spaces) and areas showing small bundles of parallel collagen fibers,

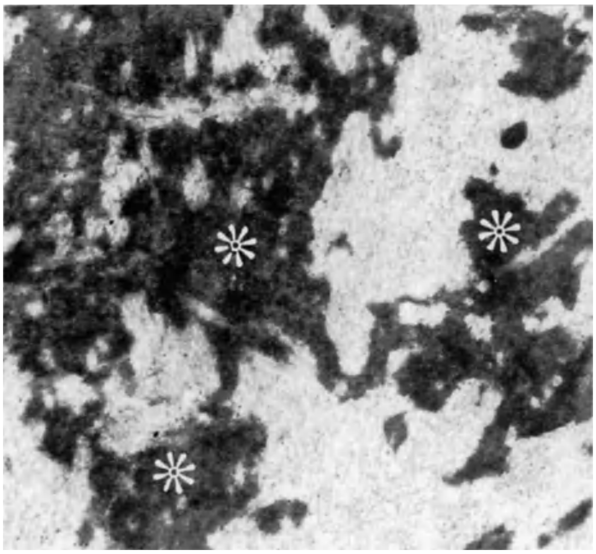


Fig. 5.43. *Herniated disc tissue of a 52-year-old patient. Large aggregates of electron-dense granular material (asterisks) in the intercellular matrix of an area showing the features of nucleus pulposus at light microscopy.*

scattered in a tissue made up of abundant amorphous ground substance and isolated collagen fibers, orientated in various directions (Fig. 5.47).

Composition of herniated tissue related to type of herniation and age

Numerous investigations have been carried out in an attempt to determine the composition of the herniated tissue. Of the 11 specimens examined by Mixter and Barr (56), four consisted of annulus fibrosus, two of nucleus pulposus and five of both components. Others have found that in all (21), or the majority (93), of the cases studied, the herniated tissue was formed by nucleus pulposus and annulus in varying proportions. Fragments of cartilage end-plate have been observed in proportions ranging from 21% (93) to approximately 60% (24, 32).

We carried out histologic studies on herniated tissue obtained at surgery in 100 patients aged 16 to 76 years. In the contained and subligamentous extruded herniations, we analyzed the first two and/or the largest of the tissue fragments excised from within the disc (contained herniations) or from the peripheral portion (extruded herniations). In the other types of herniation, all or a large part of the extruded or migrated tissue was examined. The herniations were classified according to the four patterns of intercellular matrix that can be identified histologically (page 115). When in a single herniation more than two types of tissue were found, for instance Types I and IV, the herniation was assigned to the type corresponding to the prevailing tissue. The composition of the herniated tissue was related to the type of herniation and the patient's age (Table 5.1).

In contained herniations, the material examined consisted only of nucleus pulposus in 27% of cases and of nucleus pulposus and annulus fibrosus in some one third of the patients. In half of the remaining cases, the material was represented by annulus fibrosus, whereas in the other half, the tissue did not show the typical features either of nucleus pulposus or annulus fibrosus. In 11% of cases, small fragments of cartilage end-plate were present in the tissue.

Extruded herniations consisted of nucleus pulposus and annulus fibrosus in about half of the cases and of

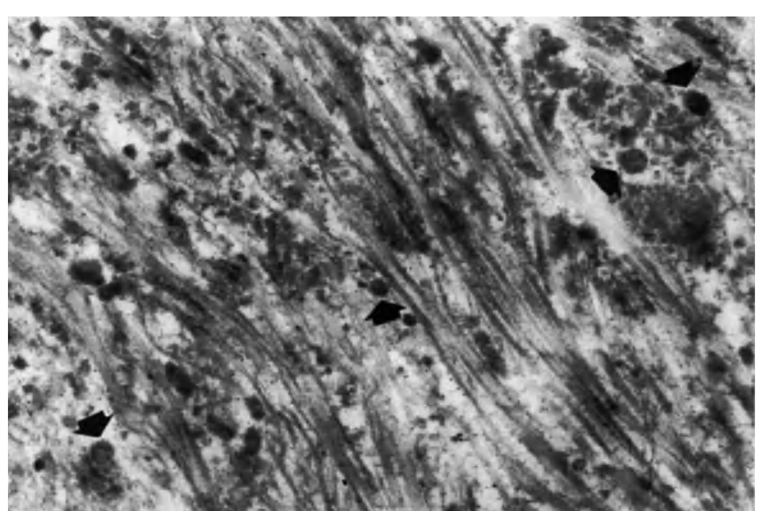


Fig. 5.44. *Electron micrograph of an area of herniated annulus fibrosus. The intercellular matrix consists of a bundle of collagen fibers separated by scarce amorphous ground substance. Matrix vesicles (arrows) and rare aggregates of electron-dense granular material are visible.*

Table 5.1. *Composition of herniated tissue compared with type of herniation and patient age.*

Compostion of herniated tissue	Type of herniation			Age		
	Contained (n. 28)	Extruded (n. 43)	Migrated (n. 29)	16–30 y. (n. 16)	31–50 y. (n. 59)	51–76 y. (n. 25)
Type I	8(27%)	6(14%)	3(10%)	9(56%)	8(13%)	0
Type II	5(18%)	10(23%)	7(24%)	1(6%)	11(58%)	11(36%)
Type III	11(39%)	23(53%)	16(55%)	6(37%)	34(58%)	9(36%)
Type IV	4(14%)	4(9%)	3(10%)	0	6(10%)	5(20%)
Cartilage	3(11%)	11(26%)	9(31%)	1(6%)	12(20%)	10(39%)

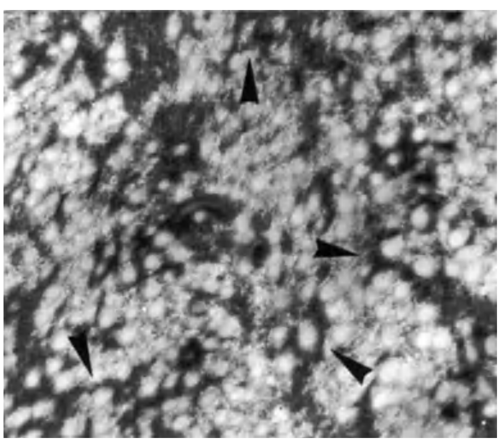


Fig. 5.45. *Fragment of herniated annulus fibrosus, consisting of collagen fibers sectioned transversely, separated by a scarce amount of amorphous ground substance containing numerous small aggregates of electron-dense granular material (arrowheads), that tends to form a kind of network between the collagen fibers.*

annulus fibrosus in almost one fourth of cases. Only in 14% of patients did the herniation consist exclusively or mainly of nucleus pulposus. In one fourth of cases,. fragments of cartilage were present.

Migrated herniations were formed by nucleus pulposus and annulus fibrosus in 55% of cases and only by annulus fibrosus in 24%. Herniations in which nuclear tissue was predominant were found in only 10% of patients. In almost one third of cases, there were fragments of cartilage end-plate of varying size.

The highest proportion of herniations consisting only, or mainly, of nucleus pulposus was found in subjects under 30 years of age. Between 30 and 50 years, there was a prevalence of herniations formed by nucleus pulposus and annulus fibrosus. Over 50 years, the vast majority of herniations consisted of annulus fibrosus or the latter and nucleus pulposus; in 40% of these subjects, cartilage fragments were found in the herniated tissue.

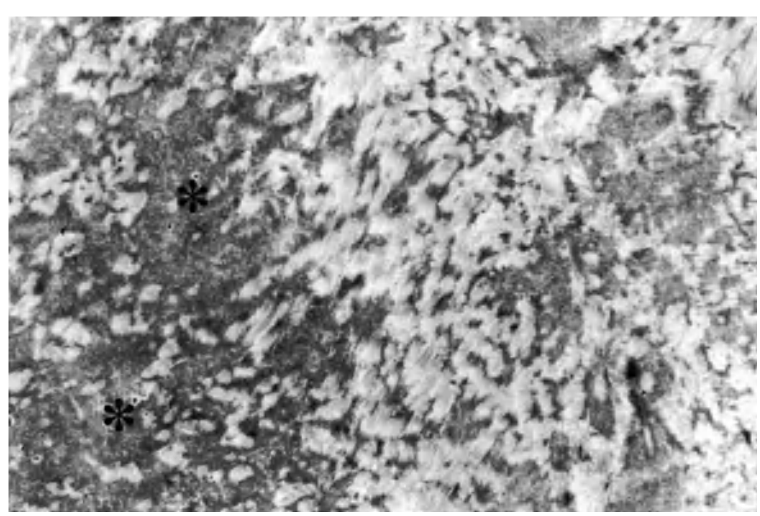


Fig. 5.46. *Extruded disc herniation. Intercellular matrix of a fragment of herniated annulus fibrosus. Large aggregates of electron-dense granular material (asterisks) are visible in the highly fibrotic intercellular matrix.*

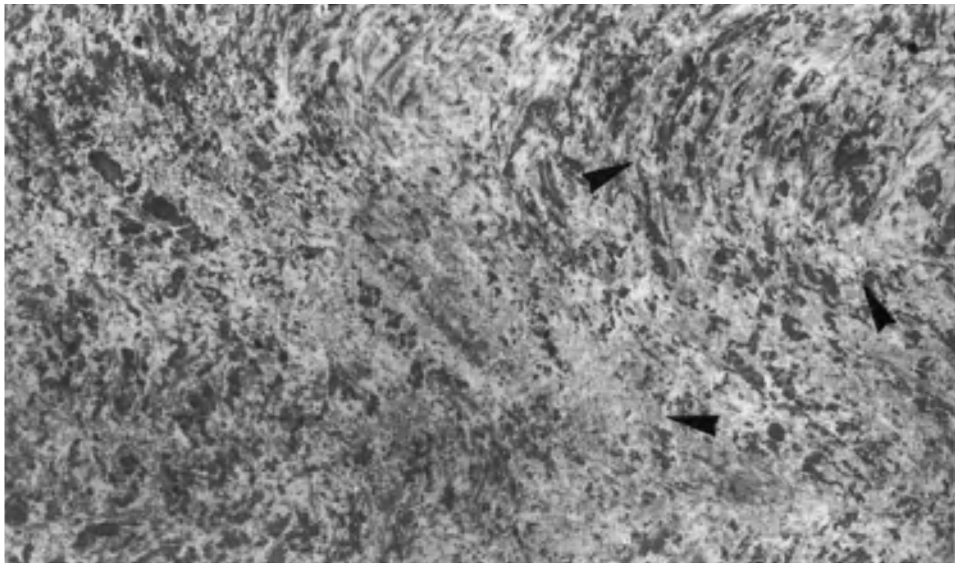


Fig. 5.47. *Migrated disc herniation. Electron micrograph. The intercellular matrix shows no clear nuclear or anular characteristics. It consists of lamella-like structures (arrowheads) and areas containing collagen fibers orientated in various directions and relatively abundant amorphous ground substance (asterisks).*

Resorption of disc herniation

Many processes of gradual herniation of nucleus pulposus are likely to reach Stage II and then stop, in the absence of an adequate centrifugal pressure on the nuclear tissue, which with time undergoes dehydration and increase in the fibrous component.

A herniation at Stage III tends with time to decrease in size. This probably occurs through a series of mechanisms: dehydration of nuclear tissue due to decreased proteoglycan synthesis; transformation of chondrocytes into fibroblasts; increase in the collagen fibers and subsequent retraction of the herniated tissue. These processes are likely to occur more easily when the herniated tissue consists of scarcely degenerated nucleus pulposus.

Extruded or migrated disc herniations may also undergo progressive, partial or complete, resorption (12, 13, 36, 50, 70). In these herniations, the main mechanism of resorption is probably related to processes of vascular invasion of the disc tissue. Areas of granulation tissue, consisting of newly formed vessels and macrophages, fibroblasts, monocytes and lymphocytes, are known to be present in the peripheral portions of extruded or migrated disc tissue (15, 22, 36, 47, 87). Granulation tissue has been observed in about 60% of these herniations, and more often in migrated than extruded herniations (22, 91) and in herniations already present for 6 months compared with those of more recent onset (15). Immunohistochemical studies have demonstrated that many cells in the granulation tissue are reactive to monoclonal antibodies to macrophages (36) and that these and/or other cells produce collagenase and stromelysin (metalloproteinase-3), Inflammatory cytokins (interleukin-1 alfa, interleukin-1 beta, interleukin-6), anti-interleukin-1, and other chemical mediators, such as the tumor necrosis factor-α, the molecule of intercellular adhesion-1 and the fibroblast stimulating factor (22, 41, 77). However, collagenase, stromelysin and several interleukins are produced also by cartilage cells in the degenerated disc and in contained herniations (19, 42, 77).

The inflammatory reaction responsible for the appearance of granulation tissue in the herniated material may be an autoimmune response to antigens of nucleus pulposus or be the result of epidural vessels invading the disc tissue in an attempt to remove a foreign material that has penetrated into the spinal canal. Invasion of vessels and inflammatory cells probably has three effects: 1) a greater production, than in basal conditions, of some enzymes, such as collagenase and stromelysin, that act directly on the intercellular matrix by digesting collagen and proteoglycans; 2) production of substances stimulating the proliferation and activity of the histiocyte system cells, which fagocytize the tissue; 3) production of chemical mediators that maintain the inflammatory process by facilitating the sprouting of newly formed vessels and migration into the tissue either of leucocytes or monocytes, which subsequently transform into macrophages.

These processes, or some of them, may possibly play a role also in the resorption of contained herniations. This holds particularly when the herniated tissue is invaded by newly formed vessels, which have penetrated into the disc through fissures in the annulus fibrosus.

Effects of disc herniation on motion segment

Intervertebral disc

Herniation occurs in a disc showing degenerative changes of varying severity. It is not known, however, whether the development of the herniation causes an increase in degenerative changes in the disc. Displacement of nucleus pulposus and/or annulus fibrosus is likely to increase the degenerative changes due to either the alteration of the disc structure or the possible decrease in disc height. Also in this respect, however, it is unclear whether the decrease in height of a disc presenting a herniation depends exclusively on the degenerative changes of the disc or, to some extent, is enhanced by the process of herniation. It is probable that a small herniation of nucleus pulposus, in a mildly degenerated disc, does not cause any significant decrease in disc height, whereas the extrusion of a large part of the nucleus and/or the annulus may lead to a decrease, or to a further decrease, in disc height.

Vertebrae

The effects of a herniation on the two adjacent vertebrae may be related to the possible decrease in disc height, the herniation itself, or to abnormal reciprocal mobility of the two vertebrae.

Disc narrowing may play a role in the development both of anterolateral marginal osteophytes of the vertebral body and degenerative changes in the facet joints. The decrease in disc height, particularly when marked, causes subluxation of the articular processes. This implies an abnormal and/or eccessive mechanical loading on articular facets, which can favor the development of arthrotic changes in the posterior joints. These changes, on the other hand, may be favored by the loss of the function of mechanical fulcrum by the nucleus pulposus and the consequent displacement of the axis of movement in the posterior joints (8).

The herniation may play a relevant role in the development of posterior osteophytes of the vertebral body. They might form, similarly to what Schmorl (73) hypothesized for anterior osteophytes (page 100), as a result of detachment of the posterior longitudinal ligament from the vertebral body by the herniation. Alternatively, posterior osteophytes might result, in patients with a contained herniation, from calcification and subsequent ossification of the annulus fibrosus in proximity to its vertebral attachment.

Rupture of the annulus fibrosus or its detachment from the vertebral body favors an increase in motion of the two adjacent vertebrae. This leads to an alteration in the articular mechanics in the posterior joints. The abnormal mobility may stimulate the development of cartilaginous tissue at the periphery of the disc and the formation of somatic osteophytes and, furthermore, may cause degenerative changes in the facet joints. This may continue until the motion segment becomes hypomobile due to decreased disc height, arthrotic changes in the posterior joints and possible increase in the fibrous components in the disc.

Disc herniation and morphometric features of spinal canal

Narrow spinal canal

The spinal canal is defined as narrow when the dimensions are close to, or below, the lower limits of normal, which are approximately 12 mm for the midsagittal diameter and 19 mm for the interpedicular diameter. In subjects with a narrow vertebral canal, the dimensions of the latter are generally reduced at all levels, the lowest values usually being found at L3 and L4.

A narrow spinal canal does not cause, in itself, compression of the vertebral nervous structures. This occurs when acquired factors further increase the narrowing to a critical extent, transforming the narrow, into a stenotic, canal.

A constitutionally narrow vertebral canal has, tendentially, short pedicles, laminae orientated transversely and abnormally short, and articular processes with a sagittal orientation. More rarely, the laminae are of normal length, but are orientated more sagittally than normal, and the articular processes are closer to each other with subsequent transverse, rather than sagittal, narrowing. In both cases, the nerve-root canal of the lower lumbar vertebrae tends to have short sagittal dimensions. When the pedicles are abnormally short, the intervertebral foramina are narrow in the sagittal plane.

Lumbar stenosis

Lumbar spinal stenosis is an abnormal narrowing of the osteoligamentous vertebral canal and/or the intervertebral foramina, which is responsible for compression of the thecal sac and/or the caudal nerve roots. Narrowing may involve one or more levels and, at a single level, may affect the whole canal or part of it (63).

Based on this definition, abnormal narrowing of the vertebral canal can be regarded as stenosis when two criteria are fulfilled: narrowing involves the osteoligamentous spinal canal, and causes compression of the nervous structures contained in the canal.

The first criterion implies a clear-cut distinction between disc disease and stenosis. This distinction may appear to be arbitrary, both on account of the fact that the intervertebral disc contributes to delimit the spinal canal and because, in stenosis, compression of the nervous structures is often caused by a coexisting disc disease. However, if the concept of stenosis is not limited to the osteoligamentous vertebral canal, even disc herniation becomes a stenotic condition. In fact, also a herniated disc produces a pathologic narrowing of the entire spinal canal or a part of it. However, disc herniation and stenosis are so different in their pathogenetic and anatomo-clinical characteristics that they cannot be considered as a single pathologic condition.

The second criterion emphasizes the concept of compression of the nervous structures, which is implicit in the term stenosis. This term, in fact, indicates a dimensional disproportion between the caliber of the container and the volume of the contents. If the latter are solid or semifluid, as in the vertebral canal, the disproportion results in compression of the contents by the container. The nerve-root canal should also be considered stenotic when compression of the nerve root is mainly or exclusively due to changes in the osteoligamentous components of the canal.

Classification

Lumbar spinal stenosis may be classified as: stenosis of the spinal canal or central stenosis, isolated nerve-root canal stenosis or lateral stenosis, and stenosis of the interverebral foramen (Table 5.2). In stenosis of the spinal canal, only the central portion of the canal may be constricted or, as usually occurs, both the central portion and the nerve-root canal on one or both sides. In isolated stenosis of the nerve-root canal, only the lateral portion of the spinal canal, where the nerve root runs, is narrowed. Stenosis of the intervertebral foramen may be isolated or associated with one of the other two forms of lumbar stenosis.

Stenosis of the spinal canal includes primary, secondary and combined conditions. Primary stenosis may be congenital or developmental. The former is due to congenital vertebral malformations. Developmental stenosis may be of known etiology (achondroplasia) or be idiopathic. In idiopathic, or constitutional, stenosis, the disorder in postnatal vertebral development, which is responsible for narrowing of the canal, is of unknown etiology. In all primary forms, compression of the nervous structures usually becomes apparent in middle or

Table 5.2. *Classification of lumbar stenoses.*

Stenosis of the spinal canal (central stenosis)

Primary
- congenital
- developmental | achondroplasic
  | constitutional (idiopathic)

Secondary
- degenerative (with or without spondylolisthesis)
- late sequelae of fractures
- late sequelae of infections
- in systemic bone diseases

Combined
- association of primary and secondary stenosis at the same level

Isolated nerve-root canal stenosis (lateral stenosis)

Primary
Secondary
Combined

Stenosis of intervertebral foramen

Primary
Secondary

early senile age, when congenital or developmental narrowing is aggravated by even mild spondylotic changes, responsible for further constriction of the spinal canal.

In secondary stenosis, the midsagittal and interpedicular diameters of the spinal canal are normal, the neural compression being exclusively due to one or more acquired conditions. These are generally represented by spondylotic changes of the vertebral body and/or the posterior joints, associated or not with degenerative spondylolisthesis. Less frequent causes of secondary stenosis are late sequelae of vertebral fractures or infections, and systemic bone diseases, such as Paget's disease.

Combined stenosis is the condition in which primary narrowing of the spinal canal is associated, at the same vertebral level, with secondary narrowing, generally spondylotic in nature.

Isolated nerve-root canal stenosis may be due to: a) disturbances of vertebral development, particularly abnormal shortness of the pedicles or anomalous orientation or shape of the superior articular process (primary stenosis); b) acquired factors, such as hypertrophy and/or posterior osteophytosis of the vertebral endplate, or late post-traumatic changes (secondary stenosis); c) association of primary and secondary conditions (combined stenosis).

Stenosis of the intervertebral foramen is occasionally associated with stenosis of the spinal canal, particularly in degenerative forms. It is uncommon, instead, to observe isolated stenosis of the neuroforamen, which can be primary, secondary or combined.

Pathomorphology

Stenosis of the spinal canal

Constitutional stenosis can be of two types (64, 65). In one type, the vertebrae and the intervertebral discs show similar morphologic characteristics to those typical of achondroplasic subjects. The pedicles are short and the posterior aspect of the vertebral body shows a marked concavity in the sagittal plane; the discs bulge into the spinal canal even in the absence of degenerative changes; the articular processes and the laminae have a more sagittal orientation than normal. The midsagittal diameter of the spinal canal is normal, whereas the interpedicular diameter is abnormally short. The ligamenta flava may be thickened and the articular processes hypertrophic, though mildly. On midsagittal section, the vertebral canal has a sinusoidal appearance, the narrow areas corresponding to the intervertebral spaces.

The second type is characterized by an abnormal shortness of the midsagittal diameter, whilst the interpedicular diameter is normal or slightly short. The pedicles are mostly short and the laminae have a more transverse orientation than normal, which results in a flattening of the spinal canal in the sagittal plane. The ligamenta flava may be slightly thickened and the articular processes moderately hypertrophic due to degenerative changes. On midsagittal section, the vertebral canal is narrow throughout its entire, or almost entire, length and shows areas of further narrowing at intervertebral level.

Degenerative stenosis. This condition results from degenerative changes of the vertebral body and/or the osteoligamentous structures of the posterior vertebral arch.

The vertebral body may show marginal osteophytes encroaching on the central spinal canal and/or the nerve-root canal or the intervertebral foramina.

Degenerative hypertrophy of the inferior articular processes causes, at intervertebral level, a transverse narrowing and deformation of the central portion of the spinal canal. Hypertrophy of the superior articular processes, associated or not with osteophytosis of their anteromedial border, contributes to deform the central portion of the spinal canal and narrows the intervertebral portion of the nerve-root canal (64, 65). Degenerative changes of the base of the superior articular process produces narrowing of the cranial portion of the lateral recess. Furthermore, the articular process, when hypertrophic, narrows the intervertebral foramen in the sagittal plane and can impinge, with its apical portion, on the nerve root coursing in it. This tends to occur more easily in the presence of a marked decrease in disc height.

The ligamenta flava are generally shortened, narrower in the coronal plane and thickened. Shortening results from the decrease in disc height; narrowing is caused by hypertrophy of the inferior articular processes, which is responsible for their medial border coming close to the spinous process. Both these changes, furthermore, may be favored by ossification of the ligamenta at their bone insertion. Thickening is caused by shortening of the ligamenta and the degenerative (fibrosis) and metaplastic (chondroid metaplasia) changes that decrease the amount of elastic fibers in the tissue (66). The increase in thickness of the portion of the ligamenta flava attached to the laminae reduces the diameter of the central-posterior portion of the spinal canal. Thickening of the portion which ventrally covers the joint capsule narrows the central-anterior part of the vertebral canal and the intervertebral portion of the nerve-root canal.

Combined stenosis. The spinal canal has the features of the developmentally narrow canal, but it is generally less narrow than the latter. Spondylotic changes are

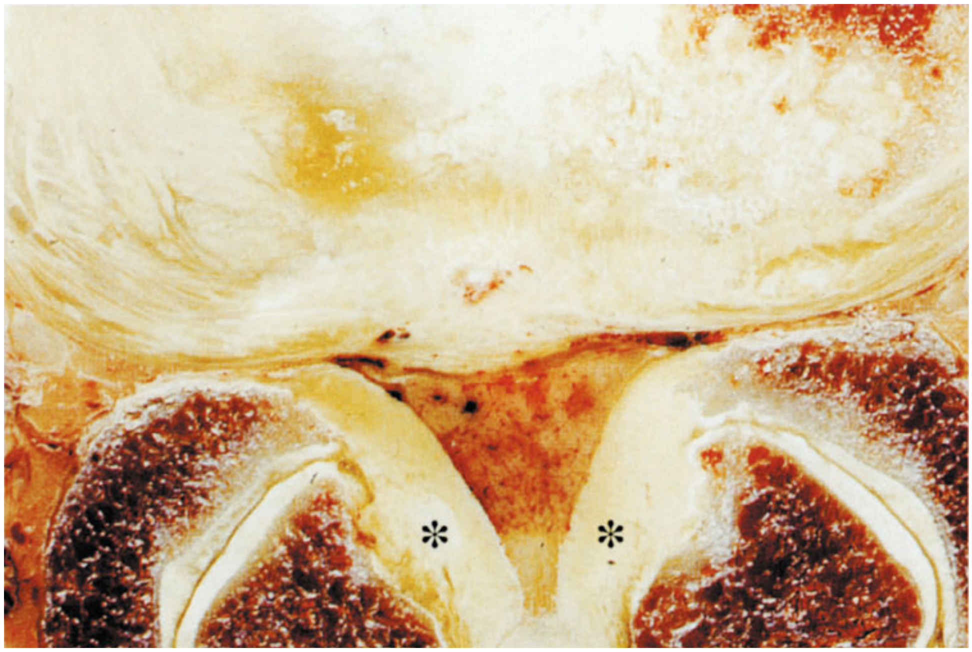


Fig. 5.48. *Anatomic section at the level of the intervertebral disc. Combined stenosis of the spinal canal resulting from moderate constitutional narrowing of the canal and thickening of the ligamenta flava (asterisks) associated with mild hypertrophy of the articular processes.*

similar, but less severe, than those found in degenerative stenosis, since less marked changes are sufficient to produce compression of the neural structures in a developmentally narrow canal (Fig. 5.48).

Isolated nerve-root canal stenosis

The nerve-root canal is generally stenotic at the level of the proximal portion, corresponding to the intervertebral disc. Stenosis results from degenerative changes of the superior articular process and the ligamentum flavum. An important role in the etiology of nerve-root compression may also be played by bulging of the annulus fibrosus. This may occur both in static conditions and extension and / or torsion of the spine due to further annular bulging caused by these movements (Fig. 5.49).

Stenosis of the distal portion, corresponding to the lateral recess, is rare, since in this portion the walls of the canal are entirely osseous. Stenosis is caused by osteophytes of the cranial end-plate or degenerative changes of the base of the superior articular process.

Stenosis of the intervertebral foramen

This is caused by the same changes as those responsible for stenosis of the neuroforamen associated with stenosis of the spinal canal. It should be considered, however, that narrowing of the neuroforamen as a result of spondylotic changes is frequent, but rarely causes compression of the nerve root, and that when this occurs, the compression is generally mild (Fig. 5.50). Stenosis, in these cases, is generally asymptomatic.

Degenerative spondylolisthesis

This pathologic condition involves narrowing of varying severity of the spinal canal and / or the nerve-root canals (65, 67). Narrowing results, in part, from the arthrotic changes of the superior articular processes and, in part, from vertebral olisthesis. Degenerative changes of the superior articular processes of the vertebra below the olisthetic vertebra produce narrowing of the nerve-root canal and, occasionally, of the intervertebral foramen that the apophysis contributes to delimit. Narrowing may be mild and not cause compression of the emerging nerve root or may be responsible for stenosis, of varying severity, of the nerve-root canal and the intervertebral foramen. The degenerative changes of the inferior articular processes of the slipped vertebra produce narrowing of the central spinal canal, which is further constricted, to a significant extent, by vertebral slipping. In fact, due to the integrity of the posterior vertebral arch, which follows the vertebral body in the slipping, the thecal sac is as if it were guillottined

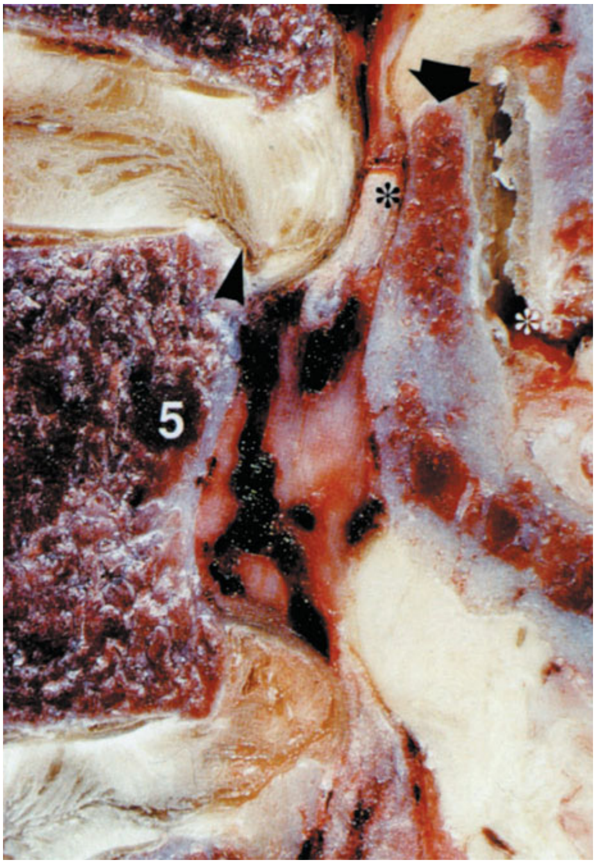


Fig. 5.49. *Sagittal section at the level of the nerve-root canal in a spine frozen in moderate rotation. The L4-L5 disc shows a few fissures, one of which extends to the attachment of the annulus fibrosus at L5 vertebral body (arrowhead). The annulus fibrosus bulges into the spinal canal and impinges on the L5 nerve root (black asterisk), which is compressed also posteriorly by the superior articular process of L5 (arrow). As a result of rotation, the L4-L5 facet joint gapes (white asterisk). Also the L5-S1 disc is fissured and shows marked posterior annular bulge.*

Fig. 5.50. *Stenosis of the intervertebral foramen caused by the tip of the superior articular process covered by the ligamentum flavum (asterisk) in a L4-L5 motion segment showing marked disc resorption* (D) *and marginal osteophytosis of the posterior border of the vertebral bodies (long arrow). The nerve root running in the neuroforamen (arrowhead) is moderately compressed in spite of marked narrowing of the foramen. The short arrow points to a vessel in the intervertebral foramen.*

between the posterior arch of the slipped vertebra and the body of the vertebra below. The effects of these two processes are, however, related to the original width of the vertebral canal. When the latter is wide and the vertebral slipping is of mild severity, compression of the nervous structures may not occur. In the presence of a normally sized spinal canal, the thecal sac is usually compressed at the level of its lateral portions. When the dimensions of the spinal canal are at the lower limits of normal or below, a marked compression of the dural sac occurs, even in the presence of spondylotic changes or vertebral slipping of mild severity.

The orientation of the articular processes of the slipped vertebra tends to be more sagittal than normal and the vertebra may show a translational or angular hypermobility in flexion-extension movements or may show no hypermobility.

Disc herniation in a narrow spinal canal

A narrow spinal canal does not represent a predisposing condition to disc herniation, but, other conditions being equal, it tends to make radicular signs and symptoms more severe.

Porter et al. (62) have measured, by echography, the oblique sagittal diameter of the lumbar spinal canal in patients with disc herniation and in asymptomatic subjects. In the former, the mean dimensions of the spinal canal were significantly lower than in the latter; furthermore, in the patients successfully treated with conservative measures, the mean dimensions of the canal were larger than in those requiring surgical treatment. In a similar study (89), the midsagittal and interpedicular diameters of the spinal canal were measured on lumbar spine radiographs in patients submitted to surgery for disc herniation and in asymptomatic subjects. In the former, the sagittal dimensions of the spinal canal were significantly smaller than in the latter. These findings indicate that patients with a symptomatic disc herniation tend to have a narrow spinal canal and that the herniation causes a more severe compression of the nervous structures in a narrow, than in a normal, spinal canal. This is due to the fact that, in a narrow canal, there is less reserve space for the neural structures. These are therefore less likely to escape compression by the herniation or, being displaced by the latter, are compressed also by the osteoligamentous walls of the canal.

No relationship appears to exist between the type of herniation and the dimensions of the spinal canal. In the series studied by Porter et al. (62), the dimensions of the canal were similar in the patients with a contained, to those with an extruded, herniation, the two groups including a similar number of subjects. In our experience, however, this does not hold for patients with a markedly narrow canal, i.e., with a midsagittal diameter measuring less than 12 mm. In these subjects there is more often a bulging of the annulus fibrosus or a contained herniation than an extruded or migrated herniation. Furthermore, the annular bulging or contained herniation are more often central than posterolateral and, even if small in size, occupy the spinal canal to a large extent. Probably this is related to the fact that an even mild disc pathology, scarcely symptomatic or asymptomatic in normal subjects, is readily symptomatic, and is diagnosed early, in those presenting severe narrowing of the spinal canal.

Disc herniation in stenotic spinal canal

Constitutional stenosis

In this form of stenosis, marked bulging of the annulus fibrosus or a contained herniation is often present at one or more of the stenotic intervertebral levels. The development of disc disease often makes a previously asymptomatic condition symptomatic. The annular bulging or herniation are often central and may thus lead to compression of the nervous structures on both sides. The discs most frequently involved are the third and fourth. The nuclear material that can be excised from the disc ranges from very little to abundant. In most cases, it is relatively meager and moderately degenerated.

In the presence of disc disease, it is often difficult to differentiate a narrow from a stenotic spinal canal. The main differences are that: a) in a stenotic canal, unlike in the narrow one, compression of the nervous structures is usually present also at intervertebral levels showing no significant disc disease; b) in a stenotic canal, the thecal sac is compressed also posteriorly or posterolaterally by the osteoligamentous walls of the canal.

Degenerative and combined stenosis

In stenosis of the spinal canal, or central stenosis, the intervertebral discs in the stenotic area are generally degenerated, however rarely show marked bulging of the annulus fibrosus or a herniation. Usually this occurs only when the disc height is normal or moderately decreased. The herniation is mostly contained and never migrated, and may be both central or paramedian, and posterolateral. Often a posterolateral herniation extends into the foraminal area, whereas only rarely is the herniation exclusively intraforaminal. Usually the contents of the disc are fairly abundant, considerably dehydrated and brownish in colour due to senile degenerative changes in the disc tissue. Encroachment on the spinal canal by the herniation tends to be less and less marked the more stenotic the spinal canal.

In isolated stenosis of the nerve-root canal, unlike in central stenosis, the disc disease plays a major role in the compression of the neural structures. That is, very often stenosis becomes symptomatic only in the presence of a bulging annulus fibrosus or disc herniation. In most cases, the latter is contained, or extruded beneath the posterior longitudinal ligament, and located posterolaterally. It is generally small in size, since a mild or moderate encroachment on the spinal canal may be sufficient to cause severe nerve-root compression.

In degenerative spondylolisthesis, the disc below the slipped vertebra is almost always degenerated, but does not usually protrude into the spinal canal. Occasionally, it is the site of disc herniation, which usually develops in the presence of mild slipping and a normal, or almost normal, disc height. The herniation is generally contained and may be central, posterolateral or lateral.

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·CHAPTER 6·

PHYSIOPATHOLOGY OF LUMBORADICULAR PAIN

G. Cinotti, F. Postacchini

Neuroanatomy

Radicular nerve and dorsal root ganglion

Radicular nerves and nerve roots may be compared, for their function, to peripheral nerves. However, at least from the anatomic point of view, there are some differences between radicular and peripheral nerves. Both are formed by bundles of nerve fibers kept together by a framework of connective tissue. Each nerve fiber includes single axons ensheathed by longitudinal invaginations of Schwann cells. The largest nerve fibers are enwrapped in myelinic sheaths, constituted by multiple layers of Schwann cell cytoplasm around the axon. The myelinic sheath increases nerve conduction along the axon, prevents diffusion of spontaneous activity to the adjacent axons and guides the regenerative processes of nerve fibers after injuries. Moreover, the myelinic sheath regulates metabolic exchanges between the axon and Schwann cell (92). A basement membrane, formed by an internal glycoproteic layer and an external layer, the Key and Retzius sheath, lies adjacent to the Schwann sheath. The Key and Retzius sheath is closely connected to the endoneurium and is particularly thick in sensory nerve fibers (Ruffini's sheath) (92).

Differences have been found in the content in, and the distribution of, connective tissue between peripheral and radicular nerves. Peripheral nerves exhibit a well-developed framework of connective tissue, including an external sheath, the epineurium, and an internal sheath, the perineurium, surrounding each nerve fascicle. Moreover, connective tissue, the endoneurium, is present between the nerve fibers and is connected to the perineurium through delicate septa. In contrast, radicular nerves have no epineurium or perineurium (48) and exhibit a reduced collagen content compared with peripheral nerves (40, 144) (Fig. 6.1). As a result, radicular nerves show different biomechanical properties with respect to the peripheral nerves, including a decreased elasticity and a greater tendency to undergo intrinsic changes when subjected to mechanical compression.

The dorsal root ganglion is enfolded in a tight fibrous capsule, which sends numerous septa into the inner ganglion. Vascular bundles run within these septa to penetrate into the ganglion. The nerve fibers are located in the central region of the ganglion between the connective tissue septa, whilst the nerve cells occupy the peripheral region (6).

Vascular support

In the peripheral nerve, the blood supply is provided by longitudinal arteries running within the epineurium and connected by anastomotic branches. Perpendicular branches originating from the longitudinal arteries penetrate into the perineurium and then into the endoneurium, where they form a capillary network. In the radicular nerve, the vascular support is supplied by arteries coming proximally from the vasa corona of the spinal cord and distally from the segmental arteries (110). These sources of blood supply anastomose in the

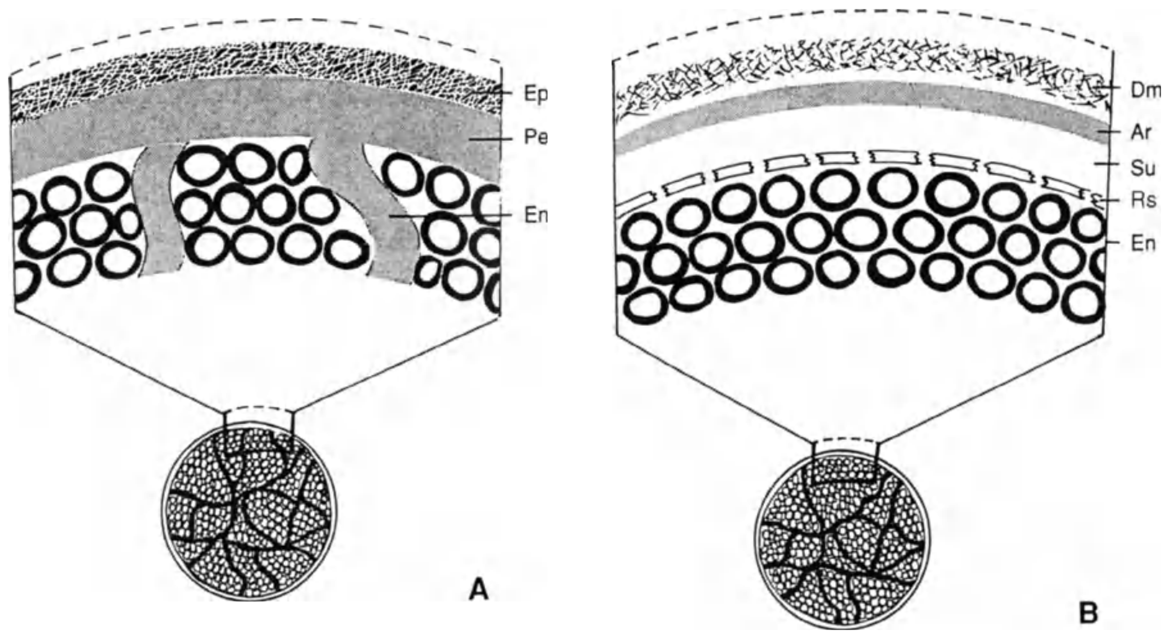

Fig. 6.1. *Connective tissue in the peripheral and radicular nerve. The peripheral nerve* (A) *shows connective sheaths, the epineurium* (Ep) *and perineurium* (Pe) *around the nerve and nerve fascicles, respectively, and the endoneurium* (En) *between nerve fibers . The radicular nerve* (B) *lacks the epineurium and perineurium, and the endoneurium is less developed compared with the radicular nerve* (Dm *dura mater;* Ar *arachnoid membrane;* Su *subarachnoid space ;* Rs *radicular sheath).*

distal third of the radicular nerve (110), at the level of the dural sheath ending, where a watershed zone in the blood supply of the radicular nerve occurs (160). However, the vulnerability of the radicular nerve to mechanical compression in this zone of relative hypovascularization does not appear to be increased (50).

The radicular nerve shows a decreased vascularization compared with the peripheral nerve; however, about 70% of its nutritional supply is provided by the cerebrospinal fluid (55, 122). Conversely, the dorsal root ganglion seems to be as rich in blood supply as the peripheral nerve (160).

Mechanical deformation and/or chemical irritation of the radicular nerve may cause intraneural edema, an event which is largely affected by the degree of permeability of the endoneurial capillaries. Both radicular and peripheral nerves exhibit endoneurial capillaries of the continuous type, i.e., endothelial cells are linked by tight junctions which, by impeding the free transfer of molecules larger than 2–3 nm, form a blood-nerve barrier (68). However, this barrier is much less effective in the radicular nerve, since the permeability of endoneurial capillaries is greater and edema occurs more likely than in peripheral nerves (68, 121). Moreover, the arachnoid membrane may act as a diffusion barrier, thus increasing intraneural edema formation, whereas this is not the case for the epineurium in the peripheral nerve. The dorsal root ganglion is even more susceptible to edema formation compared with the radicular nerve, since it exhibits endoneurial capillaries of the fenestrated type and is enfolded in a tight fibrous capsule which acts as a diffusion barrier (68). Hence, if the dorsal root ganglion is submitted to mechanical compression, a similar condition to a closed compartment syndrome might occur (125).

Sinuvertebral nerve

The sinuvertebral nerve provides innervation to the posterior and posterolateral annulus, the posterior longitudinal ligaments and the anterior aspect of the dura mater of the thecal sac (44). Conflicting opinions exist on the origin of the sinuvertebral nerve. It has been reported that the sinuvertebral nerve originates: entirely from the ventral ramus of the spinal nerve (14, 118, 156); both from the ventral ramus of the spinal nerve and the sympathetic trunk or its rami communicantes (11, 83, 113, 143); or exclusively from the sympathetic trunk or its rami communicantes (44, 73, 93). These discrepancies may be due to the difficulties in exposing such a thin nerve on anatomic dissections and to the close relationship between the rami communicantes of the sympathetic trunk and the spinal nerve in the region where the sinuvertebral nerve originates.

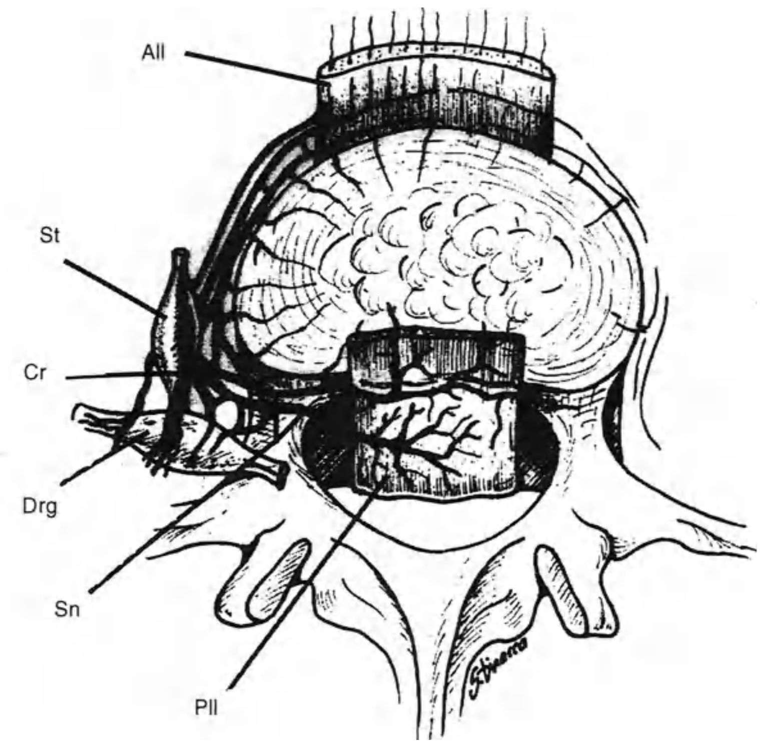

Fig. 6.2. *Origin of the sinuvertebral nerve.* Sn *sinuvertebral nerve;* St *sympathetic trunk;* Cr *communicantes rami;* Drg *dorsal root ganglion;* All *anterior longitudinal ligament;* Pll *posterior longitudinal ligament.*

It should also be borne in mind that gross dissections without any specific nerve staining have been carried out in some studies, whereas, in others, reconstructions of microscopic sections were analyzed (44). Results of recent investigations carried out exposing the sinuvertebral nerve under the dissecting microscope suggest that the sinuvertebral nerve originates almost exclusively from the rami communicantes of the sympathetic trunk (44, 73, 93) (Fig. 6.2).

Two to six sinuvertebral nerves are present in the posterior longitudinal ligament at each intervertebral level; moreover, ascending and / or descending branches may reach the level above and below on the ipsilateral or opposite side. Commonly, in the region of the posterior longitudinal ligament above the disc, a nerve plexus is present, formed by the sinuvertebral nerve of the corresponding level and branches coming from nerves of the levels above and below (44).

The sinuvertebral nerve may include nociceptive, proprioceptive and vasomotor fibers (11, 72, 113, 143). Somatic fibers with a different destination may also run with the sympathetic fibers (11, 143).

Nociceptors

Nociceptors are free nerve endings involved in the transmission of painful stimuli. They have been found to be particularly abundant in the skin, arterial walls, periosteum and joint surfaces (47). In the functional spinal unit, free nerve endings, possibly acting as nociceptors, have been detected in the articular facets and facet joint capsules (51, 59, 108, 152), in the supraspinous and interspinous ligaments (157), in the posterior longitudinal ligament and in the external annulus (11, 51, 59, 62, 85, 118, 162). In degenerated discs, free nerve endings were found even in the inner annulus (162). Although the nociceptive function of these nerve endings has not been unequivocally proven, some of them were found to contain neuropeptides, such as substance P and calcitonin gene related peptide (CGRP), which are known to be involved in the transmission of painful stimuli (2, 22, 70, 77, 153). Free nerve endings acting as nociceptors may be present in the nervi nervorum of the radicular nerve and dorsal root ganglion (50, 134).

In muscle tissue, free nerve endings were found in the connective tissue between muscle fibers and within the vessel walls (141). Moreover, about 40% of A-delta and C fibers present in muscles seem to function as nociceptive fibers (89).

In the presence of chronic inflammation, mechanoreceptors, particularly those of type III and IV, may become more sensitive to mechanical stimuli (3, 133, 159); in these instances, they may function as nociceptors or may induce a persistent spasm of paravertebral muscles, which may eventually cause low back pain (117).

Physiopathology of low back and radicular pain

Tissue damage and activation of nociceptors

Pain sensation is the result of tissue damage caused by chemical or physical agents. The injured tissue releases chemical substances that activate nociceptors, which, in turn, signal the presence of the noxious stimulus. Chemical substances activating nociceptors include non-neurogenic and neurogenic pain mediators. The former are activated by proteolytic enzymes released by mast cells after tissue injury; these include substances with a pain producing ability, such as bradykinin, serotonin, histamine, prostaglandins and leukotrienes (35, 115). It has been shown that minimal doses of bradykinin or histamine cause pain when injected intradermally in man (23, 47). These chemical agents exhibit synergic effects; for instance, the effects of bradykinin are enhanced by serotonin and prostaglandins (91, 137). Neurogenic pain mediators include neuropeptides, such as substance P, calcitonin gene-related peptide, vasoactive intestinal polypeptide, somatostatin and cholecystokinin-like substance, which are released by nociceptors as a result of chemical or physical stimuli. Substance P was found to induce plasma extravasion, edema formation and the release of histamine from the mast cells (19).

In the functional spinal unit, pain may be induced by physical or chemical stimulation of the radicular nerve and / or free nerve endings. Disc herniation, spinal stenosis, tumors or traumatic conditions may cause physical stimulation of the radicular nerve. However, even abnormal vertebral motion might produce anomalous mechanical stimulations of nociceptors located in the outer annulus, posterior ligaments and facet joint capsules.

The presence of pro-inflammatory agents may induce chemical irritation of the radicular nerve and / or nociceptors. In particular, degenerative changes of the disc or facet joints may provoke release of cytokines, prostaglandins, nitric oxide and PLA_2, which may irritate nerve endings in the functional spinal unit (64).

Afferent and efferent function of nociceptors

Nociceptors normally act as afferent sensory units, i.e., the exposure to mechanical or chemical stimuli increases the permeability of the membrane of these nerve endings to various ions, mainly Na^+, resulting in a depolarisatory chain-reaction until an action potential is set off. The painful stimulus is thus converted into a nervous impulse and transmitted from the periphery to the central nervous system (orthodromic impulse). However, when mechanical compression induces damage to a peripheral nerve, such as demyelination of nerve fibers, ectopic discharges may originate from the injury site and be propagated both centrally and peripherally. The latter (antidromic impulses) reach the nociceptors and stimulate the release of neuropeptides (16, 50, 97, 109, 147). Nociceptors may act as efferent units and release neuropeptides even when exposed to chemical or mechanical stimuli (111).

There is evidence that the efferent function of nociceptors is involved in the mechanism provoking chronic pain. Antidromically activated nociceptors release neuropeptides which may induce inflammation either directly, by releasing substance P, or indirectly by stimulating the release of non-neurogenic chemical mediators (9, 112). Furthermore, the release of neuropeptides stimulates the adjacent nociceptors to produce orthodromic impulses (50), and this may induce a vicious circle leading to chronicization of pain. In particular, after prolonged stimulation, nociceptors become sensitized, i.e., they may be activated at a lower threshold and exhibit spontaneous activity (7, 18, 86). This condition may lead to hyperalgesia, i.e., a decreased threshold to painful stimuli and increased pain in response to a painful stimulus (67).

Pain fibers

A-delta (Group III) and C (Group IV) nerve fibers are involved in the transmission of painful stimuli. Both are small fibers showing an extremely low nerve conduction velocity (0.2 m / sec in C fibers compared with 120 m / sec in A-delta); however, conduction velocity in A-delta fibers is about tenfold compared with C fibers, since the latter have no myelinic sheath (47).

Pain fibers show a different specialization in the transmission of painful stimuli. A-delta fibers are involved in the perception of a sharp pricking sensation, whilst C fibers account for burning feeling and deep pain, which is continuous, but less severe, compared with a burning or pricking sensation (17, 47). A painful stimulus commonly evokes a double pain sensation, i.e., a sharp pricking sensation followed by a burning feeling.

Dorsal root ganglion and neurogenic pain mediators

Afferent impulses generated by noxius stimuli reach the dorsal root ganglion (DRG) along A-delta and C fibers. Since DRG connects the peripheral nerve to the spinal cord and, by means of synthesis and release of neuropeptides, is involved in the modulation of nerve impulses, it has been referred to as the "brain" of the functional spinal unit (88, 152).

Cell bodies of neurons in DRG have been shown to produce various neuropeptides. Substance P, which is synthesized in the DRG and to a lesser extent in the spinal cord (53, 54), was found to be involved in the modulation of nociceptive stimuli directed towards the posterior horns of the spinal cord (15, 39, 106, 158). Moreover, an increase in substance P in DRG has been reported after mechanical compression, or after irritation, of the radicular nerve (20, 24). CGRP, a neuropeptide abundant in DRG cells, seems to promote the transmission of nociceptive stimuli by increasing the release of substance P and inhibiting its degradation (76, 99). The vasoactive intestinal peptide (VIP) has a central analgesic function (71); moreover, it stimulates the glycogenesis (84) and is involved in the process of axonal regeneration occurring after nerve injury (13). An increased content of VIP was found in the DRG of animals submitted to vibrations (151, 154). Somatostatin, Neurokin A, Cholecystokinin, dynorphin are some of the neuropeptides also produced in DRG.

Ascending pain pathway

Along the sensory nerve roots, pain fibers reach the posterior columns of the spinal cord, continue up one or two segments and terminate in the dorsal horns, where a synaptic connection with a second order neuron is formed. The message then crosses the spinal cord and, running along the spinothalamic tract, reaches the thalamus, from which the message is sent to the somatosensory cortex of the brain by a third order neuron. Further ascending pain pathways are the spinoreticular tract, the spinomesencephalic tract, the spinocervical tract and the dorsal column (19, 60).

Descending inhibitory and excitatory circuits are present in the spinal cord, as well as pain control mechanisms. It has been hypothesized that the simultaneous stimulation of mechanoreceptors and nociceptors occurring in or around the same somatic area, may significantly reduce the transmission of painful stimuli by means of presynaptic inhibition mechanisms ("gate control" theory of pain) (47, 88).

Nerve-root compression

Experimental models

Acute compression

In several studies acute compression has been simulated by removing the posterior vertebral arch and positioning an inflatable balloon over the cauda equina. The balloon is maintained in contact with the dural tube by means of a plexiglass plate, fixed to the spine with two L-shaped pins. This model allows accurate measurement of the pressure produced on the nerves; moreover, it may provoke rapid (0.05–0.01 sec) or gradual (20 sec) nerve compression (104) by varying the speed with which the balloon is inflated. In another model the inflatable balloon is positioned within the spinal canal, without removing the posterior vertebral arch (69, 129).

Acute-chronic compression (or acute compression maintained over time)

This type of nerve compression has been referred to as chronic compression, although this term is probably incorrect since nerve compression is maintained for several months but is acutely induced. Acute-chronic compression has been induced by hemostatic clips causing mechanical compression of isolated radicular nerves. Alternatively, plastic constrictor bands have been placed around the cauda equina, inducing different degrees of spinal stenosis by decreasing the cross-sectional area of the cauda equina by 25% to 75% of the original size (31).

Graded (subacute) compression

Graded compression has been accomplished using an ameroid constrictor positioned around a radicular nerve. The ameroid constrictor consists of a casein derivative, which expands slowly by absorbing water once it is placed in a biologic environment (24, 130). A rigid outer metallic shell externally enfolds the ameroid constrictor, whereby, as the ameroid ring is placed in a biological tissue, the expansion of ameroid material occurs internally, leading to compression of the radicular nerve located within the constrictor. Compression of the radicular nerve obtained with this technique reaches maximum values after two weeks.

Chronic compression

A pure chronic compression has been carried out in animal models simulating lateral or central stenosis. Lateral stenosis has been provoked by placing a siliconized rubber tube around a radicular nerve in dogs (161). The formation of scar tissue occurring beneath the tube caused progressive compression of the radicular nerve after 3 months of tubing.

Central stenosis has been induced by fastening a metallic wire around a vertebra in 3-week-old rats (58).

At the end of the growing period, the spinal canal was reduced in its cross-sectional area, resulting in a slow compression of the cauda equina without epidural space violation. This model was found to cause, on average, a stenosis of 30% after 3 months and of 50% one year after surgery.

Biomechanics of radicular nerve compression

Various spinal conditions may cause compression of the radicular nerve or nerve roots. Since intrathecal nerve roots are embedded in the cerebrospinal fluid and occupy a limited space within the dural tube, they are less vulnerable to mechanical compression compared with radicular nerves. Therefore, a more severe compression is needed to damage the intrathecal nerve roots, particularly if the spinal canal is normal in size. Radicular nerves, instead, are more likely to be damaged by a mechanical compression, since they are less mobile than intrathecal nerve roots and, being outside the dural sac, are directly exposed to injuries.

Radicular nerve deformation differs in the presence of disc herniation, spinal stenosis or both.

Disc herniation

It has been shown that disc herniation causes mechanical compression at the contact zone with the radicular nerve and intraneural tension in the areas above and below (120, 119) (Fig. 6.3). Since the mechanical compression induced by disc herniation is asymmetric, nerve fibers within the radicular nerve are displaced towards the opposite zone with respect to the direction of the compressive force. The resulting nerve deformation is more marked at the edge of the compressed area, where the nerve fibers, microvessels and connective tissue are more likely to be damaged (98, 123, 124). The intraneural tension occurring in the areas adjacent to the contact zone may cause flattening and reduction of the transverse diameter of the nerve, thus increasing intrafascicular pressure and reducing the endoneural blood supply (81). Nerve deformation greater than 15% was found to completely block endoneural circulation (81).

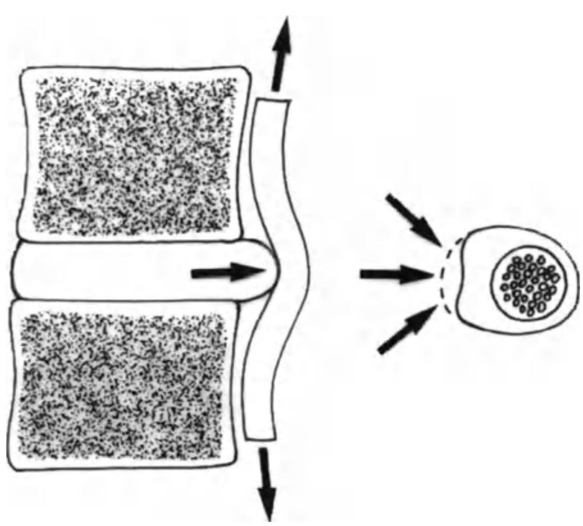

Fig. 6.3. *Compression of the radicular nerve by herniated disc. The herniation causes an asymmetric compression of the radicular nerve, whereby the nerve fibers are disclocated towards the opposite zone with respect to the applied force. Moreover, disc herniation produces tensile stresses in the zone of the radicular nerve above and below the contact area.*

A few factors may play a role in determining the severity of nerve injury caused by disc herniation. Reduced mobility of the radicular nerve may increase its susceptibility to mechanical compression. The mobility of the radicular nerve seems to be related to the dimensions of the spinal canal and to the presence of epidural ligaments anchoring the radicular nerve to the posterior longitudinal ligaments (Hoffmann's ligaments) and to the posterolateral border of the vertebral body at the level of the intervertebral foramen (139). These ligaments show a great variability in their morphology among individuals, since they have been found to be well developed in some and even absent in others (139). In the latter event, the radicular nerve may be more mobile and less likely to be injured, whereby disc herniation might result in little or no pain. The height of the herniated disc may be another factor influencing the severity of the radicular pain caused by disc herniation. In fact, it has been shown that disc narrowing, by reducing the tension of the radicular nerve, decreases the pressure on the nerve itself induced by disc protrusion (140). The relief of radicular pain reported after intradiscal percutaneous treatments, such as chemonucleolysis and percutaneous automated discectomy, may be related, at least in part, to this mechanism.

Stenosis

Spinal stenosis causes a circumferential deformation of the radicular nerve, but the resulting increase in intraneural pressure was found to be less than that induced by disc herniation (36, 98, 126). While a posterior disc protrusion of 5 mm was shown to cause a contact pressure on the nerve of 400 mmHg (140), a circumferential compression of the cauda equina causing a reduction in the cross-sectional area by 67% was found to induce a pressure of 100 mmHg on intrathecal nerve roots (131). Spinal stenosis causes nerve deformation due to

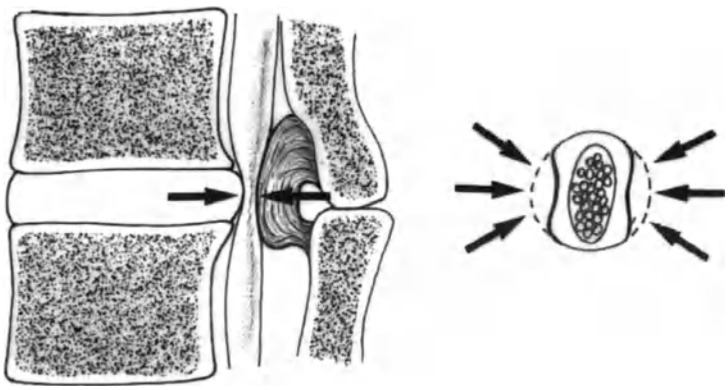

Fig. 6.4. *Disc herniation in stenotic spinal canal. In this condition compressive stresses are particularly marked because the radicular nerve is entrapped between the herniation and yellow ligament.*

mechanical compression whereas, unlike disc herniation, no tension occurs on the nerve fibers adjacent to the compressed area.

Disc herniation in stenotic spinal canal

In this condition, the radicular nerve is entrapped between the herniated disc and yellow ligament and it may not be dislocated posteriorly owing to stenosis of the spinal canal. This possibly results in higher contact pressure than in the presence of isolated disc herniation with little or no endoneural tension in the areas adjacent to nerve compression (Fig. 6.4).

Histologic changes

Studies in man

Few studies have been carried out in man on the histologic changes caused by a mechanical compression on the radicular nerve or nerve roots. A postmortem investigation has shown that the radicular nerve compressed by disc herniation undergoes histologic changes including thickening of the connective tissue network, degenerative and regenerative processes of nerve fibers and small newly-formed nerve fibers. Moreover, bulb-like structures formed by Schwann cells and fibroblasts were present in degenerated nerve fibers (80). Specimens of radicular nerves obtained by means of nerve biopsy performed during disc excision, revealed hyperplasia of dural membranes, endoneural fibrosis, loss of large myelinated fibers and Wallerian degeneration (79). In the presence of spinal stenosis, the large myelinated fibers are reduced in number and thickening of the pia-arachnoid membranes is found at the affected level (148).

Animal studies

Acute compression of the cauda equina producing a pressure at 50 mmHg may induce the formation of intraneural edema without relevant histologic changes (127, 129). A pressure at 100 mmHg was found to provoke subperineural edema formation, which increased progressively with respect to the pressure applied on the nerve. Endoneurial blood extravasion was reported in the presence of compression at 200 mmHg (78).

Acute constriction of the cauda equina by 50% maintained for 3 months was found to induce damage to the radicular nerves ranging from nerve atrophy to dystrophic and swollen axons (31). In contrast, no changes were observed in intrathecal nerve roots, confirming that, within the thecal sac, nerve roots are less susceptible to mechanical compression. However, constriction of the cauda equina by 70% produced marked changes even in intrathecal nerve roots, including nerve root atrophy with complete loss of axons at the level of the constriction and Wallerian degeneration of sensory and motor fibers located, respectively, cranially and caudally to the nerve compression. Numerous spheroids indicating a block in the axonal flow were also present. Venous and arterial circulation was impaired at the level of constriction whereas, caudad to the compression, only the venous system showed significant changes (31).

In models of chronic compression, the initial change consisted in thickening of the dura and arachnoid membrane (161). Thereafter, the nerve-blood barrier in endoneurial capillaries failed, eventually inducing intraradicular edema and endoneurial fibrosis. After 3 months, the compressed nerves showed a decreased number of large myelinated fibers, small newly-formed myelinated fibers and Wallerian degeneration in some axons (58, 161). After 6 months, Renaut's bodies filled with collagen and amorphous material were found in the nerve roots. Renaut's bodies might be the result of endoneurial edema, which, by separating nerve fibers, creates an empty cleft within which amorphous material may accumulate (161).

Electrophysiologic changes

Experimental studies have demonstrated that a pressure at 50 mmHg on the cauda equina does not cause changes in nerve function, whereas higher pressures lead to progressive alterations in nerve conduction velocity (127, 129). In particular, compression at 75 mmHg for 2 h caused changes in nerve conduction, which recovered after the removal of the compression whereas, following compression at 100 mmHg for 2 h, efferent conduction recovered completely, but afferent conduction recovered by about 50% of precompression values (114, 127). Thus, sensory fibers are more vulnerable to mechanical compression compared to motor fibers and changes in sensory nerve conduction are less likely to recover after nerve injury. These results were reported after mechanical compression of intrathecal nerve roots; however, compression of the radicular nerve probably induces more severe and less reversible changes in nerve conduction.

Acute constriction of the cauda equina by 25% maintained for 3 months was found to cause abnormalities in cortical evoked potentials without neurologic deficits (31). Constriction by 50% induced mild to moderate motor weakness and more pronounced electromyographic changes; motor strength was found to recover completely after 1 month, whereas nerve conduction was only partially recovered (60%) after 2 months. After marked constriction of the cauda equina (75%), nerve conduction was found to recover to 30% (31).

Models of chronic nerve compression have shown a sharp decrease in the amplitude of compound action potential and conduction velocity after 3 and 12 months, respectively (58, 161), these results being observed after isolated compression of the radicular nerve and following compression of the cauda equina.

Influence of blood pressure

It has been shown that spinal cord damage caused by mechanical compression may be enhanced by hypotension (1, 27, 49, 57). Hypotension has been implicated in the occurrence of neurological deficits taking place during the correction of spinal deformities or after laminectomy for cervical myelopathy (1, 27, 49). Hypotension was also found to increase the susceptibility of radicular nerve to mechanical compression, since a pressure at 50 mmHg did not lead to significant changes in nerve function in normotensive animals, whereas it caused electrophysiologic alterations in the presence of hypotension (41). Conversely, hypertension enhances blood perfusion in the radicular nerve, thus limiting the adverse effects of mechanical compression on nerve fibers (78).

Type of onset and duration of nerve compression

The influence of rapid (0.05–0.1 sec.) and slow (20 sec.) onset of compression has been investigated in animal models (104). A rapid onset of compression induced intraneural edema, impaired axonal flow and caused more pronounced alterations in nerve conduction compared with a slow onset (101, 103, 104). It has been suggested that the detrimental effects of a rapid onset of nerve compression may be related to the viscoelastic properties of nerve tissue since, when compression is applied rapidly, the nerve tissue may not have sufficient time to adapt to the mechanical compression and both nerve fibers and vessels are submitted to high shear stresses (104).

The duration of nerve compression affects the chances of recovery of nerve function. Following a compression at 100 mmHg for 1.5 h, nerve conduction was found to recover completely in motor fibers and partially in sensory fibers. However, when a compression at 100 mmHg was maintained for 4 h, nerve conduction did not recover (114).

Chemical radiculitis

Mechanical compression of the peripheral nerve may cause changes in sensory and motor function without provoking pain; therefore, it has been suggested that even a mechanical compression of the radicular nerve may not be sufficient to cause pain in the low back and lower limb. Evidence exists which seems to support this hypothesis.

In the classic study of Smyth and Wright (138), the authors passed a loop of nylon thread around the decompressed nerve after disc excision, leaving both ends of the thread outside the surgical wound. This allowed pulling on the nerve to be made after surgery, in order to simulate the effects of an anterior nerve compression. Furthermore, in several patients, a second thread was passed around the adjacent radicular nerve, to assess the effects of pulling on normal (not irritated) radicular nerve. All patients had reported complete relief of pain after disc excision and testing was performed 1 to 10 days after surgery. As the loop was pulled upon, it caused radicular pain equal to, or even more severe, than that felt preoperatively. Radicular pain was more severe when pulling was exerted on the decompressed nerve, which was probably still irritated, compared with the adjacent nerve. However, it is not clear how painful the stimulation of the normal adjacent radicular nerve was.

Animal studies have shown that acute compression of the radicular nerve does not induce hyperalgesia, i.e., a decreased pain threshold and an increased pain to suprathreshold stimuli, whereas this occurs after chronic compression (65, 66). Moreover, electrophysiologic investigations have revealed that acute compression of the radicular nerve does not provoke more than several seconds of repetitive firing, while chronic stimulation of the radicular nerve induces several minutes of repetitive firing. In contrast, compression of the normal dorsal root ganglion causes several minutes of repetitive firing even when applied acutely (56). These findings suggest that chronic nerve compression plays a role in the mechanism causing radicular pain, probably inducing inflammation of the affected nerve, while compression of the dorsal root ganglion may cause pain even when induced acutely.

Chronic irritation of the radicular nerve may also be due to inflammatory properties of the disc tissue and/or the releasing of inflammatory agents from the disc, posterior joints or sensitized nociceptors.

Inflammatory properties of disc tissue

Several investigators have suggested that disc tissue may be a source of inflammatory substances, although this hypothesis only recently has been supported with more convincing methods (100). Nucleus pulposus placed subcutaneously in pigs has provoked a leukotactic response, increased vascular permeability and induced thrombus formation within the surrounding vessels, whereas autologus retroperitoneal fat, used as control, has caused no significant changes after subcutaneous implantation (100). Epidural application of autologous nucleus pulposus, without compression of the cauda equina, was found to cause an inflammatory reaction in the epidural space and a reduction in nerve conduction velocity (105). Radicular nerves exposed to nucleus pulposus exhibited ultrastructural changes including expansion of Schwann cell cytoplasm in myelinated fibers and intracellular edema with vesicular swelling of Schmidt-Lanterman incisures (102). These changes, however, may not explain the adverse effects caused by nucleus pulposus on nerve conduction. Possibly, the negative charges of disc proteoglycans might affect nerve conduction by altering the membrane potential in nerve fibers (105).

The pathomechanism leading to an inflammatory reaction in the radicular nerves exposed to nucleus pulposus remains to be elucidated. There is evidence showing that an autoimmune response and/or the releasing of inflammatory agents may be involved in this mechanism.

Immunologic mechanism

Nucleus pulposus, following embryologic development, is no longer exposed to blood circulation due to the avascularity of the disc tissue. However, if as a result of disc herniation nuclear material is exposed to the immune system, an autoimmune reaction might occur (52, 75, 95). The antigenic properties of nuclear material may be related to proteoglycans or more likely to cellular component of nuclear tissue. In keeping with this hypothesis, Bobechko and Hirsch, in 1965, found that the injection of autologous nucleus pulposus in rabbit ears induced a lymphocytic response in lymph nodes (10). However, other investigations reported conflicting results concerning the antigenic properties of the nucleus pulposus (8, 32, 82, 96). Lundskog and Branemark did not observe any inflammatory cell following implantation of autologus nuclear tissue in rabbit ears (82) and, like other investigators, were unable to detect any increase in immunoglobulins in nuclear material or in the serum of patients submitted to discectomy (32, 96).

Biochemical mechanism: cytokines, nitric oxide and phospholiphase A_2

Herniated disc tissue excised from patients with sciatica and cultured in vitro was found to produce chemical substances involved in inflammatory reactions. In particular, a high content of nitric oxide, prostaglandins E_2 (PgE_2) and interleukin 6 (IL-6) were found in herniated discs compared with controls (64). In vivo studies are needed to confirm these data.

Nitric oxide is involved in inflammatory and immune reactions as well as in the metabolism of chondrocytes of the articular cartilage (142, 146). As a pro-inflammatory agent, it causes vasodilation and increases vascular permeability; however, it might also exhibit a paradoxical effect, i.e., it may inhibit PgE_2, and IL-6 synthesis (142). The synthesis of nitric oxide in the spinal cord has been found to be associated with the presence of termal hyperalgesia in animals (87).

IL-6 and IL-1α are produced by histiocytes, fibroblasts and chondrocytes (46, 135, 136, 145). These cytokines stimulate histiocytes to release PgE_2 (4, 5, 28–30, 90), which are known to provoke pain both directly and by enhancing the effect of bradykinin. IL-β may stimulate the synthesis of IL-6, nitric oxide and PgE_2 both in herniated and non-herniated discs (63) and also play a role in the chronicization of the inflammatory reaction. Cytokines were found to cause hyperalgesia (25, 26, 34, 150) and impair nerve function (149).

Phospholiphase A_2 appears to be involved in inflammatory conditions including rheumatoid arthritis and seronegative inflammatory arthrites. It has been suggested that phospholipase A_2 may activate nociceptors located in the annulus fibrosus and epidural space and may cause injury to the radicular nerve by means of an enzymatic action on the phospholipids of the cell membrane or by activating chemical mediators of inflammation (37, 38, 74, 128). The injection of phospholipase A_2 in animals was found to induce neurotoxic effects including loss of spontaneous nerve discharge and of response to mechanical stimulation, and inflammatory effects characterized by leukocytic infiltration and plasma extravasion (107). However, contrasting results have been reported on the content in phospholipase A_2 in herniated disc tissue (197, 128). In a recent investigation, the role played by phospholipase A_2 in the pathomechanism of epidural inflammation has been questioned, since the content of the enzyme was not found to be any higher in herniated than healthy discs (45).

Sympathetic system and low back pain

The sympathetic system seems to play an important role in the pathomechanism of discogenic low back pain, since anterior and lateral regions of the outermost annulus are innervated by nerve fibers coming from the sympathetic trunk. Furthermore, the sinuvertebral nerve, which supplies the posterolateral annulus and the posterior longitudinal ligament, has been found to originate entirely, or to a large extent, from the lumbar sympathetic trunk (44, 93). Evidence has been obtained to support the involvement of the sympathetic system in the mechanism of low back pain.

Results of an experimental study suggest that neurons in the posterior horns of the spinal cord, which are activated by noxious stimuli on the disc, spinal dura and facet joint capsules, are the same neurons as those activated by the stimulation of the lumbar sympathetic trunk (42).

The sympathetic innervation of the lumbar spine originates from T10 to L2 myelomeres (61), and this would possibly explain why a disc disease at L4-L5 or L5-S1 level causes pain at L1 or L2 dermatomes rather than at L4-S1 dermatomes (94). Moreover, the stimulation of the sympathetic trunk elicited low back pain radiating to the hips or lower limbs (155).

Sympathectomy performed in animals was found to induce an increase in the pain threshold and a loss of 45% of nerve fibers in the spinal dura containing CGRP, a neuropeptide involved in the transmission of painful stimuli (132). However, controversial results have been reported on the effectiveness of sympathetic ganglion block in relieving low back pain (12, 33, 94). A prospective randomized double-blind study has shown no significant difference in pain relief after injection of bupivacaine or saline solution (12). Moreover, low back pain was significantly lower both after anesthetic and saline injection, whereby this procedure seems to exert a placebo effect.

Hypothesis on pathomechanisms of lumboradicular pain

Low back pain

Low back pain may be elicited by chemical or mechanical stimulation of nociceptors located in the external annulus, facet joint capsules or ligaments of the functional spinal unit. In the most common situation, the nucleus pulposus exhibits various degrees of degenerative changes and the posterior annulus bulges, but is not prolapsed. In this condition, inflammatory agents, such as cytokines, prostaglandins and nitric oxide activating nociceptors in the annulus fibrosus and the epidural space, may be released by the degenerated disc or facet joints. Nociceptors do not appear to be particularly abundant in the outer annulus (162). However, inflammatory mediators may activate normally silent mechanoreceptors, which become more sensitive to the mechanical stimuli and, eventually, may function as nociceptors. As a result, mechanical stresses which normally do not cause pain, for instance those occurring during vertebral motion, may provoke severe low back pain. The activation of normally silent mechanoreceptors may also explain why the increase in intradiscal pressure occurring during discography, i.e., a mechanical stimulus, usually reproduces the patient's pain when the injection is performed in degenerated discs, but rarely in normal discs.

Disc degeneration, ligamentous laxity, spinal deformity or other unknown conditions, might produce abnormal mechanical stimulations of nociceptors in the posterior annulus, facet joint capsules and ligaments, resulting in low back pain. However, the exact mechanism leading to noxious mechanical stimulation of nociceptors which results in low back pain remains to be elucidated.

Disc herniation might provoke low back pain with little or no radicular pain, when it is contained, centrally located, and occurs in patients with a spinal canal of normal size. In some patients, disc herniation initially causes radicular pain but, after a few weeks, low back pain becomes the predominant symptom. In this event, the radicular nerve might have gradually been deformed by the herniated disc, whereby inflammation of the radicular nerve is resolved, even if the mechanical stimulation of the external annulus and longitudinal ligaments persists. An alternative, and even more frequent, event occurs when a contained herniation causes predominant low back pain until disc material is extruded from the annulus, causing sudden radicular pain and/or a motor deficit in the lower limb.

Radicular (or predominantly radicular) pain

Without nerve compression

Degenerative processes of disc and facet joints may induce a release of chemical substances with inflammatory properties, which may cause chemical radiculitis. Pro-inflammatory agents may be released by a small disc herniation which does not cause a relevant compression of the radicular nerve. As an alternative, or in addition, herniated disc tissue may cause an autoimmune reaction leading to epidural inflammation and chemical radiculitis. It should be considered, however, that if no nerve compression is present, it is extremely rare that the radicular pain is so severe as to require surgery.

With nerve compression

Acute compression of the radicular nerve without periradicular inflammation might induce little or no pain; however, there may be a few exceptions. For instance, in the presence of acute compression of the dorsal root ganglion or when a rapid mechanical compression induces endoneurial edema in the radicular nerve and dorsal root ganglion, nervi nervorum may be stimulated by the increased intraneural pressure and cause radicular pain. Furthermore, marked compression of the radicular nerve may injure nerve fibers and lead to focal processes of demyelination and remyelination, causing ectopic discharges and spontaneous activity. These areas of nerve damage will likely be a source of painful stimuli, even in the case of mechanical compression without radicular inflammation.

Mechanical compression may stimulate an inflammatory reaction in the radicular nerve. This mechanism, which has been poorly investigated so far, may occur in patients able to maintain a certain level of physical activity despite a symptomatic disc herniation. The nerve stretching occurring during physical activities and the variations in the dimensions of the spinal canal during flexion-extension of the spine, may induce abnormal mechanical stresses on the radicular nerve located over the herniated disc. This may produce tissue damage in nerve fibers, blood vessels and connective tissue, leading to the release of chemical substances activating inflammatory agents. The inflammation of the radicular nerve may persist as long as the mechanical compression is present.

In some cases, an inflammatory reaction of the radicular nerve may be the major cause of pain. This might occur in the presence of a small contained disc herniation, which causes little mechanical compression and shows no evidence of spontaneous resorption over time. In this event, it is possible that cytokines, prostaglandins and other pro-inflammatory agents are released by the herniated disc leading to chronic radiculitis. In addition, cellular or extracellular components of the nucleus pulposus may stimulate an autoimmunic response. As a result, even a slight mechanical compression on the inflamed nerve will elicit pain.

The hypothesis that an inflammatory reaction of the radicular nerve plays a major role in the pathomechanism of radicular pain has gained popularity in recent years. Investigations performed by the authors on specimens obtained during discectomy, revealed that herniated disc tissue may induce an inflammatory cell reaction, particularly in cases of chronic nerve compression. However, mechanical compression of the radicular nerve is likely to play a role as important as chemical irritation. The immediate resolution of radicular pain reported by the majority of patients after discectomy, which often occurs upon awakening of the patients from the anesthesia, may be merely due to the removal of the mechanical compression on the radicular nerve. This is particularly true considering that even in patients reporting immediate pain relief after discectomy, the inflammation of the radicular nerve persits at least for a few days after surgery (138).

Chronicization of pain

Some neurophysiologic mechanisms may be involved in maintaining a painful stimulus over time. Demyelination of nerve fibers due to mechanical compression of the radicular nerve may provoke ectopic discharges which, via antidromic conduction, may stimulate peripheral nociceptors to release neuropeptides, such as substance P or other aminopeptides. These neuropeptides may act either by stimulating adjacent nociceptors to produce orthodromic impulses or causing vasodilation, edema and release of histamine. Focal demyelination may also induce the nervous impulse to spread from the activated nerve fiber to the adjacent fibers, leading to artificial synapses (cross-talk), which may enhance central and peripheral stimulation (43, 116).

In the presence of chronic inflammation with associated antidromic conduction of nervous impulses, nociceptors are subjected to prolonged stimulation. These, in turn, may induce sensitization of the neurons in the posterior horns of the spinal cord, a condition referred to as central sensitization, characterized by hyperalgesia, enhanced response to repeated stimulation and expansion of the sensitisized receptive field (21).

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• CHAPTER 7 •

ETIOPATHOGENESIS

F. Postacchini, G. Cinotti

Epidemiology

Epidemiologic studies: definition of terms and limitations

The frequency of a disease in a given population, or morbosity, is the ratio between the number of patients suffering from that condition and healthy subjects. The morbosity of a disease is calculated on the basis of its prevalence and incidence. Prevalence is estimated by cross-sectional studies, in which the frequency of the condition and related risk factors are evaluated only once. It, thus, represents the number of patients presenting a disease at the time of investigation. Incidence, instead, is assessed by longitudinal studies, in which the frequency of the condition is evaluated at two different times. Therefore, it represents the number of new cases of a condition occurring during a certain time interval. Assessment of the prevalence is less expensive and time-consuming than the evaluation of the incidence. However, the prevalence of a condition may not accurately reflect its frequency since it is affected by the duration of the disease. For instance, in patients with lumbar disc herniation, in whom periods with radicular symptoms may be alternated with painless periods, the assessment of the prevalence may lead to underestimation of the morbosity of the condition.

Epidemiologic studies on lumbar disc herniation have some limitations that need to be taken into account. The series analyzed so far have included both patients in whom a disc herniation was documented by myelography, CT, MRI or surgery, and patients in whom the condition was diagnosed clinically. In the latter, a wrong diagnosis could have been made since different spinal or non-spinal conditions may cause leg pain. Furthermore, epidemiologic studies have not included subjects with asymptomatic disc herniations, i.e., possibly many of those with a small disc herniation and / or a wide spinal canal.

Prevalence and incidence

The prevalence of sciatica caused by disc herniation is about 1%–3% (7), the figure being influenced by the patients' age and gender (Fig. 7.1). The prevalence does not seem to vary significantly in different populations, at least in developed countries. In the U.S.A., the prevalence of disc herniation was found to be 1.6%; in England and Finland it was, respectively, 2.2% and 1.2% (17, 46, 72). Compared with disc herniation, the prevalence of low back pain is much higher, being 15% to 20% in U.S.A. and 25% to 45% in European countries. The prevalence of back pain during life exceeds 70% in industrialized countries (7).

The incidence of hospitalization on account of sciatica due to disc herniation appears to be similar to the prevalence. In a Finnish population of 57,000 subjects followed for 11 years, 1537 (2.6%) had symptoms that could be related to spinal conditions (46). Disc herniation was documented radiographically or surgically in 30% of subjects, and diagnosed clinically in 24%. Thus, a documented or possible disc herniation was found in 1.4% of the patients admitted to hospital during the 11-year period.

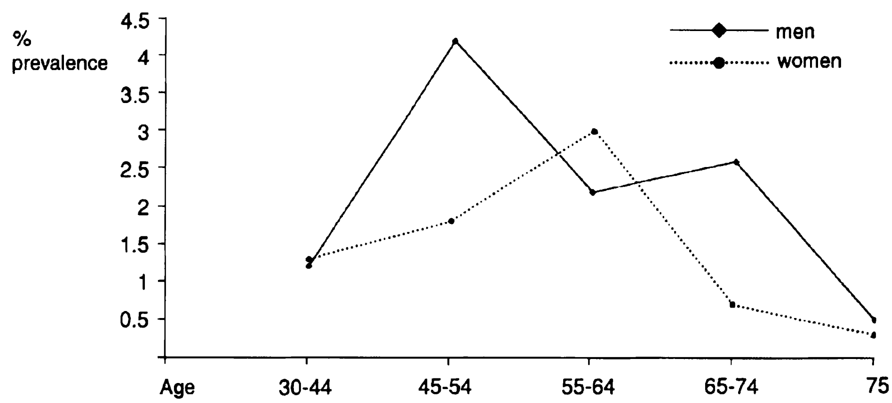

Fig. 7.1. *Incidence of disc herniation by age and gender (modified from Ref. 45).*

Age

The highest prevalence of disc herniation is found in subjects in the age range of 30 to 50 years (45). It has been shown that the prevalence during life is about 3.6% in subjects younger than 35 years and 22% in those aged 45 to 54 years (47). The average age of patients undergoing surgery for disc herniation is about 40 years (115); this figure is somewhat lower for patients hospitalized due to sciatic symptoms, but not submitted to surgical procedures (45). The mean age of patients submitted to surgery for a herniated disc was 38 years in 1950 and 44 years in 1966 (115). At present, it is about 43 years (17).

In children and teenagers, disc herniation is rare, but the exact prevalence is unknown. Considering only the patients undergoing surgery for disc herniation, children and adolescents represent 0.2% to 3.2% of this patient population (90, 127). In Japan, this figure rises to 8%–22% (71), possibly because the Japanese begin to work at a younger age than people in other countries (20).

Gender

The prevalence of disc herniation is higher in males, the male to female ratio being about 2:1 (39, 48, 63, 78, 86, 96, 103, 120, 126). Some differences in the prevalence of sciatica related to gender have been observed in various countries. In England, in 1977, the prevalence of sciatic pain was 3.1% in males and 1.3% in females (72), whilst in Finland, it was 1.9% in males and 1.3% in females (46). The majority of patients undergoing surgery due to disc herniation are males. In two large series of 16,412 (115) and 21,424 (55) patients who had disc excision, the percentage of males was, respectively, 66% and 61%. Only in patients younger than 16 years undergoing disc excision, was the percentage of females slightly higher than that of males (26, 90, 107).

Absence from work, hospitalization, surgery

In patients with sciatic pain, the time lost from work is about twice that in patients with back pain. The latter were found to be off work for an average of 11–20 days per year, whereas in patients complaining of sciatica the time off work rises to a mean of 39–40 days/year (122, 131, 132).

The hospitalization rate for disc herniation is about 110–125 per 100,000 inhabitants/year (69, 70). In women, this rate was found to be 100 for those aged 15 to 44 years and 145 in the age range of 45 to 64 years. In men, the rate increases more progressively with aging, being 126 and 262 in subjects aged 15 to 44 years and 45 to 64 years, respectively (89) (Fig. 7.2).

There are marked variations in the operation rate for disc herniation in different countries. Between 1970 and 1980, the operation rate per 100,000 inhabitants per year was 69 in U.S.A. (97), 41 in Finland (113), 20 in Sweden (85) and 10 in Great Britain (11).

Vertebral level

In some 90% of patients, disc herniation occurs at the two lower lumbar levels. In the 60's, the majority of disc herniations were found to be at L5-S1 level, whereas nowadays disc excision is performed more frequently at L4-L5 level (93, 115). Of the patients undergoing surgery, approximately 2% have a L3-L4 disc herniation. Concomitant disc herniations at two different

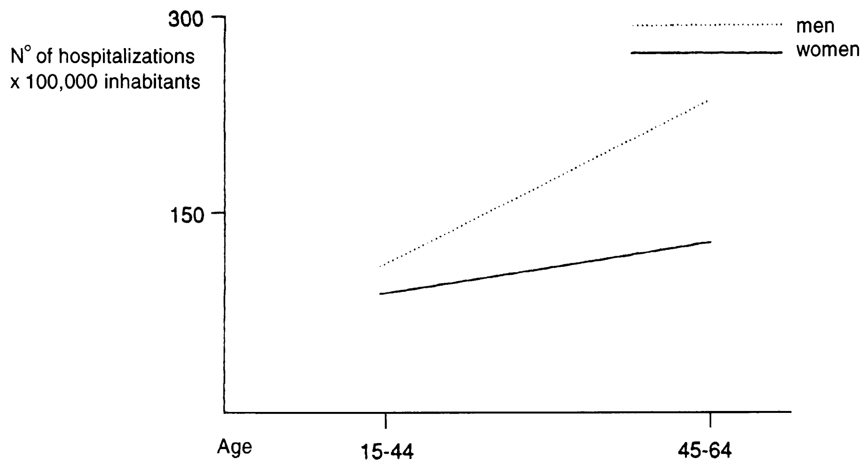

Fig. 7.2. *Hospitalization rate for disc herniation by age and gender (from Ref. 89).*

levels (L4-L5 and L5-S1) have been found in 6% to 19% of patients (93, 134).

In younger patients, disc herniation occurs more frequently at L5-S1 level, but the proportion of herniated discs at the upper lumbar levels increases with aging. It has been found that the mean age of patients with disc herniation at L5-S1 level (39 years) was significantly lower than in patients with herniation at L4-L5 (42 years) or L3-L4 (46 years) levels (115) (Figs. 7.3 and 7.4).

In a series of 21,524 patients undergoing disc excision (55), radicular pain was on the left side in 51% of patients and on the right in 42%. Bilateral radicular pain was present in 4% of patients.

Risk factors

Lifting

Physical activities overloading the functional spinal unit in flexion may cause repetitive tensile stresses,

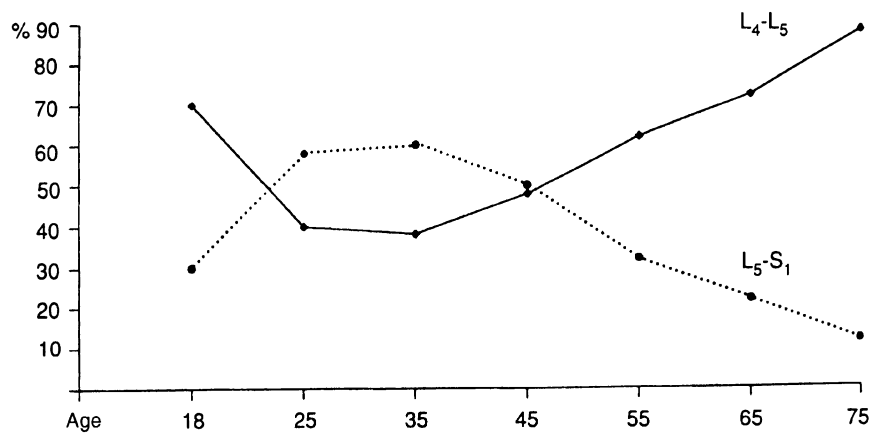

Fig. 7.3. *Percentage of operations for herniated discs at L4-L5 and L5-S1 levels by age at operation (from Ref. 115).*

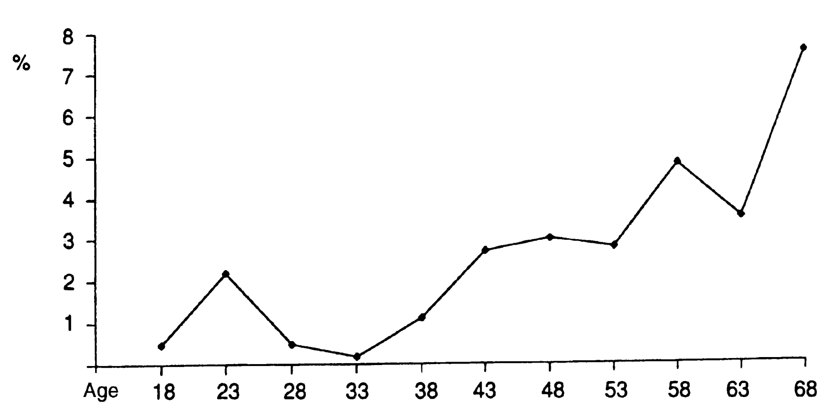

Fig. 7.4. *Percent distribution of disc herniation at levels above L4-L5 by age at operation (from Ref. 115).*

which may eventually lead to a failure of the posterior annulus fibrosus. The non-occupational activities carried out during the 2 years preceding the onset of sciatica were analyzed in 177 patients with disc herniation (84). Certain types of lifting were found to be associated with an increased risk of disc herniation. In particular, lifting objects weighing 25 pounds or more with the knees straight and the trunk bent forward, increases the risk of herniation nearly four-fold, while the risk increases about two-fold when lifting is performed with the arms extended or is associated with trunk twisting (84). The latter may increase the risk of disc herniation up to seven-fold if flexion-torsion movements of the trunk are performed more than 25 times daily (66).

Further non-occupational activities related to an increased risk of disc herniation were lifting objects starting and ending at waist or floor level (Table 7.1). The risk of herniation tends to increase with the increase in weight of the object lifted and the frequency of lifting during the day. Lifting a moderate weight, such as a child weighing 10–24 pounds, increases the risk of disc herniation only if it is performed with the knees straight and the back bent forward (84).

Driving motor vehicles

In subjects who spend half of their working day or more driving a motor vehicle, the risk of disc herniation is about three-fold compared with non-drivers (65). The risk of herniation is about five-fold in truck drivers, two-fold in car drivers, and is related to the amount of time spent driving (65). An increased risk of back pain has been found in drivers of buses (65), tractors (53) and helicopters (27). Driving old cars increases the risk of disc herniation compared with driving new cars (64). In 1984, it was found that certain types of cars increased the risk of disc herniation, possibly because these cars had higher-than-average vibration frequencies (64, 59).

Several factors influence the amount of vibrations transmitted to the spine, including the type of seating, road surface and speed of the vehicle (59, 99, 116, 130). Rapid starting and stopping, as well as a seat positioned close to the floor and lacking support for the lumbar spine, may increase the mechanical stresses on the spine (8, 121).

Table 7.1. *Relative risk for association between different modes of lifting and disc herniation (modified from Ref. 84).*

Method of lifting	Relative risk
Knees bent and back straight	0.71
Knees bent and back bent	2.02
Knees straight and back bent	3.95
Lifting starting and ending at floor level	1.84
Lifting starting and ending at waist level	2.53
Lifting started with arms extended	1.87
Twisting while lifting	1.90

Smoking

Cigarette smoking has been related to an increased risk of disc degeneration and disc herniation. However, in many studies, this correlation may be contested since the presence of concomitant risk factors for disc disease were not investigated. In a multifactorial condition, such as disc herniation, the influence of potentially confounding factors can be minimized by studying identical twins, who are discordant only in the risk factor that needs to be analyzed. In an MRI study carried out on 22 pairs of identical twins, each pair including a smoker and a non-smoker, it was found that the prevalence of disc degeneration in the lumbar spine was, on average, 18% higher in smokers than non-smokers (10). However, the detrimental effect of smoking on disc health was less than expected, since disc degeneration, in smokers, was significantly increased only at L1-L2 level.

Cigarette smoking increases the risk of disc herniation by about 20% for each 10 cigarettes smoked per day (64), the risk being about 50% greater in smokers than non-smokers (5). Ex-smokers do not show a greater risk of herniation than non-smokers (5).

It has been hypothesized that the increased risk of disc herniation in smokers is related to the fact that they are often affected by chronic bronchitis with persistent coughing. The latter causes an increase in intradiscal pressure, which may eventually facilitate disc failure (62). However, in a recent report, no relationship was found between coughing and disc herniation (64). A more convincing hypothesis is that the vasoconstriction caused by nicotine decreases the blood flow in the vertebral bodies (29, 104). The decrease in arterial perfusion may, in turn, reduce the flow of nutrients into the disc and predispose to disc degeneration. In keeping with this hypothesis, animal studies showed that nicotine injected or introduced by inhalation of smoke may affect the blood supply to the vertebral bodies and decrease the transport of solutes into the disc (38, 51). An alternative theory involves the immunogenic system. Smokers have been found to present a larger number of leukocytes, T cells, and serum IgG and IgE levels than non-smokers (6, 9, 111). Disc glycoproteins, which are known to be antigenic (13, 32), could stimulate an autoimmune response leading to early disc degeneration.

Sport

Vigorous sporting activities have been found to be associated with an increased risk of disc degeneration. In a group of top gymnasts involved in national and international competitions, 75% of subjects had one or more degenerated discs on MRI scans (117). This figure was significantly higher than in the control group (non-athletes), in whom only 31% of subjects had disc degeneration. The gymnasts showed a larger number of degenerated discs and the degree of disc degeneration was, on average, more severe than in controls. The degenerative changes occurred more frequently at the thoracolumbar junction; however, also at L4-L5 and L5-S1 levels disc degeneration was more frequent in athletes than in controls (117).

The influence of sport activities on the prevalence of disc herniation remains to be clarified. An increased prevalence of disc herniations has been reported in baseball players as well as in golfers and bowlers (61, 62). More recently, however, it has been reported that neither these sports nor playing tennis, or jogging, cycling or swimming, appear to be related to a higher risk of disc herniation (64).

Work activities

In a longitudinal study carried out on 57,000 subjects, the risk of disc herniation was found to be lowest in professional and white collar occupations and highest in motor-vehicle drivers (44) (Fig. 7.5). An increased risk was also found in industrial workers of both sexes and, in nurses, as far as concerns females (44, 129).

The amount of mechanical stresses transmitted to the intervertebral discs during life depend largely upon the physical activity performed during a working day. It has been calculated that, in subjects walking an average of 16 km per day over a period of 50 years, the lumbar discs will experience 160 million rotation cycles, whereas subjects walking 300 m per day, will submit the disc to 3 million rotation cycles (21). Since physical exercise is known to increase the diffusion of nutrients into the disc, it has been hypothesized that sedentary occupations could be associated with an increased risk of disc degeneration and disc herniation (61, 76). However, in contrast with this hypothesis, no significant differences in the rate of disc disease were found, on MRI scans, between a group of males who spent at least 80% of their working day in the sitting position, and a group of males walking a minimum of 6 miles per day (21). In conclusion, heavy work may increase the risk of disc herniation, whereas sedentary occupations do not increase the risk of disc herniation.

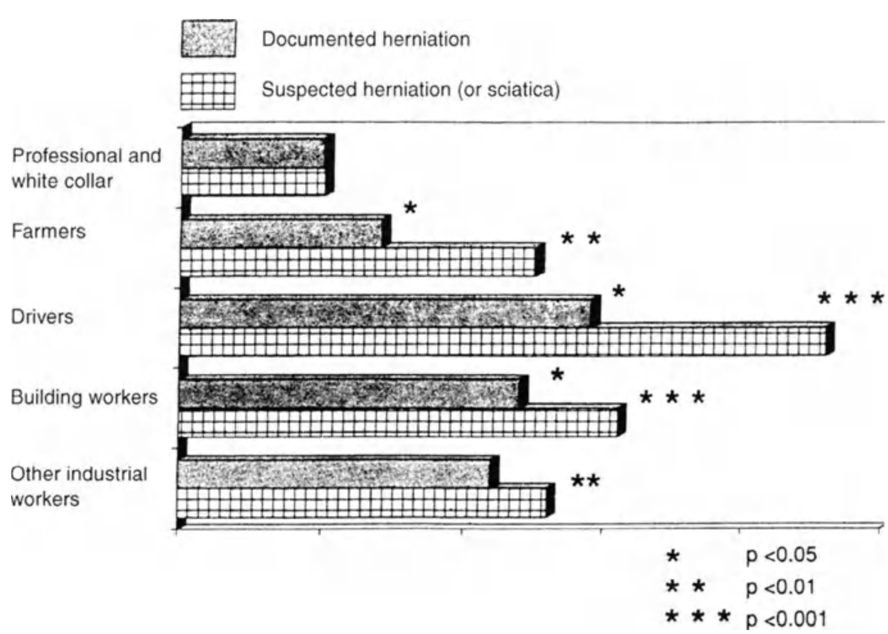

Fig. 7.5. *Relative risk of disc herniation (documented) and disc herniation (suspected) or sciatica in occupational activities (modified from Ref. 45).*

Anthropometric characteristics

Several anthropometric characteristics have been evaluated in patients with herniated disc, however none was found to be associated with an increased risk of herniation. Some authors have reported an increased prevalence of disc herniation in tall subjects (43, 52, 106), particularly in males and females over 1.8 m and 1.7 m, respectively (43). In other studies, however, not only was no correlation found between tallness and disc herniation (62, 98), but patients with herniated disc tended to be shorter than controls (14).

In a few studies, body weight and body mass index (kg/m^2) were found to be associated with an increased risk of disc herniation (43, 52), whereas other epidemiological investigations showed that neither obese nor slim subjects had an increased risk of herniated disc (14, 62, 98, 106). The percentage of body fat was also found to be comparable in patients with disc herniation and controls (14).

Controversial data have been reported on the role of leg-length inequality (even if exceeding 2 cm) (23, 28, 34, 98, 114), the degree of lumbar lordosis and the strength of flexion-extension muscles of the spine (98). These factors would not appear to play an important role in predisposing to disc herniation (Table 7.2).

Trauma

In vitro biomechanical studies have shown that a hyperflexion injury may cause disc herniation (1, 3). However, herniation may be produced only by a compressive force applied with a flexion angle exceeding the physiologic limits. This event should not readily occur during daily activities; therefore, in patients who relate the onset of sciatica to an isolated trauma, it is necessary to evaluate whether the injury was so severe, and of such nature, as to be able to cause disc herniation.

An exceedingly low percentage of patients with disc herniation relate the onset of sciatic pain to an isolated trauma. In a group of 1771 patients with a herniated disc, a definite correlation between the onset of symptoms and injury could be established only in 0.2% of cases, while a possible or uncertain association was found in 0.4% and 0.8% of patients, respectively (119). In other studies, the onset of radicular pain was found to be related to a traumatic event in 3.8% to 7.4% of cases (55, 64). In comparison, 10.7% to 19.7% of patients associated the onset of symptoms to physical efforts (55, 64).

A traumatic event appears to play a more important role in the pathomechanism of disc herniation in children and adolescents. It has been reported that 30% to 70% of young patients related the onset of radicular pain to a traumatic episode (68). However, even in adolescents, it is unclear whether an isolated trauma may cause herniation of a healthy disc or whether disc herniation occurs only in the presence of preexisting degenerative changes. Disc herniation, possibly, occurs as a result of repetitive trauma in subjects involved in sport activities known to overload the lumbar motion segments (16).

Little is known about the risk of disc herniation in concomitance with spinal fractures or fracture-dislocations. In a series of 48 patients with unstable spinal injuries, MRI revealed a concomitant cervical or lumbar disc herniation in 47% and 13% of cases, respectively (102). However, at least in some of these patients, disc herniation could have been present before the trauma.

Pregnancy

The weight of the gravid uterus and the compensatory lordosis occurring in pregnancy produce an increase in mechanical stresses on the lumbar spine; as a result, 50% to 70% of women complain of low back pain during pregnancy (42, 77). Back pain is experienced more frequently by women with a previous pregnancy and by those of older maternal age, and is about two-fold in women complaining of back pain before pregnancy (42, 94). The risk for back pain does not seem to be associated with the anthropometric characteristics of the mother or the weight of the fetus (77).

Whether or not pregnancy is associated with an increased risk of disc herniation is controversial. An MRI study revealed that disc bulgings or herniations were present at similar rates in pregnant women compared with controls (128). Although some authors have

Table 7.2. *Anthropometric characteristics associated (+) or not associated (−) with disc herniation.*

Authors	Tallness	Obesity	Leg-length inequality
Heliovaara (43)	(+)	(+)	
Hrubec and Nashold (52)	(+)	(+)	
Rowe (106)	(+)	(−)	
Kelsey (62)	(−)	(−)	
Brennan et al. (14)	(−)	(−)	
Pope et al. (98)	(−)	(−)	(−)
Soukka et al. (114)			(−)
Frieberg (28)			(+)
Giles and Taylor (34)			(+)

found an increased incidence of disc herniations in pregnant women (62, 91), it seems more likely that pregnancy may contribute to a deterioration of a preexisting sciatica (90, 125) or cause sciatic pain in women who had, prior to pregnancy, an asymptomatic disc herniation. It does not seem, however, that pregnancy can be considered a risk factor for disc herniation, even after numerous deliveries (45).

Etiopathogenetic factors

In the analysis of the pathomechanisms of disc herniation, it is necessary to evaluate: 1) the type of disc injuries which is needed to induce the extrusion of disc material and, 2) the possible mechanisms causing these injuries.

The severity of disc degeneration before the occurrence of a herniation has not yet been investigated; this because, before the onset of sciatic pain, most of the patients complain of only occasional episodes of back pain and, thus, imaging studies are not usually carried out. On the other hand, the histologic examination of the disc tissue excised during surgery may be of limited value, since disc degeneration may continue during the time interval between the diagnosis of herniated disc (on imaging) and the time of surgery. Occasionally, in young patients, disc degeneration might occur after an isolated traumatic event; more often, however, the herniated disc shows degenerative changes of varying degree, which are present before the herniation occurs. This is supported by various observations: 1) disc degeneration, of mild to considerable severity, has been found in 76% to 97% of subjects in the age range of 30 to 50 years (82); 2) a large number of patients complain of occasional or persistent back pain before the onset of sciatica, possibly due to preexisting disc injuries predisposing to herniation; 3) only occasionally, at least in adults, is the onset of sciatica related to a traumatic event (55, 64, 119).

In the evaluation of the pathomechanism of disc herniation, biomechanical, biochemical and constitutional factors need to be addressed.

Biomechanical factors

Mechanical stresses

Flexion-compression loading

Several studies have been carried out on cadaveric spines to simulate the mechanism producing disc herniation (Fig. 7.6). Adams and Hutton found that axial compression and hyperflexion loading caused disc herniation in 43% of the specimens and vertebral fractures in 57% (1). In the herniated discs, the extruded tissue was represented by nucleus pulposus in 29% of cases and annulus fibrosus in 13%. Comparing the type of herniated tissue (nucleus versus annulus) with the degree of disc degeneration (according to Galante) (31), it can be inferred that the majority of nuclear herniations occurred in discs with grade II degeneration, whereas herniation of annular tissue occurred, mainly, in grade III discs (Fig. 7.7). This experimental model has been criticized, since the compression loading was applied with a flexion angle exceeding the physiologic limits. However, hyperflexion of the lumbar motion segment may occur also in vivo in the presence of damage to the supraspinous and interspinous ligaments (1). These ligament injuries were found to be very common in patients submitted to surgery for disc herniation (105). Other studies have shown that cycling compression loading applied with a flexion angle within the physiologic limits (2,3) causes vertebral fractures (38%), distortion of annular lamellae (31%) and complete radial tears (8%) (3); however, no disc herniation occurred at the end of the test. By increasing the flexion angle of the applied load to an extent slightly exceeding

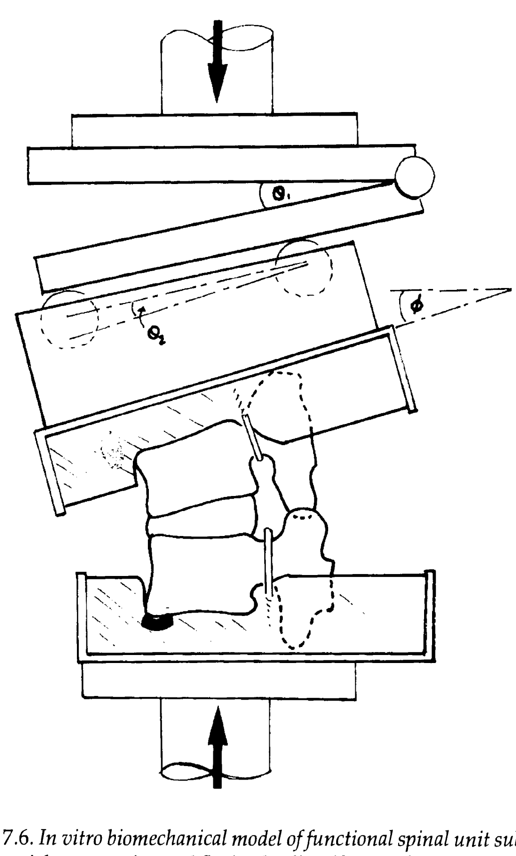

Fig. 7.6. *In vitro biomechanical model of functional spinal unit subjected to axial compression and flexion loading (from Ref. 1).*

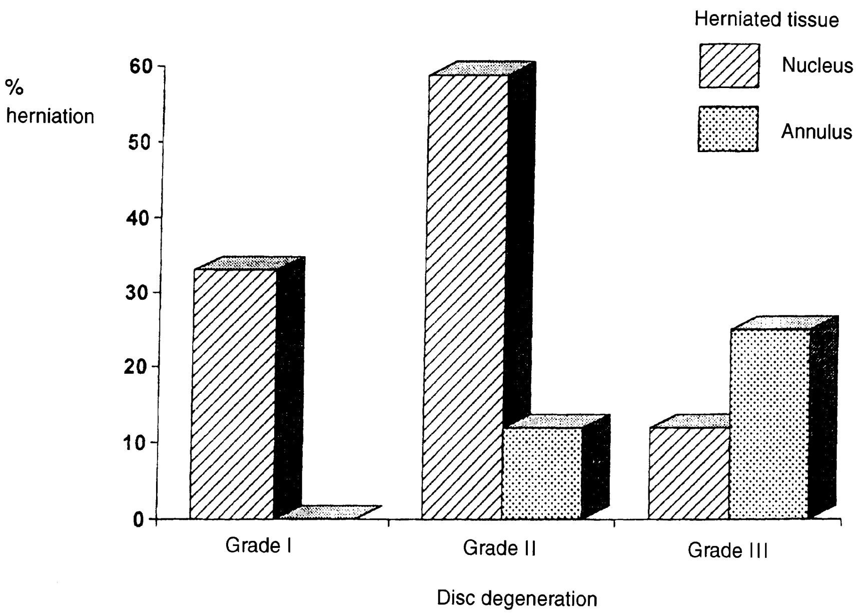

Fig. 7.7. *Relationship between type of herniated tissue (nucleus or annulus) and degree of disc degeneration in specimens subjected to compression and hyperflexion loading (data from Ref. 1).*

the physiologic limits, distortion of the annular lamellae was observed in more than 80% of L4-L5 discs (2), herniation of nuclear tissue in 7%–21% and radial tears (complete, incomplete or bilateral) in 15% of the specimens (2, 3) (Table 7.3). However, some 50% of the discs showed no deformation of the lamellae after the test.

Table 7.3. *In vitro injuries of the functional spinal unit* (FSU) *subjected to flexion-compression or to flexion-compression and axial rotation loading.*

	Type of injury and frequency			
Type of loading	Vertebral fracture	Herniation	Radial tear	Lamella distortion
Hyperflexion and compression 3000 N/sec increased until failure of the FSU * (1)	57%	30% (+ 13% protrusion)	–	–
Cyclic flexion (physiologic) and compression 500–4000 N 40 cycl/min, 5 h (3)	38%	0	8%	31%
Cyclic mild hyperflexion and compression 500–4000N 40 cycl/min, 5 h * (+) (3)	79%	21%	–	90%
Cyclic flexion (physiologic) and compression 1500–6000 N 40 cycl/min, 4 h (++) (2)	68%	7%	15%	56%
Hyperflexion and compression 2000 N increased until failure of the FSU *(81)	55%	36%	–	9%
Cyclic flexion-rotation and compression 1334 N 6.9 h (+) (35)	–	29% (+ 71% protrusion)	–	100%

* Loading applied with a flexion angle exceeding the physiologic limits.
(+) Loading applied on healthy or slightly degenerated discs as seen on MRI or discography.
(++) The cyclic loading applied for 4 hours caused a failure of the vertebral bodies in 27% of the specimens. The mechanical test was continued on the remaining specimens, which were subjected to increased loading until failure of the FSU occurred.

McNally et al. (81), analysed the stress concentration occurring in the annulus lamellae under compressive loads and anterolateral bending. They observed that, during the mechanical test, a significantly greater stress concentration occurred in the discs which had undergone herniation after application of the compressive forces. The authors hypothesized that stress concentration may cause separation of the annulus lamellae, a predisposing condition for failure of the innermost annulus fibrosus. The latter may eventually extend to the outer annulus, leading to a complete radial tear. The causes of abnormal stress concentration in some of the discs submitted to compressive loads are still unknown. It has been hypothesized that stress concentration may be due to focal biochemical changes or structural damages to the lamellae, causing significant changes in the hydrostatic behavior of the disc (81). The degree of hydration of the nucleus pulposus may also play an important role in producing stress concentration, since, as nuclear pressure decreases, the compressive forces are shifted from the nucleus pulposus to the annulus fibrosus, and this may increase the risk of stress concentration in the posterior annulus.

Axial torque

Pure axial rotation and compression loading do not appear to affect disc integrity, particularly when the configuration of the laminae and the facet joint orientation allow an axial rotation displacement less than 1.5° (24, 74). On the other hand, when the axial torque causes an initial axial rotation greater than 1.5°, failure of the functional spinal unit may occur. In this case, however, disc failure is almost consistently associated with fractures of facet joints and/or capsular tears (74). This finding suggests that torsion, in itself, should not be responsible for initial disc failures; however, if axial rotation increases, due to facet joint incongruence, it may contribute to disc degeneration.

Complex loading

Upon lifting, the lumbar spine undergoes complex loading, including flexion-compression, axial rotation and lateral bending. Gordon et al. analyzed the effects of such combined loads applied on specimens with intact or slightly degenerate discs, as seen on MRI (35). After an average of 6.9 h, 71% of the discs exhibited annulus protrusions and 29% nucleus extrusions (Table 7.3).

Using a three-dimensional finite element model, Shirazi (109) has shown that the addition of lateral bending and twisting to pure flexion (or non-symmetric lifting), significantly increases the maximum fiber strain in the posterolateral annulus. For instance, the fiber strain increases by 10% when an axial rotation of 2.3° and lateral bending of 6.6° are associated to a pure flexion load of 4000 N. Since the ultimate tensile strain of collagenous fibers ranges between 10% and 20% (12, 41, 60, 83), it appears that non-symmetric lifting plays a prominent role in the rupture of annular lamellae. Furthermore, complex asymmetric loads produce maximum fiber strain in the innermost annulus, which is where the initial disc failure occurs (109). In healthy discs, the nucleus pulposus, which is under high pressure, may readily penetrate into the annular fissure and extend the injury to the outer annulus. In degenerated discs, instead, the loss of nuclear pressure significantly decreases the tensile stresses on the innermost annulus, and the disc fibers are less likely to fail, even under non-symmetric lifting .

Facet joint tropism

This condition consists in a different orientation, in the horizontal plane, of the articular facets on the two sides. Facet joints play a significant role in limiting the axial rotation of the motion segment under torsion; thus, facet tropism might expose the annulus fibers to asymmetric strains under axial torque. Farfan and Sullivan (25) found facet tropism in 97% of patients with disc disease; furthermore, in 95% of patients with radiculopathy, the symptomatic side was that in which the facet joint had a more coronal orientation. The authors hypothesized that, in the presence of facet tropism, the disc may undergo dangerous rotational strains on the side with the more coronal facet. Consistent with this hypothesis, is the observation that patients with midline herniations have more symmetric facet joints than those with more lateral herniations (75). In biomechanical studies, however, facet tropism was found to have little influence on the behavior of the motion segment under axial torque (4, 18). Facet joints with coronal orientation, as occurs at L4-L5 level, do not allow greater axial rotation than facet joints with a more sagittal orientation, such as those at L2-L3 level. Only flat facet joints with marked coronal orientation may decrease the ability of the facet to resist axial torque. Facet tropism does not appear to cause significant strains of annular fibers and, should this occur, the changes in the strain profile would take place at different locations from the posterolateral annulus (4, 18).

Vibration

Occupations entailing prolonged exposure to vibrations, such as car or truck driving, were found to be associated with an increased risk of back pain and sciatica (36, 64, 65). However, little is known on the effects of body vibrations on the disc tissue. Ishihara et al. (54), in a study on porcine coccygeal discs subjected to various vibratory loads, found that the biological behavior of the disc was influenced by the frequency of the vibrations of the applied loads. In the nucleus pulposus, the proteoglycan synthesis rate was reduced by 60% and 50% under vibratory loads of 10 Hz and 35 Hz, respectively (54). The decreased proteoglycan synthesis might be related to disc cell damage caused by vibrations. The latter may generate dissipated energy, which is thought to be changed into heat. The dissipated energy, which increases progressively with the increase in frequency, may damage disc chondrocytes and matrix components (54). However, since in this experimental model the coccygeal discs were also submitted to axial loading, the reduced synthesis of proteoglycans could be the result of the increasing osmotic pressure caused by the loading condition (57, 92, 108).

Biochemical factors

Abnormal enzymatic activities degrading disc matrix could induce a weakening of the annulus fibrosus and predispose to disc herniation. This hypothesis is supported by the fact that different enzyme patterns have been detected in normal and herniated discs (88). Normal discs have no enzymatic activity towards Type II collagen and very low activity towards Type I collagen and elastin; the herniated discs, instead, exhibit high enzymatic activity towards Type I collagen and elastin, and little activity towards Type II collagen (88). Since Type I collagen is more abundant in the outer annulus (22) and the elastic fibers are located mainly in proximity to the vertebral end-plates (56), enzymatic activity degrading Type I collagen and elastin may weaken the external portion of the annulus and make the disc more susceptible to herniation. It should be noted, however, that the presence of degrading enzymes may be a consequence, rather than the cause, of disc herniation. Furthermore, enzymatic activities degrading elastin, collagen and proteoglycans have been detected also in degenerated (but not herniated) discs, and the concentration of these proteinases tends to increase as disc degeneration becomes more severe (30).

The mechanism underlying degradation of matrix components remains to be elucidated. Proteinase activity was found in the vertebral bodies but not in normal discs. Since the adult annulus fibrosus is largely avascular, proteinases are unlikely to be able to reach the cartilage matrix in normal conditions. However, when disc degeneration occurs, microfractures may develop in the vertebral end-plates, leading to a flow of proteinases from the vertebral bodies to the disc (30).

The biochemical changes found in herniated discs may also result from disc injuries caused by mechanical overloading of the functional spinal unit. Experimental studies have been carried out to investigate the effects of sudden annular injury on the structural and biochemical integrity of the whole disc. In these experimental models, the annular injury made with a scalpel resembled a radial tear or a rim lesion (58, 95). Disc incision extended to the nucleus pulposus causes, in the early stage, a sharp decrease in proteoglycan and water content. Subsequently, attempts to repair the annular lesion may be observed, leading to temporary restoration of the proteoglycan and water content. In a later phase, the proteoglycan and water contents decrease progressively and irreversibly (73).

When an annular incision leaves the nucleus intact, reparative processes occur in the outer lamellae, while the nucleus undergoes marked biochemical changes (58). When the disc incision leaves the nucleus and the inner third of the annulus intact, a progressive failure may be observed in the inner annulus and in the nucleus. In a later phase, reparative processes may occur, but only in the outermost annulus (95) (Fig. 7.8). In conclusion, these experimental studies suggest that discrete tears of the external annulus may progress and cause nuclear degeneration; these may represent an early event in the pathomechanism of disc degeneration.

Constitutional factors

Constitutional weakness of the annulus fibrosus may play a role in predisposing to disc herniation, particularly in young subjects (37, 80). Patients under the age of 20 years with disc herniation show, on MRI scans, a high prevalence of disc degeneration at multiple levels (33, 118). An epidemiologic study (87) has shown that 34% of the adolescents with disc herniation, compared with 2% of the general population, had a familial predisposition to low back pain. The prevalence of back pain in relatives of patients undergoing discectomy was found to be significantly higher than in controls (100).

It has been shown that 32% of patients under 21 years of age at the time of discectomy had one relative, and 14% had two or more relatives, previously operated on for disc herniation (123); of the patients under 16 years of age, 42% had one relative previously submitted to discectomy. In the control group, only 6% of the subjects had one relative, and none had two relatives, submitted to surgery for disc herniation ($p = 0.003$). In accordance with these findings, Matsui et al. (79) found that, in patients under 18 years of age undergoing disc excision, 19% had one relative who had undergone the

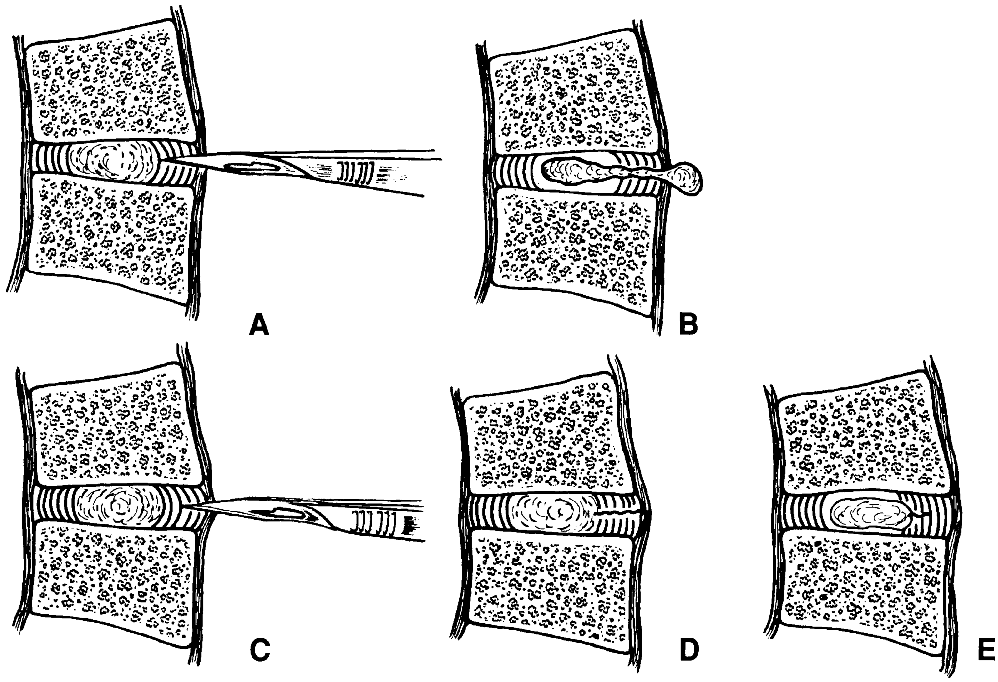

Fig. 7.8. *Effects of annular incision on the structural integrity of the disc. An annular incision extended to the nucleus pulposus* (A) *causes herniation of nuclear material* (B). *An annular incision not reaching the nucleus and the inner annulus* (C) *causes a progressive failure of the nucleus and of the innermost annulus* (D). *In a late phase, the defect of the external annulus tends to heal* (E), *whereas the nucleus pulposus shows marked features of degeneration.*

same operation compared with 3% of the controls ($p = 0.02$). It is interesting to note that the relatives of patients in the study group had undergone discectomy at a mean age of 19 years and about half of them had two disc herniations.

The prevalence of a positive family history for disc herniation seems to decrease with the increasing age of patients undergoing discectomy. Of 134 patients (mean age 39 years) operated on for disc herniation, 10% had a relative who had undergone disc excision compared with 1% in the control group (101).

Postacchini et al. (101) analyzed the HLA antigen frequencies in patients undergoing discectomy and in their first-degree relatives to determine whether the familial predisposition to disc disease might be related to genetic factors. Although no significant difference was found between the HLA antigen frequencies in patients with disc herniation and in controls, it cannot be excluded that genetic factors, not linked to the HLA system, may play a role in the familial predisposition to disc disease.

In conclusion, the high prevalence of a positive family history for disc herniation in patients undergoing disc excision indicates that, at least in young patients, there is a familial predisposition that makes the intervertebral disc more susceptible to failure. This may be true even in the presence, in the familial setting, of other risk factors for disc herniation.

Pathogenetic hypotheses

To explain the occurrence of disc herniation, different pathogenetic mechanisms may be hypothesized, depending on the grade of disc degeneration. The various mechanisms may act independently or, in some cases, the herniation may occur as a result of the association of multiple mechanisms.

Healthy or mildly degenerated disc

Disc herniation in a healthy or slightly degenerated disc may occur in adolescents or young adults, in the presence of constitutional structural weakness of the annular lamellae. An alternative, or additional, possibility is that repeated mechanical stresses, or a single trauma, may produce a tear in the inner lamellae of the annulus fibrosus. In many of these cases, there is no preexisting radial tear in the annulus fibrosus, but the nucleus, under high pressure, penetrates the fissure of the innermost annulus and, by rupturing the adjacent

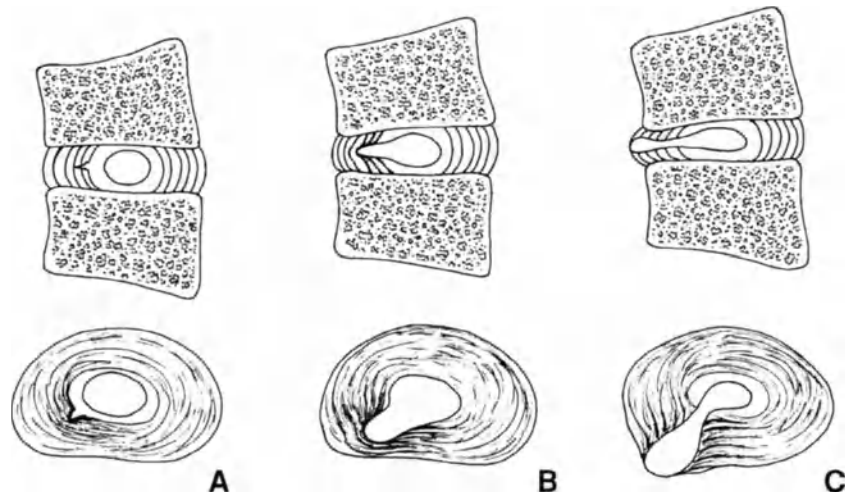

Fig. 7.9. *Herniation of a healthy or mildly degenerated disc. The initial lesion* (A) *may be a fissure of the innermost lamellae. The nucleus pulposus, which is under high pressure, penetrates into the annular fissure* (B) *and, causing a progressive rupture of the adjacent lamellae, eventually reaches the external annulus.*

outer lamellae, gradually or suddenly reaches the external layers of the annulus, thus forming a contained herniation (Fig. 7.9).

Mildly to moderately degenerated disc

In a disc with mild degenerative changes, herniation may occur soon after the occurrence of a radial tear. In this instance, the nucleus initially preserves its hydrophilia and subsequently degenerates as a result of the annular tear. For a certain period of time, therefore, a nucleus under high pressure may wedge with relative easiness into the radial tear (Fig. 7.10). In animals, a similar mechanism produces herniation of the nucleus pulposus almost immediately (67, 73, 95, 112). This "at risk" phase probably ends as soon as the radial tear undergoes reparative processes in the outer portion of the annulus, and the nucleus, starting to degenerate, exerts less mechanical stresses on the inner annular lamellae.

Moderately degenerated disc

In this condition, in order the nucleus pulposus to herniate posteriorly, more marked annular changes are needed. One possibility is that weakening of the posterior portion of the annulus fibrosus is caused by enzymatic activity directed towards type I collagen fibers and elastic fibers, which are located mainly in the outer annulus (88). The abnormal enzymatic activity may

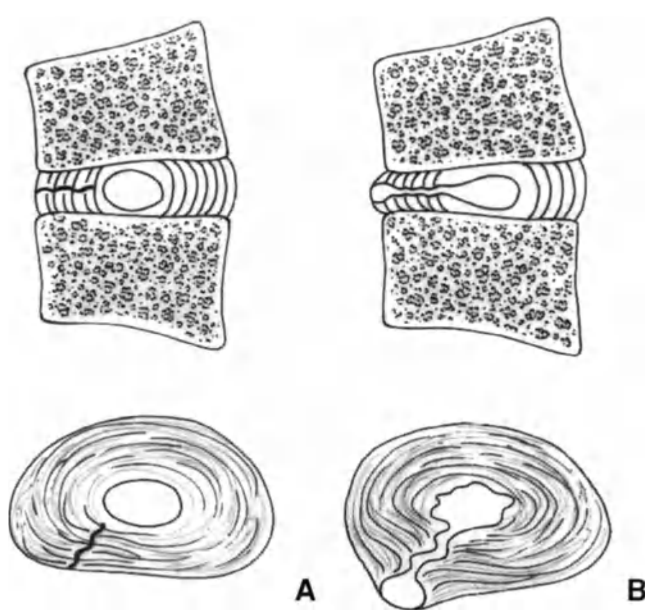

Fig. 7.10. *Herniation of a mildly-moderately degenerated disc. The predisposing conditions may be a fresh radial tear* (A) *and a highly hydrated nucleus pulposus. When the two conditions are present concomitantly, nuclear material may easily penetrate through the radial tear* (B) *and reach the external annulus.*

occur as a result of an interruption in the continuity of the vertebral end-plates (due to microfractures or detachement of annular lamellae from the end-plates), allowing diffusion of degrading enzymes from the vertebral bodies to the disc. This event should not occur rarely, since, in vertebral motion segments submitted to flexion-compression forces, fractures of vertebral end-plates occur more easily than disc herniation (1, 2, 3) (Table 7.3). It should also be borne in mind that fragments of cartilage end-plates have been found in the herniated tissue in up to 60% of cases (19, 40).

An alternative hypothesis is that a decrease in the hydrostatic pressure of the nucleus pulposus causes stress concentration in the posterolateral region of the annulus fibrosus, with subsequent massive tear in the annulus (81) (Fig. 7.11). The decreased hydrostatic pressure of the nucleus may result from decreased synthesis of proteoglycans due to prolonged exposure to vibrations (54), cigarette smoking or unfavorable complex loading.

Moderately to markedly degenerated disc

The intervertebral disc may undergo a progressive increase in degenerative changes due to altered biomechanical behavior and/or accumulation of enzymatic degradation products, which further stimulate the proteolytic systems (49). In the markedly degenerated disc, the fiber layers, submitted to less tensile forces, become lax and carry compressive forces individually; in this condition they may easily fail (109). Portions of nucleus pulposus or free fragments of cartilage end-plate may thus be extruded posteriorly (15). More often, however, the herniated tissue consists of annulus fibrosus resulting from the separation of the lamellae of the middle portion from those of the outermost portions of the annulus. The latter, under axial loading, bulge posteriorly until they herniate (133) (Fig. 7.12). A further possibility is that the herniation occurs in the presence of two radial tears intersecting a circumferential fissure, thus giving rise to a fragment of annular tissue which, no

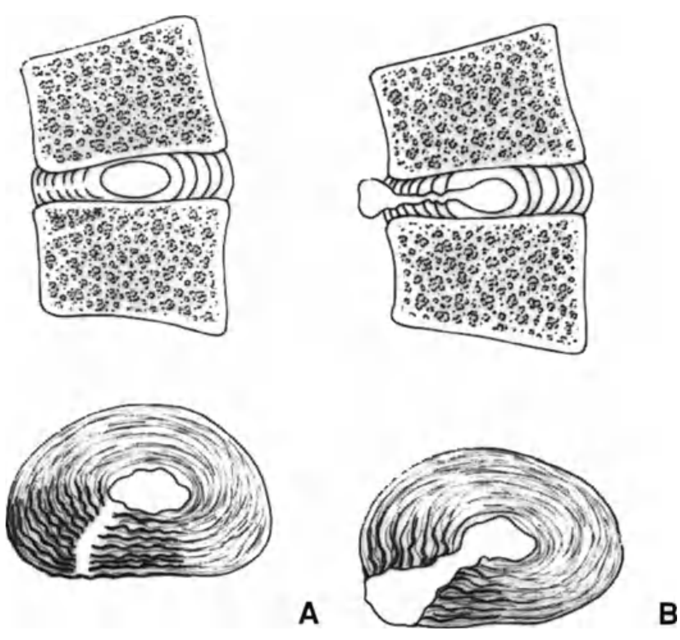

Fig. 7.11. *Herniation of a moderately degenerated disc. A large failure of the posterolateral annulus needs to be present* (A) *to allow the migration of degenerated nuclear material through the external annulus fibrosus* (B).

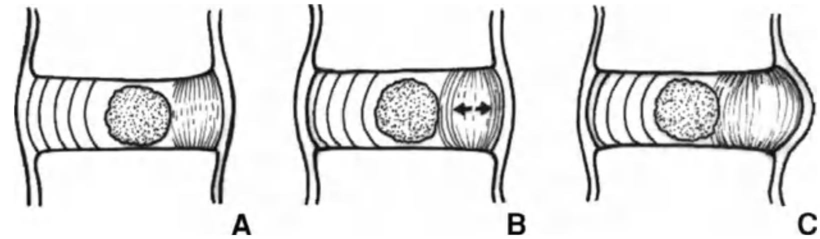

Fig. 7.12. *Herniation of a moderately to markedly degenerated disc. The marked degenerative changes of the disc causes increasing compressive stresses on the external annulus. As a result, radial stresses occurring within the annulus act to separate the lamellae of the middle and external layers, the outer lamellae being pushed outward and the inner lamellae inward* (A *and* B). *The separation of the outer lamellae may progress and cause extrusion of annular tissue* (C).

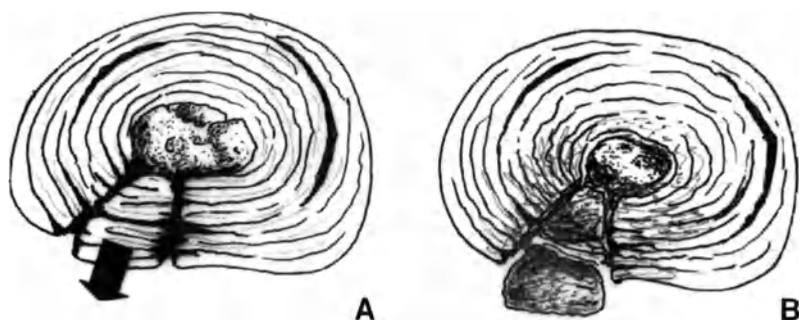

Fig. 7.13. *Herniation of a markedly degenerated disc. Two radial tears may intersect a circumferential fissure* (A). *This condition isolates a fragment of the posterolateral annulus which, no longer being connected to the adjacent layers, may easily be extruded from the disc* (B).

longer being in connection with the annulus, is free to herniate (Fig. 7.13).

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·CHAPTER 8·

CLINICAL FEATURES

F. Postacchini, S. Gumina

Principles of radicular anatomophysiology

Dermatomes of the lower limbs

Numerous authors, using different methods, have studied the innervation of cutaneous territories by the individual spinal nerve roots. Bolk (7) studied the distribution of the cutaneous nerves during anatomic dissections to identify the nerve roots from which they originate. Head (39) analyzed the areas of cutaneous dysesthesia in patients with diseases of the nervous system. Foerster (30) identified the regions of decreased sensitivity after surgical rhyzotomy, whilst Keegan (47) studied the sensory changes in patients with a herniated disc. Hansen and Schliack (38) used data obtained by other authors with varying methods. Several dermatomal charts have stemmed from these studies (Figs. 8.1 and 8.2). Of these, the chart most closely corresponding to the true situation appears to be the Keegan's.

Cutaneous sensitivity

Nitta et al. (70) have recently studied the areas of tactile sensory impairment after selective anesthetic block of the L4, L5 or S1 nerve roots. They identified very similar dermatomal areas to those in Keegan's chart. Their observations indicate that the dermatomes may have the shape of either a continuous band extending from the trunk to the distal portions of the limb, or an insular area. The latter is much more frequent for the L4 and L5 nerve roots, than for the S1 root. This study, furthermore, indicates that cutaneous areas of limited extension exist, which are innervated by a specific nerve root in the vast majority of subjects. In the other individuals, the area which is generally electively supplied by a nerve root is innervated by an adjacent root. This might be due to anomalies of the furcal nerve, abnormal anastomoses between nerve roots or spinal nerves, or an anomalous peripheral distribution of the nerve roots. The dermatomal areas of the L2 to S1 roots is shown in Figs. 8.3 to 8.7, where the whole area supplied by the individual roots is indicated; the dotted areas are innervated by the root in the majority of subjects, according to Nitta et al. (70) and our own experience. Figure 8.8 depicts the dermatomal areas innervated by the S3-S5 roots.

Dermatomes are known to present a certain degree of superimposition, so that a cutaneous area is innervated by two or more spinal nerve roots. However, in a few cutaneous areas, the density of nerve endings afferent to a nerve root is only slightly greater than the density of endings afferent to other roots. In contrast, in other zones the vast majority, or perhaps all, nerve endings depend on a single root. The areas with these characteristics are generally located in the distal portion of the dermatome. In these areas, a radicular deficit causes a more marked sensory impairment than in those with a more dense radicular superimposition.

Pain

In patients with nerve-root compression, radiated pain may extend in a band-like form along the entire dermatome or be felt only in a insular area, for instance the calf due to compression of the S1 nerve root.

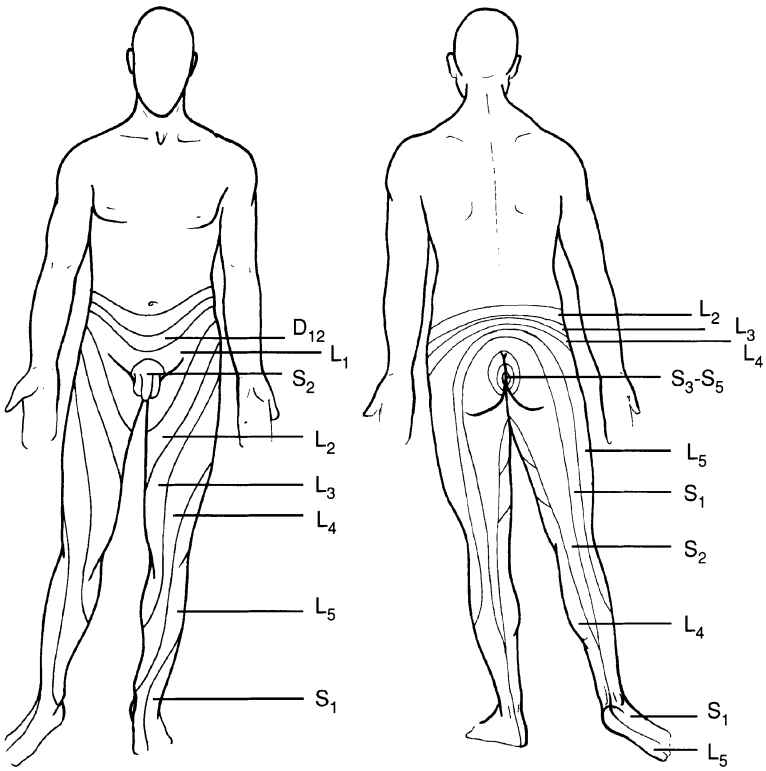


Fig. 8.1. *Dermatomes of the lower limbs according to Keegan.*

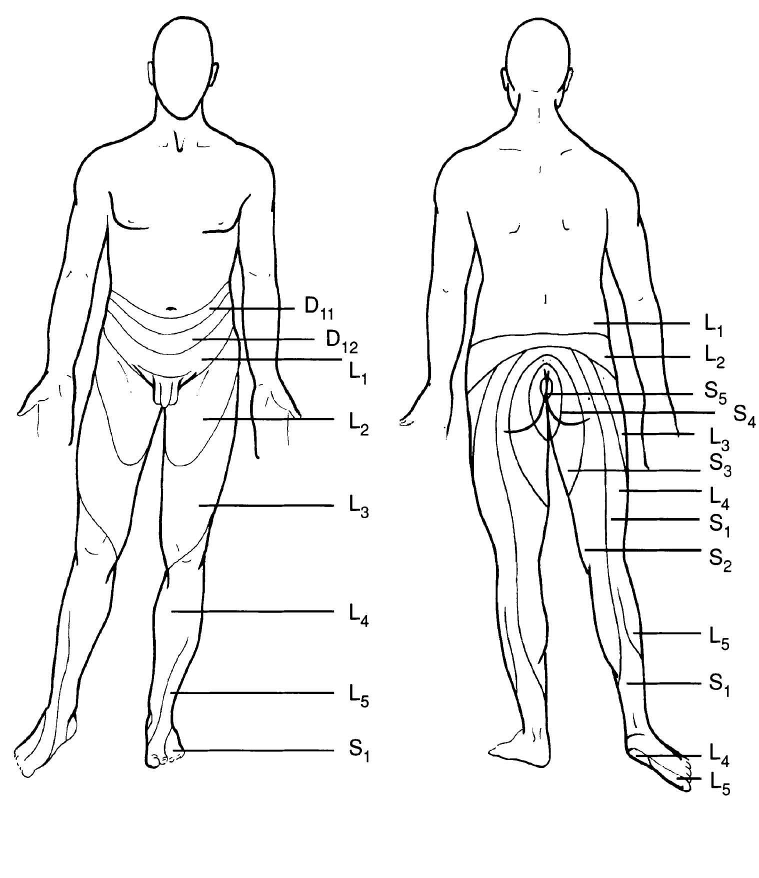


Fig. 8.2. *Hansen and Schliack's dermatome chart.*

Alternatively, the pain may be felt in two or, occasionally, more insular areas. For example, for L5 nerve-root compression, the pain may be felt in the buttock and the lateral aspect of the leg, or in the buttock, trochanteric area and external malleolus region. Insular localization of pain is more frequent than band-like radiation over the whole dermatome.

Pain may be located in the dermatome supplied by the involved root or in a different dermatome. Occasionally, it may be located partly in a dermatome and partly in another. In our experience, some two thirds of patients with compression of a single nerve root feel pain in the dermatome of the involved root, whilst the remaining patients have pain also, or only, in other dermatomes. This clearly emerges when the patient is invited to mark the site of painful areas on an outline drawing of the human body. Involvement of dermatomes different from that supplied by the compressed nerve root may be due to the same anatomic anomalies responsible for the variability of tactile sensory innervation.

Radicular innervation of muscles in the lower limb

Studies on the myotomes of the lower limb indicate that most, if not all, muscles are innervated by two or more nerve roots (27, 37, 42, 90, 91). However, clinical experience demonstrates that each root takes part in the innervation of a muscle to a different extent compared with the other roots, so that, for each muscle, there is a functionally prevalent nerve root. The degree of prevalence is highly variable. In a few muscles, there is a clear-cut, but not absolute, prevalence of a nerve root compared with the others. In other muscles, particularly the smaller ones, such as the extensor hallucis longus, one nerve root plays such a predominant role that complete loss of function of the root leads to paralysis of the muscle. Furthermore, unlike dermatomes, which appear to have relatively variable borders, the modality of muscle innervation is quite constant, particularly in the lower limb. Weakness of a muscle, therefore, is often pathognomonic of functional impairment of a specific nerve root. This does not exclude that impairment of a nerve root may cause weakness of a muscle which is normally innervated in a prevalent manner by another root. This possibility, however, is rare for the lower limb. More often, differences may be observed in the degree of functional impairment between muscles innervated prevalently by a same nerve root. Two explanations may be offered for this occurrence: functional impairment is not uniform for all motor fibers of the root, so that those destined to one of the muscles innervated prevalently by the root are more spared

Table 8.1. *Muscles in the lower limb prevalently innervated by the L3-S2 roots.*

L3	Hip adductors
L4	Quadriceps
L5	Gluteus medius Tibialis anterior Peronei Extensor hallucis longus Extensor digitorum longus
S1	Gluteus maximus Gemelli Soleus
S2	Interossei

than the others; the muscles, or some of the muscles, normally innervated by a nerve root are entirely or partially innervated by contiguous roots due to anatomic variations of the furcal nerve or anastomoses between spinal nerves.

Our clinical experience, based on the evaluation of patients with severe impairment or paralysis of a nerve root, indicates that in most subjects the L3-S2 roots clearly innervate prevalently the muscles listed in Table 8.1. This table does not include the muscles which are innervated to almost the same degree by two roots. Impairment of a motor rootlet may cause a constant muscle weakness and/or muscle exhaustion, which becomes apparent after a certain number of contractions, particularly if maximal. Muscle exhaustion, of which neurogenic intermittent claudication is, somewhat, an expression, is probably related to a decrease in frequency and/or width of the nervous impulses reaching the muscle. This may be a direct effect of compression of the nerve fibers or be due to hypoxy of the nerve tissue as a result of intraradicular circulatory disturbances.

Reflexes

Osteotendinous reflexes are monosynaptic reflexes which occur through a diastaltic arch formed by a sensory neuron with its afferent fiber and an α motor neuron. Reflex activity is modulated by the inhibitory action of cord neurons, the efferent fibers of which run into the pyramidal tracts. In the production of a reflex, one or more nerve roots may be involved, as occurs in voluntary muscle innervation. When multiple roots take part in the production of the reflex, such as the patellar reflex, the function of one of them prevails. This may be due to the different contribution of the single roots to muscle innervation or to the fact that one root electively supplies the portions of the muscle that are

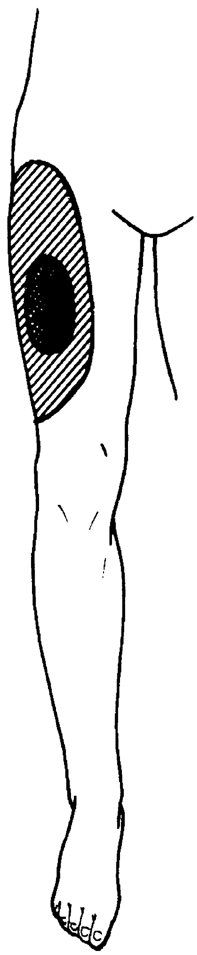


Fig. 8.3. *Cutaneous sensory distribution of the L2 nerve root.*

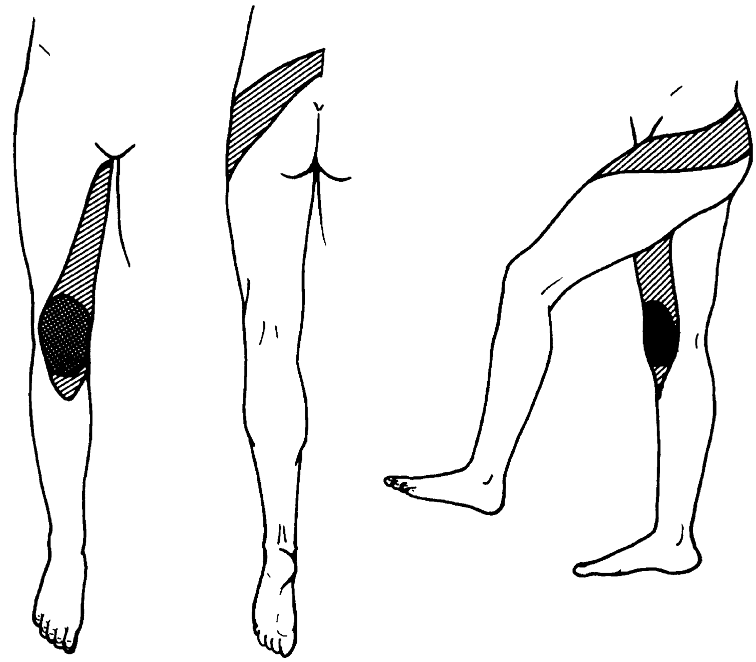


Fig. 8.4. *Cutaneous sensory distribution of the L3 nerve root.*

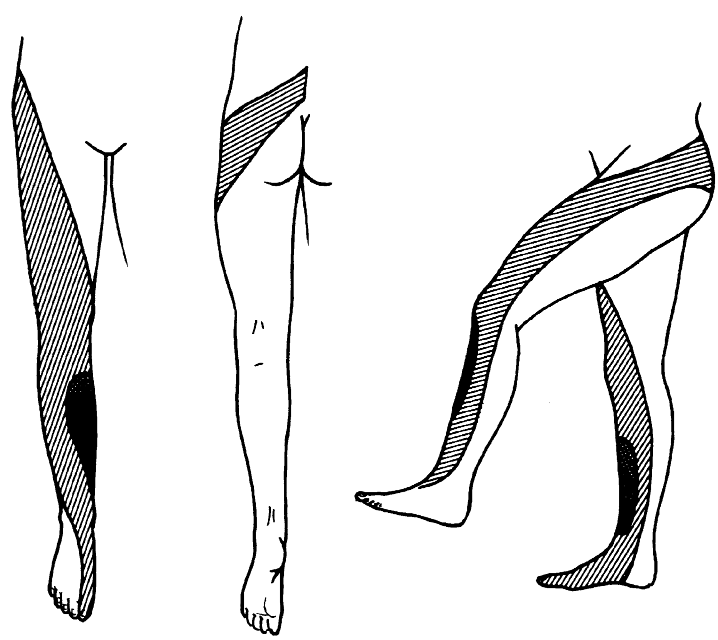


Fig. 8.5. *Cutaneous sensory distribution of the L4 nerve root.*

stimulated to a greater extent by the percussion on the tendon.

The superficial or cutaneous reflexes of the trunk and limbs are polysynaptic medullary reflexes mediated by facilitatory cortical fibers. They consist in involuntary muscle contractions as a result of cutaneous or mucous stimuli. Alteration in these reflexes may be due to cord lesions or nerve-root impairment. In the latter instance, they are abolished due to failure of conduction of the nervous stimulus through the afferent or efferent fibers.

Autonomic nervous system

Sympathetic and parasympathetic nervous systems play a strictly integrated role, regulating the function of smooth muscles in the viscera and circulatory system, as well as in the cardiac muscle, endocrine glands and cutaneous annexes.

The sympathetic chain consists of two neurons (Fig. 8.9). The afferent fiber of the first-order neuron reaches, by the way of the dorsal nerve roots, the lateral portion

Fig. 8.6. *Cutaneous sensory distribution of the L5 nerve root.*

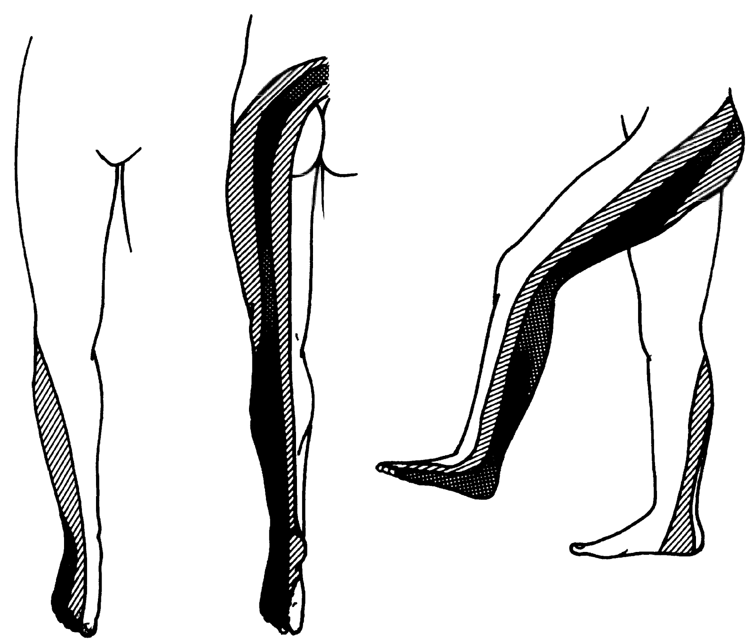


Fig. 8.7. *Cutaneous sensory distribution of the S1 nerve root.*

of the gray matter in the spinal cord (from D1 to L2), where the cell body is located. The efferent fiber, traveling through the motor nerve root and the white communicans ramus, reaches the sympathetic chain. Here, it may: 1) terminate in a sympathetic ganglion, or 2) reach a mesenteric ganglion through the splanchnic branches of the sympathetic chain. In one of the two ganglions, the cell body of the second-order motor neuron is found, the efferent fiber of which reaches the end organ either through the gray communicans ramus, or directly from the mesenteric ganglion.

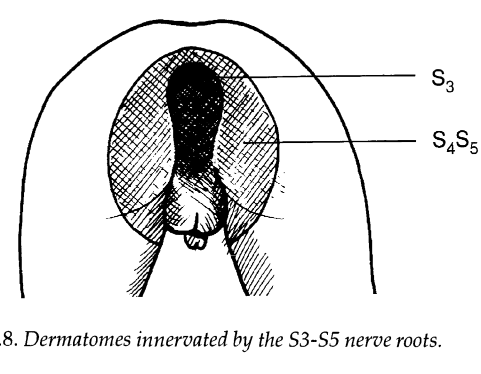


Fig. 8.8. *Dermatomes innervated by the S3-S5 nerve roots.*

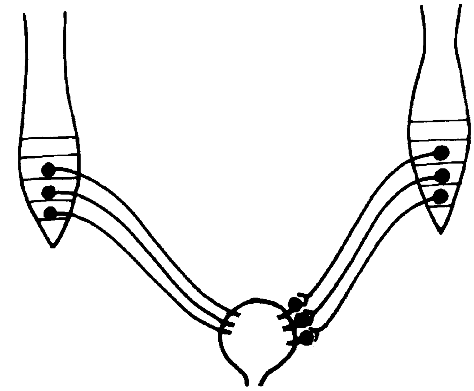


Fig. 8.9. *Schematic drawing of the sympathetic pathways of bladder innervation.*

The parasympathetic system, in addition to a brain center, has a sacral center in the S2-S4 segments of the cord, which provides innervation to the pelvic viscera (Fig. 8.10). The afferent fiber of the neurons in the sacral center reaches the lateral portion of the gray matter of the spinal cord. The efferent fiber travels in the ventral nerve root, the sacral plexus, the pudendal plexus and the terminal branches of the latter. The second-level neuron is located in the intramural ganglions of the pelvic viscera.

Both components of the autonomic nervous system are controlled, in a facilitatory or inhibitory sense, by the reticular substance of the pons, which, in turn, is controlled by higher centers.

Knowledge on the function of the autonomic nervous system is important to better understand the disorders of micturition and defecation, as well as the sexual disorders occurring in the cauda equina syndrome.

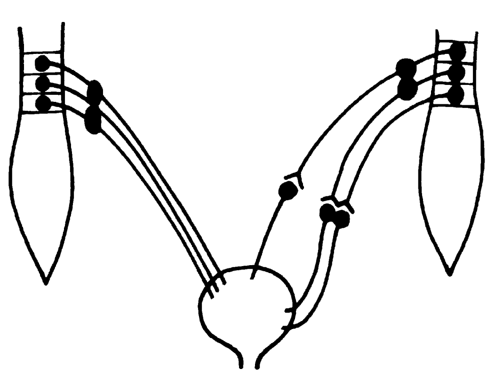


Fig. 8.10. *Schematic drawing of the parasympathetic pathways of bladder innervation.*

Bladder and rectum

Bladder distension due to the accumulation of urine stimulates the mechanoreceptors in the bladder-wall. The second-level neuron of the sympathetic chain elicits contraction of the smooth sphincters of the bladder neck and the proximal urethra and inhibits the detrusor bladder-wall muscle. Voiding, stimulated by the sensation of bladder distension reaching the cortical centers, implies three processes: relaxation of the smooth sphincters due to inhibition of the sympathetic system; contraction of the detrusor muscle as a result of activation of the parasympathetic system; relaxation of the striated sphincter due to inhibition of the impulses from the somatic system (S3-S5) which maintain the tone of the sphincter, and voluntary contraction of the muscles of the abdominal wall.

The action of the autonomic nervous system on the rectum is not unlike that on the bladder. The sympathetic system inhibits peristalsis and increases the tone of the smooth sphincter. The parasympathetic system activates the peristalsis. On defecation, the sympathetic system is inhibited, the parasympathetic system is activated and the impulses of the somatic nervous system lead to relaxation of the external sphincter.

Bladder function may be impaired, in lumbar pathologic conditions, due to lesions of the conus medullaris or, much more often, of the sensory and / or motor nerve roots. When the sensory roots are involved, the patient looses the sensation of bladder distension and, in the absence of stimuli, the micturition mechanism is not activated; this leads to retention and subsequent overflow incontinence. A lesion of the motor roots does not affect the sensation of bladder distension, but makes the patient unable to void; in this instance, urinary retention is painful. When both nerve roots are involved, there is a loss of sensation of bladder distension and paralysis of the bladder, which results in retention and overflow or dribbling incontinence. Lesions of the conus medullaris involving inactivation of the parasympathetic system and the somatic neurons (S3-S5) lead to paralysis of the bladder detrusor and striated sphincter.

Impairment of rectal function, which is more rare than that of the bladder, leads to constipation and/or fecal incontinence.

Genital organs

Sexual function is regulated by a reflex arc controlled by the autonomic and somatic systems, under the control of cortical centers. The excitement phase is controlled by the parasympathetic system, which induces vasodilation in the genital organs responsible for penile or clitoris erection and vagina dilation. Orgasm, in both sexes, is controlled by the sympathetic and somatic systems. In the male, ejaculation is produced by the sympathetic system, which elicits contraction of the seminal vesicles, and by the afferent parasympathetic and somatic pathways, which stimulate the contraction of the ischiocavernous, bulbocavernous and urethral muscles.

Sexual function may be lost due to lesions of the sensory and/or motor nerve roots or the conus medullaris.

Level at which nerve roots emerge in lumbosacral transitional anomalies

In our experience, transitional anomalies do not affect the level at which the lumbosacral nerve roots emerge from the thecal sac. In patients with sacralization of the fifth lumbar vertebra, the L5 root usually emerges from the thecal sac at the level of the last completely mobile disc and leaves the spine through the intervertebral foramen situated caudally to the pedicle of the sacralized vertebra. In the presence of complete lumbarization of the first sacral vertebra, the L5 root runs in the last but one, and the S1 root in the last, intervertebral foramen.

These observations are not in keeping with the findings of McCulloch and Waddell (61). These authors, based on electrophysiologic studies in patients with lumbar disc herniation, held that, in the subjects with lumbosacral transitional anomalies, the L5 root emerges from the spine through the intervertebral foramen situated at the level of the last completely mobile disc. Nerve roots emerge symmetrically on the two sides.

Symptoms

Low back pain

Low back pain refers to pain in the lumbosacral area, originating from the spine or myofascial perivertebral structures; the pain is located in the central region of the trunk and tends to radiate transversely on one or both sides. Radiation to the flank or abdomen is atypical and would exclude the vertebral origin of the pain and, particularly, that it is caused by degenerative disc disease.

Low back pain is an almost constant symptom in disc herniation. Often, however, there is no back pain at all or it is present only at the onset of symptoms or for a limited time during the course of the disease. On the other hand, low back pain may occasionally be the only symptom of disc herniation. This usually occurs in the presence of a midline herniation or a posterolateral herniated disc causing no significant compression of the nerve roots due to its small size and/or the large size of the spinal canal. Both the prevalence and severity of low back pain tend to be greater in middle-aged patients. In adolescents and elderly patients, low back pain is less frequent and tends to be less severe.

The most typical features of discogenic low back pain are: onset following a physical strain, a cough or a brusque trunk movement; the presence of postural scoliosis; an increase in pain on trunk flexion and in the sitting position, due to the high intradiscal pressure that these postures involve (66, 67). However, none of these features is pathognomonic of discogenic low back pain. On the other hand, there are no clinical features allowing the low back pain of patients with disc herniation to be differentiated from that of patients with only disc degeneration.

Low back pain, although extremely variable in quality and severity, can usually be of three types: 1) Severe pain, associated with postural scoliosis, and increased by a cough, sitting and erect posture, and any physical effort. 2) Chronic, continuous pain of moderate severity, affected only slightly, or not at all, by posture and spine movements. 3) Low back pain with recurrent acute episodes between intervals of varying duration in which the pain is absent or, more often, mild or moderate in severity; in the acute episodes, the characteristics of pain are generally those of the first type.

Most patients with discogenic low back pain report typically painful symptoms. Others complain of a gravative or burning sensation. A feeling of spasm or painful cramp in the lumbar area is rarely reported. Pain is usually located in the lower lumbar region, even when the upper lumbar discs are involved. Pain strictly in the sacral area is rare, at least as an isolated symptom, not associated with back pain. Pure sacral pain, therefore, should lead us to suspect a pathologic condition in the sacral region, rather than a herniated disc.

The severity of back pain may change even considerably during the day. In the morning, pain tends to be more severe. This may be related either to prolonged nocturnal immobility or to disc imbibition due to the higher intradiscal osmotic pressure when spine is unloaded. Taking a standing position, initially leads to an increase in the intradiscal pressure and, thus, in distension of the annulus fibrosus. The subsequent decrease in the water content of the disc induced by prolonged loading probably leads to a decrease in the intradiscal pressure and, thus, in pain. During the second half of the day, low back pain often increases in severity, particularly in patients with postural scoliosis. This increase is probably due to the prolonged asymmetric loading on the posterior joints and the prolonged muscle spasm.

Radicular symptoms

Radicular symptoms, particularly pain, are typical of a herniated disc. Although modern imaging modalities occasionally show a typical herniated disc even in patients with only low back pain, the prevalence of radicular symptoms in patients with herniation is so high as to make these symptoms those characterizing disc herniation. In other words, a herniated disc should be considered by definition, at least in clinical terms, a condition in which radicular symptoms are present. This concept is useful not only from the taxonomic, but also, and particularly, from the therapeutic, viewpoint, since management of patients with only low back pain may differ considerably from that of patients with radicular symptoms.

Pain

Definition of terms

The expression radicular pain refers to pain caused by stimulation (mechanical, chemical or electric) of a nerve root. The radicular pain caused by disc herniation would result, according to some authors, (100–102), from stimulation of the nociceptors of the nerva nervorum situated in the nerve-root sheath. Thus, this pain would be somatic in nature, being such the pain caused, in the presence of a normal nervous system, by stimulation of the nociceptors of an anatomic structure. This pain, furthermore, is of the referred type, since it radiates at a distance from the involved anatomic structure. According to Van Akkerveeken (100), the concept of pain located in the dermatome supplied by the involved nerve root is not implicit in the term radicular pain, since stimulation of a nerve root may cause pain even outside the dermatome that the root innervates, whilst, on the other hand, stimulation of different roots may induce pain in a single dermatome. It should be borne in mind, however, that no clear-cut borders exist between the various dermatomes and, thus, that a cutaneous area may be supplied by two or more nerve roots. Stimulation of a nerve root, therefore, may cause pain in the same area in which there may be pain due to stimulation of an anatomically close nerve root. On the other hand, most patients with lumbar disc herniation experience pain, or the most severe pain, in a specific area in the lower limb, corresponding to the dermatome innervated by the involved root. In our opinion, the term radicular pain implies the concept of pain radiated to a specific dermatome. This does not imply that pain is located over the whole dermatome, since it may be limited, as often occurs, to only a part of it.

Radicular pain of a different nature is that due to deafferentation. This is a non-somatic pain, caused by direct stimulation of nerve fibers and occurs in the presence of a traumatic lesion or a pathologic condition of the root. This pain is causalgic in nature and it is often associated with impairment of nerve conduction.

It is defined as pseudoradicular, a somatic, referred, pain caused by stimulation of the nociceptors located in vertebral or perivertebral structures other than the nerve root. This pain is felt on the iliac or gluteal region or in the lower limb, but it is not localized in a specific dermatome (48, 64). Furthermore, it may be felt in different sites in individuals in whom the same anatomic structure is stimulated.

The term sciatica is derived from the neolatin term ischialgia and literally means pain in the ischium. With time, however, the term has assumed the meaning of "sciatic neuritis", i.e., pain along the course of the sciatic nerve and its branches. As such, it has a similar meaning to that of radicular pain, but is less precise due to the presence, in the sciatic nerve, of fibers originating from several nerve roots. Similar considerations are valid for the expression "crural pain", which indicates pain along the femoral nerve. The same expression is used when the upper lumbar nerve roots running in the obturator nerve are involved.

Features

Site. Radicular pain may be located only in the buttock or may radiate, as usually occurs, down the lower limb. Alternatively, there may be pain only in the lower limb, in the whole dermatome or a limited part of it. The more severe the nerve-root compression, the more distal the pain tends to be radiated. This is consistent with the findings of Smith and Wright (92), who demonstrated that the spreading of pain along the limb is related to the intensity of the mechanical stimuli on the nerve root.

Pain in the buttock is much more frequent when the L5, S1 or S2 roots are involved, whilst it is fairly rare when the upper lumbar roots are involved. In this instance, the equivalent of buttock pain may be pain in the groin. The latter can be reported, although rarely, by patients with L5 nerve-root compression. It may be due to anomalies of the furcal nerve, which may emerge together with the L5 root and contribute to the innervation of the inguinal region through the branches which run in the lumbar plexus.

Quality. The patient generally describes the sensation which bothers him using the terms pain or discomfort. Occasionally, a sensation of burning, rather than true pain, is reported. Almost always, this sensation corresponds to an irritative radicular syndrome of mild severity. Even more rarely, the patient has no pain, but is troubled by numbness.

Severity. The severity of pain varies either in absolute terms, or in relation to the way the patient lives and relates the painful experience. It is of paramount importance to evaluate the severity of the patient's pain as well as his/her psychologic traits, since the diagnostic and therapeutic approach may depend to a large extent upon these two elements (Chapter 12).

The severity of pain is generally related to the severity of the nerve-root compression, which, in turn, is affected by the size of the herniation and the position of the latter with respect to the nerve root. The patients with the mildest radicular pain are usually those with a contained midline herniation, whilst the most severe pain is usually reported by patients with migrated herniation. In these, the severity of pain often depends upon the position of the disc fragment with respect to the nerve root, rather than the size of the fragment itself. A small disc fragment migrated ventrally to the root may cause much more severe pain than a large fragment situated ventrally to the thecal sac. The most painful, or among the most painful, are lateral herniations. This may be due to the fact that the latter are often migrated herniations or that the herniation impinges on the nerve-root ganglion, rather than on the root.

The severity of pain and, more in general, of nerve-root compression, is related to the width of the spinal canal. Porter et al. (79), in a series of patients with disc herniation diagnosed on clinical grounds, found that the patients who had to undergo surgery had smaller mean dimensions of the spinal canal than those in whom the clinical syndrome had resolved with conservative care. The patients with a narrow or stenotic canal tend to present signs and symptoms of more marked nerve-root compression, the dimensions of the disc protrusion being similar, than the patients with a normally-sized, or larger than normal, spinal canal.

Bilaterality. Radicular pain in both lower limbs is not frequent. Pain may be bilateral in the presence of a midline large disc herniation, a large disc fragment migrated in the median or almost median portion of the spinal canal, bilateral disc protrusion or two-level herniation located on opposite sides. The two latter conditions, however, are rare. In the vast majority of cases, pain is more severe, and/or radiated to the limb, on one side. Alternatively, pain is present only on one side, whilst on the opposite side only sensory disturbances, muscle weakness or decreased reflexes are present. Another possibility is that pain begins on one side and, with time, decreases or disappears, concomitantly with the appearance of pain on the opposite side. Often, in these cases, there is initially an extruded disc fragment, which then migrates in the median portion of the spinal canal or on the opposite side to that of the initial herniation.

In patients with pain of similar severity in both extremities, one should always be wary as to whether that pain is truely radicular in nature. This holds particularly if the pain is mild and investigations fail to reveal any neurologic deficit.

Posture-related changes. Radicular pain tends to increase in the standing, and to decrease in the horizontal, position. This behavior, however, is not uniform and is more often found in patients with irritation, than in those with marked compression, of the nerve root. In the latter patients, the pain may be even more severe in the horizontal, than in the standing, position. The prone position is usually more painful than the supine, since in the latter the nerve root lies above the herniation and, due to the effect of gravity, may be more severely compressed. This interpretation is supported by myelographic findings: on the posteroanterior myelogram in the prone position, a filling defect of the nerve-root sleeve is usually more clearly visible than on the myelogram in the supine position (which, for this reason, is not usually performed).

The sitting position often exacerbates radicular pain, particularly buttock and thigh pain. Exacerbation in this position is typical of patients with disc herniation and tends to occur more easily in the presence of moderate or marked compression, than irritation, of the nerve root. Furthermore, an increased pain is more often observed in the presence of contained or extruded, rather than migrated, herniation. In patients with contained herniation, exacerbation of pain may be due to an increase in intradiscal pressure, and thus in the prominence of herniation, that the sitting position involves (66, 67); an additional element may be the trunk flexion that the sitting position implies. In patients with migrated herniation, the exacerbation of pain is probably due to a change of the reciprocal spatial relationships between the disc fragment and the nerve root and/or to increased nerve-root compression produced by trunk flexion.

A few patients report that radicular pain decreases in the horizontal, or in the standing or sitting, position or in other, at times even strange, positions. A few positions clearly represent a form of sciatic scoliosis. Other postures may possibly decrease, in a given patient, the pressure exerted by the herniation on the nerve structures.

Changes with walking. Pain caused by mild nerve-root compression generally tends to decrease on walking, whilst that produced by marked compression tends to increase. This anamnestic element may contribute to differentiate the patient with mild radicular irritation from that with marked nerve-root compression.

Increase with cough and sneeze. Lumboradicular pain tends to exacerbate on coughing and sneezing. However, this is not a frequent phenomenon, since it usually occurs in patients with an acute syndrome, particularly in the presence of severe nerve-root compression. Exacerbation of pain is due to an increase in CSF pressure. This leads to: distension of the nerve-root sleeve, which is thus more severely compressed by the herniation; and stretching of the meninges, which is transmitted to the nerve root in the extrathecal course and possibly results in an increase in compression by the herniation.

Sensory disturbances

These may be represented by paresthesias in the form of tingling, pins and needles, or by numbness. Often, however, it is not easy to determine whether the patient complaints should be interpreted as paresthesias, pain or numbness.

Numbness in a region of the lower limb is fairly frequent in patients with disc herniation. Quite often, however, the pain is so severe that the patient is almost not aware of the sensory disturbance. The latter may be located in the same area as the pain or, more often, in a different area, however, usually comprised in the same dermatome. For instance, a patient with S1 nerve-root compression may feel pain down the posterior aspect of the thigh and leg and numbness on the outer border of the foot.

There is no close correlation between the presence of numbness and the severity of nerve-root compression; nonetheless, the latter is often severe in patients with marked numbness. Similarly, it is unusual to find any direct relationship between the degree of motor loss and the severity of numbness. Often, in fact, the patient with a marked motor deficit reports numbness, which, however, is considerably less severe than muscle weakness. Occasionally, the subjective symptoms are represented mainly by sensory disturbances, even in the presence of clinical signs of mild nerve-root compression. Unlike pain, sensory loss is hardly affected by posture or walking.

The outer aspect of the thigh is often the site of numbness or paresthesias. In this area, the patient may feel numbness, which becomes painful due to contact with clothes, or a sensation of burning. These symptoms, which often exacerbate in the prolonged standing position, may be present in patients with irritation or compression of various roots – from L2 to L5 – since the outer aspect of the thigh, normally innervated by L2 and L3 roots, may also belong to the L4 or L5 dermatomes (70). However, sensory disturbances on the lateral aspect of the thigh are more often due to annular bulging or pathologic conditions of the facet joint than a herniated disc. It is thus likely that these symptoms may be caused either by direct involvement of the sensory fibers in the nerve root, or by antidromic impulses originating from the branches of the sinuvertebral nerve which supplies the annulus fibrosus and the facet joint.

Motor deficits

A herniated disc often causes muscle weakness in the lower limb, but in most cases it is so mild, that the patient is not aware of it. Only severe weakness produces a disability of which the patient is easily aware. Also in these cases, the patient's attention is concentrated mainly on the pain, to which the disability caused by muscle weakness is often attributed.

The two most common motor deficits spontaneously reported by the patient are that of the quadriceps due to disorder of L4 nerve-root function and those of the tibialis anterior and the peronei, when the L5 root is involved. The patient reports, in the former case, that the knee gives way or that he/she has difficulty in climbing up or down stairs and, in the second, episodes similar to ankle sprains or uncertainty in walking. More rarely the patient is aware of a severe impairment of the calf muscles causing difficulty in walking or climbing the stairs.

A severe motor loss usually becomes apparent at the onset of the radicular pain and does not increase in severity with time. Alternatively, it may initially be absent or mild and then become suddenly severe in the course of the disease. A further possibility is that muscle weakness progressively worsens over time. This occurrence is very unusual, if not exceptional. A severe motor deficit, in fact, is due to a sudden, marked compression of the nerve root, mostly caused by a disc fragment that has migrated into the spinal canal either at the onset of the clinical syndrome, or suddenly in the course of the latter. When this occurs, the nerve-root impairment remains stable or tends to regress, rather than to increase in severity.

Usually, patients with a severe motor loss are able to report, even only approximately, how long the weakness has been present. At times, it is not possible to determine the duration of muscle weakness, particularly when pain or motor loss are long-standing. This information, on the other hand, is important, since the possibility that weakness regresses is related, although not strictly, to its duration.

Cramps and fasciculations

Cramps

These are fairly frequent in patients submitted to surgery, who often complain of cramps during the first few months or years after the operation. In non-operated patients, cramps are usually reported when nerve-root compression is of long duration. In both instances, the cramps probably result from intra- and perineural fibrosis affecting the threshold of excitability of the nerve-root sensory fibers.

There is no relationship between the size, site and type of herniation and the severity of cramps. Conversely, the vertebral level appears to play a role: the root most frequently involved is the S1, followed by L5. The muscles most often affected by cramps are the triceps surae, hamstrings and plantar muscles. Muscle spasm usually occurs at night and lasts a few seconds to several minutes. During the daytime, the cramps tend to occur following brusque muscle stretching or contraction. Frequency varies considerably; they may occur at intervals of weeks or months, or even several times during the course of one night.

Fasciculations

These would be present, either spontaneously or due to mechanical stimuli, such as repeated percussions with the reflex hammer, in more than 50% of patients (33). In a few cases, however, fasciculations would be so rare and of such short duration that the patient is not even aware of them. In our experience, this clinical manifestation is very rare and is only exceptionally spontaneously reported by the patient.

Fasciculation is a typical sign of degenerative diseases of the anterior horn of the cord as well as an expression of abnormal excitability of any portion of the motor neuron. In lumbar disc herniation, it might result from mechanical or chemical stimuli exerted by the herniation on the nerve root. Summation of the stimuli at cord level might trigger off mono- or plurisegmentary spinal reflexes, which are transmitted peripherally in the form of clonic muscle contractions (87).

Intermittent claudication

Various radicular or cord conditions may be responsible for neurogenic intermittent claudication. The form caused by involvement of the cauda equina can be referred to as lumboradicular intermittent claudication (83). It is characterized by the onset, upon walking, of radicular symptoms absent at rest. The latter, consisting in pain, paresthesias and / or disesthesias, progressively increase in severity until the patient is forced, in many cases, to stop or sit down. With rest, the symptoms improve or disappear, thus allowing walking to be resumed. Waking ability ranges from a few to several hundred meters.

Intermittent claudication is typical of lumbar stenosis. It is rare in patients with disc herniation and occurs mostly in the presence of a midline disc herniation, particularly of the second to the fourth disc, when it is responsible for severe compression of the thecal sac and emerging nerve roots. Claudication, however, is not rare in patients with a herniated disc in a stenotic spinal canal, in whom this clinical manifestation is probably due to stenosis.

The rare occurrence of claudication in patients with disc herniation alone might be related to the fact that a herniated disc responsible for marked cauda equina compression is generally present at a single level. Claudication, in fact, appears to be more easily caused by cauda equina compression at two or more adjacent levels than by compression at a single level (82). This may be due to the fact that compression at a single level does not produce, or produces to a lesser extent, changes in radicular blood circulation – venous stasis and reduced capillary flow – responsible for the hypoxy and decreased radicular metabolism, to which claudication is probably due (46, 73, 76).

A similar clinical manifestation to claudication, however not identifiable with the latter, is the increase in radicular pain on walking. This often occurs in patients with disc herniation, when the latter causes severe nerve-root compression. In these instances, pain is usually monoradicular and decreases at rest, but does not disappear. Furthermore, whilst it may be associated with paresthesias if these are present at rest, it is not associated with tiredness.

Clinical history

Onset

The types of onset, which, in our experience are encountered with progressively decreasing frequency can be schematically identified as follows:

1) In a patient who has never complained of low back discomfort, or has had rare and short episodes of back pain, acute pain appears, which, after a few days or weeks, becomes associated with radicular pain of varying severity.

2) The patient reports having suffered, a few months before, from an episode of low back pain associated,

or not, with mild radicular pain of short duration. Subsequently, occasional episodes of back pain occurred, intercalated with asymptomatic intervals. In the last episode, which was of gradual or sudden onset, persistent radicular pain became associated with back pain.

3) The clinical syndrome begins with radicular pain, associated with no or mild low back pain, which subsides after a few hours or days. The radicular pain may be either very mild or exceedingly severe already at the onset of symptoms.

4) The clinical history is characterized by continuous or recurrent low back pain of long duration. In this context, leg pain, usually associated with back pain of varying intensity, appears gradually or suddenly.

5) The patient reports only acute low back pain of recent onset or a history of recurrent acute episodes of back pain.

6) The patient, following a sudden low back and/or radicular pain of short duration, found difficulty in walking, due to weakness of muscles in the lower limb (paralyzing sciatica). Muscle weakness may be associated with an area of numbness in the limb. Alternatively, only numbness is present.

7) In the course of a few hours, days or weeks, a cauda equina syndrome appears, associated, or not, with low back pain.

Numerous authors (3, 4, 58, 75, 104) have analyzed the frequency with which low back, or radicular, pain appears as the first symptom of the disease. The first symptom was found to be low back pain in some two thirds of cases, radicular pain in some one fourth and both symptoms in some one tenth. These, however, are only very rough estimations, because they stem from retrospective analyses or because of the frequent difficulty in establishing whether the onset of the clinical syndrome coincides with the first episode of low back pain or whether only the last episode, usually associated with sciatica, should be considered.

Evolution

Analysis of the evolution of lumboradicular symptoms coincides, to a large extent, with analysis of the natural history of the disease. In this chapter, we analyze only the evolution during the first few weeks after onset.

In most cases, particularly those with a sudden onset of symptoms, pain progressively exacerbates or remains stable for the first few days after onset and then tends to decrease. This occurs in a variable interval of time, the duration of which may be affected by conservative treatments. This interval is usually 2 to 6 weeks. Thereafter, lumboradicular symptoms may regress completely or almost, may remain constant over time at moderate levels of severity, or may exacerbate again after a variable interval of time. There are no element by which to predict the evolution of the clinical syndrome. Nevertheless, patients who initially have moderate symptoms, mild muscle weakness, and a contained small herniation tend to present regression of symptoms. According to Nachemson (65), more than half of the patients with acute sciatica are considerably improved or asymptomatic 2 months after onset. Conversely, in patients both with severe pain and motor deficit, the symptoms tend to persist for the first few months after onset, particularly in the presence of a large extruded or migrated herniation. In our experience, after 2 months of onset, the chances of complete resolution of the symptoms progressively decrease with time.

Another, less frequent, modality of evolution is characterized by the little variability in the initial symptoms. These may present changes from one day to the next, but remain essentially unchanged in quality and severity, at least for the first 6–12 weeks. This modality of evolution is independent of the severity of the initial symptoms and is, perhaps, more frequent in patients with moderate symptoms, gradual in onset.

The third modality is characterized by progressive worsening both of pain and motor loss. This may often occur during the first few days, but very rarely 3 weeks or more after the onset of symptoms. In other words, patients with muscle weakness will only rarely show a progressive increase in the severity of weakness after the first few weeks of onset, in the absence of physical strain or trauma. By contrast, motor loss often tends to regress, even if not completely, 2–4 weeks after presentation. This holds for moderate or marked weakness, however not for paresis or paralysis.

Physical examination

Spine

Physical examination may detect modifications in posture, postural scoliosis, decreased spinal motion and pain upon pressure and percussion on the lumbar spine. The clinical patterns, however, vary to such an extent that none can be considered pathognomonic. The two extremes are represented, one, by the patient with no abnormal objective findings and, the other, by the patient with clear positivity of all the clinical signs typical of disc herniation. These two conditions do not, however, represent the most frequent occurrence, namely moderate positivity of only some of the typical clinical signs of disc herniation. Nonetheless, it should be stressed that none of these signs is pathognomonic of a herniated disc, which is usually diagnosed clinically only on the basis of the signs and symptoms involving the lower limbs.

Posture

In the phase of extremely acute pain, the patient may be unable to take up a standing position and, in bed, prefers to assume the fetal position. In the presence of less severe pain, the characteristic posture appears to be: rigid lumbar spine, flattened due to disappearance of lumbar lordosis, trunk bent forwards and on the side of radicular pain, hips and knees flexed and foot held in plantar flexion. In the presence of postural scoliosis, the trunk is listed to the side of the concavity of the curve. The patient may prefer not to sit down and, when he does it, he may tend to put his weight only on the buttock of the asymptomatic side and to keep the hips extended to avoid bending the lumbar spine, thereby decreasing the axial load on it.

Postural scoliosis

This is one of the most typical signs of lumbar disc herniation. Trunk list may be present in the standing position (orthostatic scoliosis) (Fig. 8.11) or become apparent only upon flexion of the trunk. Upon flexion, scoliosis may remain unchanged or be aggravated. The concavity of the curve, and thus the inclination of the trunk, may be on the same side as the herniation (homologous scoliosis) or on the opposite side (heterologous scoliosis); rarely, scoliosis may occur alternately on both sides (alternating scoliosis), as described by Remak (86) and Carpener (10).

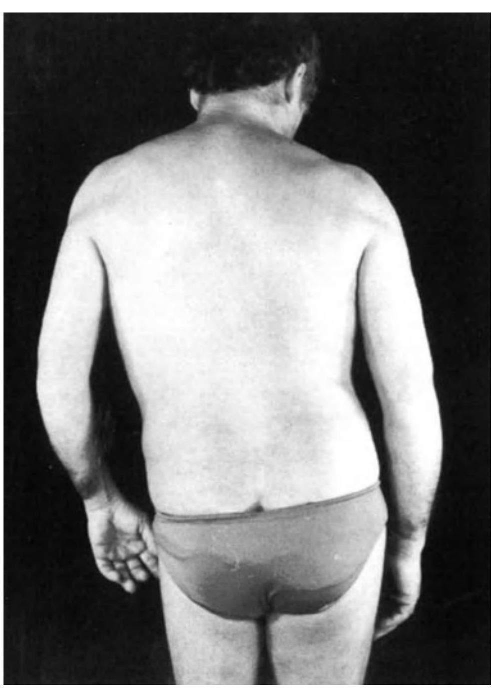


Fig. 8.11. *A patient with an L4-L5 herniated disc showing homologous sciatic scoliosis.*

Postural scoliosis is not a frequent finding. A personal analysis of 100 cases of disc herniation submitted to surgery revealed that trunk list was present preoperatively in 21% of patients, most of whom were males (71%) under 45 years of age (76%). Fineschi (28), in patients with postural scoliosis, found the latter to be homologous in 54% of cases, heterologous in 43% and alternating in 2%. It has been observed that postural scoliosis, unlike structural scoliosis, disappears in the supine position (80). This has not been a consistent finding in our experience.

The presence of postural scoliosis is not strictly related to the pathologic type and size of the herniation. Very often, however, an extruded, or a large contained, herniation is present in patients with trunk list. Also the severity of scoliosis is not strictly related to the type and size of the herniation. The disc most frequently

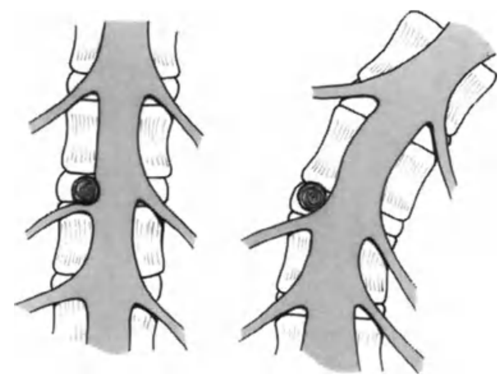


Fig. 8.12. *Pathogenetic mechanism of heterologous sciatic scoliosis according to the classic interpretation: the concavity of scoliosis is on the side opposite to the herniation, when this is situated laterally to the emerging nerve root.*

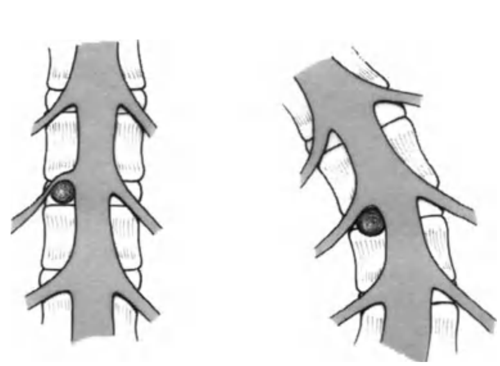


Fig. 8.13. *When the herniation is located medially to the emerging nerve root, the concavity of scoliosis would be on the same side as the herniation.*

responsible for postural scoliosis is the fourth lumbar (18).

According to the classic pathogenetic interpretation (4, 33, 53, 77, 89), scoliosis is heterologous in herniations situated laterally to the nerve root (Fig. 8.12) and homologous in those located medially to the root (Fig. 8.13); in midline herniations, scoliosis would be alternating. The list would represent an attempt to ease away the nerve root from the herniation in order to reduce the compressive effects of the latter. This interpretation is not in keeping with the findings of Porter and Miller (80) who, in 20 patients with postural scoliosis, found twice as many patients listing to the left as to the right and no relationship with the side of herniation or the topographic position of the latter with respect to the nerve root. Only left-handed patients listed to the right; the majority of patients who were most comfortable crossing their left leg over the right listed equally to the left and right, whilst those who crossed the right leg over the left tended to list to the left. These authors, thus, hypothesize that the side of the list may be related to hand or leg dominance, rather than to the topographic position of the herniation. These findings, however, refer to a small series of patients who, preoperatively, underwent myelography, rather than CT or MRI, which are better able to demonstrate the position of the herniation. Furthermore, it should not be forgotten that even in the presence, for instance, of a herniated disc located laterally to the emerging nerve root, the latter may be less involved when the scoliosis is homologous rather than heterologous. This depends on the topographic relationships of the herniation with the nervous structures, and these relationships are so variable that they cannot easily be schematized on the basis not only of the imaging studies, but also of the surgical findings, since these refer to a posture which is different from the standing position.

In our opinion, trunk list, although possibly related to limb dominance or some other unknown factors, essentially represents an attempt to decrease the compression of the neural structures by the herniation. The true situation, in any case, is likely to be much less schematic than hypothesized by the classic theory.

Mobility of lumbar spine

Flexion of the lumbar spine is usually limited, to a varying extent. Patients with mild low back and radicular pain may show an almost normal spinal mobility, whereas those complaining of severe symptoms may present an extremely limited range of active motion (Fig. 8.14 A). The limitation of movements is due only to back pain or, more often, to an increase also, or only, in radicular pain. To reduce nerve-root tension, the patient typically tends to flex the hip and knee on the symptomatic side: this is an extremely reliable sign of nerve-root compression. In a few patients, a list occurs from the beginning of trunk flexion. This has the same significance as postural scoliosis. The degree of spine

A B

Fig. 8.14. *A young patient with an L5-S1 disc herniation on the left. Trunk flexion is considerably reduced* (A), *whereas extension is almost normal* (B).

flexion is determined by visually evaluating the distance of the hands from the ground or by measuring it with an inclinometer. The degree of limitation, however, is of a relative importance, since it is strictly related to constitutional elasticity of the hamstrings.

Extension is mostly limited, but to a lesser extent than flexion (Fig. 8.14 B). Limitation is due to an increase in low back pain, but not, or only rarely, to onset of, or an increase in, leg pain. When this occurs, one should suspect, particularly in an elderly patient, lumbar stenosis, either isolated or associated with disc herniation.

Lateral bending is usually normal or moderately reduced and does not lead to an increase in radicular pain. This may occur in patients with lateral herniation (1). Lateral bending, in fact, may increase the protrusion of the disc into the intervertebral foramen and accentuate compression of the nerve root.

Trunk rotation with the patient in the upright position does not usually cause pain and is unrestricted. This is also related to the fact that this movement occurs to a limited extent in the lower lumbar spine.

Lumbar stiffness may be detected, in the patient lying prone, by Neri's maneuver (69): flexion of the knee normally involves an increase in lumbar lordosis; the patient with lumbar stiffness, by contrast, raises the pelvis from the bed in order not to change the antalgic posture of the spine.

Pressure and percussion

Deep pressure may elicit pain at the level of the interspinous process corresponding to the site of the herniated disc, the adjacent spinous processes or the paravertebral muscles. These findings, which are very frequent in patients with low back pain of various origin, are usually of little diagnostic value.

Fig. 8.15. *Pressure in proximity to the spinous processes may elicit local discomfort or radiated pain along the symptomatic lower limb. The examiner's left hand is placed on the iliac crest in order to identify the vertebral level.*

Pressure at 2 cm from the spinous processes (Fig. 8.15) may elicit pain, either local or radiated to the symptomatic leg (17). This clinical sign may occasionally be positive in patients with marked nerve-root irritation and the thinner the patient, the easier the finding. Radicular pain might be caused by transmission of pressure to the compressed nerve root through the muscle layer and the ligamentum flavum. This tends to occur more easily if the patient is standing upright with the trunk slightly bent or is in a kneeling position, since this increases the interlaminar distance.

Percussion on the spinous processes or the interspinous space at the level of herniation may produce or increase both low back and radicular pain (14). This clinical test, however, is rarely positive.

A few patients complain of pain upon pressure, as well as spontaneously, in close proximity to the posterior iliac spine or, occasionally, along the adjacent portion of the iliac crest. Pain in this site, which is usually observed in the presence of mild radicular involvement, might be due to irritation of the fibers of the posterior ramus of the spinal nerve.

Lower limb

Nerve-root tension tests: L5,S1,S2 roots

Lasègue's maneuver

This maneuver was first described by Forst (32) in 1881 in his doctoral thesis produced under the guidance of Lasègue. Forst reports that the maneuver, well known to Lasègue, is aimed at differentiating sciatic, from hip, pain. Lasègue, however, has never mentioned this maneuver in his writings (21). This test includes two stages. The first consists in raising the lower limb with the knee fully extended (Fig. 8.16); the patient's foot is then placed on the bed and the hip is further flexed. Positivity of the first maneuver, currently known as Lasègue's test, is an expression of sciatic pain. Persistence, or appearance, of pain in the second part of the maneuver, indicates a pathologic condition of the hip.

Straight leg raising test (SLRT)

This test corresponds to the first part of the Lasègue's maneuver.

The patient is placed supine with the hips and knees in full extension and the ankles in a relaxed position.

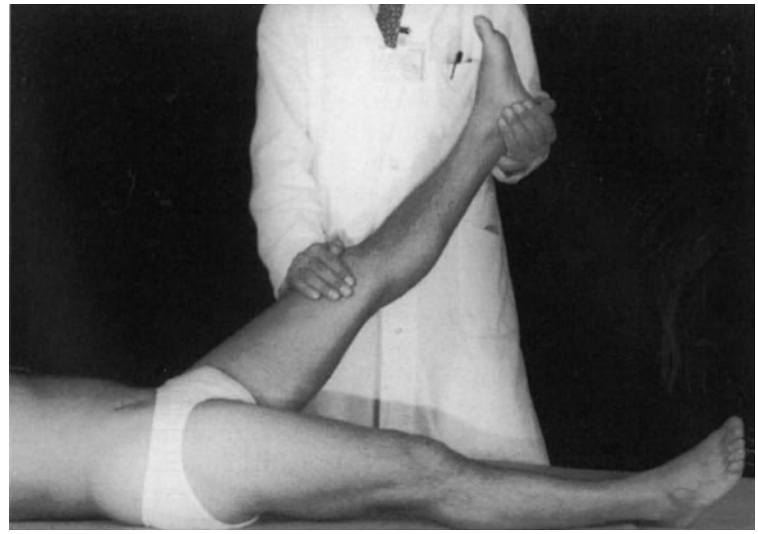


Fig. 8.16. *Stretching of the lumbosacral nerve roots by the SLRT. This maneuver corresponds to the first stage of the classic Lasègue's maneuver.*

The examiner takes the heel with one hand, while exerting, with the other, a slight pressure on the knee to avoid it bending when raising the limb. Normally, the limb can be raised through at least 60° without causing the patient any discomfort. Patients with radicular pain experience a progressive increase in discomfort, upon limb raising, to which they begin to resist as soon as pain becomes severe. Resistance is effected initially by contracting the hamstrings and then by raising the homologous hemipelvis from the bed. The angle reached before the patient begins to offer resistance represents the extreme value of the maneuver. Positivity of the latter may be expressed by the degrees corresponding to the extreme value or by +. In this instance, + may be used for an angle of 60°–90°, ++ for an angle of 30°–59° and +++ for a smaller angle.

In asymptomatic subjects, the degree of SLR ranges between 50° and 120°, depending on various factors, such as patient's age, constitutional muscle elasticity and level of physical activity. Considering the variability of these parameters, clinical evaluation is generally made in relation to the opposite side. Troup (97) considered a difference of at least 15° between the two sides as abnormal, whereas Blower (6) considered a difference of 30° or more as pathologic. In effect, it is neither nor necessary to establish precise values of normality, since what, indeed, characterizes the pathologic SLRT is the presence of pain, as opposed to the muscle stretching felt by the asymptomatic subject.

Numerous studies have evaluated the sensitivity of SLRT in patients with disc herniation: the values range from 80% (19) to 99% (72). Specificity, however, does not exceed 40% (19). In a prospective study, an almost linear relationship was found between the degree of positivity of SLRT and pain at rest, pain at night or upon coughing, and decrease in the ability to walk (44).

The degree of limitation of SLR varies when the test is performed by different examiners (interobserver variability), but the differences are generally slight (> = 10°) (51). The degree of limitation may also vary when the maneuver is performed by the same examiner (intraobserver variability) after intervals of a few hours, however also in this case the differences are mostly slight (> = 10°) (68, 81).

Pathogenetic mechanism. Radicular pain in straight leg raising, as in the Lasègue's maneuver, results from stretching of the nerve root compressed by herniation.

In several studies on cadavers, the motion of the lumbosacral roots was examined upon SLR (12, 26, 35, 40). Smith et al. (93) observed that both the nerve root (or

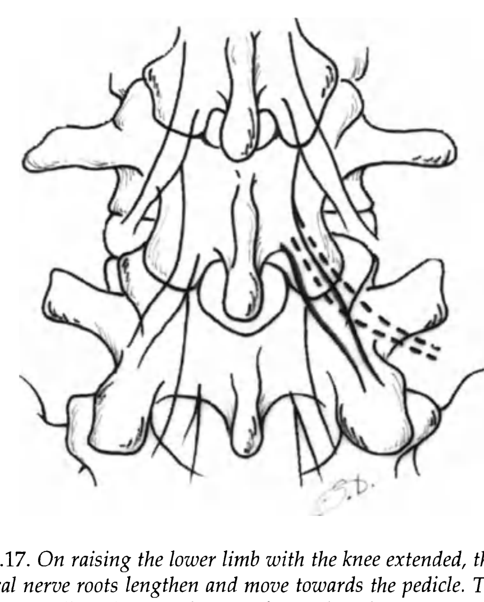


Fig. 8.17. *On raising the lower limb with the knee extended, the lumbosacral nerve roots lengthen and move towards the pedicle. The new position is indicated, on the drawing, by the dotted root.*

radicular nerve) and the dura mater undergo translation and lengthening movements. Between 0° and 30°, motion is very limited; between 30° and 60° the root moves in the vertical direction; and between 60° and 90° the displacement occurs perpendicularly to the direction of the root, i.e., towards the pedicle (Fig. 8.17). The average mobility is about 2 mm and the average lengthening is 3%. The dura mater is less displaced, but is lengthened more than the root.

When a nerve root is deviated and compressed by a herniated disc, even mild displacement and/or lengthening of the root may stimulate the nociceptors of the dural sheath (or the nociceptive fibers in the nerve root), thus leading to increased radicular pain. The more inflamed the root, the more likely this will occur (88). This interpretation may explain why the more acute the pain, the more positive the maneuver, regardless of the severity of nerve-root compression, and why in a few conditions, such as lumbar stenosis, characterized by chronic nerve-root compression with no significant inflammatory processes, the maneuver is usually negative or weakly positive.

The greater positivity of the maneuver in posterolateral herniations is due to the site of herniation, which when is lateral directly compresses the root, and to the fact that the root displaces both vertically and transversely, and thus tends to move towards the lateral portion of the disc.

Muscle elasticity-related changes. In the presence of little elasticity of the hamstrings, not only may it be impossible to raise the limb with the knee extended beyond 60°–70°, but the patient may feel pain at even lower degrees. Usually, radicular pain can be easily differentiated from the discomfort caused by muscle stretching. The latter, in fact, differs from true pain and is felt only in the thigh or behind the knee. When doubts persist, the maneuver is performed on the asymptomatic side and the resistance encountered on raising the leg, as well as the discomfort elicited on the two sides, are compared. This may be done by watching the patient's face while carrying out the maneuver or asking him/her whether the sensation is different on the two sides.

The opposite may occur in patients with high tissue elasticity, in whom the leg may be raised through a wide angle without eliciting any pain, even in the presence of marked nerve-root compression. Furthermore, in these patients the symptomatic leg may be raised, without effort, well beyond 90°. The subjects with the greatest ability to raise the limb with the knee extended are most often women (5, 63).

Age-related changes. In young subjects the SLRT tends to be more positive, under comparable pathologic conditions, than in subjects of more advanced age. This holds particularly for teenagers, in whom the leg may often be raised, in the presence of disc herniation, by only few degrees. Conversely, in elderly patients the maneuver tends to be less positive. These differences in the SLR, which often parallel the limitations of trunk bending, seem to be related to the degree of muscle spasm that the subject is able to develop in response to stimulation of the dural nociceptors or the nociceptive fibers of the nerve root. The different behavior in relation to age might also result from different intensity of the inflammatory process stimulated by herniation in the radicular and periradicular tissues.

Posture-related changes. Positivity of the SLRT may decrease by 10° or more after a few hours in a standing position and increases again after recumbency (81). The increase probably results from increased hydration of the disc when the spine is unloaded. This may cause an increase in bulge of the outer annulus fibrosus, if this is intact. The opposite occurs when the patient stands upright. This interpretation may explain why posture-related changes of the SLRT are usually observed in patients with a contained herniation, whilst they do not occur, or are mild, in the presence of an extruded or migrated herniation. The posture-related changes are more marked for the L4-L5, than the L5-S1, disc. This is probably related to a lower concentration of proteoglycans and hydration in the lowermost lumbar disc (98).

SLRT performed in the standing position (standing SLRT) is generally less positive than in the supine position. This might be due to the less marked compression of the nerve root in the standing position.

Crossed-leg SLRT. Raising of the asymptomatic leg may cause pain on the symptomatic side. This clinical maneuver, first described by Fajersztajn (25), generally elicits pain on the buttock and/or the posterior aspect of the thigh and only rarely along the whole limb.

The patients who most frequently present a positive crossed-leg SLRT are those with a paramedian herniation. In these cases, stretching of the contralateral nerve roots involves traction on the thecal sac and, through this, the compressed nerve root. The latter tends to displace towards the midline, and is thus compressed by herniation. However, contralateral pain in lifting the asymptomatic leg may also be observed in patients with midline or posterolateral herniation (23). The mechanism of production of pain, also in these cases, is likely to be similar to that previously described.

The sensitivity of crossed-leg SLRT is only 25%–44% (19, 23), but specificity is as high as 90% (19). This maneuver is extremely reliable for diagnosis not only of disc herniation, but particularly of herniation responsible for marked nerve-root compression. Most patients

Fig. 8.18. *Reinforced SLRT. With foot dorsiflexion, radicular pain tends to appear at lower degrees of leg raising.*

with crossed-leg SLRT, in fact, have a medium-sized or large contained herniation, or an extruded or migrated herniated disc (49).

Reinforced SLRT. In lifting the lower limb with the knee extended, the ankle is dorsiflexed by applying the hand which raises the limb on the heel or sole of the foot (Fig. 8.18). The sciatic nerve is thus further stretched through the tibialis posterior nerve and pain may, therefore, be elicited when SLRT is negative or, anyway, at lower degrees of leg raising. This maneuver, first described by Lazarevic (57), may be helpful when the standard maneuver is only slightly positive. The result of the reinforced maneuver, however, should not be overestimated, since the test may be weakly positive even in normal subjects due to stretching of hamstrings and calf muscles. On the other hand, a patient with a negative SLRT, and a slightly positive reinforced test, has little likelihood of presenting a condition responsible for significant nerve-root tension.

A similar maneuver is the so-called ankle dorsiflexion maneuver described by Fajersztajn (25). The limb is raised until the patient feels radiated pain and then is lowered until the pain decreases or disappears. At this point, a forced ankle dorsiflexion is performed, which again elicits radiated pain, when the maneuver is positive. This clinical test, which is less sensitive than the former, may confirm the positivity of SLRT. Its practical usefulness, however, is very limited.

Bilateral SLRT. This maneuver, described by O' Connell (71), consists in raising the two lower limbs simultaneously. The level to which the limbs can be raised before the patient feels pain is higher than in unilateral SLR. If, immediately before reaching the angle at which pain begins, the asymptomatic limb is lowered, the patient feels radiating pain along the symptomatic limb. This might be due to sudden caudal stretching of the symptomatic nerve root due to upward movement of the thecal sac induced by lowering the healthy limb.

Knee extension with the hip flexed

This test, described by Fajersztajn (25), and, sometimes, erroneously referred to as Lasègue's test, is a variant of the SLRT. It consists in extending the knee after flexing the hip at about 70°. The drawback of this maneuver is that it often does not allow us to determine whether the patient's resistance to forced knee extension is due only to radicular pain or also to poor elasticity of the hamstrings. This test may be useful when results of the SLRT are dubious.

Knee extension in the sitting position

To perform this clinical test, known as the flip test, the patient sits with the knees dangling over the side of the bed and the leg is raised until the knee is fully extended. When the test is positive, the greater the nerve-root tension, the less the knee extension and the greater the radiated pain felt by the patient. Furthermore, the patient will simultaneously throw back his trunk and take his/her hands away from the edge of the bed (Fig. 8.19).

This maneuver, described by Oppenheim (74), has the same clinical significance as the SLRT. However, it is less sensitive and may, thus, be negative or weakly positive when the SLRT is clearly positive. The flip test may be useful in those patients with severe lumboradicular pain who have difficulty in taking up a supine position.

Knee extension on the asymptomatic side may cause pain on the symptomatic leg. This test has the same clinical significance as the crossed-leg SLRT and, like the latter, is of great diagnostic value.

Knee flexion in the prone position

This maneuver, described by Postacchini et al. (84) as knee flexion test (KFT), is performed with the patient's knee, on the symptomatic side, flexed at 90°. Further flexion of the knee elicits pain in the buttock and / or the posterior aspect of the thigh (Fig. 8.20). Only rarely, does pain radiate distally to the knee and equally rarely pain is provoked on the symptomatic side upon bending of the knee on the asymptomatic side. Patients in whom this test is positive do not present simultaneous positivity of the femoral nerve stretch test.

Fig. 8.19. *Flip test. The test is positive when the patient bends the trunk backwards and removes his/her hands from the edge of the bed to decrease nerve-root tension caused by leg extension on the symptomatic side.*

KFT is positive in some 15% of patients with disc herniation at the two lower lumbar levels. However, its predictive value as far as concerns the presence of a herniated disc is extremely high: 94% in a series of patients evaluated by the authors. Furthermore, the majority of patients presenting a positive test display severe nerve-root compression resulting from a large contained, or an extruded or migrated, herniation.

The mechanism by which this maneuver provokes sciatic pain is unknown. Knee flexion is likely to stretch not only the high lumbar nerve roots, but also the lumbosacral roots; even a slight movement of the latter, in the presence of severe nerve-root compression, might cause radiated pain. Another possibility is that stretching of the lumbar plexus is transmitted to the sacral plexus through anastomotic branches between the two plexuses: this may occur when anastomoses are abnormally numerous or the L5 nerve root runs in the

Fig. 8.20. *Knee flexion with the patient in the prone position (KFT). Flexion of the knee beyond 90° on the symptomatic side often causes pain in the buttock and/or the posterior aspect of the thigh. When performed on the asymptomatic side, the test may elicit pain on the symptomatic side.*

lumbar plexus (96). A further possibility is related to an abnormal emergence of the furcal nerve, particularly to the variety in which the nerve emerges together with the L5 nerve root or L4 and L5 roots (50). A pathogenetic mechanism related to anatomic abnormalities might explain why this test is positive only in a minority of patients with low lumbar disc herniation.

Nerve-root tension tests: L2, L3, L4 roots

Femoral nerve stretch tests (FNST)

The femoral nerve stretch test may be carried out in various ways, with the patient in the prone position. The simplest modality, described by Wassermann (103) is to bend the knee until pain appears on the anterior aspect of the thigh (Fig. 8.21 A). In most normal subjects, this maneuver causes a feeling of painful stretching of the quadriceps. This feeling differs from true radicular pain and usually occurs beyond 120° of knee flexion. The patient with nerve-root compression experiences true pain as soon as 90° are reached and pain becomes progressively more severe if knee flexion is increased even slightly. The test may be reinforced if the hip is extended by placing a hand under the knee to raise the thigh (Fig. 8.21 B).

An alternative method is to extend the hip, while keeping the knee extended (Fig. 8.21 C). This is done by placing one hand on the buttock to keep the pelvis in position, whilst the other hand, placed under the knee, raises the limb. The FNST may also be performed with the patient in the lateral decubitus, and head flexion may be associated in order to increase tension of the cauda equina roots (20).

These maneuvers are comparable, as far as concerns clinical significance and mechanism of pain production, to the SLR. They cause stretching of the femoral nerve, which is transmitted to the lumbar plexus and, through this, to the L2, L3 and L4 roots.

A B C

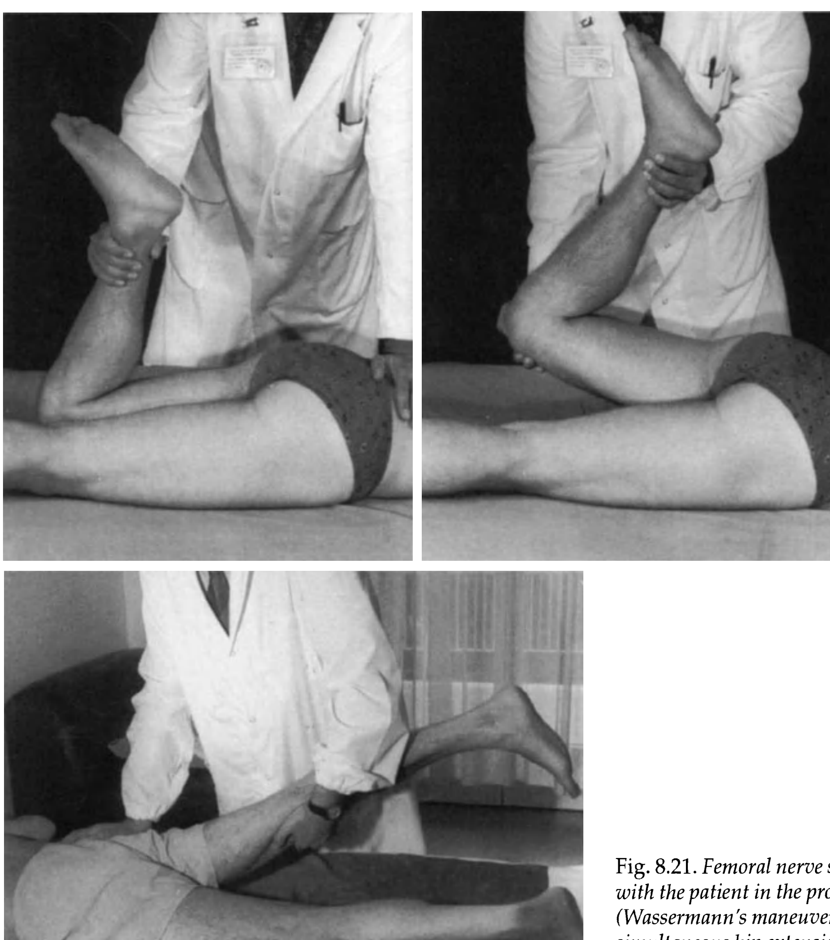


Fig. 8.21. *Femoral nerve stretch test. The maneuver can be carried out with the patient in the prone position by bending the knee beyond 90° (Wassermann's maneuver)* (A), *performing knee flexion and simultaneous hip extension* (B), *or extending the hip with the knee extended* (C).

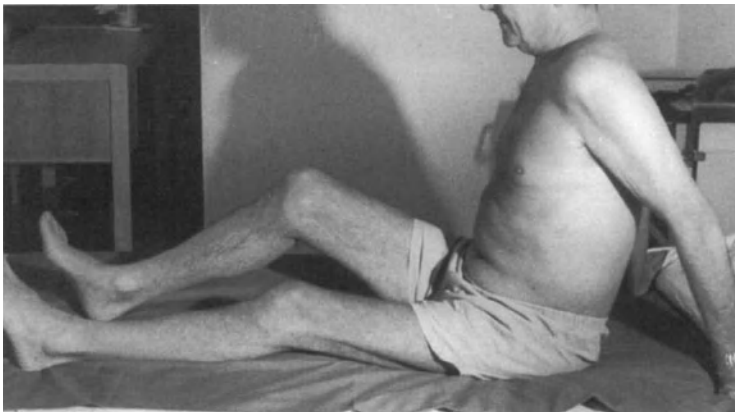


Fig. 8.22. *The patient flexes the knee and hip on the symptomatic side to reduce nerve-root tension when he is invited to bend the trunk whilst in the sitting position.*

Stretching of the femoral nerve on the healthy side may cause anterior thigh pain on the symptomatic side. The crossed-leg FNST is much more rarely positive than the crossed-leg SLRT. It is also fairly unusual for low back pain to appear or exacerbate in the various maneuvers of stretching of the femoral nerve.

Minor tests

We define as minor those tests which add little clinical information to that provided by the major tests. Moreover, since a few of these are positive only in a small minority of patients, they may thus generally be omitted in the patient's examination.

Neck flexion. Flexion of the neck with the patient in the supine position and the limbs fully extended may elicit pain both on the lumbar area and the symptomatic leg, whatever the level of herniation. This maneuver is commonly known as Kernig's test.

In patients with sciatic pain, this may be further increased if neck flexion is carried out while performing the Lasègue's maneuver or SLR. If the latter is performed until the limit beyond which pain appears and the neck is then flexed, leg pain may be experienced. The appearance or exacerbation of radicular pain on neck flexion is related to upward traction of the meninges and the resulting increase in nerve-root tension.

Flexion of the trunk with the patient sitting. If the patient, placed in a sitting position with the hips and knees extended, flexes the trunk, he may feel pain radiating to the symptomatic leg. If flexion is continued, the patient tends to bend the knee and hip on the symptomatic side to reduce nerve-root tension (Fig. 8.22).

Pain on pressure

Valleix's points

In the presence of L5 or S1 nerve-root irritation, deep pressure on specific points along the course of the sciatic nerve or its branches – Valleix's points (99) (Fig. 8.23) – may cause pain or exacerbate the patient's spontaneous pain. These points are: for the L5 root, the central zone of the buttock, the middle portion of the posterior aspect of the thigh, the head of the fibula and the areas situated anteriorly or below the external malleolus; for

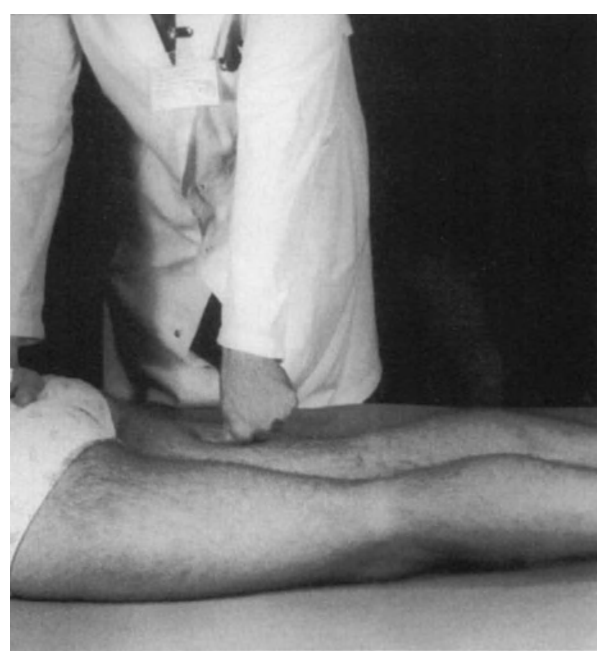


Fig. 8.23. *Pressure on certain points along the course of the sciatic nerve or its branches (Valleix's points) may cause or exacerbate radicular pain.*

the S1 nerve root, the buttock, the middle portion of the thigh, the central zone of the calf and the region of the Achilles tendon. Of these points, the most painful are those in the buttock, thigh and calf.

Pain on the Valleix's points is of little clinical value, since pressure on these points may produce discomfort also in subjects with no radicular involvement. This holds particularly for calf, which may be painful in the absence of any pathologic condition. However, in patients with disc herniation, Valleix's test is that most often positive after nerve-root tension tests. As such, it may be useful, when positive, to confirm the results of nerve-root stretch tests.

Popliteal region

The examiner performs the SLRT and, as soon as radicular pain appears, the patient's knee is allowed to flex and the foot to rest on the examiner's shoulder. Firm pressure is then applied with the thumbs on the popliteal nerve in the popliteal fossa (Fig. 8.24). The test is positive when the patient experiences radiated pain. In most cases, this is felt in the thigh and, very occasionally, the buttock or leg. The test is negative when pain is felt only in the popliteal fossa.

This clinical sign, described by Cram (13) as bowstring sign, is a good indicator of nerve-root irritation (60). However, it is positive in a minority of patients with disc herniation. Furthermore, it is often difficult to be certain that the test is truely positive and, if so, the degree of positivity.

Motor points

Pressure on motor points (in an electromyographic sense) of a few muscles of the lower limb may be painful in patients with pathologic disc conditions, as well as in subjects who have sustained spine traumas (36). Tender motor points are located in the myotomes innervated by the involved nerve root. Detection of these points may be useful in patients with involvement of high lumbar nerve roots, in whom the nerve-root tension tests and neurologic examination are often negative.

Maneuvers increasing CSF pressure

These maneuvers – Valsalva's test and prolonged jugular compression (2) – produce a slight increase in CSF pressure and, thus, some thecal sac distension, which causes both stretching of the nerve roots and distension

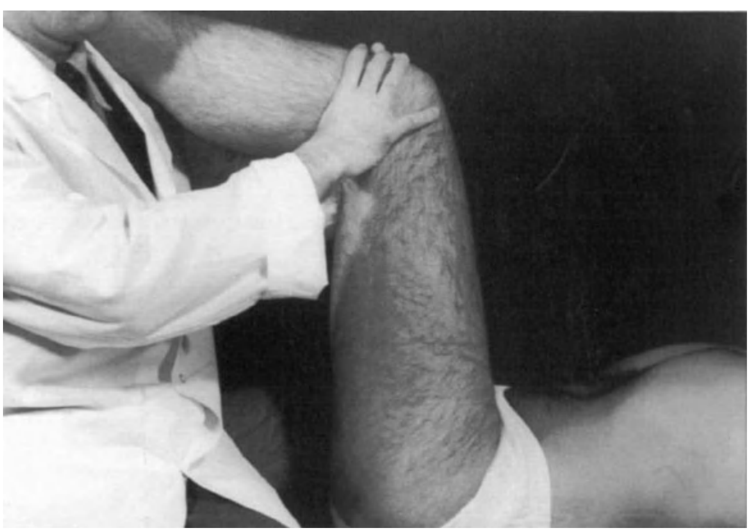


Fig. 8.24. *Bowstring sign.*

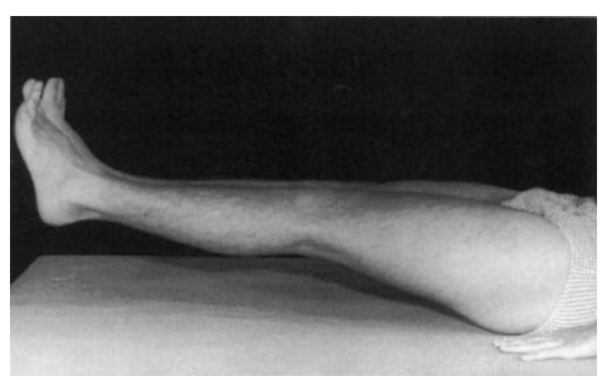


Fig. 8.25. *Milgram's maneuver.*

of the nerve-root sleeves. If a root is already tense, stretching and distension of the dural sleeve induced by the maneuver may produce further nerve-root compression, resulting in radiated pain. These maneuvers are rarely positive. Furthermore, their diagnostic value is quite limited, since they are generally positive in the presence of severe nerve-root compression, i.e., when also the common nerve-root tension tests are clearly positive.

Milgram's test

The patient, placed in the supine position, is asked to simultaneously raise, by about 5 cm, both lower limbs with the knee fully extended from the bed and to hold this position for at least 30 seconds (Fig. 8.25). The patient with disc herniation, or intradural conditions, is unable to hold this position on account of the immediate onset of lumboradicular pain, due to an increase in CSF pressure.

Foot flexion or extension

Forced plantar flexion (Sicard's test) or forced dorsiflexion of the foot (Roch's test) may exacerbate the radiated pain in patients with sciatica.

SLRT with only low back pain

SLR may produce only low back pain. This often occurs in patients complaining only of acute low back pain and, occasionally, in the presence of chronic back pain. In both instances, the cause of low back pain is often a disc disease, but rarely a herniated disc. The latter is usually located on the midline, thus impinging on the thecal sac, rather than the emerging nerve roots. However, even in this case, only occasionally does the patient experience pure low back pain; it is generally associated with at least mild radiated pain to the buttock or thigh.

The cause of pain in patients who have no disc herniation is unknown. It is presumably related to flexion of the lumbar spine as a result of flexion of the hip and, through this, of the pelvis, and / or stretching and possible reflex contraction of the paraspinal muscles due to raising of the limb. In patients with disc herniation, pain is probably produced by stimulation of nociceptors of the anterior wall of the dura mater (23), tractioned distally by stretching of the nerve roots induced by limb raising.

Muscle examination

Wasting

Severe nerve-root impairment, particularly if long-standing, may lead to wasting of the muscles innervated by the compressed nerve root. The muscles which, due to their volume and superficial position, may more easily show wasting are the glutei, quadriceps, tibialis anterior, peronei and triceps surae.

Wasting of the gluteal mass generally results from impairment of the S1 nerve root, since the latter supplies the gluteus maximus, which is the muscle contributing most to the volume of the buttock. Only rarely does the gluteal mass appear hypotrophic due to impairment of the L5 nerve root, which innervates the gluteus medius. Wasting of the glutei may be detected upon inspection, by asking the patient, placed in the prone position, to squeeze the buttocks tightly.

The quadriceps, on account of its multiradicular innervation, rarely shows overt wasting. This occurs almost exclusively for severe L4 nerve-root impairment or a moderate deficit of two or more upper lumbar roots. Hypotrophy of the quadriceps on one side may be detected either upon inspection, or by measuring the circumference of the thigh.

Tibialis anterior is the muscle which most frequently appears hypotrophic. This is due to the fact that, since this is a medium-sized muscle, its wasting can be better detected than that of the larger muscles, and the fact that it is electively supplied by the L5 nerve root, i.e., that most frequently presenting severe functional impairment. Similar considerations are valid for the peronei muscles. Wasting both of the tibialis anterior and the peronei is detected upon inspection, either with the muscle relaxed or in contraction.

The triceps surae may become hypotrophic due to functional impairment of the S1 nerve-root. However, wasting of the calf is not a frequent finding unless nerve-root compression is long-standing. Wasting may be detected upon inspection, as well as by measuring the circumference of the leg.

Strength

In patients with suspected disc herniation, the examiner should in theory evaluate the strength of all muscles both of the pelvic girdle and the lower limb. Evaluation of all these muscles, however, is usually unnecessary, for several reasons: 1) Almost all herniations are located in the three lower lumbar discs and, thus, evaluation of the mucles supplied by the L1 and L2 roots is generally useless. 2) A few muscles are more important than others from a diagnostic, as well as a functional, viewpoint. Many muscles, in fact, have multiradicular innervation with no clear-cut functional prevalence of one nerve root with respect to the others; they rarely become weak and only when one of the roots is very severely impaired, which, however, becomes evident due to severe weakness of the muscles electively innervated by the involved root. 3) The muscles supplied by a nerve root which determines a reflex that is easily elicited, such as the ankle jerk, may present weakness only if the reflex is reduced; examination of these muscles is thus superfluous if the reflex is normal.

Evaluation of muscle power may usually be made in two stages. The first is aimed at testing the muscles commonly involved in disc herniation, particularly those supplied by nerve roots which do not determine reflexes that are easily elicited; the aim is to diagnose nerve-root compression, as well as to detect the interspace involved and the severity of compression. The second stage is aimed at evaluating all, or the main, muscles supplied by a single root when this appears to be severely impaired, or at testing the muscles innervated by the upper lumbar nerve roots when the clinical data suggest possible involvement of these roots.

The muscles of the pelvic girdle and the lower limb may, therefore, be classified, in the evaluation of patients with disc herniation, as muscles of major, intermediate or minor importance.

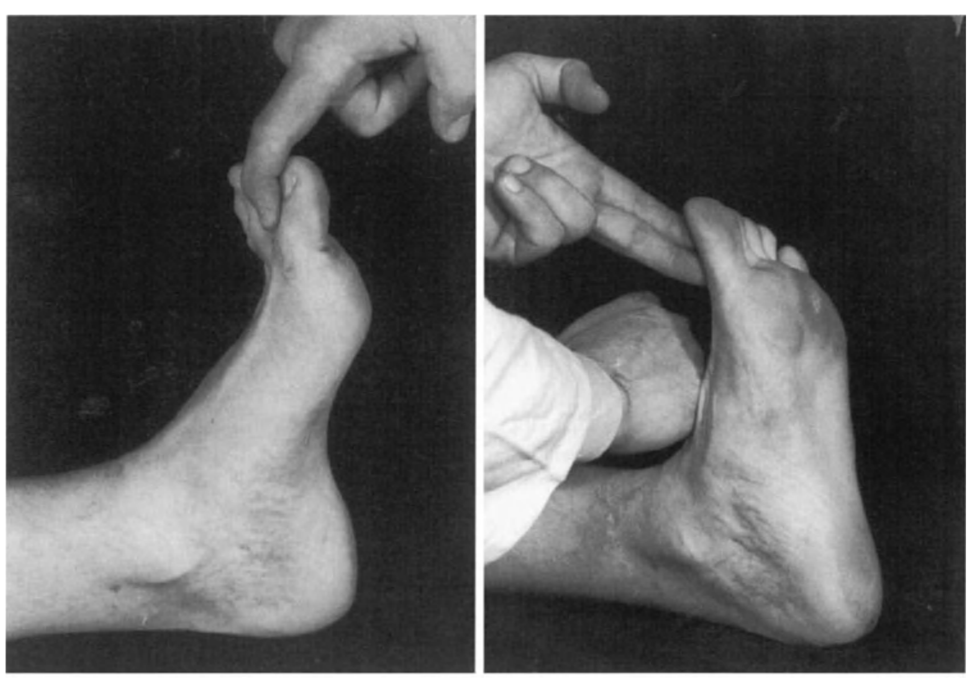
Muscles of major importance

These are the extensor hallucis longus, tibialis anterior, peronei, triceps surae, quadriceps and adductor muscles. These muscles are of paramount importance in the clinical evaluation due to the frequency with which they are involved, as well as the important diagnostic value of their functional impairment. It should be noted, however, that the quadriceps and triceps surae should, as a rule, be tested only when the knee and ankle reflexes, respectively, appear to be reduced. The adductor muscles should be tested only in the presence of a cruralgic syndrome.

Extensor hallucis longus

The extensor hallucis longus (EHL) is electively innervated by the L5 nerve root and is, thus, a reliable indicator of impairment of this root. Furthermore, since it is a small muscle, it is easy to detect an even slight decrease in its strength. The EHL, therefore, is of paramount importance from a diagnostic viewpoint and its weakness is one of the most classic signs of L4-L5 posterolateral or paramedian disc herniation.

The most common way of evaluating the strength of the EHL is for the examiner to stand at the end of the bed, ask the patient to extend the big toe and resist the



A B

Fig. 8.26. *Testing the strength of the extensor hallucis longus.* (A) *Incorrect technique. The examiner, standing at the patient's feet, resists the extension of the big toe with the index finger.* (B) *Correct technique. The examiner, positioned at the patient's side, resists foot dorsiflexion with one hand and big toe extension with one or two fingers of the other hand.*

extension with the forefinger (Fig. 8.26A); the maneuver may be performed on one side at a time or simultaneously on both sides. With this technique, one easily detects a marked weakness, but false findings, either positive or negative, are often obtained. False positives (strength assessed as decreased when it is, in fact, normal), because the patient is unable to develop the entire strength of which he/she is capable or because the examiner places his/her finger on the second phalanx, which may often be pushed down even in the absence of any weakness of the EHL. False negatives (strength assessed as normal when it is, in fact, reduced), when the force exerted with the forefinger is lower than that of the EHL; this may easily occur if the finger is placed too close to the metatarso-phalangeal joint.

The correct technique to test the strength of the EHL is to stand on the patient's right side, to resist foot dorsiflexion with the dorsum of the right hand and resist the extension of the big toe with the middle finger (which is stronger than the forefinger), or the index and middle fingers together, of the left hand. The examiner's finger(s) should be placed at the level of the interphalangeal joint of the big toe in an oblique direction with respect to the big toe itself, in order to develop more force (Fig. 8.26B). Both big toes should be tested while standing on the same side with respect to the patient. The greater efficacy of this technique is due to the fact that the simultaneous maximal contraction of the tibialis anterior enhances the contractile ability, and thus the strength, of the EHL, probably due to a mechanism of synergic reinforcement of the muscle contractile power. Furthermore, with this technique, the examiner is able to develop a greater force than with the previously described method and to more easily use the index and middle fingers together. It is, therfore, possible to detect an even very mild weakness of the EHL, whilst, not rarely, an EHL assessed as weak with the current technique may be found to be normal.

Tibialis anterior

In many charts depicting the radicular innervation of the muscles of the lower limb, the tibialis anterior (TA)

A B C D

Fig. 8.27. *Various methods of testing the strength of the tibialis anterior: with the patient in the prone position and the knee extended* (A); *by inviting the patient to raise the soles of the feet from floor* (B); *with the patient in the supine position and the knee flexed* (C) *or in the sitting position* (D). *The latter two methods are more sensitive.*

Fig. 8.28. *Testing of the strength of the peronei muscles.*

is supplied by the L4 and L5 nerve root. In effect, the TA is innervated almost exclusively by the L5 nerve root. Therefore, weakness of this muscle is, as a rule, the result of L5 nerve-root impairment. The TA is of primary importance in the evaluation of patients with herniation, since weakness of this muscle is a very reliable indicator of a severe deficit of the L5 nerve root, and the more marked the deficit, the greater the impairment.

Several techniques may be used to evaluate the strength of TA. One technique is with the patient supine and the knee fully extended (Fig. 8.27 A): the examiner asks the patient to dorsiflex the ankle as strongly as possible and then tries to push the foot down with the palm of his/her hand, against the patient's resistance. This maneuver, however, reveals TA weakness only if this is severe. Another method is to ask the patient, standing upright, to raise the soles of both feet from the ground (Fig. 8.27 B). This method does not allow precise quantitative evaluation of the weakness.

The test performed with the patient supine and the knee flexed at 30° is more sensitive (Fig. 8.27 C). In this position, the maximal strength that the muscle may develop is less than that developed with the knee extended. This not only allows detection of even mild weakness, but more readily reveals, compared to the maneuver with the knee extended, a moderate or marked weakness. Evaluation with the patient sitting on the edge of the bed is even more sensitive (Fig. 8.27 D): the pressure exerted by the examiner, which may accentuate the force of the hand by adding his/her own body weight, is also associated with the force of gravity, which further decreases muscle resistance.

Peronei

The peronei are predominantly innervated by the L5 root and may thus be weak in the presence of functional impairment of this root. It is possible, however, that the strength of these muscles is normal in the presence of severe weakness of the other two muscles – TA and EHL – electively innervated by the L5 root. On the other hand, it is possible, even if rare, that in patients with exclusively compression of the L5 nerve root, the peronei are considerably weaker than the tibialis anterior. This variability may be explained in several ways: existence of multiradicular innervation, with individual variations as far as concerns the contribution of the single nerve roots; anomalies of the furcal nerve; possibility that, due to the spatial relationship between the nerve root and the compressive agent, the fibers destined to a muscle may be compressed to a larger extent than others.

To test the strength of the peronei, the patient is asked to dorsiflex the foot and then to evert it against the resistance of the examiner's hand, who, at the same time, grasps the ankle with the opposite hand to avoid external rotation of the limb (Fig. 8.28). If the patient does not understand how to perform this maneuver correctly, the examiner may simply ask him to make a powerful external rotation of the limb while keeping the ankle in dorsiflexion.

Triceps surae

The triceps surae is electively supplied by the S1 nerve root and, to a lesser extent, the S2. Weakness of this muscle is pathognomonic of impairment of the first sacral root.

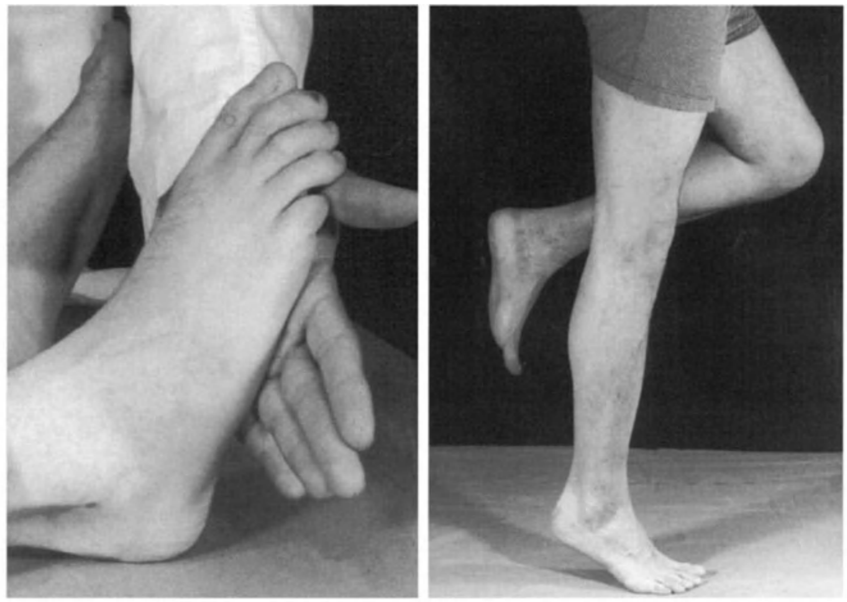


Fig. 8.29. *The strength of the calf muscles can be evaluated by resisting plantar flexion of the foot* (A) *or inviting the patient to rise on tiptoe on one side only* (B). *The maneuver in* (A) *is positive only when motor loss is extremely severe.*

Numerous textbooks report that the power of the triceps surae may be tested by resisting plantar flexion of the patient's foot with the hand (4, 34, 54, 56) (Fig. 8.29 A). This maneuver, however, will reveal weakness of the triceps surae only if it is extremely severe. The triceps, in fact, is able to develop a considerable strength, which, even if reduced, easily overcomes the resistance opposed by the examiner's hand.

The strength of the triceps surae should be tested by asking the patient to raise on tiptoe on the symptomatic side three or four times (Fig. 8.29 B). The maneuver is positive when the patient is unable to rise on tiptoe as high as on the asymptomatic side or is unable to raise the heel off the ground. The latter indicates a severe deficit of the S1 nerve root. An alternative method is to ask the patient to walk on tiptoes. This method, however, is less sensitive than the former and leads to less precise evaluation of the severity of muscle weakness.

The ability to rise on tiptoe should be evaluated only when the ankle jerk is absent. It is useless to carry out the maneuver if the reflex is only reduced, since, in this instance, muscle strength is never reduced to the extent that the test is positive. However, the test should be performed in patients with S1 radicular syndrome who show an absence of the ankle jerk on both sides. Bilateral absence of the reflex, in fact, since it may be physiologic or pathologic, does not allow us to determine whether the S1 root is impaired.

Quadriceps

The quadriceps is innervated by L2, L3 and L4 nerve roots, but predominantly by the latter. Weakness of the quadriceps is, therefore, found essentially in the presence of functional impairment of the L4 nerve root. A severe deficit of the L3 root may cause moderate or mild weakness of the quadriceps, whilst involvement of the L2 root does not usually lead to muscle weakness. However, even when the L4 root is involved, impairment has to be severe in order for weakness of the quadriceps to be detected clinically. This muscle, in fact, is so large and, thus, powerful, to make it difficult for the examiner to overcome muscle strength when the innervation is preserved to a large extent.

Evaluation of the strength of the quadriceps may be performed with the patient in the supine, sitting or prone position. The best is the prone position (Fig. 8.30), since it is easier for the examiner to resist the strength of the quadriceps; in fact, the more the knee is flexed, the less the strength exerted by the muscle.

Adductor muscles

The adductor muscles, which are predominantly innervated by the L3 nerve root, may be weak in the presence of marked compression of this root. These muscles are also innervated, in part, by the L2 and L4 nerve roots and may, thus, be slightly weak when these roots are impaired.

The strength of the adductor muscles is tested with the patient supine and hips and knees flexed, feet together, and limb externally rotated by about 40°. The examiner resists the simultaneous adduction of the

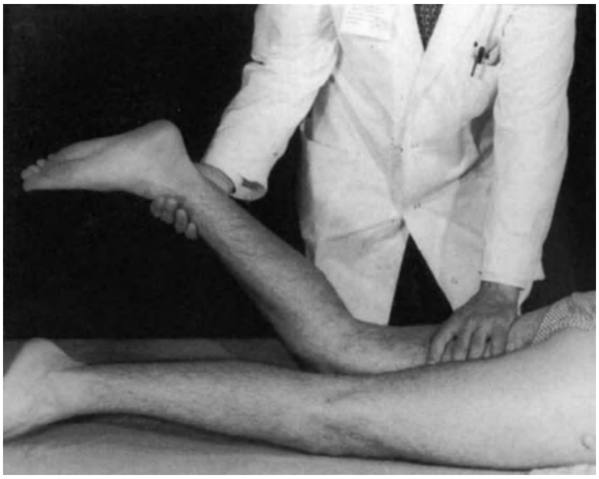


Fig. 8.30. *Testing of the strength of the quadriceps with the patient in the prone position.*

Fig. 8.31. *Evaluation of the strength of the adductor muscles. The patient is placed with the knees flexed, hips flexed and externally rotated, and feet together. The examiner resists adduction of the thigh.*

thighs (Fig. 8.31) or, preferably, of one thigh at a time, since in this way he may offer greater resistance to the movement.

Muscles of intermediate importance

These are the glutei, knee flexors, tibialis posterior, flexor hallucis longus and hip flexors. Examination of these muscles may help to determine the severity of nerve-root compression (glutei and leg flexors), to diagnose root impairment in the absence of other clinical signs (flexor hallucis longus) or to detect impairment of upper lumbar roots (hip flexors).

Glutei

The gluteus maximus is supplied by the S1, and also, in part, by the S2, nerve root. Muscle strength is tested with the patient prone, by resisting hip extension with the knee extended.

The gluteus medius is prevalently innervated by the L5 root. It abducts and internally rotates the thigh. Muscle strength is tested by resisting abduction and internal rotation of the hip with the patient in the lateral and prone decubitus, respectively. When the gluteus medius is very weak, the Trendelenburg test may be positive.

Weakness of these muscles of such severity that it can be detected clinically is rarely observed. It is usually an expression of marked impairment of the competent nerve roots.

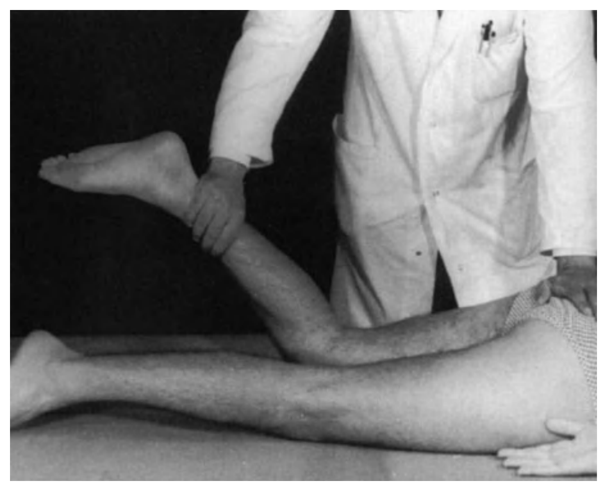


Fig. 8.32. *Maneuver to test the strength of the leg flexor muscles.*

Knee flexors

Knee flexor muscles – biceps femoris, semitendinosus, semimembranosus, gracilis, sartorius and gemelli – are supplied partly by the L5, and partly by the S1, nerve root. Therefore, functional disorders of one or other root may lead to decreased strength of knee flexion. This, however, usually results from L5 nerve-root impairment, and then only when this is severe. The best position to test the strength of knee flexors is with the patient prone. Their action is resisted with one hand placed proximally to the Achilles tendon (Fig. 8.32).

Tibialis posterior

This is prevalently innervated by the L5 nerve root. Muscle strength is evaluated with the patient supine, by grasping the leg with one hand just above the ankle and resisting adduction and supination of the foot with the opposite hand.

Flexor hallucis longus

This muscle is supplied by the S1 and S2 roots, but predominantly by the former. Since it is a small muscle, like the EHL, it is easy to detect its weakness, which may occasionally represent the only sign of impairment of the S1 root. The strength of the flexor hallucis longus is tested by resisting flexion of the big toe with the thumb or forefinger placed on the distal phalanx.

Hip flexors

Flexion of the thigh is carried out using several muscles: sartorius, iliopsoas, rectus femoris, tensor fasciae latae, pectineus. The former two, which are among the main hip flexors, are supplied by the L1 and L2 roots. Impaired function of these roots may cause decreased strength of hip flexion. A similar finding may also be observed, however, due to severe impairment of the L3 or L4 roots, on account of the large number of muscles and lumbar nerve roots involved in hip flexion. Power of these muscles may be tested with the patient in the supine or sitting position.

Muscles of minor importance

These muscles can be examined for complete evaluation of nerve root function, particularly in the presence of radicular paresis or paralysis. Except in these circumstances, it is usually unnecessary to test the strength of these muscles, since examination will usually be negative or will add little or nothing to the diagnostic work-up. Muscles of minor importance are the internal and external rotators of the hip, tensor fasciae latae, and flexor and extensor digitorum longus.

Deep tendon reflexes

Examination of deep tendon reflexes of the lower limb may allow us to identify the involved nerve root or to determine the severity of root impairment. The importance of this examination lies in the fact that alteration of reflex activity is the most objective clinical sign, since it is independent of the patient's effort or perception. A few reflexes of the lower limb can easily be detected and have a precise diagnostic significance. Others may be more difficult to elicit or are a duplicate of other reflexes and are, thus, of less value in clinical practice. The reflexes in the first group may be considered as "major" and should always be tested. Those in the second group, to be considered as "minor", may be disregarded at clinical examination or need to be tested only in particular circumstances.

The degree of reflex activity is an individual characteristic. In a few subjects the reflexes are highly excitable, whereas in others they are physiologically weak or absent. Low reflex activity may involve all the reflexes, only those of the upper or lower limb, or only a few reflexes of the limb. Often, in subjects with weak reflexes in the lower limb, those of the upper limb are also weak and most reflexes in the limbs are involved. In all cases, physiologic weakness of a reflex is symmetrical, that is bilateral and of similar degree on both sides. Physiologic weakness of reflexes in the lower limbs may be observed in young age individuals, but is far more frequent in senile age and, in this case, it concerns in particular the ankle jerk. In a prospective study (8) on 1074 asymptomatic subjects, bilateral absence of the ankle jerk was found in no subjects under 30 years and in only few subjects aged 30 to 40 years; in the successive decades, the frequency increased progressively with advancing age, reaching 80% between 90 and 100 years. Unilateral absence of the reflex was found in 3%–5% of subjects aged 40 to 60 years and in 7%–10% over 60 years.

In subjects with a constitutional weakness of the reflex activity, this may be facilitated with reinforcement maneuvers, such as that of Jendrassik. However, this maneuver, which is more efficacious in young than in elderly subjects, does not increase the reflex activity when this is reduced as a result of a pathologic condition.

A reflex, when it has decreased or disappeared due to pathologic conditions, very often remains depressed or absent for ever. In the examination of reflex activity, therefore, the patients clinical history should be taken into account.

The degree of reduction of reflex activity is strictly related to the severity of impairment of the root function. This holds until the reflex is lost. Beyond this degree of compromise, the reflex is no longer informative concerning the degree of root dysfunction. In other words, whilst a slight or moderate depression of the reflex corresponds to a slight or moderate radicular deficit, respectively, absence of reflex may correspond to variable degrees of root impairment, from moderately severe to complete.

To detect slight differences in reflex activity on the two sides, the same strength should be applied to the

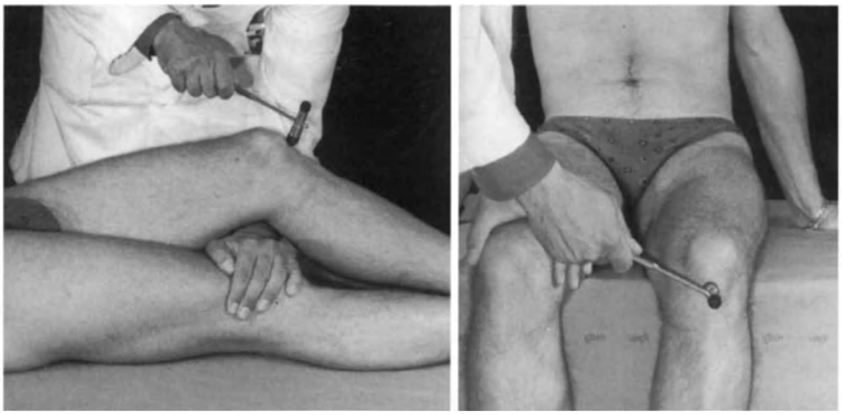
A  B

Fig. 8.33. *The patellar reflex can be elicited with the patient in the supine* (A) *or sitting* (B) *position.*

reflex hammer and the less the decrease in reflex, the less this strength should be. When the reflex is slightly depressed, in fact, a hard strike on the tendon may produce a normal response, whilst a slight tap may easily reveal the depression. Occasionally, it may be convenient to use the middle finger, or this and the ring finger together, to give the tendon slight taps which will better detect a mild decrease in reflex activity.

Major reflexes

Patellar

The patellar reflex depends on both the L3 and L4 nerve roots, however prevalently the latter. Thus, it easily becomes depressed due to impairment of L4 root conduction. When the L3 root is involved, the reflex is usually normal or decreased, and only very occasionally abolished.

The knee jerk can be elicited with the patient in the supine or sitting position. In the first instance, the examiner flexes the patient's knee to 40° by means of the left forearm placed under the thigh and elicits the reflex with the other hand when the quadriceps appears to be completely relaxed (Fig. 8.33 A). If reflex activity is weak, the degree of knee flexion is increased. When testing in the sitting position, the entire thigh should be comfortably on the bed to obtain full muscle relaxation (Fig. 8.33 B). To detect slight extension movements of the knee, it may be useful to grasp the leg with the left hand, while striking the patellar tendon with the right.

When reflex activity is normal in the supine position, it is useless to test the reflex also in the sitting position. This should be done, instead, when it is reduced. At times, in fact, the knee jerk appears depressed in the supine position, whilst it is normal in the sitting position. In these cases, the reflex activity should be considered as normal, since a knee jerk which is pathologically depressed will be the same in both positions. If the knee jerk cannot be elicited on both sides in the supine position, it should be tested in the sitting position with or without Jendrassik's maneuver.

Ankle

The ankle jerk, being produced exclusively by the S1 nerve root, is an indicator of the functional integrity of this root. The reflex can be elicited with the patient in various positions: supine, prone, sitting or kneeling (Fig. 8.34 A, B, C, D).

To test the reflex in the supine position, the examiner places the patient's knee in his armpit, keeping it immobile by clinching his arm; then, while he holds the foot by grasping the sole with one hand, with the other he elicits the reflex. A somewhat erroneous way of testing the ankle jerk is to grasp the foot without supporting the knee. In this instance, the patient cannot fully relax and it may thus be difficult to detect a slight depression of the reflex.

For testing in the sitting position, the patient's thighs should be slightly apart and entirely placed on the bed to obtain full relaxation of the extremities. The examiner grasps the sole of the foot with one hand whilst keeping the ankle at a right angle, eliciting the reflex with the other.

In the kneeling position, a chair should be used, so that the patient may fully relax by leaning his/her hands on the back of the chair.

The activity of the ankle jerk may change depending upon the position in which it is elicited. In a study on 210 patients with unilateral S1 radicular syndrome, the reflex activity was found to be affected, in one third of the cases, by the patient's position (85). In most cases, the reflex was normal, slightly depressed or moderately depressed in the supine, sitting or kneeling position,

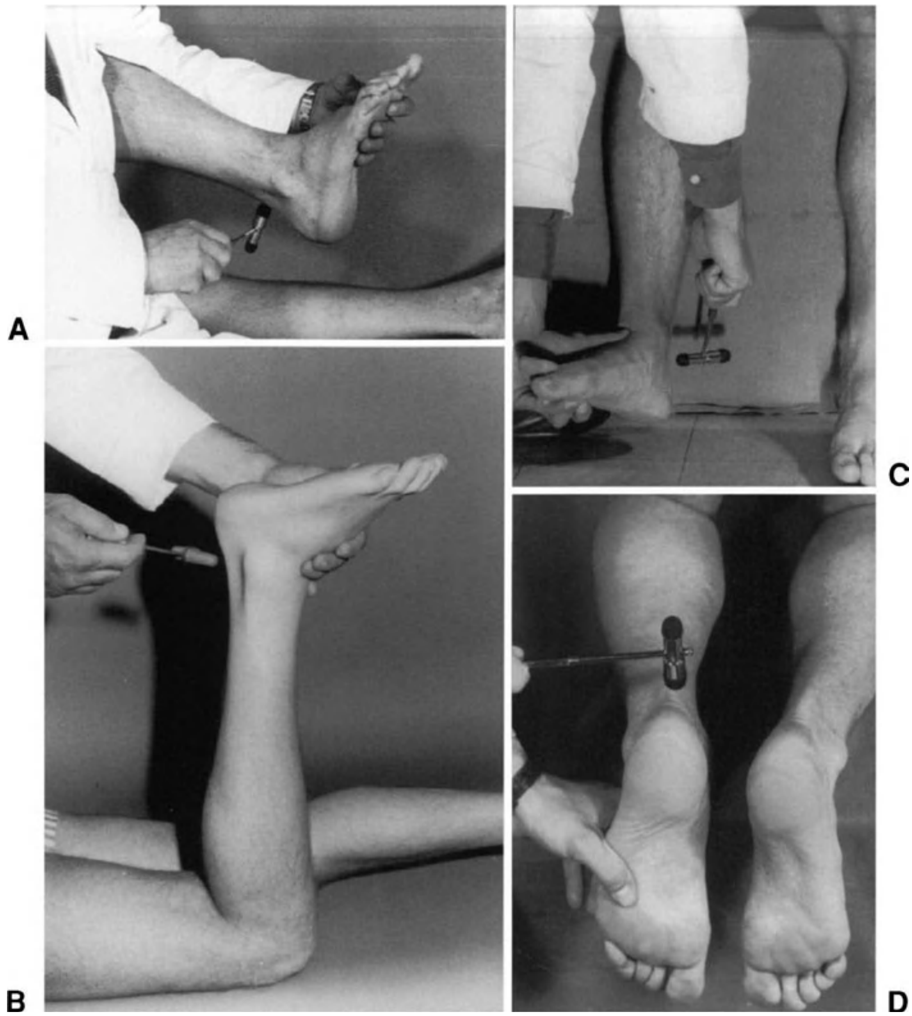


Fig. 8.34. *Ankle jerk elicited with the patient in the supine* (A), *prone* (B), *sitting* (C) *and kneeling* (D) *position.*

whilst it was, respectively, slightly depressed, markedly depressed or absent in the prone position; in other cases, it was uncertain whether the reflex was normal or reduced in the three positions, whereas it was clearly depressed in the prone position. After the latter, the sitting position was that in which the reflex was more often found to be depressed or absent. The most feasible explanation for the decreased activity of the ankle jerk in the prone position is that the normal reflex activity is slightly reduced in this position and, thus, a pathologic depression may become more marked. Yet another possibility is that the prone position, which allows full relaxation of the triceps surae, permits better assessment of even slight differences in the reflex activity on the two sides. This is likely to be the only reason for the changes in reflex activity in the sitting position compared with the other positions.

In patients with S1 radicular syndrome, the ankle jerk should first be tested in the supine position. If the reflex appears to be normal or slightly depressed, or it is uncertain whether it is normal or decreased, examination should be repeated in the prone position, in which the reflex may easily be found to be depressed or more severely depressed. If, in the latter position, it still appears normal or there is some uncertainty, it may be useful to test also in the sitting position.

Minor reflexes

Adductor

This reflex is elicited by striking the adductor magnus muscle at the level of the adductor tubercle with the patient in the supine position, the hip externally rotated and the knee flexed (Fig. 8.35). It may be reduced or

Fig. 8.35. *Technique of eliciting the adductor reflex.*

absent due to impairment of the L3 nerve root. This reflex, however, is of relatively little diagnostic value since in many subjects it is physiologically weak, and moreover because the L2 and L4 roots, which also supply the adductor muscles, may preserve reflex activity in the presence of L3 nerve-root impairment.

Midplantar

This reflex, depending on the S1 root, is elicited by striking the sole of the foot with the patient in the supine or prone position. It has a similar clinical significance to the ankle jerk. Compared with the latter, the midplantar reflex is less sensitive, in the sense that it is more difficult to detect a slight or moderate depression. Thus, testing of this reflex is of little use in clinical practice.

Tibialis posterior

This reflex may be elicited by striking the tendon of the tibialis posterior muscle close to its insertion on the navicular bone. The reflex may be reduced or absent due to impairment of the L5 nerve root. However, this reflex is of little diagnostic importance, since it is difficult to elicit and its pathologic absence is always associated with weakness of at least the extensor hallucis longus, which, in itself, clearly indicates L5 nerve-root impairment.

Extensors of the big toe

These include the reflexes of the extensor apparatus, the extensor hallucis longus, and the extensor hallucis brevis (95). These reflexes may be impaired due to L5 nerve-root dysfunction. The examiner can test them by placing the patient's foot in plantar flexion and slight supination, and striking his/her index finger applied on: 1) the distal end of the first phalanx of the big toe, pushed in slight plantar flexion (extensor reflex); 2) the tendon of the extensor hallucis longus (identified by asking the patient to dorsiflex the big toe against resistance) proximally to the ankle; 3) the extensor hallucis brevis on the dorsum of the foot.

Superficial reflexes

In patients with lumbar degenerative conditions, it may be useful to test the superficial reflexes for differential diagnosis with pathologic conditions of the cord. To this end, the main reflexes are the abdominal, cremasteric, anal wink and plantar reflexes.

The spinal centers of the abdominal reflexes – epigastric, mesogastric and hypogastric – are located in the thoracic cord. These reflexes are elicited by rapid scratching on the skin of the abdomen. The response is contraction of the muscles of the abdominal wall on the side of stimulation or, occasionally, on both sides. These reflexes may be abolished in the presence of lesions of the gray medullary matter or the pyramidal tract.

The cremasteric reflex, the medullary centers of which are in the L1 and L2 myelomeres, consists in raising of the testicle as a result of contraction of the cremasteric muscles, when scratching on the skin of the medial aspect of the upper one third of the thigh. The reflex may be absent unilaterally due to L1 or L2 root impairment.

The spinal centers of the anal wink are located in the S2-S5 myelomeres. It is elicited by scratching on the perianal skin, which leads to reflex contraction of the anal sphincter. The reflex may be abolished due to impairment of the S2-S5 nerve roots.

The plantar reflex, the spinal center of which is situated in the S1 and S2 myelomeres, is among the most reliable indicators of lesions of the pyramidal tract. The cutaneous reflexes of Oppenheim or Chaddock and other proprioceptive reflexes, such as Giordano's or Schaefer's reflexes, are of similar significance to that of the plantar reflex.

Sensory examination

Superficial sensitivity

In most patients with lumbar disc herniation, testing of cutaneous sensitivity is, in a certain way, of secondary importance in physical examination for several reasons: 1) Sensory loss can be detected in a minority of patients and these usually present motor loss or reflex changes, which, in themselves, allow diagnosis of nerve root compression, and often also of the level of compression. 2) Sensory examination represents the most subjective part of the physical examination, which, on the other hand, is seeking data as independent as possible from the patient's will. As such, the sensory examination may provide findings of uncertain interpretation, particularly when sensory impairment is mild. 3) The dermatomes of the lower limb show a certain degree of overlapping and there may be anatomic variations in dermatomal topography within the population. This implies that sensory loss resulting from impairment of nerve-root function may not be clinically manifest due to the functional integrity of adjacent roots or the sensory deficit is comparatively less than the nerve-root impairment, and that sensory examination is not entirely reliable for identification of the level of the herniation.

Sensory examination is, instead, of paramount importance in two situations: in the presence of severe motor and sensory loss, which may fail to recover with treatment and should, thus, be accurately documented prior to management; and in the presence of a cauda equina syndrome, in which there may be severe sensory loss, particularly in the perineum and genitals, in the absence of, or with mild, motor loss in the lower limbs.

Of the three forms of cutaneous sensation – tactile, painful and thermic – those commonly tested are the former two, particularly the second, since they are more sensitive and easier to examine. The cutaneous areas in which the innervation depends prevalently or exclusively upon a single nerve root are the outer border of the dorsum of the foot and the fifth toe (S1), the big toe and the adjacent portion of the dorsum of the foot (L5), and the anteromedial aspect of the leg (L4). We may also add to these, the medial aspect of the knee, innervated less electively, but to a large extent, by the L3 root and the perianal region, supplied by the S3-S5 roots, which are usually involved together. Only these areas should be examined if sensation is found to be normal or slightly reduced; conversely, when the sensory deficit is severe, the whole dermatome(s) corresponding to the root(s) involved should be examined.

Deep sensitivity

The form most often affected in patients with lumbar disc herniation is vibratory sensation, which is tested by placing a vibrating diapason on bony surfaces. The areas to examine are the lateral malleolus and the fifth metatarsus (S1), the medial malleolus and the first metatarsus (L5), and the patella and femoral condyles (L4). Changes in vibrating sensitivity, however, are found in a minority of patients with disc herniation. Thus, the examination is of little use in the diagnosis either of nerve-root compression, or the level of compression.

In the presence of severe superficial sensory loss, there may be an impairment in deep tactile or pain sensitivity.

Neurovegetative disorders

Dysfunction of the fibers of the neurovegetative system contained in the posterior roots manifest with circulatory distrurbances, which may be responsible for cutaneous hypothermia and edema in the lower limb. Hypothermia, which subjectively results in a sensation of coldness in the dermatome involved, usually affects the leg and foot. It is usually found in the presence of severe deficit of the L5 or S1 roots.

Edema in the lower limb is a rare, but not exceptional, finding in patients with disc herniation. It is usually located in the foot and ankle and, less frequently, in the leg. A role is played, in its etiology, not only by impairment of the neurovegetative system, but also by muscle deficit, due to the reduced pump action exerted by the venous system on hypotonic muscles. This may explain why edema is usually found in patients with severe motor loss.

Clinical syndromes

Lumbar disc herniation may be responsible for pure low back pain, neuroalgic or neurocompressive syndromes, or cauda equina syndrome. These clinical syndromes correspond, although not strictly, to progressively more severe degrees of compression of the nervous structures. In a single patient, clinical symptomatology may start with any of these syndromes and may remain unchanged over time, or signs and symptoms indicating a progressive increase in nerve-root involvement may appear.

Pure low back pain syndrome

In most patients, the clinical onset of lumbar disc herniation manifests with low back pain, to which, with time, radicular symptoms become associated. In some cases, however, low back pain with the features of discogenic pain remains the only symptom.

No clinical feature is able to identify, among patients with pure low back pain, those with a herniated disc. Suspicious elements are the marked severity of pain, its long duration (more than 3 weeks), persistent postural scoliosis and the patient's report of pain radiating to the buttock.

Neuroalgic syndrome

This syndrome corresponds to that known as nerve-root irritation syndrome (56, 60). It is characterized by radicular pain, and often paresthesias, in the absence of clinical evidence of an impairment of nerve-root function. In patients with disc herniation, the main cause of radicular pain is likely to be nerve-root compression by the herniated disc. The neuroalgic syndrome, therefore, should also be considered as a root compression syndrome, even if the severity is so mild that it does not determine any neurologic deficit. Distinction of the two types of syndrome, however, is useful from a practical point of view, since the neuroalgic syndrome is mostly caused by a small contained disc herniation, whilst the neurocompressive syndrome often corresponds to more marked invasion of the spinal canal by the herniation and more severe nerve-root compression. Furthermore, the former condition has a marked tendency to resolve spontaneously, whereas the latter is generally characterized by more severe symptoms and shows less tendency to spontaneous regression.

In patients with a neuroalgic syndrome, radicular pain often radiates to the cranial portion of the dermatome supplied by the involved nerve root. Furthermore, pain may decrease or disappear on walking, unlike in patients with marked nerve-root compression. Only occasionally do patients report numbness, and paresthesias, when present, are often mild and discontinuous. Nerve-root tension tets are usually slightly or moderately positive.

Neurocompressive syndrome

This syndrome is characterized by very mild to extremely severe impairment of nerve-root function. A few authors (33, 56) identify two syndromes, characterized by partial nerve-root deficit or root paralysis, respectively. In our opinion, this distinction is unnecessary, since the two syndromes represent different grades of the same clinical condition and, on the other hand, it is exceedingly rare for a herniated disc to cause complete loss of nerve-root function.

One or more caudal nerve roots may be impaired. Usually, in the latter instance, two contiguous nerve roots on the same side are affected. In most of these cases, the functional deficit of one root is severe, whilst that of the other is mild or moderate. This is almost the rule when nerve roots on both sides are involved.

All components of the nerve root – motor, sensory and sympathetic – or only one or two components may be affected. Impairment of the motor component leads to a decrease or loss in reflex activity and reduced strength of only a few, or all muscles, supplied by the root. In the presence of marked compression of long duration, wasting of muscles innervated by the root may be present.

In patients with a compressive syndrome, there is a tendency for the greater the nerve-root compression, the more marked the motor and sensory deficit. This, however, is not the rule. Even very large herniations may produce a less severe deficit than that caused by a small disc fragment migrated into the spinal canal. Similarly, there is no direct relationship between intensity of radicular pain and severity of nerve-root compression.

When the impairment of nerve-root function becomes very severe, radiated pain may decrease and even disappear due to functional interruption of the fibers of pain sensitivity. At the same time, sensory deficit increases, whilst the nerve-root tension tests tend to become negative.

Grades of nerve-root compression

Based on clinical features, four grades of nerve-root compression, corresponding to increasing degrees of root impairment, may be identified.

Grade I. If the root innervates a reflex, this is decreased but not abolished. When the root supplies both small and medium-size or large muscles (for instance, EHL, tibialis anterior and triceps surae, respectively), the former show mild weakness, whilst the latter displays normal strength. There may be sensory loss, but only in narrow, distal areas of the dermatome. The severity of radicular pain varies considerably.

Grade II. When the nerve root produces a reflex, this is abolished. The strength of small muscles is moderately decreased, whilst that of medium-size or large muscles is slightly decreased or normal. Numbness may be more marked than in Grade I, but still located in a narrow area. Radicular pain is generally severe.

Grade III. Even large-size muscles show moderate or marked weakness. Numbness may be present in a large area of the involved dermatome. The patient may complain of a sensation of cold, and skin temperature may be slightly decreased, in the distal portions of the dermatome.

Grade IV. This corresponds to a very severe impairment of root function or root paralysis. There is severe to complete loss of strength of all muscles supplied by the root and marked hypoesthesia or anesthesia in a large area of the dermatome involved. Skin temperature is decreased. When the L5 or S1 nerve roots are affected, there may be edema in the foot and ankle. Radicular pain is mild or absent.

Cauda equina syndrome

According to the classic description, this syndrome is characterized by multiple nerve-root compression responsible for pain, bilateral motor and sensory loss in the lower limbs, saddle anesthesia and bladder and bowel dysfunction, to which sexual dysfunction may be associated (16, 43). This condition with massive paresis or paralysis of the caudal nerve roots, including S3, S4 and S5, which supply the bladder, rectum and genital organs, is, in effect, exceedingly rare. A more widely accepted definition considers as cauda equina syndrome any condition characterized by signs and symptoms of compression of one or more roots innervating the lower extremities and by bladder dysfunction (52, 62). Therefore, disorders in micturition are the necessary and sufficient condition for a lumboradicular syndrome to be considered a cauda equina syndrome. Thus defined, this condition is rare, however not exceptional.

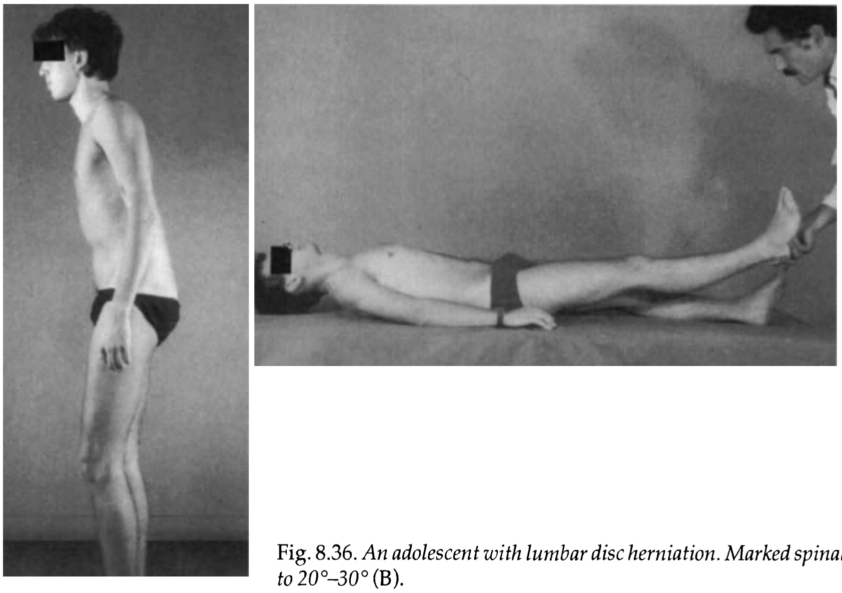
Cauda equina syndrome may occasionally manifest only with bladder dysfunction (22). In the most common form, the syndrome is characterized by unilateral or bilateral radicular pain, severe motor and / or sensory deficit of one or more nerve roots (excluding the S3-S5 roots), saddle hypoesthesia or anesthesia and bladder dysfunction, usually represented by urinary retention. Disturbance of bowel function, which is less common than bladder dysfunction, consists in constipation due to paresis or paralysis of the rectal smooth muscles. Sexual dysfunction is fairly frequent. In the male, it consists in difficulty in initiating or maintaining an erection, or impotence. In the female, it is essentially related to sensory loss in the labbra and vagina, which may present paresis or paralysis of the constrictor muscles.

Tandon and Sankaran (94) have identified three groups of patients with cauda equina syndrome: Group I, those with a sudden onset of the syndrome in the absence of previous lumboradicular symtoms; Group II, patients with recurrent episodes of lumboradicular pain and sudden appearance of the syndrome during the last episode; Group III, patients with a slow and progressive manifestation of the syndrome. Kostuik et al. (52) have identified only two groups, one of which includes patients with an acute syndrome and, the other, those with a slow onset, over a few days or weeks. The latter represented two thirds of the 31 reported cases. Almost half the patients had been treated in a same hospital and represented 2.5% of patients with disc herniation operated in that hospital in the period under consideration. In the vast majority of cases, herniation was located at L4-L5 or L5-S1 level. One fourth of patients showed a large contained herniated disc, whilst the others presented migrated herniation. All patients presented with urinary retention and one third also had sexual dysfunction. Just over half the patients complained of unilateral radicular pain; a similar proportion presented saddle sensory loss, consistently associated with a decrease in anal sphincter tone.

Clinical features in adolescents

Adolescents usually complain of mild or moderate low back pain, whereas radicular pain is mostly severe, even if often limited to the buttock or thigh. Severe paraspinal muscle spasm is present, which may be responsible for such a degree of spinal rigidity as to allow the patient to bend forwards only a few degrees (Fig. 8.36 A). In the upright position, there may be postural scoliosis, however this is rarely marked. The SLR is often limited to 20°–30° (Fig. 8.36 B) and, in most cases, the limb can hardly even be raised beyond 40° without the patient raising the hemipelvis. In many patients, no muscle weakness or depression of the reflex activity is found, even in the presence of considerable nerve-root tension (9, 11, 41, 55, 59).

In most adolescents with lumboradicular symptoms, the clinical picture is so typical as to allow diagnosis of disc herniation, or at least of nerve-root compression, on the basis of two features: the marked limitation of trunk flexion and positivity of the SLRT. However, it is often impossible to determine the level of herniation from the clinical data either because pain is absent or shows no



A B

Fig. 8.36. *An adolescent with lumbar disc herniation. Marked spinal rigidity is present* (A) *and the SLR is limited to 20°–30°* (B).

clear-cut distribution distally to the knee, or due to the lack of sensory and/or motor deficits. In almost all cases, however, the herniated disc is the last or the next to the last (15, 24, 55). A similar clinical picture to that described above may also be observed in 20- to 30-year-old subjects, whilst it is very rare in older patients.

Clinical features in the elderly

In elderly subjects (aged 65 years or over), the clinical features are often considerably different from those in younger patients. In the elderly, low back pain tends to be milder and rarely has the typical features of discogenic low back pain. Trunk flexion is often normal or only slightly decreased. Similarly, nerve-root tension tests may be negative or slightly positive, even in the presence of marked nerve-root compression. In the elderly, therefore, diagnosis of nerve-root compression may be more difficult than in the younger patient. This is also due to the fact that the ankle, and at times also the knee, jerk may be bilaterally absent due to physiologic depression of the reflex activity.

The mildness of low back pain in the elderly, compared with the young subject, may be due to the more severe degenerative changes in the disc. This may involve either less pressure of the nucleus pulposus on the peripheral portion of the annulus fibrosus, or greater chances for the herniation to become extruded or migrate into the spinal canal. Slight positivity of the nerve-root tension tests might be related to increased pain threshold or lesser muscle spasm due to reduced contractility of paraspinal or hamstring muscles.

Radicular syndromes (Table 8.2)

L1

Isolated involvement of the L1 nerve root is so uncommon that the clinical syndrome of compression of this root is almost unknown. Pain and sensory disturbances are located in the iliac crest, the iliac fossa and/or the groin (29, 31). In Grade III and IV neurocompressive syndromes, the strength of hip flexion may be decreased (34).

L2

Pain is usually located along the lateral or anterolateral aspect of the thigh. Alternatively, it is felt in the proximal part of the anteromedial region of the thigh. In the same areas, there may be paresthesias, as well as numbness, in the presence of severe root dysfunction. In Grade I and II neurocompressive syndromes, there is no motor deficit or only a slight decrease in strength of hip flexion. In Grade III and IV, the strength of hip flexion is moderately or severely decreased, and mild weakness of the quadriceps may be present (31). The adductor reflex may be depressed.

L3

Pain is usually located in the anteromedial aspect of the thigh; in a few cases, it is also or only felt in the area of the groin or the knee. Occasionally, the patient experiences pain in the anteromedial region of the thigh.

Table 8.2. *Symptoms and signs in L2-S2 radicular syndromes.*

	L2	L3	L4
Pain	Anterolateral aspect of thigh	Anteromedial aspect of thigh	Anterior aspect of thigh
Sensory impairment	Lateral aspect of thigh	Medial aspect of knee	Pretibial region
Muscle weakness Quadriceps	Hip flexors	Thigh adductors Quadriceps	
Reflexes decreased	Adductor	Adductor Patellar	Patellar
	L5	**S1**	**S2**
Pain	Posterior aspect of thigh, lateral aspect of leg	Posterior aspect of thigh and leg	Posterior aspect of thigh
Sensory impairment	Lateral aspect of leg, big toe	Outer border of foot, heel, sole of foot	Posterior aspect of thigh
Muscle weakness	EHL Tibialis anterior	Triceps surae Gluteus maximus	Interossei, Flexors of toes
Reflexes decreased	Tibialis posterior	Ankle Midplantar	–

Paresthesias are usually felt in the knee, particularly in its medial aspect. In this area, there may be numbness, which may also extend to the anteromedial aspect of the thigh, when nerve-root impairment is severe.

In Grade I neurocompressive syndromes, the adductor reflex can be, at the most, decreased, whereas in Grade II syndromes the reflex is generally absent. In Grade III syndromes, the adductor muscles are moderately or markedly weak, the knee jerk may be reduced and, at times, the quadriceps is slightly weak. Grade IV syndromes are characterized by severe weakness of the adductor muscles; the strength of the quadriceps is moderately decreased.

L4

Pain is generally felt in the anterior aspect of the thigh and, occasionally, extends to the pretibial region. A few patients complain of pain also, or only, in the lateral aspect of the thigh and others only in the knee or the area of the tibial crest.

Paresthesias are located in the pretibial region and, occasionally, the anterolateral aspect of the thigh. Numbness is felt in the proximal half of the pretibial region and, when root compression is severe, also the anterior aspect of the thigh may be numb.

In Grade I neurocompressive syndromes, the knee jerk is decreased, but no motor loss is present. In Grade II syndromes, the patellar reflex is absent and, occasionally, the quadriceps is slightly weak. Grade III syndromes are characterized by moderate or severe weakness of the quadriceps. Patients with a Grade IV syndrome show severe weakness or paralysis of the quadriceps, to which a motor deficit of varying severity of the adductors, hip flexors and abductors (tensor fasciae latae and gluteus medius), and tibialis anterior may be associated.

L5

In most patients, pain radiates down the posterior or posterolateral aspect of the thigh and lateral aspect of the leg. Pain may be felt in the entire dermatome or only in part of it, for instance, the outer aspect of the leg or the area above the external malleolus. Severe pain only in the latter site is almost pathognomonic of compression, often severe, of the L5 root. A few patients complain of pain in the area of medial gastrocnemius or, less frequently, down the tibial crest or the medial aspect of the leg.

Paresthesias are frequent and are generally located in the outer aspect of the leg and/or the big toe or the whole first ray. In the same sites, but particularly in the big toe, there may be sensory loss.

In Grade I neurocompressive syndromes, only the strength of the EHL is decreased. In Grade II syndromes, also the tibialis anterior and/or the peroneal muscles are slightly weak and the tibialis posterior reflex is abolished. In Grade III syndromes, moderate or severe weakness of the tibialis anterior, peronei and tibialis posterior is found; often, also the gluteus medius and the leg flexors are weak and, in cases of long-standing root compression, wasting of the tibialis anterior and peronei muscles can be observed. In Grade IV syndromes, foot drop is present and the Trendelenburg test may be positive.

S1

Pain radiates to the posterior aspect of the thigh and leg. Many patients with S1 syndrome, however, complain of pain in the posterolateral aspect of the leg, along the lateral head of the gastrocnemius. When only part of the dermatome is involved, this usually is the median posterior aspect of the thigh and calf. Occasionally, pain is located on the lateral, or rarely, the medial, aspect of the leg.

Paresthesias affect the calf and the outer border of the foot. The most frequent sites of numbness are the little toe and the outer border of the foot, followed by the heel, sole of foot and calf.

In patients with Grade I neurocompressive syndrome, the ankle jerk is reduced and the flexor hallucis longus may be slightly weak. In Grade II syndromes, the ankle reflex is absent, but the large muscles supplied by the root show no weakness. Grade III syndromes are characterized by moderate or marked weakness of the triceps surae and gluteus maximus, which may be clearly hypotrophic; the strength of the knee flexors may be moderately decreased. Already at this stage, the patient's gait may be abnormal due to inability to raise the heel from the ground. In Grade IV syndromes, active plantar flexion and hip extension are extremely weak or abolished, and there is marked hypoesthesia or anesthesia in the calf and sole of the foot.

S2

This nerve root is an ancillary of the S1 root. It supplies the skin of the posterior thigh and the same muscles innervated by the S1 root, playing a complementary role to the latter. The only muscles supplied predominantly by the S2 root are the intrinsic muscles of the foot and toe flexors (34).

Pain and sensory disorders are located in the posterior region of the thigh. In Grade III and IV neurocompressive syndromes, moderate or severe weakness of the intrinsic muscles and flexors of the toes is found and the muscles prevalently supplied by the S1 root may show slightly weak.

S3, S4, S5, Co.

These closely contiguous roots are usually involved simultaneously.

The patient may experience pain in the scrotum, labbra or perianal region, however this rarely occurs. Involvement of these roots usually produces saddle hypoesthesia or anesthesia and may be associated with the bladder, bowel and sexual dysfunction which characterizes the cauda equina syndrome. When impairment of root function is marked, the tone of the anal sphincter is reduced and the anal wink reflex is abolished.

Syndromes due to herniation of the three lowest lumbar discs

Herniation of a single lumbar disc may impinge on different nerve roots depending both on the site where the protrusion develops or a disc fragment migrates, and the size of the protrusion or the migrated fragment. Herniation of a single disc may, therefore, produce different clinical syndromes, each of which may be caused by disc herniation at an adjacent interspace.

L3-L4 Disc

Midline herniation

If the herniated disc is small, only low back pain will be present. When herniation is large, multiple nerve roots are involved, which results in clinical syndromes of various types and severity, ranging from unilateral neuroalgic L4 and/or L5 syndrome to cauda equina syndrome with neurologic disorders in both limbs. The most common is a bilateral cruralgic or sciatic syndrome, occasionally associated with intermittent claudication, with signs of a slight dysfunction of the L4, L5 or S1 roots, on one or both sides.

Paramedian herniation

Clinical syndromes are generally biradicular (L4 and L5) or triradicular (L4, L5 and S1). There are different types of syndrome, but usually the L4 root is that most affected and shows a mild or moderate deficit, whilst the L5 or S1 syndrome are Grade I neuroalgic or neurocompressive.

Posterolateral herniation

Herniation in this site may cause a pure L4 syndrome, particularly in the presence of a small disc fragment migrated into the nerve-root canal, or a combined L4 and L5 syndrome. Usually, the latter is a Grade II or III neurocompressive syndrome as far as concerns the L4 root and neuroalgic or Grade I or II neurocompressive syndrome as far as concerns the L5 root.

Intraforaminal herniation

This herniation produces a pure L3 syndrome, which may be only neuroalgic, if herniation is contained, or neurocompressive with motor and sensory loss of varying severity, when a disc fragment has migrated into the intervertebral foramen. Occasionally, the L4 root may also be mildly involved. Based on the clinical features, however, an L3 syndrome is often indistinguishable from an L4 syndrome. Physical examination usually demonstrates involvement of only upper lumbar nerve roots.

Extraforaminal herniation

Extraforaminal herniation is consistently responsible for a pure L3 syndrome, generally characterized by mild or moderate root dysfunction.

L4-L5 Disc

Midline herniation

A small or medium-size herniation may be responsible for low back pain alone or an L5, and occasionally also S1, unilateral or bilateral neuroalgic syndrome. A larger herniated disc usually causes an L5 neurocompressive, and S1 neuroalgic, syndrome in one or both extremities. When both limbs are affected, signs and symptoms usually prevail on one side. Cauda equina syndrome rarely occurs.

Paramedian herniation

Depending on the size of the herniation, there can be an L5 neurocompressive, and an S1 neuroalgic, syndrome, a combined L5 and S1 neurocompressive syndrome or, rarely, an S1 neurocompressive, and L5 neuroalgic, syndrome.

A combined L5 and S1 neurocompressive syndrome, caused by a paramedian herniation or a disc fragment migrated in the axilla of the L5 root, is usually characterized by pain in the L5 dermatome or, less frequently, L5 and S1 dermatomes, moderate or severe motor deficit of the L5 nerve root and depression or absence of the ankle jerk, occasionally associated with weakness of the triceps surae. This type of syndrome should lead us to suspect, first of all, nerve-root compression at L4-L5 level. Only rarely, in fact, is it produced by discal or non-discal pathologic conditions at other levels.

Posterolateral herniation

Usually, a syndrome of irritation or compression of the L5 nerve root alone is found. A large contained herniated disc may cause an L5 neurocompressive syndrome and an S1 neuroalgic syndrome due to intrathecal compression of this root. Conditions of a more severe deficit of the L5 root are observed in patients with a disc fragment migrated into the nerve-root canal. When the fragment is located in the nerve-root axilla, there can be a combined L5 and S1 neurocompressive syndrome.

Intraforaminal herniation

The L4 nerve root may be involved either alone or together with the L5 root if the disc protrudes also posterolaterally. In this instance, a neuroalgic or Grade I neurocompressive syndrome is observed. When the herniation is contained, the L4 syndrome may be neuroalgic or, more often, neurocompressive of Grade I or II. In the presence of a disc fragment migrated into the neuroforamen, a neurocompressive syndrome is consistently present, which is usually of Grade II or III.

Irrespective of the pathologic condition, the clinical picture is characterized by mild or no low back pain and severe radicular pain, particularly at the onset of symptoms. These features, in the presence of an L4 syndrome, should lead us to hypothesize, first of all, an intraforaminal L4-L5 herniation, which is certainly a more frequent condition than L3-L4 herniation.

Extraforaminal herniation

This is characterized by a pure L4 syndrome, which is usually of the Grade I or II neurocompressive type. Severe nerve-root compression, as easily occurs in intraforminal herniations, is rarely observed. This is due to the fact that an extraforaminal herniation is usually contained and the nerve root can more easily escape compression than in the presence of a herniation within the neuroforamen.

L5-S1 Disc

Midline herniation

Midline herniation may cause pure low back pain or a unilateral or bilateral S1 compressive syndrome, depending on the size of the protrusion or the possible presence of a migrated disc fragment. When both limbs are affected, both the pain and the motor and sensory deficits prevail on one side. A large midline herniation may cause a cauda equina syndrome.

Paramedian herniation

The clinical syndrome is similar to that produced by a posterolateral herniation. The only difference is that a large paramedian herniated disc may impinge on the lowermost sacral roots (S3-S5) and cause pain in the scrotum and sensory impairment in the perineum and genitals.

Posterolateral herniation

Herniation in this site produces an S1 neuroalgic syndrome or a neurocompressive syndrome of varying severity. This holds also when a migrated disc fragment impinges on both S1 and S2 nerve roots. The clinical syndrome resulting from compression of the two roots, in fact, is usually indistinguishable from that due to compression of only the S1 root.

Intraforaminal herniation

Usually, there is a migrated disc fragment in the neuroforamen. In most cases, therefore, the patient presents an L5 compressive syndrome of Grade I, II or III, depending on the site and size of the disc fragment. Usually, the condition is clinically indistinguishable from that produced by posterolateral or paramedian L4-L5 herniation.

Extraforaminal herniation

Disc herniation in this site causes an L5 syndrome, which may be neuroalgic or, more often, of the Grade I or II neurocompressive type.

Intradural herniation

Intradural herniation, regardless of the level at which it occurs, may produce a clinical picture of mono- or pluriradicular compression with no sphincter dysfunction or a cauda equina syndrome. In the first instance, neurologic disorders are usually severe, but nerve-root paralysis rarely occurs. Cauda equina syndrome was present in 10 out of the 17 cases analyzed by Peyser and Harari (78). In both pathologic conditions, the clinical picture, generally characterized by severe lumboradicular pain, cannot be distinguished from that usually produced by extradural herniations. The onset of symptoms is mostly abrupt and often related to physical strain or trauma. However, most patients, like those with the usual disc herniation, report a history of continuous or recurrent low back and/or sciatic pain of a few years' duration (45).

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·CHAPTER 9·

IMAGING STUDIES

F. Postacchini, G. Gualdi

Radiography

Numerous studies have shown that plain radiographs of the lumbar spine are of little diagnostic value in patients with low back and/or radicular pain, since most of the radiographic changes that may be observed are found, with similar frequency, in asymptomatic subjects. This holds for many radiographic findings, such as decreased disc height and spondylotic changes (119, 199, 212, 235), degree of lumbar lordosis (70, 91, 212), retrolisthesis of L5 (72), scoliosis (235), pelvic obliquity (198), spina bifida occulta and vertebral transitional anomalies (71, 199).

However, a clear-cut distinction should be made between the value of radiographs in the screening of patients with low back and/or radicular pain and the usefulness of radiographs in the clinical evaluation of individual patients with a suspected lumbar disc herniation. In the latter, radiographs of the lumbar spine may be helpful not only to make a correct diagnosis, but also for correct interpretation of the clinical signs and symptoms, the choice and interpretation of further diagnostic investigations and the planning and carrying out of treatment.

Plain radiographs

Technique

The patient may be placed either in the horizontal or standing position for both standard projections, or the anteroposterior radiograph may be obtained in the horizontal, and the lateral radiograph in the standing, position. In patients with low back pain, the anteroposterior view in the standing position does not provide significantly more information than that obtained in the supine position. On the other hand, the lateral radiograph performed in the standing position allows more precise measurement to be made of the height of the disc spaces (160).

Evaluation

The anteroposterior and lateral views may reveal various abnormalities, such as congenital or acquired vertebral deformities, osteolytic or osteosclerotic changes of neoplastic or infectious nature, erosive or osteoproductive bone changes caused by chronic infectious diseases, and degenerative vertebral changes. All abnormalities in the radiographic picture should obviously be evaluated. However, in the patient with "benign" low back or lumboradicular pain, a few radiographic findings may be of particular importance.

In the anteroposterior view, four types of radiographic changes should be carefully evaluated in patients with a suspected lumbar disc herniation: lumbar scoliosis, transitional anomalies, changes of the posterior joints and orientation of the laminae.

The presence of lumbar scoliosis may determine not only the clinical diagnosis, but also the choice and carrying out of further imaging diagnostic studies, and the mode of treatment. In scoliotic patients, axial CT or MRI scans should be carried out on oblique planes, perpendicular to the longitudinal axis of the vertebrae examined. Sagittal MRI scans should be parallel to the longitudinal axis of the portion of the spine examined; when this is not possible, it is preferable, in the case of a marked scoliosis, to carry out CT or myelography on account of the difficulties in correctly interpreting MRI images obtained on vertical sagittal planes (164). In a scoliotic patient with a herniated disc and/or lumbar stenosis requiring surgical treatment, the destabilizing effects of laminotomy or central laminectomy should be carefully evaluated.

It is important to determine whether the patient has a transitional anomaly (sacralization or lumbarization) in order to interpret the clinical signs and symptoms in the presence of nerve-root compression and correctly identify the disc space where the herniation is located either on CT or MRI scans, or prior to surgical treatment. When it is impossible, from lumbar spine radiographs, to determine whether a transitional anomaly is present, it may be useful to obtain an anteroposterior radiograph of the thoracic spine and then count the vertebrae starting from T1.

Degenerative hypertrophy and/or an abnormally sagittal orientation of the articular processes may lead to the suspicion of lumbar stenosis (Fig. 9.1). Even in the absence of this condition, it is important to determine whether hypertrophy of the articular processes is present, which could make surgical access to the spinal canal more difficult.

An abnormally horizontal orientation of the craniocaudal axis of the laminae may be suspected when the latter show a reduced height (Fig. 9.2). This anomaly, which is usually observed at L5 level, may make it easier to explore an erroneous vertebral level at surgery and more difficult to carry out laminotomy.

In the lateral view, the following abnormalities should be detected: a decrease in height of one or more discs; spondylolysis, spondylolisthesis or retrolisthesis; lumbosacral transitional anomalies; osteophytes of the vertebral body; and bone abnormalities due to defective development of the vertebral body.

In normal conditions, the height of the lumbar discs increases progressively from the first to the fourth; the fifth lumbar disc is slightly narrower than the fourth (210). The height of all lumbar discs, measured at the level of the anterior margin of the vertebral bodies is greater than that measured at the level of the posterior border. The anterior or posterior height of a disc can be measured by marking the most anterior or posterior point of the adjacent vertebral end-plates and by tracing the shortest line between the anterior or posterior points (60). This method, however, may give rise to erroneous measurements in the presence of lateral inclination or axial rotation of the motion segment (8, 160). Decreased height is a sign of disc degeneration.

Unilateral spondylolysis may not be appreciable on the lateral view, whilst a bilateral lysis is generally visible, particularly in the presence of a large bone defect. In this instance, the defect is often visible also on the anteroposterior view. In the presence of spondylolisthesis, it is important to determine the etiology, isthmic or degenerative, of the vertebral slipping. In the degenerative form, which is often associated with lumbar stenosis, the posterior vertebral arch is intact

Fig. 9.1. *Degenerative hypertrophy of the articular processes at L4-L5 level, suggesting lumbar stenosis.*

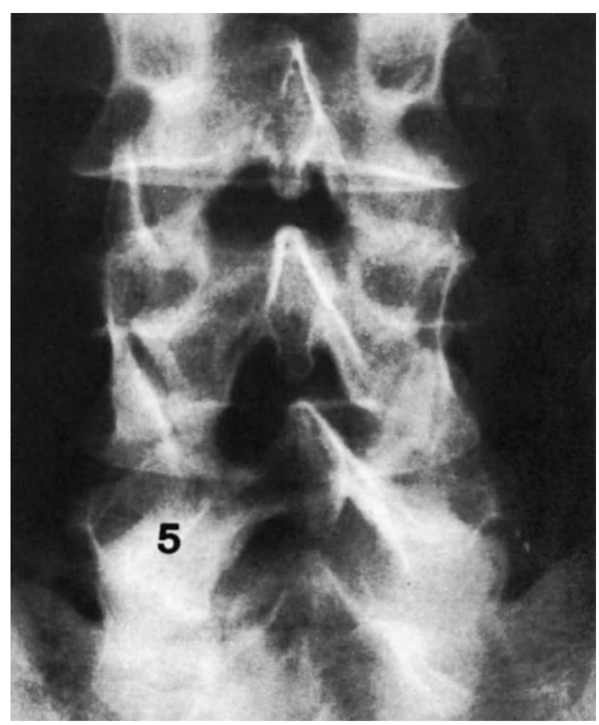


Fig. 9.2. *Marked shortness in the vertical direction of the L5 laminae, which tend to be orientated horizontally.*

(Fig. 9.3). It is important to recognize an even mild vertebral slipping (Fig. 9.4). Olisthesis of even mild severity may, in fact, cause stenosis or be an expression of vertebral instability. Retrolisthesis is a sign of disc degeneration and / or vertebral instability; when severe, retrolisthesis may be responsible for lumbar stenosis.

Lumbarization of S1, or sacralization of L5, vertebra may be suspected in the presence of an abnormally short or long sacrum, respectively. Caudally to the transitional vertebra, particularly a sacralized L5 vertebra, there may be a vestigial disc, which is usually narrower than a normal disc. A vestigial disc may be differentiated from a degenerated disc due to the absence of any radiographic evidence of disc degeneration.

Two types of vertebral body osteophytes have been described: more or less arcuate osteophytes, originating from the border of the vertebral body, which may form a complete or incomplete bridge between two adjacent vertebrae; and traction spurs, originating at 5 mm or more from the margin of the vertebral body, which are horizontally orientated for a few millimeters (132). The former result from fissuring or bulging of the annulus fibrosus, or are an expression of idiopathic spondylohyperostosis, characterized by ossification of the annulus fibrosus and the adjacent soft tissues. The latter would be due to abnormal mechanical stress on the peripheral attachment of the annulus fibrosus as a result of vertebral instability. The significance of traction spurs is still unclear, since they are often absent in the presence of evident vertebral hypermobility.

In subjects with a constitutionally narrow spinal canal, and even more in achondroplasic patients, the pedicles may be shorter and often thicker than normal, whereas the intervertebral foramens may appear constricted in the sagittal diameter (Fig. 9.5). Some subjects may also show marked concavity of the posterior aspect of the vertebral body, with consequent posterior prominence of the vertebral end-plates. The sagittal diameter of the vertebral canal may be measured by tracing a tangent line to the posterior aspect of the vertebral body and a line passing through the tip of the superior and inferior articular processes; the segment joining the two lines at the level of the midpoint of the pedicles should correspond to the sagittal diameter of the spinal canal (56, 232). This measurement, however, is approximate and cannot be considered reliable.

The oblique views are useful in the evaluation of any pathologic conditions of the pars interarticularis or the articular processes. The oblique view may show a spondylolysis even when the bone defect is narrow and not evident, or clearly evident, on the other views.

Functional radiographs

These are lateral radiographs of the lumbar spine carried out in maximum flexion and extension, or anteroposterior radiographs performed in maximum lateral inclination. Flexion-extension radiographs may be

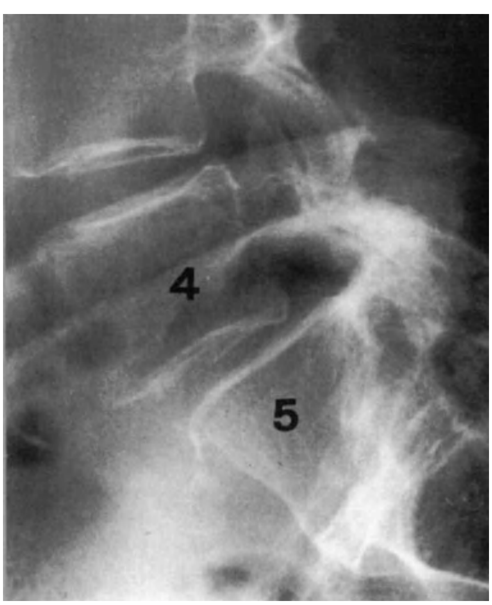


Fig. 9.3. *Degenerative spondylolisthesis of L5. Note the integrity of the pars interarticularis.*

Fig. 9.4. *Mild degenerative spondylolisthesis of L4 (arrow). The vertebral slipping suggests lumbar stenosis and/or vertebral instability.*

Fig. 9.5. (A) *Lumbar vertebrae with pedicles of normal length.* (B) *Vertebrae with abnormal shortness of the pedicles, indicating constitutional narrowing of the vertebral canal. The intervertebral foramens, due to shortness of the pedicles, have short sagittal diameters.*

performed in either the standing or sitting position (169). Radiographs in lateral inclination may be carried out in the supine position to avoid distorsions due to low back pain.

On lateral radiographs, an abnormal translational or rotatory motion of one or more vertebrae may be observed. Numerous methods for the measurement of both types of motion have been described (13, 18, 51, 52, 69, 122, 144). In a study on autopsy material (193), the most accurate method was found to be that of Morgan and King (144). However, measurements of both types of motion may be considerably affected by the quality of the radiographs and the degree of vertebral torsion (193).

In most asymptomatic subjects, translational motion does not exceed 3 mm. However, some one fourth of subjects show, at one or more levels, values of translational motion which exceed 3 mm and may even reach 6–8 mm (94). Generally, rotatory motion is not greater than 14°, but may reach values of 20° or more. Some controversy exists concerning the usefulness of flexion-extension radiographs in detecting vertebral instability on account of the absence of definite limits for physiologic vertebral motion (94).

On the anteroposterior view, it is possible to evaluate vertebral motion in the lateral inclination. In normal conditions, no slipping of a vertebra with respect to the vertebra below is observed and the individual spinous processes are situated within the concavity of the curve that they themselves form (51).

Radiographic changes

Disc degeneration

The radiographic signs of disc degeneration are represented by decreased disc height, occasionally associated with vacuum phenomenon, osteophytosis, and sclerosis of the adjacent vertebral bodies.

The disc decreases in height when degenerative changes are associated with resorption of the nucleus pulposus. This occurs in the presence of advanced degenerative changes. Normal disc height on plain radiographs does not, therefore, exclude the presence of mild or moderate degenerative changes of the disc tissue. The vacuum phenomenon is due to the presence of gas, essentially represented by nitrogen (64), within clefts in the disc. This phenomenon is usually observed in severely degenerated discs.

Disc degeneration is often associated with osteophytosis of the vertebral bodies. In most cases, the osteophytes have the characteristics of the so-called traction spurs or are represented by short bony spicules originating from the vertebral body. Large osteophytes bridging two vertebrae are not due, or exclusively due, to disc degneration. The vertebral bodies adjacent to a degenerated disc may show sclerotic changes of the subchondral bone, probably related to excessive mechanical stress on the vertebrae as a result of disc degeneration. Occasionally, a large portion of one or both vertebral bodies are sclerotic. This occurs primarily in females, at L4-L5 level (230). This condition, referred to as idiopathic (225), discogenic (183) or benign (45) vertebral sclerosis, is occasionally associated with erosions of the subchondral bone of the vertebral body. It is unknown whether the latter is a form of extensive subchondral sclerosis or the result of discitis due to poorly virulent germs (231).

Disc herniation

This condition does not cause pathognomonic radiographic changes. Even a decrease in disc height should, in no way, be considered proof of disc herniation. The latter cannot, therefore, be suspected on the basis of radiographs, the only exception being cases of calci-ossification of the protruding annulus fibrosus. However, in these cases, the herniation is long-standing and often asymptomatic.

Lumbar stenosis

In patients with constitutional stenosis of the spinal canal, the laminae may appear shorter than normal in the transverse plane and the angle between the caudal borders of the laminae of a vertebra is often very acute. The space between the medial margin of the laminae and the spinous processes is abnormally narrow. The articular processes have a more sagittal orientation than normal, resulting in better visualization of the joint space. The pedicles tend to be short and the posterior aspect of the vertebral body may show a marked concavity.

In degenerative stenosis, the facet joints show marked osteoarthrotic changes and hypertrophy of the articular processes causes narrowing, of varying entity, of the interlaminar space. Posterior osteophytes of the vertebral body may be present, encroaching on the spinal canal. Degenerative spondylolisthesis is often visible at one or multiple levels; on flexion-extension radiographs, the slipped vertebra may show translational and/or rotatory hypermobility. Degenerative scoliosis associated or not with lateral slipping of one or more vertebrae may occasionally be present. The slipping may appear, or be increased, on the functional radiographs in lateral bending.

Indications for radiographic studies

A large number of radiographic examinations are carried out in patients with low back or lumboradicular pain without obtaining, in most cases, any clinically useful information (71, 146). This results in high costs in terms of health expenditure and exposure to ionizing radiation (55, 89, 156, 172). These considerations should lead us to limit the use of radiographs and the number of views when clearly the chances are that the radiographic findings will be of little practical usefulness.

When should radiographs be obtained ?

Acute low back pain. Patients, aged 18 to 50 years, with a first episode of acute back pain do not usually need radiographic studies. In the vast majority of cases, in fact, the results of the latter do not influence the treatment (146). The same holds for the patient with a history of a few episodes of low back pain occurring at intervals of months or years. Plain radiographs should be performed, however, when back pain is not considerably decreased 3 weeks after onset.

Radiographic studies should be carried out in children and adolescents with low back pain of more than 2 weeks duration, since back pain is uncommon at these ages and may be due to pathologic conditions requiring specific treatment. The same is true for elderly subjects with no previous history of low back discomfort, since pain may result from osteoporotic fractures or neoplastic lesions.

Chronic low back pain. Patients of any age with continuous low-back pain of more than 6 weeks' duration or frequently complaining of back pain for few days or weeks should be submitted to radiographic investigation. Certainly, it is unlikely that, in these cases, the radiographic findings will influence treatment. However, they allow us to exclude pathologic conditions needing further investigations or different treatments from those routinely performed for chronic low back pain. In the vast majority of cases, the radiographic study should not be repeated before 2 years from a previous study, unless the clinical picture has changed significantly.

Low back and radicular pain. In the case of lumboradicular pain, the approach is similar to that indicated for pure low back pain. That is, radiographic studies should always be carried out in children, adolescents or elderly patients, whilst they can usually be avoided in young or middle age subjects, unless the duration of symptoms exceeds 3 weeks. Another problem, nowadays, concerns whether, in a patient with a suspected disc herniation, plain radiographs should be obtained before carrying out CT or MRI studies. In general, in a patient with no clinical evidence of vertebral deformities, it is unnecessary to perform plain radiographs before MRI. The latter, in fact, allows visualization of the whole lumbar spine and is able to demonstrate most of the pathologic conditions revealed by radiographs. In contrast, it is useful, before CT, to obtain plain radiographs, thus allowing a paramount vision of the lumbosacral spine to be obtained; the alternative is that the anteroposterior and lateral scanograms of the lumbar spine are reported with such a magnification, on the radiographic film of CT, as to be easily read. Plain radiographs are mandatory when the MRI or CT findings are not in keeping with the clinical findings.

It is always useful to carry out radiographic studies in patients indicated for surgery not only to exclude extravertebral pathologic conditions, but also to reveal vertebral deformities or bony anomalies, knowledge of which is helpful or necessary to plan and perform the surgical procedure.

Operated patients. Plain radiographs are indispensable in the evaluation of an operated patient with persistent or recurrent lumboradicular symptoms. In this case, radiographic studies should precede any other imaging studies, since the correct interpretation of the latter may be influenced by the radiographic findings. Radiographs are particularly useful to identify the site of operation and the width of bone decompression. Furthermore, the evaluation of radiographs carried out after surgery may allow us to determine whether the posterior vertebral arch removed at surgery has regrown (165, 185). Bone regrowth is probably less marked following surgery for disc herniation than in patients operated for lumbar stenosis. However, when a very limited laminotomy has been performed, as in microdiscectomy, even mild regrowth of the posterior arch may prevent recognition of the site of surgery.

Which radiographs?

Radiographic examination may consist only of standard anteroposterior and lateral views, or also of a coned, angled lateral view of the lumbosacral area, oblique views, and functional radiographs. Usually, only the anteroposterior and lateral views are sufficient.

A coned lateral view provides good visualization of the lumbosacral area, but it is of little practical usefuless. This radiograph needs to be obtained only when the lateral radiograph of the entire lumbar spine fails to allow sufficiently good visualization of the lumbosacral area or when detailed evaluation of this region is required.

Oblique views are useful to reveal spondylolysis, particularly when this is unilateral. Considering the rarity of this condition, oblique views need not to be routinely obtained either in the adult (171, 186) or child (173).

Usually, functional radiographs are not necessary in patients with a herniated disc. They may be indicated: in patients with spondylolisthesis or retrolisthesis; in those with lumbar scoliosis and lateral slipping of one or more vertebrae in the scoliotic area; in the presence of congenital anomalies (for example, aplasia of the articular processes) or sequelae of traumatic, infectious or neoplastic lesions suggesting vertebral instability; and in patients previously submitted to wide unilateral or bilateral laminoarthrectomy.

Myelography

Technique

It is not usually necessary for the patient to be in the fasting state and, normally, premedication can be avoided. It may be useful, however, to place a needle in the vein for the possible rapid administration of liquids and drugs, in the event of arterial hypotension.

If the lumbar puncture is performed in the lateral decubitus, the patient is positioned preferably on the side corresponding to the radicular symptoms, with the hips and knees flexed and the lumbar spine placed in kyphosis to widen the interspinous spaces. The interspace in which the spinal needle will be inserted is detected on palpation; generally, the interspinous space L3-L4 or L2-L3 is chosen. If these spaces and the respective interlaminar spaces appear to be exceedingly narrow on plain radiographs, the lumbar puncture may be performed at L5-S1 level, where the interspinous space is generally wider.

External cutaneous anesthesia may be performed with ethyl chloride and, subsequently, deep anesthesia with 3–5 ml of carbocaine, using a standard needle. The lumbar puncture is performed with a 22 G or, preferably, 25 G or 26 G spinal needle.

Lumbar puncture is more difficult in the lateral decubitus than in the sitting position, since in the former the lumbar spine may assume a scoliotic curve; this may be corrected by placing a pillow under the patient's flank. If difficulties are encountered in performing the lumbar puncture in the lateral decubitus, the patient may be placed in the sitting position with the trunk bent forward. This position makes it easier to insert the needle into the spinal canal. However, when the patient is subsequently placed in the horizontal position, there is a risk of causing a dural tear, favoring postprocedural leakage of cerebrospinal fluid (CSF). The prone position is not normally used. The spinal needle should be inserted slowly, removing the stylet at intervals to ascertain whether there is a leakage of CSF. If this leaks with difficulty, it is possible that the thecal sac has been punctured in an area which is markedly compressed or partially occupied by newly formed tissue; more often, this is due to the fact that the needle bevel has incompletely penetrated into the thecal sac or is situated between the dura mater and the arachnoid. In these cases, the needle should be plunged deeper in or extracted and reinserted, until flow of CSF to the outside is established. This is an important step to obtain good myelograms. Otherwise, opacification of the theca due to detachment of the arachnoid may occur, rather than a homogeneous opacification of the CSF, and, thus, non-diagnostic myelograms are obtained. When 25 G or 26 G spinal needles are used, CSF flow may not be spontaneous. In these cases, an insulin syringe may be used to draw a few drops of CSF. In addition, jugular veins can be compressed to increase CSF pressure.

Before injecting the contrast medium (or performing the lumbar puncture), the radiologic table should be inclined in the anti-Trendelenburg position by some 10°. The contrast medium should be injected slowly both to avoid mixing with the CSF and the onset, or increase in severity, of the radicular pain. After 2–3 ml of the contrast agent have been injected, a fluoroscopic control should be carried out to ensure of the correct opacification of the subarachnoid space. The total volume of contrast medium to be injected ranges from 10 to 15 ml (using concentrations of 300 mgI/ml), depending on the site of the pathologic condition (lumbosacral or high lumbar) and the caliber of the thecal sac. The most suitable types of radiologic equipment for myelography are those allowing radiographs to be obtained with a horizontal beam. With these types of equipment, myelograms in the right and left oblique projections are initially obtained, using a horizontal beam. The patient is then placed in the prone position and the cross table lateral, and the posteroanterior myelograms are obtained. When using standard equipment, the position of the patient is changed each time to obtain, in succession, radiographs in the lateral view, as well as posterior oblique of one side, posteroanterior, and posterior oblique of the opposite side, views. The patient should be moved slowly to avoid dilution of the contrast medium.

In patients with only a herniated disc, functional myelograms are usually unnecessary. In stenotic patients, on the other hand, it is often useful to obtain lateral functional myelograms in the standing position. Radiographs should be performed in the erect position and in maximum flexion and extension of the trunk (157).

After the examination, the patient should remain in bed in a semi-sitting position for 6–8 hours to avoid rising of the constrast agent and then in the horizontal decubitus for a further 12 hours. Alternatively, the patient may be invited to assume the standing position and deambulate for a few hours after the examination. This would favor closure of the lumbar puncture hole, thus reducing or avoiding leakage of CSF (217). Myelography may be performed on an outpatient basis without a significant increase in the prevalence of headache and other adverse effects (31, 42, 166, 217). The patient should be informed, however, of the possible occurrence of headache or nausea and of the need, in this event, to remain in bed for 1 to 3 days.

Adverse effects

The most common adverse effect is headache, which usually appears 4 to 12 hours after the examination and lasts, with decreasing severity, for 2 to 7 days. Headache usually appears, or increases in severity, in the standing position.

Headache may be due to irritation of the meninges and/or the central nervous system by the contrast agent or to decreased pressure of the CSF as a result of leakage of the latter through the hole in the thecal sac produced by the spinal needle. The latter pathogenetic mechanism is likely to be involved more frequently than the former. In fact, the prevalence of headache in patients undergoing myelography is similar to that observed after simple withdrawl of CSF (147, 182, 213). Furthermore, the frequency of headache after myelography is significantly lower when the lumbar puncture is performed with a 25 G needle than when a 20 G or 22 G needle is used (217). On the other hand, the prevalence of headache appears to be directly related to the type and volume of contrast medium injected, as well as to the iodine concentration. This suggests that the neurotoxicity of the contrast agent also plays a role. With metrizamide, the first non-ionic water-soluble contrast agent, some 50% of patients undergoing myelography had postprocedural headache (98). With iopamidol (Iopamiro, Isovue), administered at doses not exceeding 300 mgI/ml, postprocedural headache has been reported in 7% to 41% of cases (16, 24, 166, 194). However, in a few of these series, lumbar puncture had been performed using needles of relatively large caliber (20–22 G). Urso et al. (217), in 140 outpatients and 100 inpatients submitted to iopamidol myelography using a 25 G needle, found the frequency of headache to be 2% and 3%, respectively. In another series (42), in which ioexol had been used, severe headache, or headache lasting longer than 24 hours, occurred in 5% of 200 patients in whom a 25 G spinal needle had been used and in 13% of 200 cases following use of a 22 G needle. Similar results were obtained when 26 G and 22 G needles were compared. The prevalence of headache is higher in females and in patients presenting no clinical and myelographic signs of nerve-root compression (42, 98, 181). In elderly patients, headache is very uncommon.

Treatment of headache consists in bed rest and administration of analgesics. Furthermore, it may be useful to give 500–1000 ml of saline or hypotonic solution pro die for 1–2 days. The therapeutic role of saline might be to reintegrate the CSF that may have been lost through the thecal hole or to decrease the concentration of contrast medium in the CSF.

The second adverse effect, in order of frequency, is nausea, which is occasionally associated with vomiting. With the newest non-ionic contrast media, the prevalence of nausea is about 10% (24, 42, 166). Treatment is similar to that of headache, which is generally present in patients with nausea. Vomiting may be treated with antiemetic drugs.

Rare disturbances are: vertigo, tinnitus, fever, psychic disturbances, and myoclonic spasms and convulsions. The latter two are extremely rare with the non-ionic contrast media. Nevertheless, myelography should not be carried out in epilectic patients or on drugs decreasing the convulsive threshold (phenothiazines and MAO inhibitors). Treatment consists in the administration of anticonvulsive drugs.

It is well known that myelography may cause adhesive arachnoiditis. The condition is probably due to an increase in osmolarity of CSF with subsequent inflammatory reaction and fibrosis of the arachnoid membrane. Arachnoiditis is exceedingly rare with the non-ionic contrast agents due to their low osmolarity.

Normal myelogram

The contrast medium allows visualization of the nervous structures where they are surrounded by CSF, particularly of the nerve roots in their extrathecal course (or radicular nerves). In the intrathecal course, the nerve roots are generally hardly recognizable, since they are packed together and masked by the CSF opacified by the contrast agent. They appear as radiolucent striae, descending with a slight obliquity towards the site where they emerge from the thecal sac. The nerve roots are best visible on the oblique view, since in this view they run parallel to the plane of the radiographic film. In the extrathecal course, the nerve root corresponds to the radiolucent portion delimited by the two streaks of contrast medium opacifying the CSF contained in the nerve-root sleeve. The latter contains CSF only proximally to the dorsal root ganglion. Therefore, only this portion is outlined by the contrast agent. The nerve roots which are best visible are the L5 and S1 roots due to their wide diameter and long extrathecal course. The L3 and L4 roots are clearly visible if the CSF in the thecal sac is well opacified also in the high lumbar region; the L1 and L2 sleeves are usually slightly opacified (Fig. 9.6). In the presence of a large thecal sac, visualization of the roots tends not to be as good, due to less radio-opacity of the CSF (with the same volume of contrast medium injected) and the shorter length of the nerve-root sleeve. The opposite occurs in subjects with a narrow or short thecal sac, in whom the CSF is usually well opacified and the lower lumbar and sacral roots have a longer extrathecal course.

Myelography clearly demonstrates both nerve-root anomalies and cysts of the thecal sac.

Fig. 9.6. *Normal left oblique myelogram. The L3 and L4 nerve-root sleeves are also clearly visible. The L2 nerve-root sleeve is only slightly opacified.*

Pathologic features

Disc herniation

A herniated disc may cause various modifications in the normal image of the nerve roots and the thecal sac.

Nerve roots

Four elementary types of abnormality may be identified: 1) Poor filling of the nerve-root sleeve (Fig. 9.7). When the emerging root is moderately compressed, the contrast medium may penetrate partially into the nerve-root sleeve, which thus appears less opacified than the contralateral one. 2) Cut-off of the nerve-root sleeve (Fig. 9.8). This is the most typical abnormality produced by a herniated disc. It is due to inability of the contrast agent to fill the nerve-root sleeve at the site of, and distally to, the compression. 3) Trumpet-like deformation (Fig. 9.9). This involves the portion of the nerve root situated proximally to the site of compression. Only the extrathecal portion, or the latter and the intrathecal portion situated in close proximity to the site where the nerve-root emerges, may be enlarged. Deformation is due to edema in the nerve root as a

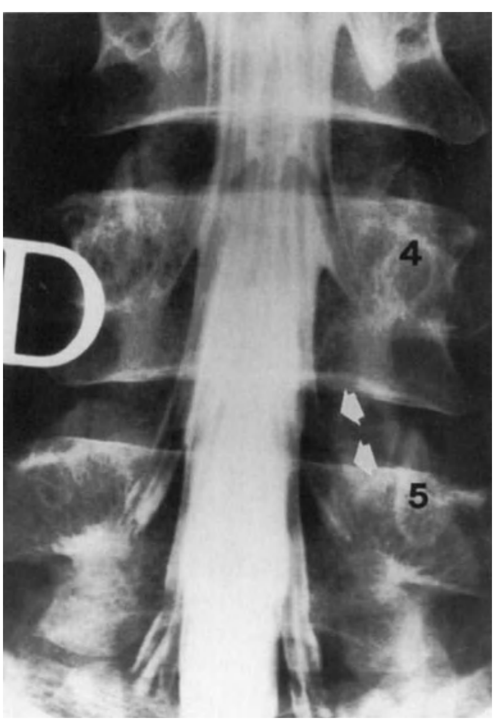


Fig. 9.7. *Posteroanterior myelogram of a patient with a small contained L4-L5 disc herniation on the left. The left L5 nerve-root sleeve (arrows) is less opacified than the contralateral sleeve.*

Fig. 9.8. *Left oblique myelogram. The S1 nerve-root sleeve is cut off (arrow).*

Fig. 9.9. *Oblique right myelogram. The S1 nerve-root sleeve is interrupted (arrow) and shows a slight trumpet-like dilation proximally to the cut-off.*

result of obstructed flow of the radicular venous blood. 4) Deviation of the root. The nerve root emerging from the thecal sac may be deviated towards the midline by a herniation located laterally to the root. More often, it is the root emerging at the level below, that is deviated in the intrathecal course. This occurs particularly in paramedian herniations (Fig. 9.10). 5) Absence of the nerve-root sleeve. This is a rare finding, usually due to a nerve-root anomaly, marked periradicular fibrosis or arachnoiditis of the root sleeve.

These abnormalities are visible on the posteroanterior and / or oblique view. The alterations may be isolated or two or more may be associated. The most common associations are: cut-off of the nerve-root sleeve with

A

B

Fig. 9.10. *Posteroanterior* (A) *and left oblique* (B) *myelograms of a patient with a left paramedian disc herniation. The L5 nerve-root sleeve is cut off and the S1 nerve root is deviated in the intrathecal course.*

enlargement of the root in proximity to the compression; and cut-off of the sleeve of the emerging root and medial deviation, in the intrathecal course, of the root emerging at the level below.

Thecal sac

The dye column may show a niche-like indentation, a partial block or a complete block. The indentation is visible on the lateral view at the level of the disc space (Fig. 9.11), or at a distance from the disc in the presence of a migrated herniation. Occasionally, lateral indentation on the thecal sac may be seen on the posteroanterior view. In the presence of a partial block, the contrast medium may opacify the CSF also distally to the site of compression (when injected cephalad to the block). On the lateral view, the sagittal dimensions of the thecal sac are considerably reduced in the compressed area. The latter, on the posteroanterior view, appears very mildly opacified compared with the suprajacent and subjacent areas. A complete block consists in a total interruption of the image of the dye column. The block caused by a herniated disc shows, on the posteroanterior view, a fringed or brush-like appearance (Fig. 9.12). The block is situated at the level of the disc space or, more often, of the caudal end-plate of the vertebra above. On the lateral view, the thecal sac may show a typical anterior indentantion (Fig. 9.12); more often, a circumscribed filling defect is visible, of which the anterior wall appears displaced posteriorly in proximity to the margin of the block of the contrast medium. In this event, the end of the sac may have a tapered appearance.

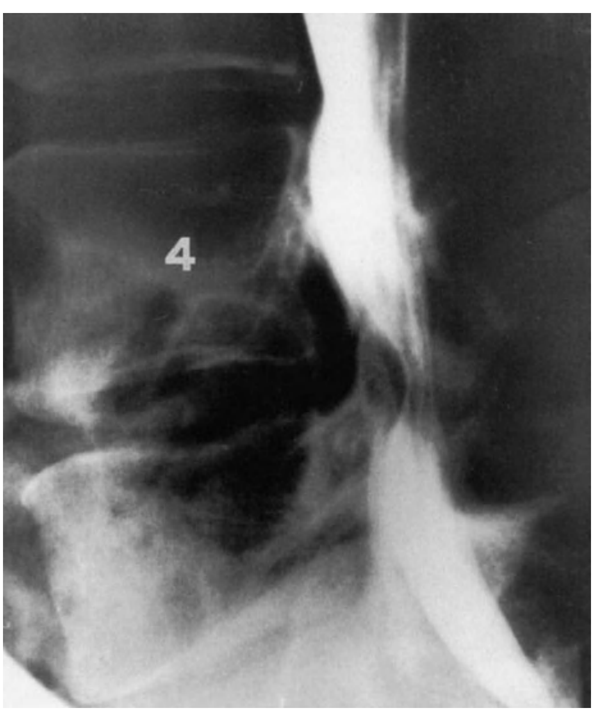


Fig. 9.11. *Niche-like indentation of the thecal sac at L4-L5 level.*

Site and type of herniation

The site of herniation is usually easily identified with myelography, with the exception of intraforaminal and, particularly, extraforaminal herniations. Numerous reports (9, 33, 76, 118, 121) have stressed the limitations of myelography in demonstrating an intraforaminal herniated disc. In effect, many intraforaminal herniations may be diagnosed by myelography (167) (Fig. 9.13). It is also true, however, that: the

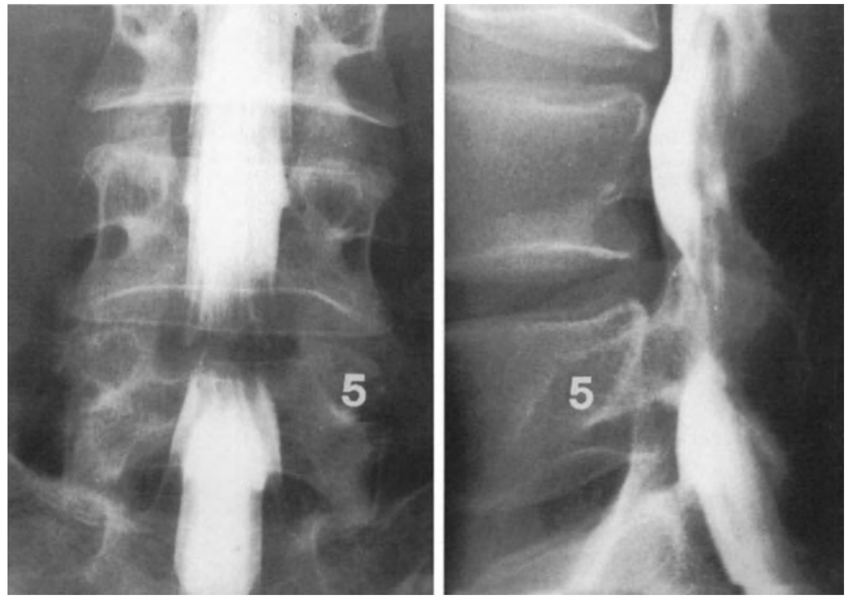


Fig. 9.12. *Complete block of the contrast medium at L4-L5 level with brush-like appearance of the thecal sac on the posteroanterior view. On the lateral view, the sac shows an anterior indentation at the level of the disc.*

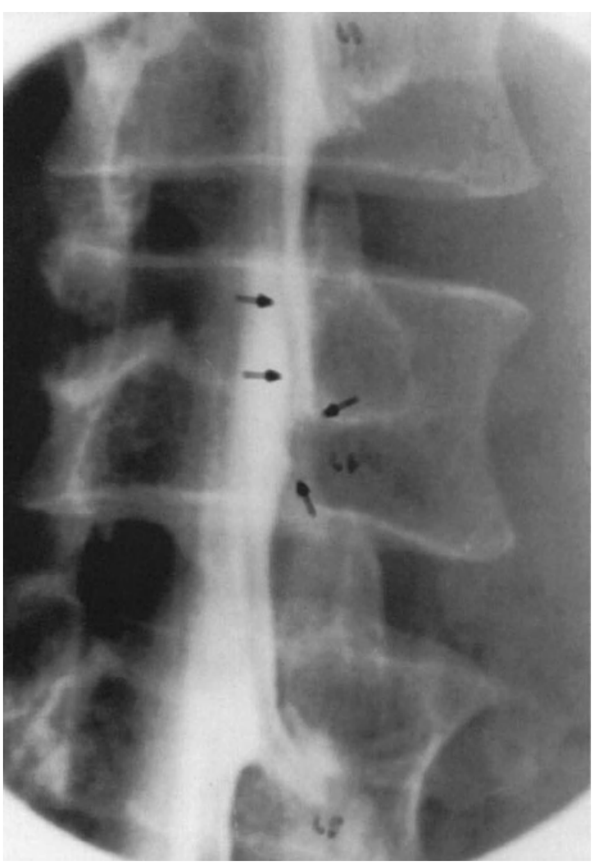


Fig. 9.13. *Left oblique myelogram. The L4 nerve-root sleeve is cut off at the level of the pedicle (arrows) by an intraforaminal L4-L5 disc herniation.*

myelographic signs of an intraforaminal herniation may be very subtle; myelography should be technically excellent; and the investigation usually reveals the nerve-root compression caused by a large fragment migrated into the intervertebral foramen, but may easily be negative in the presence of a contained herniation responsible for a moderate compression of the root. On the other hand, it is not usually possible with myelography to reveal compression of the root by an extraforaminal herniation.

Very often a contained herniation cannot be differentiated from an extruded subligamentous herniation. Extruded retroligamentous herniations can often be identified, even if with relative certainty. In general, a herniated disc causing a marked indentation of the thecal sac is much more likely to be extruded than contained. No myelographic signs are pathognomonic of a migrated herniation (44). However, an indentation of the thecal sac, with irregular margins and located at a distance from the disc, tends to suggest migration of the herniated tissue in the spinal canal. The type of herniation cannot usually be determined in the presence of an intraforaminal herniated disc.

Lumbar stenosis

The elementary signs of stenosis are: uniform narrowing of the thecal sac, deformations of the sac, abnormal image of the nerve roots in the intrathecal course, and abnormalities of the nerve root sleeves (163).

Uniform segmental narrowing of the thecal sac indicates stenosis. Generalized narrowing of the thecal tube, instead, is usually an expression of a narrow, rather than a stenotic, spinal canal.

Deformations of the thecal sac include indentations, hour-glass deformities, and block of the dye column. The indentations may be anterior, lateral or posterior. The former are generally caused by osteophytes of the vertebral body or bulging of the annulus fibrosus. Lateral indentations are caused by hypertrophy and / or osteophytosis of the articular processes, associated or not with hypertrophy of the ligamentum flavum. Posterior indentations, which represent the most typical sign of stenosis, are caused by the inferior articular processes, with, in some instances, contribution of thickened ligamenta flava.

Two lateral indentations at the same intervertebral level produce an hour-glass deformity of the thecal sac on the coronal plane. This also occurs on the sagittal plane when, at the same level, an anterior and a posterior indentation are associated. Hour-glass deformities on the coronal plane can be distinguished from those caused by a bilateral herniation, since in stenosis the lateral indentations usually surpass, in the vertical direction, the limits of the disc and the dye column appears deviated towards the midline, rather than brusquely interrupted at the level of the disc, as usually occurs in disc herniation.

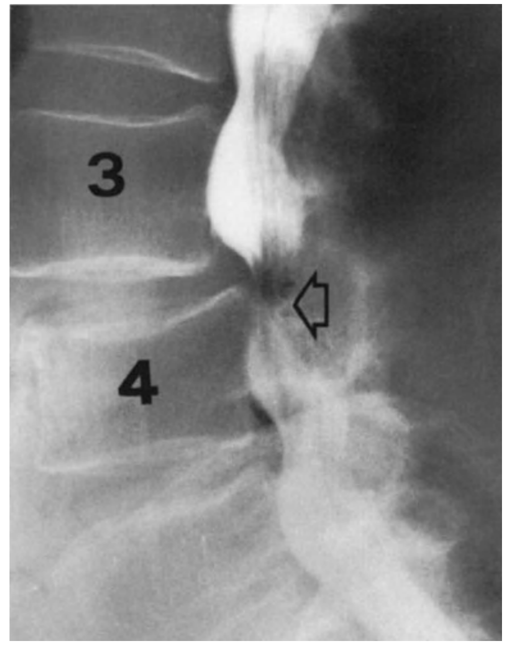


Fig. 9.14. *Lumbar stenosis at L3-L4 level and degenerative spondylolisthesis of L3. Almost complete block of the dye column due to posterior compression (arrow) at the level of the proximal vertebral end-plate of L4.*

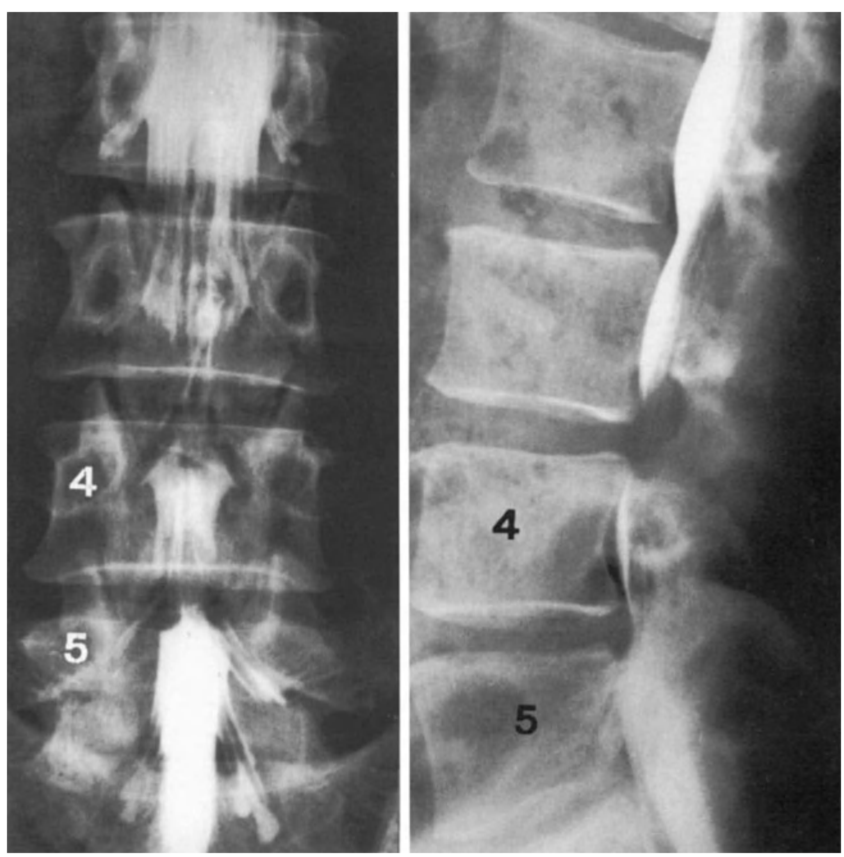


Fig. 9.15. *Complete block of the dye column at L3-L4 level and subtotal block at L4-L5 level due to constitutional lumbar stenosis. At L2-L3 level, compression of the thecal sac is milder.*

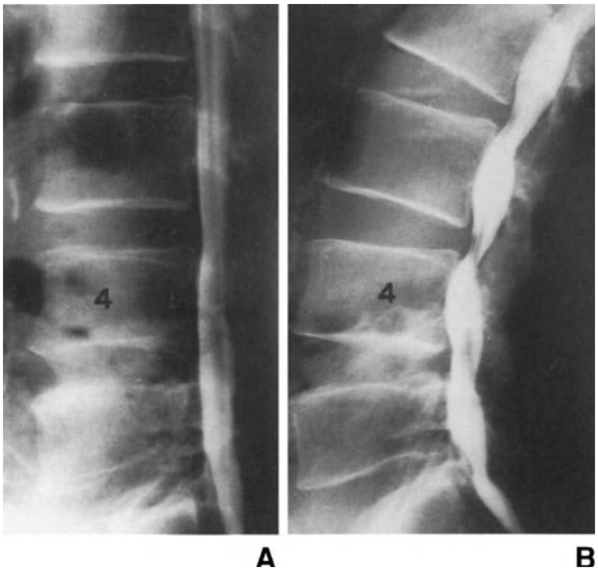


Fig. 9.16. *Flexion* (A) *and extension* (B) *myelograms in a patient with constitutional lumbar stenosis at L2-L3 and L3-L4 levels. At these levels the thecal sac shows, in extension, a posterior compression, which disappears upon flexion.*

Block of the dye column produced by stenosis may be differentiated from that caused by disc herniation in a normal or constitutionally narrow spinal canal, since in the latter instance the thecal sac usually shows a marked ventral indentation or, when the block is subtotal, the posterior margin of the dye column is rectilinear. In the typical block due to stenosis, the ventral indentation is mild or absent and the posterior margin of the dye column is mostly oblique anteriorly, proximally and/or distally to the block (Fig. 9.14). In multisegmental stenosis, multiple blocks of the dye column, or a total block and one or more subtotal blocks, may be present (Fig. 9.15).

Abnormalities of the intrathecal roots are represented by: increased radiolucency of the caudal roots due to decreased volume of the opacified CSF surrounding them, as a result of the reduced caliber of the thecal sac; and redundancy of the nerve roots, i.e., serpiginous course of the roots proximally and distally to the stenotic area.

The abnormalities in the nerve root sleeves caused by stenosis are not pathognomonic. Often, however, compression due to stenosis produces different abnormalities from those generally caused by a herniated disc; namely, in compression of stenotic type, the root does not usually show edematous changes and, thus, a trumpet-like deformation proximally to the compression, as often occurs in the presence of disc herniation.

These myelographic changes are variably associated, in any individual patient, either at the same level or at different levels. Furthermore, myelographic aspects may vary considerably, depending on the number of levels involved and the type of stenosis (stenosis of the spinal canal or isolated stenosis of the nerve-root canal; constitutional, degenerative or combined stenosis). Functional myelography in flexion may show a decrease in severity or disappearance of anterior, and particularly, posterior indentations of the thecal sac. The opposite occurs in hyperextension, which increases the narrowness of the spinal canal and, thus, compression of the nervous structures (Fig. 9.16).

Disc herniation in stenotic spinal canal

Myelography does not allow us, at a stenotic intervertebral level, to determine whether a herniated disc coexists and the role it plays in the compression of the nervous structures. This holds particularly in two situations: a multisegmental stenosis with a complete block of the dye column at a level above that in which the two conditions coexist; and an isolated stenosis of the nerve-root canal associated with a small, contained, posterolateral disc herniation.

The elements that may lead to the diagnosis of a herniated disc in a stenotic spinal canal are: a marked disc indentation on the thecal sac at intervertebral level; an anterior or anterolateral indentation at the level of the vertebral body, as it may be produced by a migrated herniation; cut-off associated with a marked edema of the root emerging from the thecal sac.

Myelography in operated patients

In the presence of periradicular fibrosis, the nerve-root sleeve may be thinner and shorter than normal and/or its end may have a tapered appearance, but no radicular edema is usually observed (Fig. 9.17). The thecal sac does not show anterior indentations or, when present, the latter are mild and often irregular in shape.

A recurrent herniation usually causes a cut-off of the nerve-root sleeve at the level of, or proximally to, the disc space. The involved root may be edematous, and thus enlarged, proximally to the compression. The thecal tube often shows an anterior and/or lateral indentation, similar to those found in primary herniations. Occasionally, a partial or complete block of the thecal tube may be observed at the level of the involved root.

With myelography, however, it may be difficult or impossible to differentiate periradicular fibrosis from a recurrent herniation, particularly when the herniation is small in size or arachnoiditis coexists. The latter is rarely observed following the introduction of non-ionic

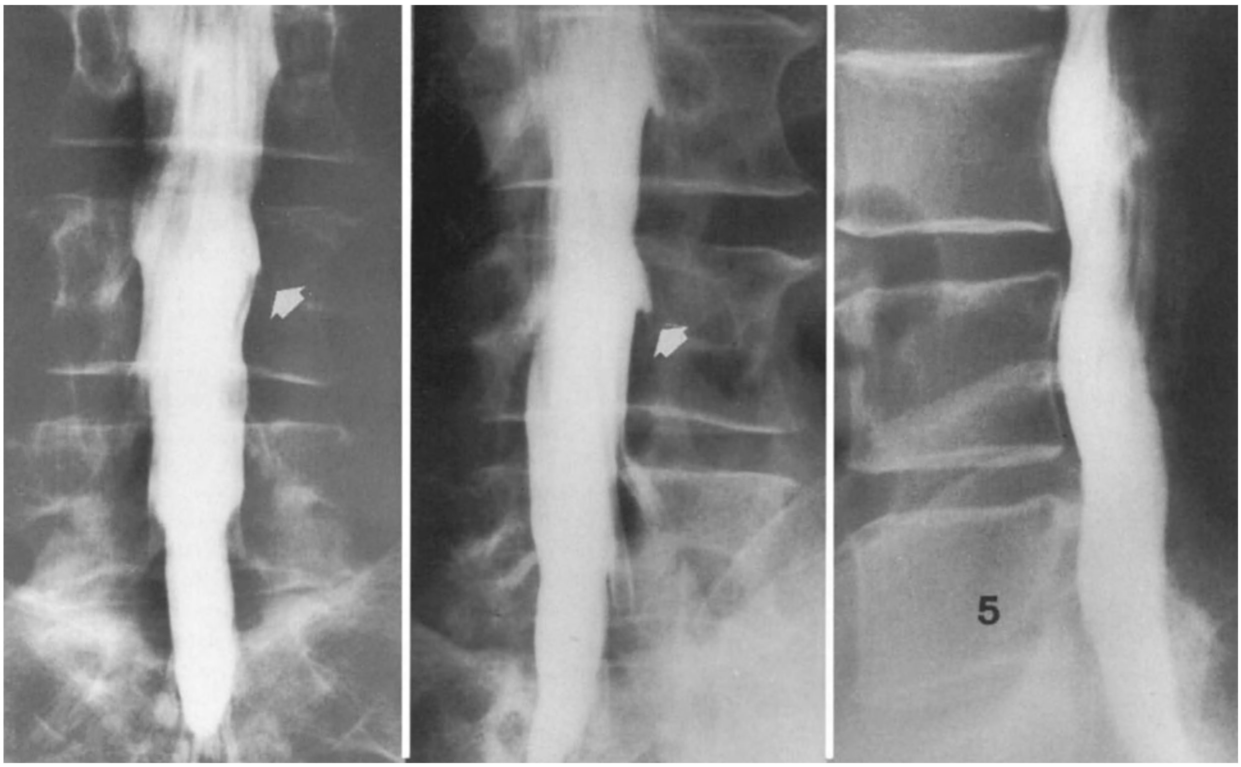


Fig. 9.17. *Myelograms of a patient operated for an intraforaminal disc herniation at L4-L5 level on the left. The left L4 nerve root sleeve is opacified only in the proximal portion and has a tapered appearance on the oblique view due to periradicular fibrosis.*

water-soluble contrast agents, at least in patients who have not previously undergone myelography. Arachnoiditis is characterized by: non-visualization of the caudal nerve-root sleeves or visualization only of their initial portion; homogeneous appearance and increased radio-opacity of the contrast medium in the thecal sac due to absence of the radiolucent images of the roots; thinning of the caudal portion of the thecal tube, which may be abnormally short and ends like the tip of a pencil or finger of a glove; jagged or smooth appear-

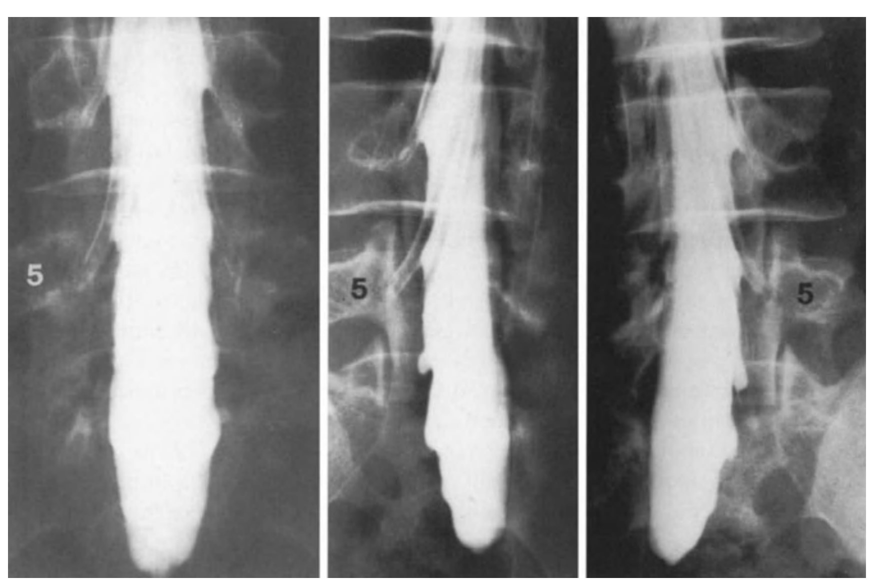


Fig. 9.18. *Arachnoiditis of the caudal portion of the thecal sac in a patient previously submitted to myelography. The S1-S3 nerve-root sleeves are not visible on the posteroanterior view and appear opacified only in the proximal portion on the oblique views.*

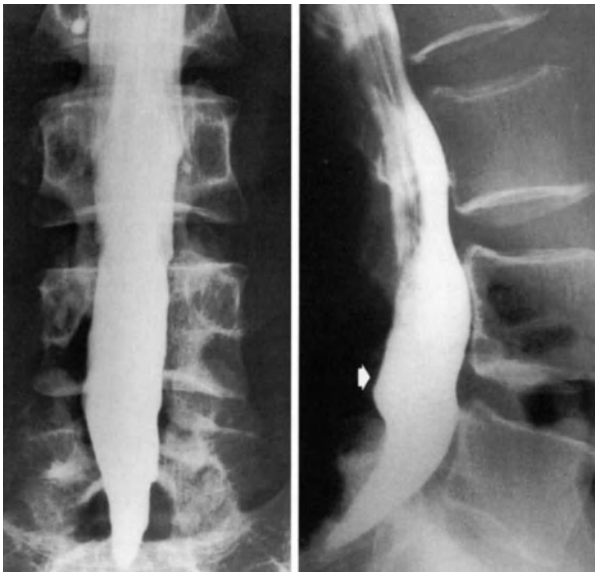


Fig. 9.19. *Arachnoiditis in a patient previously submitted to two myelographic studies and bilateral laminectomy at L4-L5 level. On the posteroanterior view, the thecal sac has a tapered appearance and the margins are smooth due to failed opacification of the L4-S2 nerve-root sleeves. On the lateral view, the sac shows posterior dilation at the level of laminectomy (arrow).*

ance of the thecal sac margins due to the lack of opacification of the nerve-root sleeves (Figs. 9.18 and 9.19).

In the myelogram of the operated patient, a characteristic feature, however devoid of pathologic significance, is the presence of a posterior protrusion of the thecal sac at laminotomy or laminectomy level (Fig. 9.19).

Diagnostic accuracy

The diagnostic accuracy of an investigation cannot be established by comparing the results with the surgical findings, since, in a condition such as disc herniation, the indication for surgical treatment is based upon the pathologic features emerging from that investigation. In the event of normal diagnostic findings, which generally lead to surgery not being performed, it is not possible to determine whether the investigation has provided a correct diagnosis or a false negative result. On the other hand, it is well known that disc herniation may be asymptomatic (25, 100, 226); in these cases, in which surgery is not carried out, it may be impossible to determine whether the results are false positive. A comparative analysis of the diagnostic accuracy of two or more investigations is easier, since the positivity of one or several of them may lead to surgical treatment being carried out.

Bell et al. (19) compared myelography and CT in a prospective study in which the results of one investigation were evaluated without knowing the clinical picture and the results of the other investigation. Diagnostic accuracy of myelography was found to be 83%, compared with 72% of CT. In other comparative studies (93, 145, 170, 179), the diagnostic accuracy ranged from 83% to 93%, but only in one study (145) was myelography more accurate than CT.

Indications

Until a few years ago, myelography was the investigation commonly performed to diagnose the cause of a lumboradicular syndrome. With the advent of CT and MRI, the indication for myelography has progressively decreased, and patients have become less and less willing to undergo the examination. Nowadays, myelography should be carried out only when CT and/or MRI do not provide adequate information for diagnosis of the pathologic condition responsible for a lumboradicular syndrome to be made.

The main prerogative of myelography is that it is able to visualize lumbar nerve roots in the portion comprised between the site where they emerge from the thecal sac and the entrance into the intervertebral foramen. The investigation is thus indicated when it is useful or necessary to demonstrate compression of the nerve root in the extrathecal course, rather than visualize the compressive agent, as occurs with CT and MRI. In patients with a simple disc herniation, myelography may be indicated: 1) When CT findings are dubious or in contrast with the clinical picture and it is difficult or impossible to obtain MRI (non-availability of the equipment; patients with pace-makers or metallic implants; claustrophobia). 2) In the presence of lumbar scoliosis which makes interpretation of CT and MRI images difficult. 3) When CT and/or MRI suggest, but do not adequately demonstrate, a nerve-root anomaly, which may be useful to identify in view of the surgical treatment. 4) When CT and MRI do not show significant pathologic conditions, whilst the clinical features suggest nerve-root compression. However, in these cases, which are fairly rare, the probability that myelography will be positive is very low; for this reason, the examination should generally be performed in the presence of clear clinical evidence of nerve-root compression. 5) In patients with persistent radicular symptoms after surgery, to demonstrate a possible nerve-root compression not clearly demonstrated by non-invasive imaging techniques; also in these cases, however, myelography rarely provides adequate diagnostic information. 6) Extremely obese patients who do not fill within the gantry of CT or MRI, in whom, on the other hand, it may at times be difficult to obtain sufficiently good images with the non-invasive techniques.

Rather than for simple disc herniations, myelography may be indicated in the presence of lumbar stenosis. The investigation, in fact, is able to reveal variations in the severity of compression of the nervous structures in flexion and extension of the lumbar spine; in the presence of mild osteoligamentous compression of the thecal sac visualized on MRI scans, it may be useful to determine whether the compression increases in severity, and to what extent, in the standing position and / or in extension of the spine (218). Furthermore, stenotic patients occasionally present idiopathic or degenerative scoliosis, which may make it difficult to determine the severity of compression of the caudal nerve roots with CT and / or MRI (165).

In patients with isthmic spondylolisthesis, CT and / or MRI may not be able to demonstrate compression of the emerging nerve root at the level of isthmic pseudarthrosis. It may occasionally be useful to carry out myelography in these cases.

Computerized tomography (CT)

Technique

The patient is placed in the prone position with a support under the legs to reduce lumbar lordosis. The gantry is tilted to direct the X-ray beam parallel to the intervertebral space. This is important, particulary for the L5-S1 disc, the angulation of which with respect to the horizontal plane may exceed the degree of gantry tilting. If the scan plane is not parallel to the intervertebral space, the resulting image may simulate disc bulging.

Scan time and amperage are usually preselected to reduce the radiation dose. In obese patients, however, both scan time and amperage should often be increased, since the X-ray beam is weakened when passing through fat tissue.

The radiation dose for standard CT studies of the lumbar spine is low, since the X-ray beam is collimated and there is, thus, no secondary radiation. The usual dose to the skin is about 3–5 rads, i.e., similar to that absorbed in a routine radiographic study including lateral, anteroposterior and oblique views of the lumbar spine. The further away from the skin and primary beam, so the radiation dose absorbed progressively decreases. The deep tissues, therefore, are less and less irradiated as the distance from the skin increases; furthermore, gonadal irradiation ranges from 0.15 to 0.75 rads when the CT study does not reach caudally beyond the S1-S2 level (96).

The CT image results from the attenuation of the primary X-ray beam by the tissues. The degree of attenuation depends on the atomic number of the examined substance and corresponds to density of the latter. The density is measured as Hunsfield Unit (HU). The scale of densitometric values ranges from −1000, which corresponds to air, to 1000, which corresponds to bone. Fat tissue has negative values (−100), whereas all other tissues have positive values. Water has a neutral value (0).

The examination begins with digital radiographs of the lumbar spine in the lateral and anteroposterior views. Radiographs are useful to identify the spine segments to be studied after recognition of the lumbar vertebrae, starting from L5 or D12. In addition, radiographs allow detection of possible spondylolisthesis, decrease in height of the intervertebral spaces or structural changes in the vertebrae, including the upper lumbar vertebrae usually not examined on axial section. The lateral view radiograph should be taken in an adequate scale, with optimal window values, and both with and without the scan lines in order to increase its diagnostic efficacy (152). The anteroposterior view should also be photographed, particularly if the patient has not undergone plain radiographs.

Standard CT study is performed with contiguous or overlapped, 2–4-mm thick, slices. Thin slices provide better spatial resolution (ability to identify small structures presenting different contrast), but less contrast resolution (ability to identify structures presenting different density). Slices thicker than 4 mm should be avoided when a herniated disc is suspected, since they cause partial average artifacts (i.e., the section includes many structures with different densities which sum up) leading to a decrease in spatial resolution. The gap between the slices should be zero or less than the section thickness in order to reduce partial average artifacts and to increase spatial resolution in reformatted images. If the examination is performed for suspected spinal stenosis, it is preferable to perform 4-mm thick, 1 mm overlapped, sections to improve the quality of sagittal reformatted images.

Usually the axial sections are obtained at L3-L4, L4-L5 and L5-S1 levels, whilst the L2-L3 level, and very occasionally the L1-L2 level, are examined when deemed necessary on account of the particular clinical features. In the latter instances, the referring physician should ask for studies to be made at the upper lumbar levels, since the radiologist, who is unaware of the exact clinical features, may not be able to decide whether or not the examination should be extended to the upper lumbar spine.

For each intervertebral level, sections should be obtained from the lower edge of the pedicle of the cranial vertebra to the upper margin of the pedicle of the caudal vertebra. If a disc fragment is seen to have migrated into the spinal canal, sections should include the proximal and distal edge of the fragment to allow the surgeon to localize the exact site of the latter. The field of view (FOV) should include the whole vertebra, paravertebral muscles and retroperitoneal vessels. This allows identification of possible pathologic conditions of the aorta or other retroperitoneal structures.

After obtaining axial sections, multiplanar reconstructions may be made, in two or three dimensions. Reformatted images are not usually indispensable for diagnosis, but they can be useful for better evaluation of the pathologic condition.

Image photography is important in the interpretation of the pathologic condition and should be obtained with both soft tissue and bone algorithms (Figs. 9.20 and 9.21).

When a herniated disc is suspected, CT study is usually performed without contrast medium. Intravenous contrast medium is used primarily in previously operated patients, when recurrent disc herniation is suspected. In non-operated patients, contrast medium is usually employed to exclude tumors, such as neurinomas or ependymomas, or to enhance a venous plexus simulating disc herniation. Disc tissue, in fact, is not significantly enhanced after administration of contrast medium, since it is not vascularized, or contains only a few vessels, unlike neoplastic lesions or vessels. The usual dose of contrast medium is about 2 ml/kg body weight and non-ionic media are preferred in order to reduce the risk of an allergic reaction.

Anatomy of lumbosacral spine

Vertebrae and intervertebral discs

On axial sections, the body of the lumbar vertebrae shows a slightly ovoid shape due to the larger dimensions of the transverse, compared with the sagittal, diameter. The foramen through which the basivertebral vein emerges can be seen in the middle portion of the posterior aspect of the vertebral body.

The spinal canal appears to be entirely delimited by bony walls only at the level of the pedicles (Fig. 9.20). Caudally to these, the posterolateral wall of the canal is incomplete, on each side, due to the presence of the intervertebral foramen. Immediately below the pedicle, the posterolateral bony wall is formed by the pars interarticularis and the lamina and, more caudally, by the inferior articular process of the vertebra examined. On sections close to the caudal apophyseal ring, the superior articular process of the vertebra below becomes apparent. It is situated anteromedially to the inferior articular process and, proceeding caudally, the transverse area increases, whilst the area of the inferior articular process decreases. The sagittal diameter of the intervertebral foramen increases progressively from its cranial end to the middle portion of the intervertebral disc and then begins to decrease.

The L5 vertebra can generally be recognized on account of the larger dimensions of the transverse processes, which are often roughly triangular in shape on the scans at the level of the middle portion of the vertebral body (Fig. 9.20). Furthermore, the vertebral canal of L5 often has a trefoil shape, which is rarely observed at L4 level and is normally absent at the level above. The L4 vertebra can often be distinguished from L3 due to the less sagittal orientation of the posterior joints and the shape of the vertebral canal, which tends to be more triangular. The S1 vertebra is easily recognizable due to the presence of the sacral alae on the sides of the vertebral canal, which is triangular in shape. The images obtained with a window level for soft tissues (Fig. 9.20) may not allow adequate visualization of the bony structures, particularly of the articular processes, which, on the other hand, are well visible using a window level for bone (Fig. 9.21).

The transverse area of the bony vertebral canal measures 150–300 mm^2 when the spine passes from flexion to maximum extension (191).

The intervertebral disc has a density of 70–80 UH, i.e., similar to, or slightly greater than, the muscle tissue. Generally, the nucleus pulposus cannot be distinguished from the annulus fibrosus. However, the peripheral portion of the disc occasionally displays a slightly greater density than the central portion. This usually occurs in young subjects, in whom the nucleus is only mildly fibrotic. On axial sections, the posterior border of the upper three lumbar discs is generally concave on the sagittal plane, whilst the border of L4 disc is rectilinear and that of L5 disc is slightly convex (Fig. 9.20). The posterolateral margin of the disc (which delimits the intervertebral foramen) is slightly and uniformly convex at all lumbar levels.

On midsagittal and paramedian reformatted images, the posterior border of the intervertebral disc is normally flat or slightly convex. Lateral sections allow visualization of the articular processes and the posterior joints, the pars interarticularis and the intervertebral foramen. The latter is clearly visible on the sections through the pedicles.

Ligaments

The anterior longitudinal ligament is not generally visible on conventional CT scans. The posterior longitudinal ligament is occasionally visible on the scans through the middle portion of the vertebral body, on which the two structures are separated by fat tissue and the branches of the basivertebral vein. The ligament

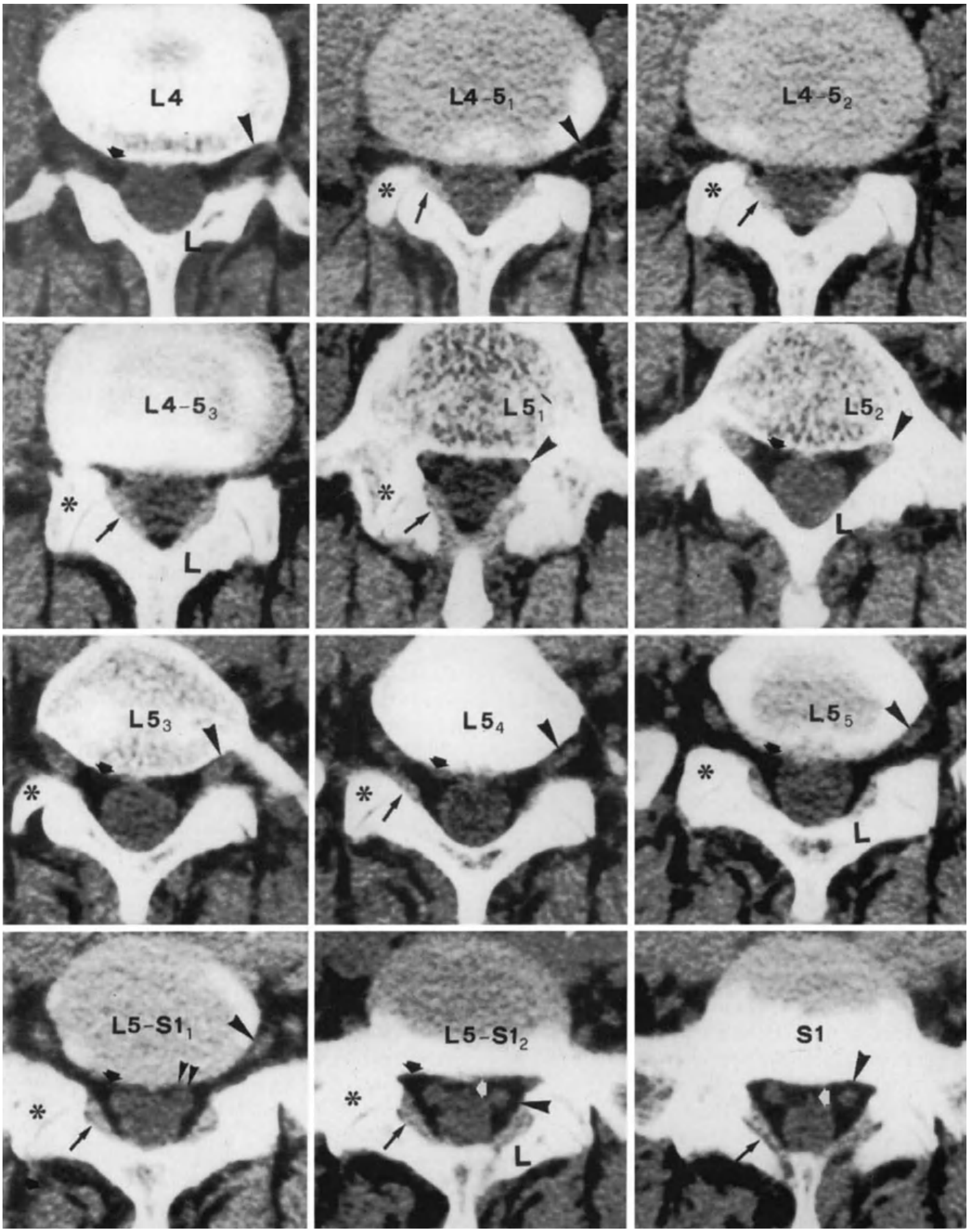


Fig. 9.20. *Sequential axial CT scans from the caudal half of L4 to the vertebral end-plate of S1. The arrowheads indicate the L4 nerve root in the L4-L5 intervertebral foramen (L4 and L4-5_1), the L5 root in the L5 radicular canal (L5_1 and L5_2) and L5-S1 intervertebral foramen (from L5_3 to L5-S1_1), and the S1 nerve root in the S1 radicular canal (L5-S1_2 and S1). The double arrowheads indicate the S1 root emerging from the thecal sac (L5-S1_1). The short black arrows indicate the epidural fat, which is typically hypodense, whilst the thecal sac shows the neutral density of the CSF. The asterisks are placed on the superior articular processes of L5 (from L4-5_1 to L5_1) and S1 (from L5_3 to L5-S1_2); the inferior articular processes are situated medially to the superior processes and are well visible at L5_1 (inferior articular processes of L4) and L5-S1_1 and L5-S1_2 (inferior articular processes of L5). The long black arrows indicate the ligamenta flava: the portion of the ligamentum located anteriorly to the facet joint can be seen at L4-5_1 and L5_4. The white arrow indicates the median meningovertebral ligament. Letter L indicates the laminae of L4 (from L4 to L4-5_3) and L5 (from L5_2 to L5-S1_2).*

Fig. 9.21. *Axial CT scan at intervertebral level, obtained with a window level for soft tissues. Bony structures are clearly visible, whereas the structures with low and intermediate density, such as muscles, CSF and nerve roots, are not easily identified.*

may be identified, using high window levels, particularly in the presence of abundant epidural fat, compared to which it displays a greater density.

The ligamenta flava appear as laminar structures, with a similar density to that of the intervertebral disc, which delimit the vertebral canal posteriorly and are prolonged in front of the articular processes as far as the intervertebral foramen (Fig. 9.20).

The meningovertebral ligament is occasionally visible, particularly at L5-S1 level and in the presence of abundant epidural fat, due to the different density of the two tissues (Fig. 9.20) (184). On high resolution images, the ligament usually appears as a septum connecting the thecal sac to the vertebral body. At times, it is possible to observe two septa, one on each side, directed towards the posterolateral portion of the vertebral body. The small spur which is often visible at the center of the posterior border of the vertebral body corresponds to the area of insertion of the anterior meningovertebral ligament to the posterior longitudinal ligament and the endosteum of the vertebral body, and may be particularly prominent when the ligament is calcified (184). The lateral meningovertebral ligaments are very rarely visible.

High resolution CT scans (sections 1 mm thick) may allow visualization of the ligaments of the intervertebral foramen (151). They appear as thin bands with fibrous density connecting the posterolateral border of the disc to the anterior wall of the superior articular process, the pedicle and / or the ligamentum flavum.

Thecal sac and spinal nerve roots

The thecal sac presents densitometric values close to zero due to the prevalently liquid content (Fig. 9.20). Occasionally, the caudal nerve roots may be seen within the thecal sac on account of their greater density compared with the CSF. With the patient in the supine position, they appear as pointed structures close to each other, generally situated in the posterior half of the thecal sac. With change of position, the roots tend to be displaced within the sac. The area of the thecal sac on axial sections normally ranges from 130 to 230 mm^2 (28, 191). The epidural fat may be easily recognized due to its negative densitometric values. Little fat is present in the upper lumbar region, whilst in the low lumbar and sacral regions it becomes more and more abundant, in parallel with the progressive thinning of the thecal sac.

The spinal nerve roots in the extrathecal course (radicular nerves) appear as symmetrical roundish structures, running in the nerve-root canal on the sides of the thecal sac, of which they have the same density (Fig. 9.20). In the absence of nerve-root anomalies, the root on one side is similar in diameter to that on the opposite side. In the intervertebral foramen, the nerve root has an oblique course, which tends to approach the horizontal plane outside the foramen (Fig. 9.20). In the intra- and extraforaminal portion, the root is in very close proximity to the intervertebral disc and it varies in shape depending on the width of the angle between the scanning plane and the plane parallel to its longitudinal axis. When the angle is small, the nerve root appears as an elliptical structure, whilst if the angle is wide, the root tends to be roundish in shape.

On sagittal reformatted images, the thecal sac appears as a tubular structure adherent to the posterior wall of the vertebral bodies and the discs, or separated from the latter by a thin layer of low-density tissue, corresponding to the epidural fat. Usually, the nerve roots in the extrathecal course are not clearly identifiable on the scans through the nerve-root canals, whilst they are visible, surrounded by the periradicular fat, on the scans through the intervertebral foramen.

Coronal reformatted sections through the spinal canal show the thecal sac and the spinal nerve roots running in the nerve-root canals and the intervertebral foramina. The roots are clearly visible on the sections through the pedicles. However, the image of the nervous structures may be ill defined in the presence of marked lumbar lordosis, which may prevent visualization of the entire extrathecal course of the nerve root on a single scan.

Nerve-root anomalies

These anomalies are responsible for an asymmetric axial image of homologous nerve roots (radicular nerves) if, as often occurs, the anomaly is unilateral. This holds particularly for the anomalies characterized by two or three contiguous roots emerging through a single dural hole or closely adjacent holes. In these cases, the transverse area of the anomalous nerve trunk is considerably larger than that of the normal contralateral root. The nerve-root canal in which the anomalous nerve trunk has its course may be wider than normal (97).

Generally, the anomalous nerve trunk shows a similar density to that of the thecal sac and normal nerve roots (159); occasionally, however, the density may be higher. In the latter instance, it may be difficult to exclude that the anomalous structure is not a disc fragment or newly-formed tissue. Coronal reconstructions, however, will easily allow identification of the structure on scans through the anomalous nerve trunk (Fig. 9.22). In dubious cases, it may be useful to perform the examination after intravenous administration of contrast medium or to carry out myelo-TC.

Epidural venous plexuses

Axial CT images often allow visualization of the anterolateral epidural venous plexuses. They appear as symmetrical structures with a similar density to that of the disc, but greater than that of the CSF. Dilated epidural veins may occasionally simulate a herniated disc. In these instances, the use of intravenous contrast

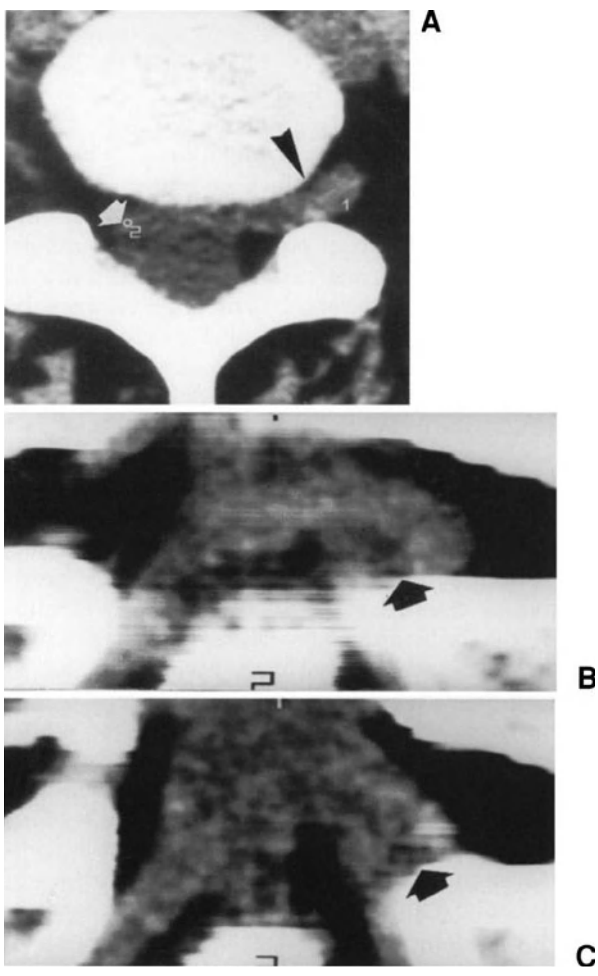


Fig. 9.22. *Type-IV nerve-root anomaly of right L5 and S1 nerve roots.* (A) *Axial CT scan at L5-S1 level. On the left, the L5 root can be seen in the intervertebral foramen (arrowhead), whereas on the right no root is visible in the foramen. On this side, the thecal sac shows an anomalous morphology (arrow) due to the presence of the two roots conjoined.* (B) *and* (C) *Coronal reconstructions showing, on the right, an abnormally large nerve trunk (arrows) probably consisting of two conjoined roots (L5 and S1).*

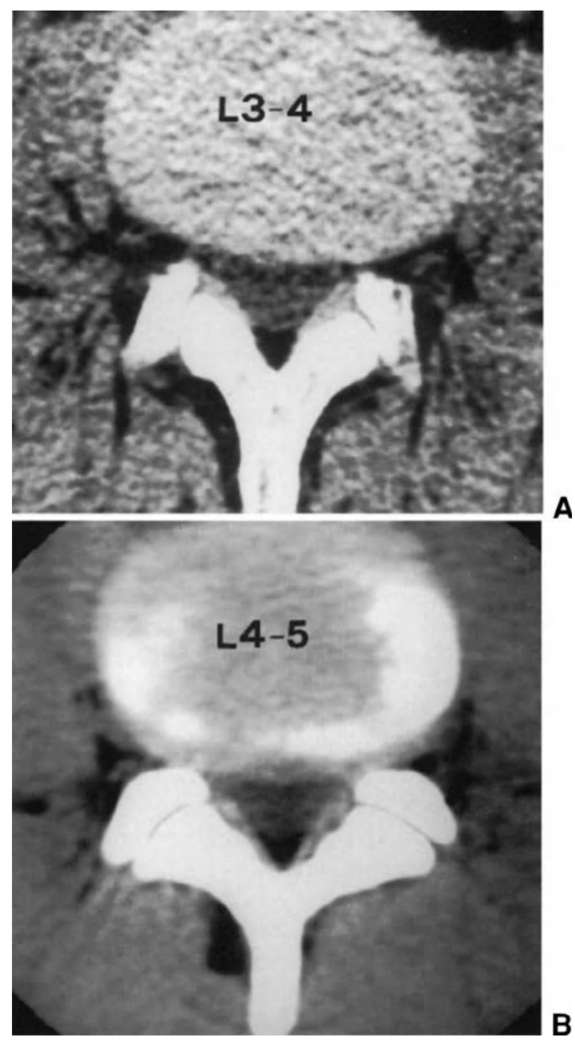


Fig. 9.23. *Axial CT scans at L3-L4* (A) *and L4-L5* (B) *levels showing a bulging annulus fibrosus. The posterior border of the L3-L4 disc, which is normally rectilinear or concave, appears to be convex. At L4-L5 level, the posterior border of the disc exceeds the limits of the vertebral endplate.*

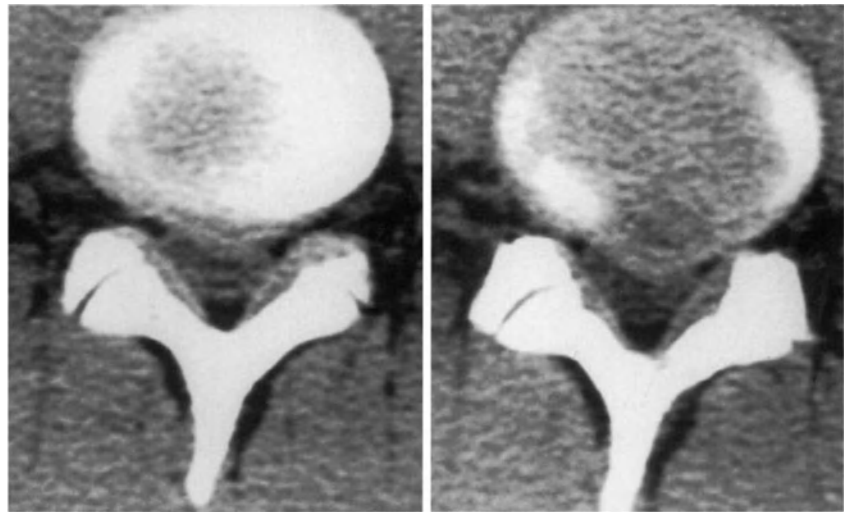


Fig. 9.24. *Axial CT images showing a contained herniation at L4-L5 level. The posterior border of the disc shows a focal paramedian convexity on the left and produces an indentation on the corresponding portion of the thecal sac.*

medium allows the differential diagnosis to be made, since vessels, unlike the disc, show an increase in density. The intervertebral veins running in the neuroforamen are visible on the lateral sagittal reconstructions visualizing the intervertebral foramen.

Bulging of annulus fibrosus

This condition is characterized by the prominence of the entire, or of a large part of the posterior, lateral or anterior aspect of the annulus fibrosus (Fig. 9.23). In the upper lumbar discs, which normally present a slight concavity of their posterior border, bulging of the annulus fibrosus produces convexity of the posterior border of the disc. The prominence of the annulus is generally mild and, thus, extends only slightly beyond the borders of the vertebral bodies. Furthermore, bulging is uniform, without focal areas of more marked protrusion of the disc and, in a spinal canal of normal width, does not cause any compression of the nervous structures. In spite of these distinguishing features, it may, at times, be difficult to differentiate this condition from a contained disc herniation, particularly of the middle posterior portion of the disc. The most important distinguishing feature is the integrity of the annulus fibrosus, which, however, cannot be demonstrated by CT.

Disc herniation

A disc herniation appears as a tissue, showing a similar density to that of the intervertebral disc, which usually occupies the anterior extradural portion of the spinal canal. The herniated tissue obliterates the epidural fat and generally deforms the anterior border of the thecal sac; the nerve roots emerging from the thecal sac may appear to be compressed.

A contained herniation appears as a focal convexity of the posterior or lateral margin of the disc (Fig. 9.24). Due to the integrity of the posterior longitudinal ligament, the herniation has clear-cut and regular margins, showing no lobulation. The herniation does not usually extend cranially or caudally to the disc, but it may be visible on the sections through the vertebral end-plate above or below.

An extruded herniation has lobulated margins and is generally in continuity with the disc from which it originates by means of a pedicle. Part of the tissue often extends cranially or caudally to the disc, but remains in close proximity to the vertebral end-plate above or below (Fig. 9.25). In an extruded transligamentous or retroligamentous herniation, the disc material occupies a large part of the vertebral canal at the level of the intervertebral disc, to which it may appear to be joined by a thin pedicle of tissue. Very often the herniated tissue extends also cranially or caudally to the disc. CT scans should visualize the caudal and cranial ends of the herniated disc tissue in order to give the surgeon adequate information on the site of herniation.

A migrated herniation appears as a mass of disc tissue situated at a variable distance from the disc, with no continuity with it. On sagittal reconstructions, a thin pedicle may be visible, which from the migrated tissue appears to be directed towards the disc of origin. In these cases, it is easy to identify the disc from which the migrated material originates. In some instances, instead, particularly when the disc fragment migrates at a considerable distance, it my be difficult to identify the disc of origin. Useful elements in this respect are the site of the migrated fragment and the characteristic

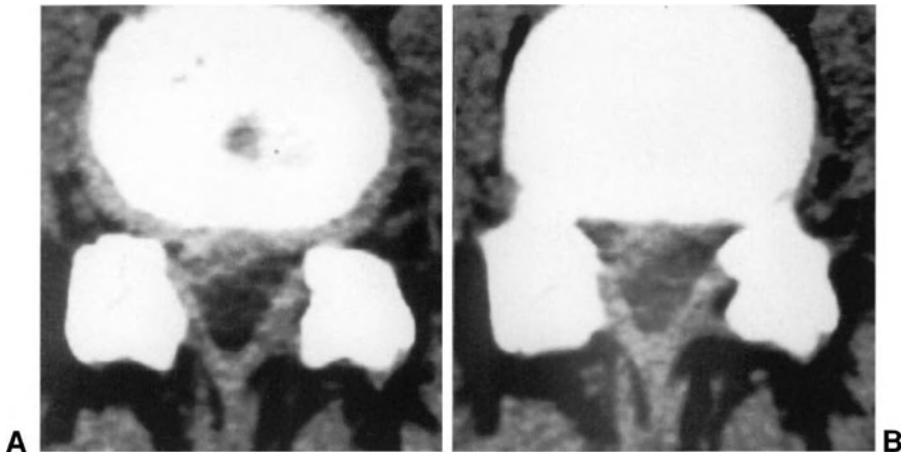


Fig. 9.25. *Right pedunculated L4-L5 extruded herniation, with caudal dislocation of the disc fragment. The herniated tissue is isodense compared with the disc* (A) *and hypodense compared with the thecal sac; the herniation reaches the proximal margin of the L5 pedicle* (B).

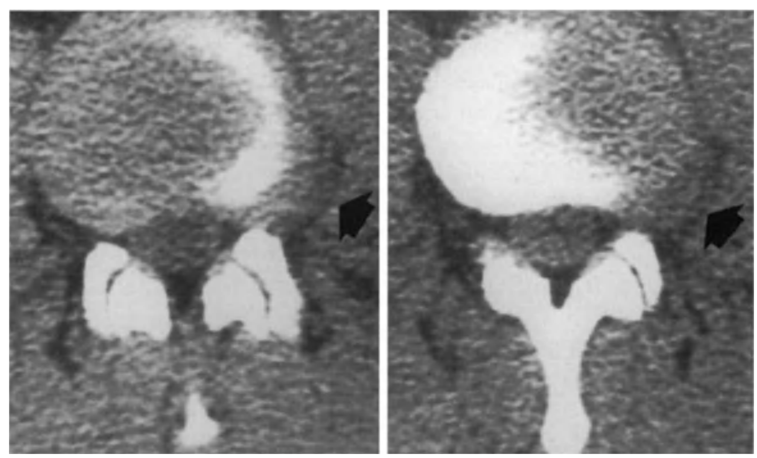


Fig. 9.26. *Axial CT scans at L3-L4 level. The disc border shows a focal convexity in the intraforaminal and extraforaminal zones, due to the presence of a lateral herniation (arrows). This herniation should be referred to as extraforaminal, since it is situated lateral to the intervertebral foramen for most of its transverse dimensions.*

features of the disc of origin. The migrated fragment usually comes from the closest disc; a fragment located in the axilla of the nerve root is generally derived from the disc above; a fragment in the intervertebral foramen originates, almost always, from the disc below. The disc from which the migrated fragment is derived often shows a mild posterior or posterolateral bulging or protrusion; when the fragment is small in size, the parent disc may show the focal convexity typical of a contained or extruded subligamentous herniation. A small fragment of disc tissue located in the lateral recess appears as a hyperdense structure, clearly recognizable by comparing the two recesses; in these cases, the epidural fat may be normal or partially obliterated. It may be impossible to visualize a migrated fragment with CT if it is located in the subpedicular portion of the spinal canal, which generally is not examined.

A lateral herniation may be entirely intraforaminal or extraforaminal. Very often, however, the herniation is located partly within and partly outside the intervertebral foramen (Fig. 9.26). In these cases, the herniation should be classified according to the site in which most of the herniation is located. For example, a herniation with 60% of its transverse dimensions contained within the limits of the intervertebral foramen, and 40% laterally to the external border of the pedicle above, should be considered intraforaminal.

Morphologic characteristics of lateral, contained or extruded, herniations are similar to those of posterolateral or midline herniations, i.e., focal convexities of the disc or lesions with lobulated margins that occupy the intervertebral foramen. A peculiar sign, present in some half of extraforaminal herniations, is the serrated appearance of the border of the vertebral end-plate, resulting from detachment of Sharpey's fibers by the herniated tissue (29) (Fig. 9.27). An extruded herniation may at times be differentiated from a migrated herniation. In the former, the herniated tissue is visible only at the level of the lower end-plate, and the most caudal portion of the body, of the cranial vertebra (Fig. 9.28). In the latter case, the disc fragment is visible (or it shows large dimensions) also on the axial sections immediate-

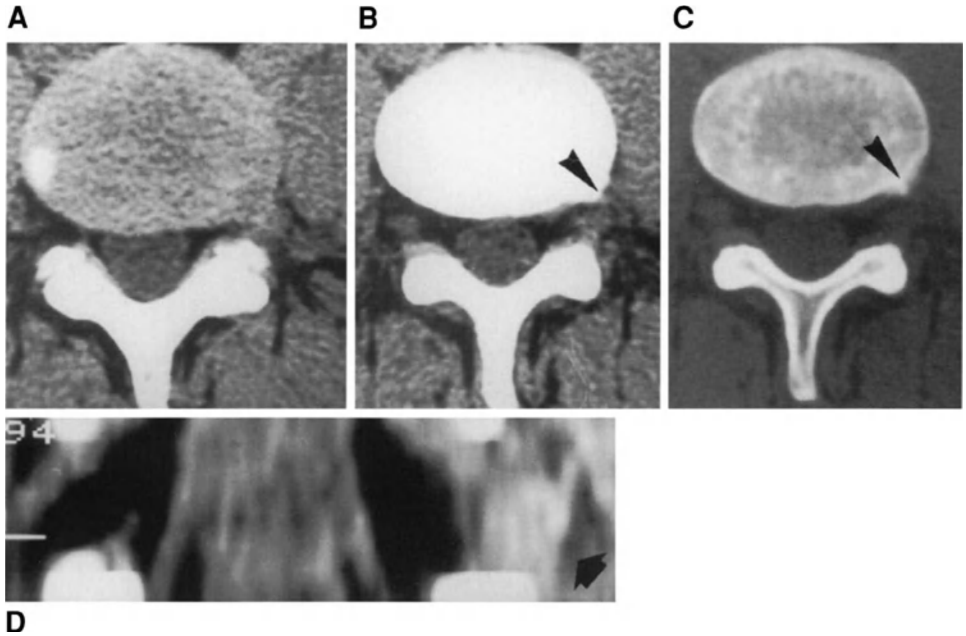


Fig. 9.27. *L4-L5 intraforaminal disc herniation on the left, associated with avulsion of Sharpey's fibers of the caudal end-plate of the vertebra above.* (A) *Focal convexity of the intraforaminal portion of the disc and presence of a nucleus of disc tissue compressing the L4 root.* (B) *and* (C) *Sections at the level of the vertebral end-plate, showing irregularities in the lateral margin due to detachment of the Sharpey's fibers (arrowheads); the two images have been obtained with a window level for soft tissues and bone, respectively.* (D) *Coronal reconstruction. The intervertebral foramen is largely occupied by a hyperdense tissue, corresponding to the herniation (arrow).*

ly below the pedicle of the cranial vertebra (Fig. 9.29). Usually, multiplanar reconstructions (sagittal, coronal and para-axial) easily allow the extent of the herniation and the relationships of the latter with the nearby structures to be demonstrated (222).

The image of the spinal nerve root leaving the intervertebral foramen may occasionally be mistaken for a lateral herniation. The parameters allowing distinction between the two structures are the dimensions and, especially, the morphology and density. The shape of the nerve root is linear, whilst that of herniation is lobulated; the density of the root is close to zero, unlike that of the disc tissue, which shows considerably higher values. In a few cases, the lateral margin of the disc in a scoliotic area, a perineurial cyst or a paravertebral lesion may simulate an extraforaminal herniation. Differential diagnosis may be made based on the density of the abnormal structure, possibly with the use of intravenous contrast medium (233).

The nerve root emerging from the thecal sac may be reduced in caliber as a result of compression or, more often, has a larger transverse area than that of the contralateral root due to intraradicular edema. In this instance, the hypodensity of the root with respect to the disc tissue allows easier identification of the margins of the herniation. A disc fragment migrated in the nerve-root axilla may obliterate the image of the root, particularly when the latter is in close proximity to the disc tissue or is surrounded by it. The same may occur for a disc fragment migrated into the intervertebral foramen.

Occasionally, the disc tissue may display a low density and, thus, be poorly differentiated from the thecal sac (Fig. 9.30). This is more likely to occur when the herniation is of recent onset, in young subjects, in whom the disc has a greater hydration, or when the disc tissue is only slightly degenerated. In these cases, CT shows indirect signs of disc herniation, related to the "mass effect". With use of contrast medium it is possible to exclude neoplastic tissue, which, unlike a herniated disc, shows an increase in density. In the presence of a suspected herniated disc, isodense to the thecal sac, diagnosis may usually be confirmed by MRI, the higher resolution of which easily allows distinction of the two structures (Fig. 9.31).

Long-standing herniations, in which the disc tissue has undergone dehydration processes, may display a higher density compared with the disc. In a long-standing herniation, there may be calcium deposits, which appear as small granules or a continuous band, mostly convex posteriorly. Calcification of the herniated tissue is usually observed in contained or, less frequently, extruded herniations, whilst it is extremely rare in migrated herniations.

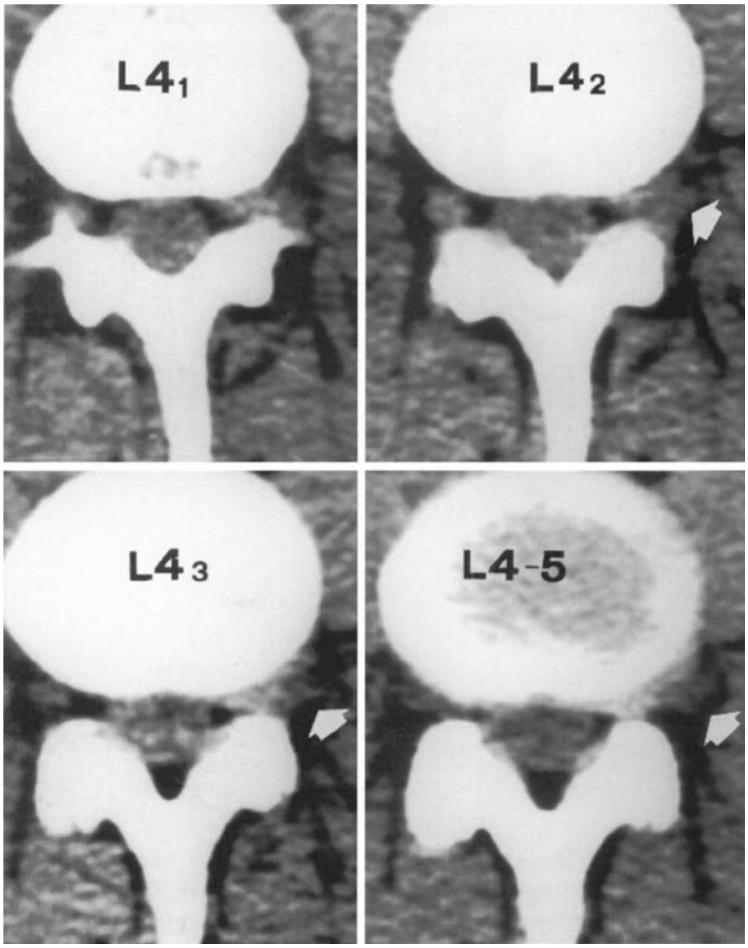
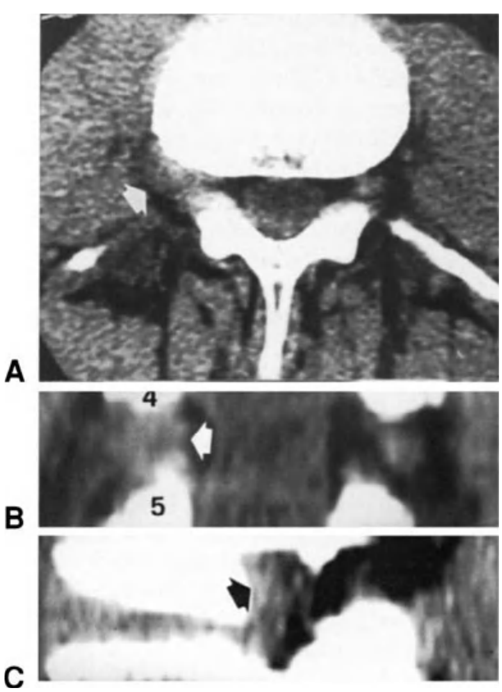


Fig. 9.28. *L4-L5 extruded intraforaminal disc herniation on the left. The herniated fragment (arrows) shows the greatest dimensions on the sections through the vertebral end-plate (L4-5), and immediately above the vertebral end-plate, of L4 ($L4_3$ and $L4_2$). On the most proximal section ($L4_1$), only a small nucleus of tissue is visible. Diagnosis of extruded herniation was confirmed at surgery.*



When the disc is considerably degenerated, a portion of it may display gas-containing vacuoles, which have markedly negative densitometric values. Gaseous vacuoles may occasionally be present also within the spinal canal. They are usually located in the anteroposterior portion of the canal, at times in close contact with the thecal sac and the emerging nerve root.

In the presence of an intradural herniation, CT reveals a mass of tissue displaying a greater density than CSF, which occupies the lumen of the thecal sac. The intradural disc tissue may occasionally show an extrathecal projection, which may be in continuity with the disc.

When the spinal canal is stenotic, diagnosis of disc herniation may be difficult due both to the paucity of epidural fat, and the close proximity of the structures contained in the spinal canal, and it is therefore difficult

Fig. 9.29. *L4-L5 migrated intraforaminal herniation on the right. The disc fragment (arrow) is visible on the axial scan* (A) *immediately above the L4 pedicle. Coronal and sagittal reconstructions* (B) *and* (C) *show the herniated tissue (arrows) reaching the L4 pedicle.*

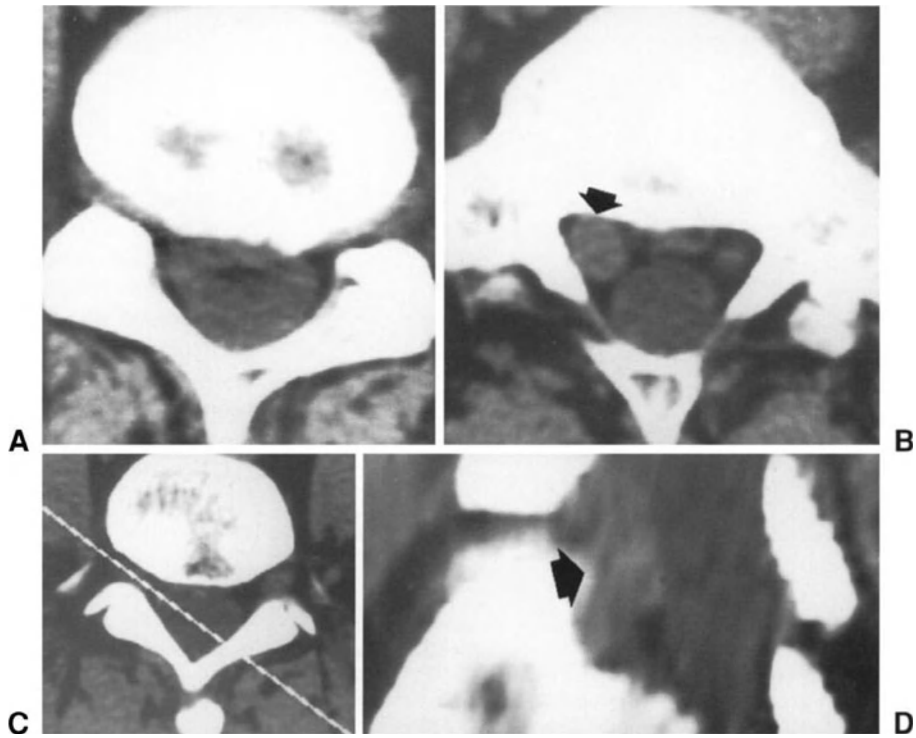


Fig. 9.30. *Disc fragment migrated caudally to the L5-S1 disc with a very similar density to that of the nervous structures.* (A) *Axial CT scan at L5-S1 level.* (B) *Axial CT scan at the level of the proximal portion of the sacrum; on the right, a low density structure (arrow) is visible, which might be due to anomalous nerve roots or a disc herniation.* (C) *and* (D) *Parasagittal reconstruction showing the herniation migrated caudally (arrow).*

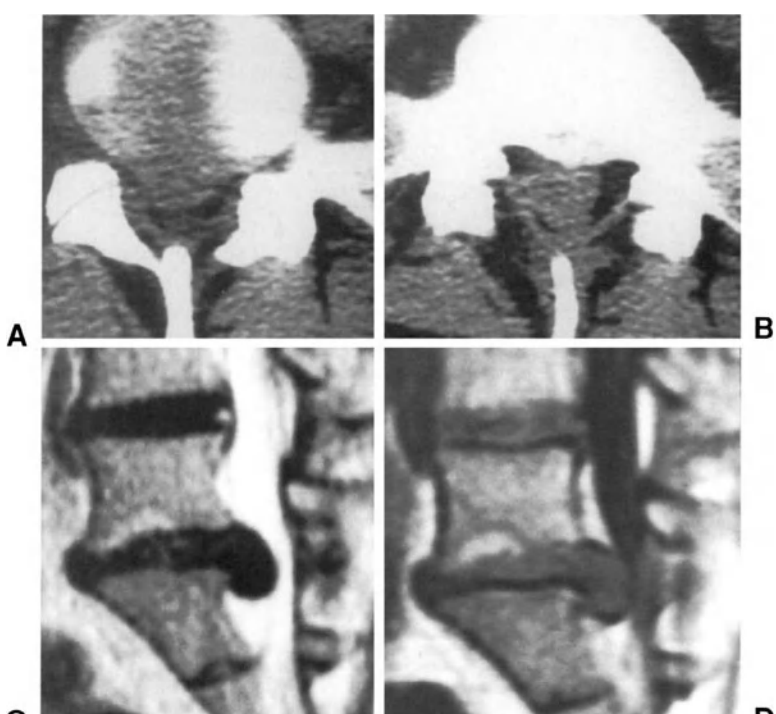


Fig. 9.31. *L5-S1 disc herniation showing a low density and, thus, poorly distinguishable from the thecal sac on axial CT scans. The CT scan at the level of the disc* (A) *appears to display a focal convexity of the disc border and compression of the thecal sac. However, on the CT scan at the level of the S1 vertebral end-plate* (B), *the disc herniation cannot be distinguished from the thecal sac. The turbo spin-echo T2-weighted* (C), *and the spin-echo T1-weighted* (D), *MR images show a large disc herniation which extends caudally to the S1 vertebral end-plate. On the turbo T2-weighted image, the lower two lumbar discs show a marked hyposignal due to degenerative changes and a puntiform hyperintense area is present in the posterior portion of L4-L5 annulus fibrosus.*

to distinguish the hyperdensity of the herniated disc tissue.

Occasionally, in middle-aged or elderly subjects, the herniation appears to be surrounded by a calcified rim, which may be due to annular calcification or a detachment of the margin of the vertebral body in the presence of a posterior Schmorl's node (78) (Fig. 9.32). In young subjects with an osteochondral avulsion, the

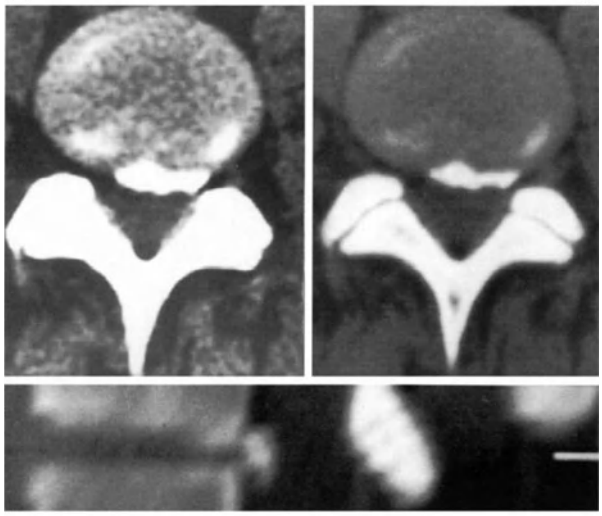


Fig. 9.32. *Calcification of the posterior annulus fibrosus. Axial CT images with a window level for soft tissues* (A) *and bone* (B), *and sagittal reconstruction with a window level for bone* (C). *Only from the reconstruction is it possible to determine that the hyperdense bar visible on axial images does not originate from the vertebral end-plate, but is an annular calcification.*

axial images show a curved bony structure parallel to the posterior wall of the vertebral body and associated with the hypodense herniated tissue (15) (Fig. 9.33). Sagittal reconstructions reveal the defect in the vertebral edge.

Postoperative CT

The changes in vertebral bony structures produced by surgery depend on the extent of the surgical approach to the spinal canal. Hemilaminectomy or central laminectomy are easily recognized due to the absence of a variably large portion of the posterior arch on one or both sides. In patients submitted to laminotomy, it is possible to observe a mild defect or an irregularity of the caudal border of the proximal lamina, the cranial border of the distal lamina and the medial border of the articular processes, associated with the absence of a variably large portion of the ligamentum flavum. The less bone removed at surgery, the less evident will be the bone defect or irregularity. When microdiscectomy has been carried out, bone removal may be so limited that it is not detected on the axial images. In these cases, it may be difficult to identify the site of the previous operation, particularly when only the most lateral portion of the ligamentum flavum has been removed. If a fat graft has been placed on the site of laminotomy or laminectomy, the axial scans will clearly show the fat tissue.

CT carried out in basal conditions very often does not allow a clear-cut distinction between peridural fibrosis and persistent disc herniation or recurrent herniation. The distinction is difficult particularly in the first few weeks after surgery. In this period, in fact, peridural scar tissue is more abundant and lax, thus displaying a more comparable density to that of the disc, than in a later period. On the other hand, in the first few weeks the herniated disc often shows a persistent protrusion, being at times only slightly smaller than that present preoperatively (142); this occurs, above all, in patients with a contained central herniation or when the nucleus pulposus is only slightly degenerated.

At long time interval from operation, CT should always be performed without, and with, contrast medium, since the latter allows scar tissue to be more easily differentiated from the herniated disc tissue (63, 204).

In CT without contrast medium, scar tissue is hypodense compared with the herniated tissue (47). More important distinguishing features, however, are the site and morphology of the abnormal tissue (32). A disc herniation has the characteristics of a soft tissue originating from a limited area of the disc and tends to produce a mass effect on the thecal sac. The scar tissue has a cord-like appearance and often surrounds

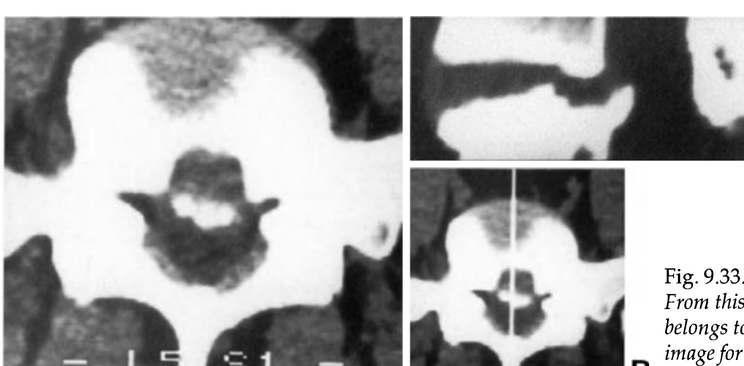


Fig. 9.33. *Osteochondral avulsion of S1 vertebral body.* (A) *Axial image. From this image it is not possible to determine whether the calcified nucleus belongs to the disc or is derived from the S1 vertebral end-plate.* (B) *Reference image for the sagittal reconstruction.* (C) *Sagittal reconstruction showing the osteochondral avulsion of the posterior border of S1 vertebral body.*

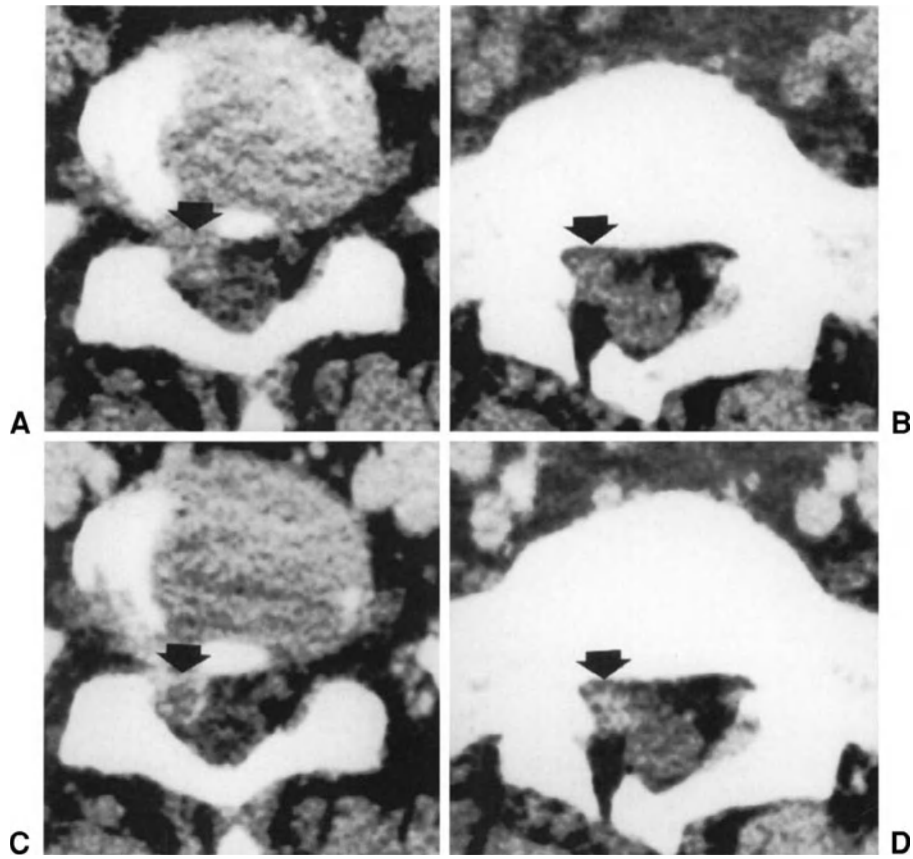


Fig. 9.34. *Right L5-S1 recurrent disc herniation (same level and side).* (A) *and* (B) *Axial CT scans obtained in basal conditions: a soft tissue isodense compared to the disc is visible in the spinal canal, on the right (arrows).* (C) *and* (D) *After administration of contrast medium, density of the tissue (arrows) shows no significant changes.*

and retracts the thecal sac, with no mass effect on it. After administration of contrast medium (fast infusion of 2 ml/kg b.w.) a recurrent herniation shows no change in density, whereas the fibrous tissue shows an increase in density, thus enabling it to be more easily distinguished from disc tissue (Figs. 9.34 and 9.35). The increase will depend upon the volume of contrast agent injected (47), as well as the degree of vascularization of the fibrous tissue.

In the operated patient, stenosis of the spinal canal or the nerve-root canal may be present at the level of surgery. In these cases, the stenosis was generally present prior to the operation and was not significantly modified by the latter. This holds particularly when the articular processes have been left almost intact or laminotomy was not extended adequately proximally or caudally to the disc. However, in patients submitted to discectomy since a long time, stenosis may result from degenerative changes which have developed over the years following surgery.

With CT, it is often difficult to determine whether narrowing of the nerve-root canal causes compression of the emerging root, due to difficulty in identifying the nerve root within the scar tissue present in the spinal canal. Use of the contrast medium may help in making the diagnosis, since the scar tissue becomes hyperdense with respect to the nerve root, which does not take up the contrast agent.

Lumbar stenosis

Stenosis of spinal canal

With the exception of rare forms of stenosis (post-traumatic, congenital or due to Paget's disease), the axial CT scans at the level of the middle portion of the vertebral body consistently show a normal or narrow spinal canal, but not stenosis. The latter appears to be present only on the sections between the zone immediately proximal to the lower apophyseal ring of a vertebra and the cranial portion of the pedicle of the vertebra below (Fig. 9.36).

In constitutional stenosis, degenerative changes, if present, are only mild. The intervertebral disc often shows bulging of the annulus fibrosus or a herniation, mostly on the midline. Usually the nerve-root canals are moderately constricted. The same holds for the

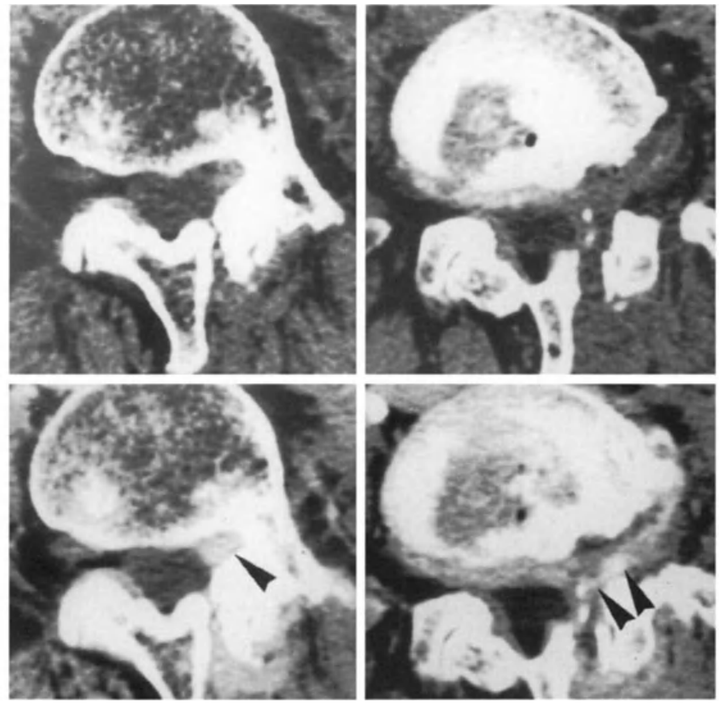


Fig. 9.35. *Postsurgical fibrosis in a patient operated on for a left L4-L5 intraforaminal herniation.* (A) *and* (B) *Axial CT scans in basal conditions.* (C) *and* (D) *After injection of contrast medium: increased density of the tissue situated in the site of previous surgery (arrowheads). The tissue surrounds the thecal sac, but does not produce any mass effect on it.*

central spinal canal, which may be constricted in the transverse and / or midsagittal plane.

Degenerative stenosis is characterized by marked spondylotic changes in the presence of normal primary dimensions of the spinal canal (168). At times it is difficult, on the sections at intervertebral level, to determine whether the primary dimensions of the spinal canal are within normal limits. The size of the canal may be easily evaluated on the scans through the transverse processes. The arthrotic articular processes invade and deform, to varying extent, the central spinal canal and the nerve-root canals. The ligamenta flava often appear thicker than normal. They may be calcified and / or ossified, usually in the portion situated anteromedially to the articular processes.

In degenerative spondylolisthesis, the axial scans may show various types of alterations of the articular facets, generally showing arthrotic changes of varying severity. The orientation of the facets vary considerably: from more coronal than normal to abnormally sagittal. Particularly in the former case, the medial margin of the articular facets often shows osteophytes encroaching on the central spinal canal and the nerve-root canals. These are generally constricted by the superior articular processes of the vertebra below the slipped one. When the articular processes have an abnormal sagittal orientation and vertebral slipping is severe, the nerve-root canals may be constricted by the inferior articular processes subluxated ventrally. On axial scans at the level of the disc, this often presents a uniform posterior prominence, which may simulate annular bulging or a midline disc herniation. Generally this is a pseudoprotrusion, i.e., a partial volume, produced by the presence, on the same section, of the inferior apophyseal ring of the slipped vertebra and the disc below, the posterior margin of which is situated dorsally to the posterior border of the slipped vertebra. When the disc height is decreased and the CT section is thick or oblique with respect to the longitudinal axis of the spine, it is possible to observe, on the same scan, the disc and the posterior border of the underlying apophyseal ring, which appears as a transverse bony bar located anteromedially to the disc.

Thecal sac and extrathecal nerve roots

In a stenotic spinal canal, the thecal sac is uniformly constricted in the sagittal and transverse planes and / or is deformed as a result of the asymmetrical compression by the walls of the canal. Stenosis of the spinal canal may be easily diagnosed by comparing the transverse area of the thecal sac at intervertebral level with the area of the sac at the level of the middle portion of the adjacent vertebral bodies. A decrease in the transverse area at intervertebral level, associated with an increase at the level of the vertebral bodies above and below, is a typical indication of stenosis. A decrease in the area of the thecal sac at intervertebral level compared with that found at the level of the vertebral body

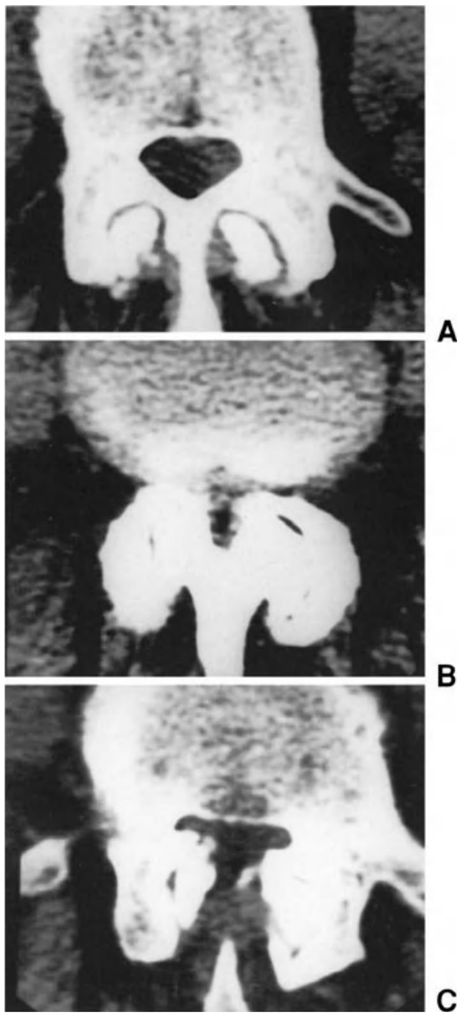


Fig. 9.36. *Stenosis of the spinal canal at L4-L5 level. The axial CT scan at the level of the pedicle of the L4 vertebra* (A) *shows that the spinal canal has a normal width, whilst the scan at L4-L5 level* (B) *reveals marked narrowing of the canal, which again shows normal dimensions at the level of the pedicle of the L5 vertebra* (C).

above, but not of the vertebral body below, may be due to stenosis, or only to constitutional narrowing of the spinal canal and / or the thecal sac, or abnormal shortness of the sac, which becomes progressively thinner as it approaches the sacrum.

Schönström and collaborators (28, 191, 192) measured the transverse area of the thecal sac in normal subjects and in patients with stenosis of the spinal canal: values of less than 100 mm^2 were cosidered an expression of significant stenosis. However, there is a risk of erroneous diagnosis if in the evaluation of the absolute values of the area of the sac, no comparison is made with the values in the adjacent areas. In fact, an abnormally large thecal sac may be constricted due to degenerative vertebral changes even if dimensions of less than 100 mm^2 are not attained and, on the other hand, a narrow thecal sac (constitutionally or abnormally short) may have a transverse area below the limits of normal without being significantly compressed.

When stenosis is severe, the image of the thecal sac may not be detected on axial scans. In this instance, not only can the area of the sac not be evaluated, but it may be difficult to determine the severity of stenosis. Failure to visualize the sac is in any case a sign, in itself, of severe stenosis.

In stenosis of the spinal canal, particularly when severe, the nerve roots running in the radicular canals are not generally visible. This is due to: disappearance of the periradicular fat, with resultant decrease in contrast of the image of the roots; narrowing of the radicular canal, which makes it difficult to visualize its contents; and the reduced transverse area of the compressed nerve roots.

Isolated nerve-root canal stenosis

Stenosis of the intervertebral portion of the nerve-root canal is due to anomalous orientation and / or degenerative changes in the superior articular process. Usually, also the inferior articular process shows degenerative changes and may contribute to narrowing of the radicular canal with its anterior border. The intervertebral disc often presents annular bulging of varying severity or disc herniation, usually small in size. Occasionally, stenosis is caused, in the presence of a constitutionally narrow nerve-root canal, by an osteophyte arising from the proximal end-plate of the caudal vertebra of the motion segment (Fig. 9.37).

In stenosis of the distal portion of the radicular canal, the lateral recesses appear constricted and the spinal canal may be trefoil-shaped. However, narrowing of the radicular canal in the portion facing the pedicle does not involve compression, except in rare instances, of the nerve root, since in this portion there are no osteoligamentous structures which may undergo degenerative changes. The sagittal dimensions of the nerve-root canal may be measured between the anteromedial border of the superior articular process and the posterior aspect of the vertebral body at the level of the superior end of the pedicle. A width of 4 mm or less is usually an expression of nerve-root canal stenosis (39). Measurements performed in the intervertebral portion are not very reliable due to the absence of an anterior bony structure allowing the size of the canal to be precisely evaluated.

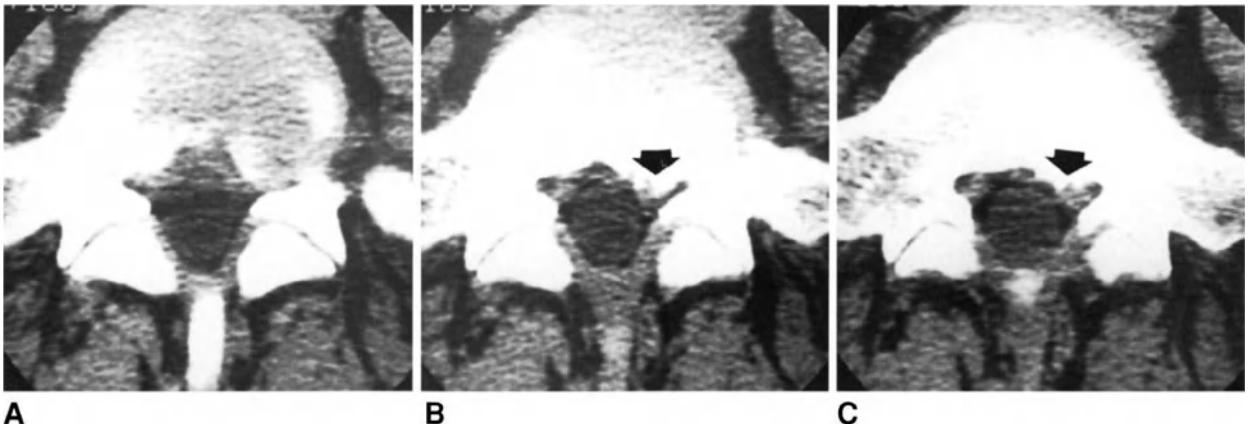


Fig. 9.37. *Stenosis of the S1 nerve-root canal on the left. The axial section at the level of the disc* (A) *shows no pathologic conditions. The sections at the level of the upper vertebral end-plate of S1* (B) *and* (C) *show anterior osteophytes on the left, encroaching on the nerve-root canal and impinging on the S1 root (arrows).*

Stenosis of intervertebral foramen

The dimensions of the intervertebral foramen can be evaluated on axial CT scans. The sections, however, should be parallel to the transverse plane passing through the foramen on both sides. Otherwise, the images of the two sides cannot be compared, and thus it may be impossible to make diagnosis of stenosis. Diagnosis, in fact, is essentially based on this comparison, rather than upon the assessment of the dimensions of the foramen. In the presence of scoliosis, therefore, the axial scans do not allow us to determine whether stenosis of the neuroforamen is present or not when the scan plane is not perpendicular to the longitudinal axis of the vertebra. Anyway, to make diagnosis of stenosis it is mandatory to obtain sagittal reconstructions, since, in the latter, the image of the neuroforamen is little influenced by the possible obliquity of the scan plane with respect to the longitudinal axis of the vertebra.

CT scans often show narrowing of the intervertebral foramen. Narrowing, however, is rarely responsible for compression of the nerve root, which occupies only the proximal one third of the foramen. Often, therefore, diagnosis of nerve-root compression is only suspected, since CT may not adequately visualize the nerve root running in the constricted neuroforamen and demonstrate that it is compressed.

Magnetic resonance imaging (MRI)

Technique

The atoms consist of protons in the center and electrons at the peripheral area. Movement of the electrons around the nucleus generate an electric field, which may be represented as a vector presenting a positive end and a direction. Usually, the vectors are orientated in all directions, since in nature there is no stable North and South.

The MR phenomenon occurs when the atoms are placed in a magnetic field, which is characteristically a stable field with fixed North and South, so that all the vectors acquire a specific North-South orientation. Subsequently, the stable magnetic field is modified by a radiofrequency pulse (RF), which changes the vector alignment. The RF pulse corresponds to a radiowave with a specific wavelength, which depends upon the precession frequency. This, in turn, is an expression of the rotating movement of the spins around the magnetic field. The electric field generated by movement of the electrons around the nucleus is called spin. The greater the intensity of the magnetic field, the higher the precession frequency and the greater the frequency of the RF pulse. When the RF pulse stops, the vector returns to the previous equilibrium condition. The time necessary to return to the previous condition is called relaxation time. The vector returning to the initial position emits a signal, which is received by an antenna and transformed into an image by a computer.

Each tissue has its own relaxation times T1 and T2, which correspond to the time necessary for the spin to return to the equilibrium position when radiowave stops. T1 relaxation time corresponds to the longitudinal relaxation or spin-spin and T2 time, to transverse relaxation or spin-reticulum. T1 is longer than T2, and both depend on chemical and physical characteristics of the examined substance. For example, the T1 of pure water is 3 sec, but decreases to 1.5 sec if water contains proteins. T1 of fat is 0.15 sec, whilst that of other tissues is approximately 0.5 sec. T2 values of tissues range from

40 to 100 msec. Liquids have considerably longer T2 values, which are inversely proportional to the protein concentration. T1 and T2 values are amongst the parameters affecting the signal intensity of a tissue in the MR images. T1 and T2 values are intrinsec to each substance and cannot be modified by the operator, who can, instead, select other parameters.

Various sequences may be used to evaluate the T1 and T2 characteristics of a tissue: spin echo (SE), inversion recovery (IR), saturation recovery (SR), partial saturation (PS), gradient echo (GE), and fast spin echo (FSE). Each sequence has specific characteristics allowing the image to be weighted on T1, T2 or both.

The most used sequence is spin echo, which allows the image to be weighted on T1 or T2, after selection of the specific values. The operator selects a repetition time (TR), representing the interval between two RF pulses, and an echo time (TE), representing the interval between the RF pulse and the signal emitted by the tissue. Thus, the signal intensity in the MR image depends on the selected TR and TE and on the T1 and T2 values of the tissue. The mathematic formula is: I = K(1 – e – TR/T1)e – TE/T2, in which "I" represents the signal intensity, "K" the proton density, TR and TE the repetition time and the echo time, and T1 and T2 the relaxation times of the tissue. This formula indicates that signal intensity increases as TR increases and TE decreases, and that tissues with a short T1 and a long T2 display a high signal. The operator can select optimal TR and TE to emphasize the T1 or T2 value of the tissue under examination.

By selecting short TR (TR < T1) and TE (TE < T2) values, T1-weighted images are obtained, in which areas of high signal intensity indicate substances with a short T1, like fat. TR is short when it is 500 msec and long when it lasts 1500 msec. A 15–20 msec TE is short, whereas a TE over 90 msec is long.

Examination time

The examination time for a standard SE sequence is directly related to TR, number of acquisitions [(AC), i.e., number of repetitions of the sequence] and matrix (MA) used. The matrix is the division of the acquisition volume in small cells; it is usually 256 × 256. Increase in matrix improves the spatial resolution, but also increases imaging time and negatively affects the signal, thus making it necessary to increase the number of acquisitions to obtain a good signal.

The imaging time is about 4–6 min for a routine SE T1-weighted sequence and about 8–11 min for a routine SE T2-weighted sequence. To reduce the examination time, particularly for T2-weighted images, fast gradient echo, and turbo spin-echo, sequences may be used. Using turbo sequences, it is possible to select very long TR (i.e., 5000 msec), high acquisition number (4–6), high matrix (more than 256) and to keep the examination time very low (2–3 min). In our opinion, turbo T2-weighted images are the best for spine imaging, particularly in the evaluation of disc degeneration.

Field of view (FOV), matrix and slice thickness affect spatial resolution. By decreasing the FOV and slice thickness and increasing the matrix, the signal decreases, resulting in poorer quality of the images; however, spatial resolution increases. The optimal values for lumbosacral imaging are slices 3–5 mm thick (SL), 280–320 mm FOV and 192–256 × 256 matrix. A standard examination includes sagittal T1-wieghted (TR = 600, TE = 15, SL = 4, AC = 2, FOV = 280), sagittal turbo T2–weighted (TR = 5000, TE = 120, AC = 4, SL = 4, FOV = 280) and axial T1-weighted, images at L3-L4 to L5-S1 level (SL = 3, AC = 2, TR = 700, TE = 20, FOV = 240).

For optimal evaluation of the intervertebral foramen, sagittal sections should include also the lateral portions of the spine, lateral to the pedicles. Axial sections should be performed continuously from L3-L4 to L5-S1 level; in fact, examination of only the intervertebral spaces may lead to the risk of not detecting a migrated disc fragment. Axial sections should be performed also at the uppermost lumbar levels if called for by the clinical features.

Lumbosacral anatomy

Bone tissue contains no mobile protons. Therefore, on T1-weighted sequences, the cortical bone produces no signal, whilst cancellous bone generates an intermediate intensity signal, due to the presence of bone marrow (Fig. 9.38). On T2-weighted sequences, the vertebral body shows a low signal intensity due to the short relaxation time of the fat tissue contained in the bone marrow (Fig. 9.38). On T1-weighted images of elderly subjects, the signal intensity of the vertebral body increases due to an increase in the amount of yellow marrow. The cancellous bone of the vertebral body, on T1-weighted sequences, may show, at any age, islets of hypersignal corresponding to areas where the bony structure is entirely, or to a large extent, replaced by yellow marrow.

The cartilage of the articular facets, as well as the cartilage end-plate, may be seen on T1-weighted images, particularly on gradient echo sequences. Cartilage appears as a thin rim of low signal intensity, covering the subchondral cortical bone, which generates no signal (Fig. 9.39). On T2 star sequences, cartilage shows a marked hypersignal.

The intervertebral disc, on account of its high water content, has long relaxation times, which are responsi-

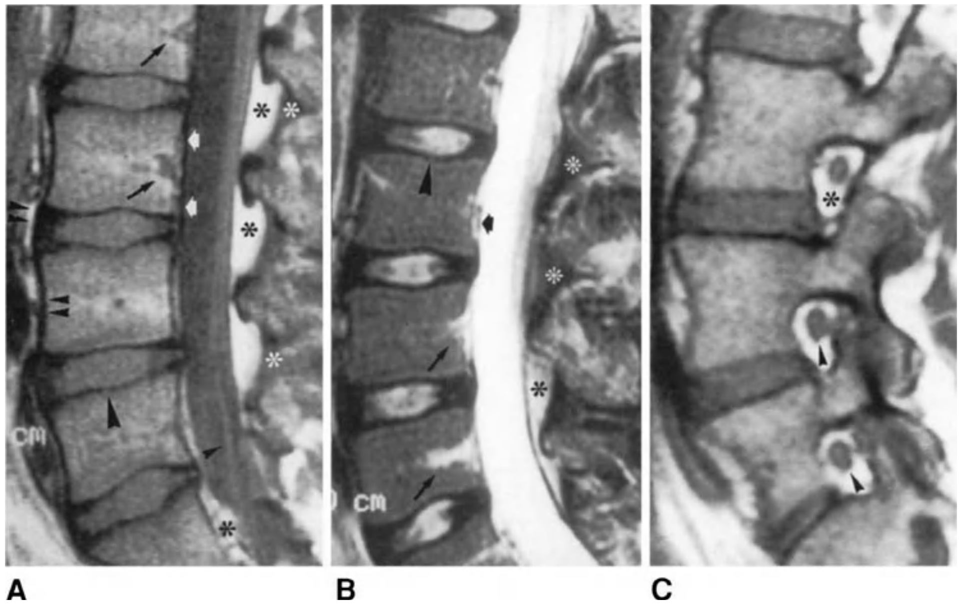


Fig. 9.38. *Normal sagittal MR images.* (A) *Spin-echo (TR 500, TE 20) T1-weighted slightly paramedian image. The vertebral end-plates (large arrowhead) display a low signal intensity, since they consist of compact bone, whereas the trabecular bone of the vertebral body is hyperintense due to the presence of bone marrow. The intervertebral discs have normal height and are isointense to the muscle tissue. The thecal sac is considerably hypointense due to the presence of CSF; a few rootlets of the cauda equina, showing slightly higher signal intensity, are visible within the sac (small arrowhead). The epidural fat (black asterisk) displays high signal intensity. The posterior longitudinal ligament (short arrows) and the anterior longitudinal ligament (double arrowhead) appear as thin hypointense lines. The basivertebral vessels (long arrows) are hypointense. The interspinous and yellow ligaments (white asterisks) are visible between the spinous processes.* (B) *Spin-echo (TR 3000, TE 9) turbo T2-weighted midline image. The vertebral bodies are hypointense; an hyperintense area (long arrows) due to the basivertebral vessels is visible in some of them. The intervertebral discs show a peripheral hypointense portion corresponding to the annulus fibrosus, and a central hyperintense portion corresponding to the nucleus pulposus. Within the latter, small hypointense areas can be seen in a few discs. The hypointense area between the nucleus pulposus and the vertebral body (large arrowhead) corresponds to the vertebral end-plate. The CSF gives the thecal sac a marked signal hyperintensity. The epidural fat (black asterisk) is visible only dorsally to the thecal sac and is only slightly less intense than the CSF. The short arrow indicates the posterior longitudinal ligament. The ligamenta flava (white asterisks) are hypointense.* (C) *T1-weighted sagittal image at the level of the intervertebral foramens. The nerve roots (small arrowhead) surrounded by epidural fat (black asterisk) are clearly visible.*

ble for the hyposignal on T1-weighted, and the hypersignal on T2-weighted, images. The annulus fibrosus is slightly hypointense compared with the nucleus pulposus due to its lower water content. In adult subjects, and particularly in the elderly, the nucleus pulposus often shows a transverse hypointense stria, resulting from age-related fibrotic changes. With increasing age, the decrease in water content results in diffuse reduction in signal intensity of the disc.

The posterior longitudinal ligament is often clearly visible on T2-weighted midsagittal scans. It appears as a linear structure, adhering to the discs and the vertebral end-plates, but not to the posterior aspect of the vertebral bodies. The space between the ligament and the vertebral body, occupied by fat tissue and the branches of the basivertebral vein, generates the marked hypersignal typical of the slow blood flow. On axial sections the ligament appears as a midline septum, hypointense with respect to the fat tissue separating it from the thecal sac (Fig. 9.39). In these sections, the middle and lateral meningovertebral ligaments can be seen, connecting the thecal sac to the vertebral body (Fig. 9.39).

The ligamenta flava are not visible on midline sagittal sections, whilst they can be clearly seen on paramedian scans and T1 axial sections (Fig. 9.39). They appear as hypointense structures, which fill the interlaminar space, on sagittal sections, and delimit the spinal canal posterolaterally, on axial scans.

The ligaments contained in the intervertebral foramen have been visualized with high resolution techniques (151). In vivo, they may be visible on subpedicular sections (Fig. 9.39).

The epidural fat, on T1-weighted images, shows a high signal intensity, which clearly differentiates the adipose tissue from the surrounding structures (Figs. 9.38 and 9.39). On T2-weighted sequences, the epidural fat is hypointense and, thus, poorly distinguished from the other structures, except for the CSF. The latter, which have long relaxation times, generates a low intensity signal on T1-weighted sequences and a high intensity signal on T2-weighted sequences. Turbo T2

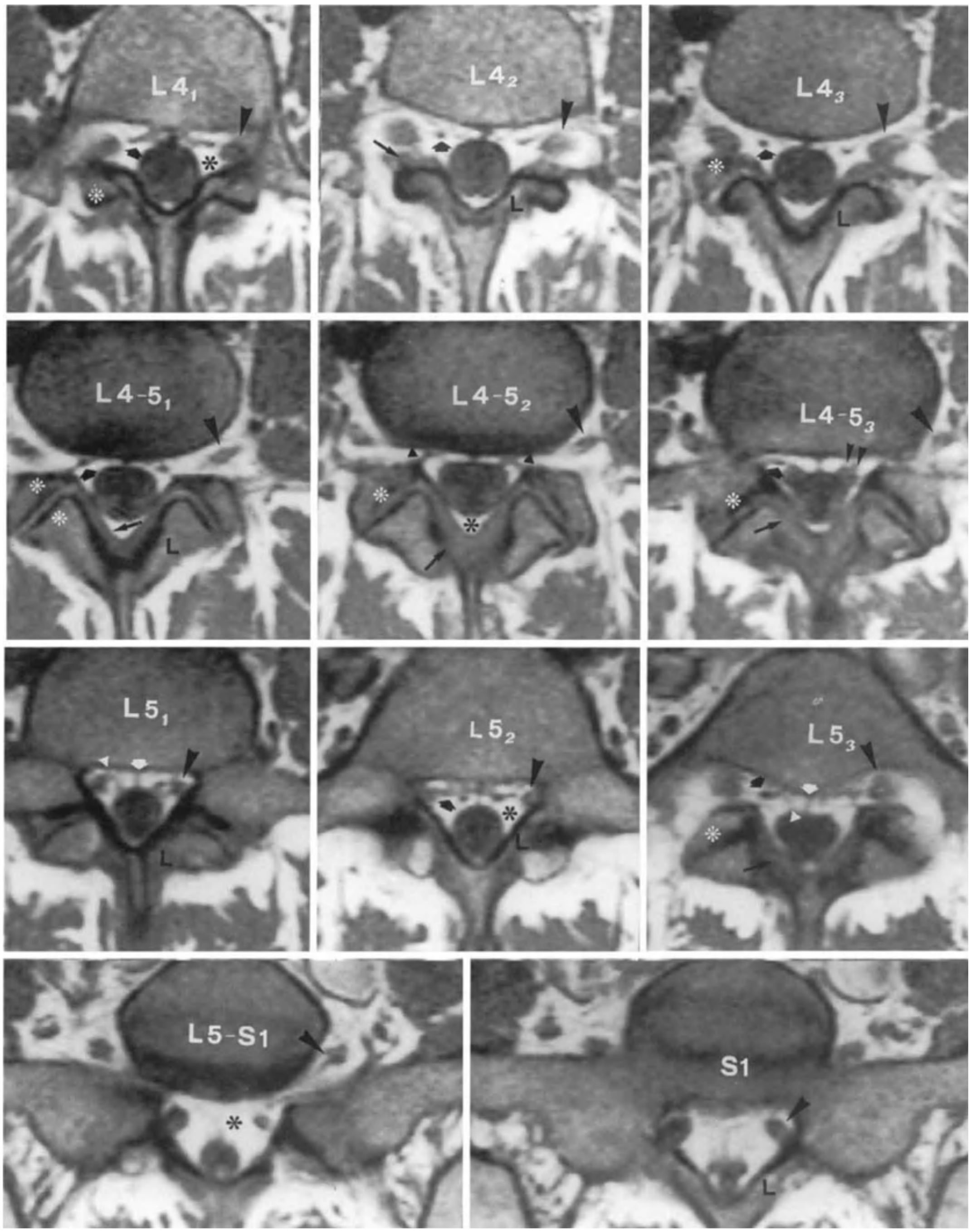


Fig. 9.39. *Spin-echo T1-weighted axial MR images. The images are sequential from the caudal half of the L4 vertebra to the S1 vertebral end-plate. The arrowheads indicate the L4 nerve root in the L4 radicular canal ($L4_1$) and the L4-L5 intervertebral foramen (from $L4_2$ to $L4\text{-}5_3$), the L5 root in the L5 radicular canal ($L5_1$, $L5_2$) and the L5-S1 intervertebral foramen ($L5_3$, L5-S1), and the S1 root in its radicular canal (S1). The double arrowheads indicate the L5 root emerging from the thecal sac ($L4\text{-}5_3$); the nerve roots are visible, in the sac, as roundish structures displaying a similar signal intensity to the CSF. The short arrows point to the anterolateral venous plexuses of the spinal canal. The black asterisks indicate the considerably hyperintense epidural fat. The white asterisks are placed on the superior articular processes of L5 (from $L4_3$ to $L4\text{-}5_3$) and S1 ($L5_3$). At $L4\text{-}5_1$ level, an asterisk is placed also on the inferior articular process of L4; the two asterisks are separated by two linear structures with no signal corresponding to the cortical bone, between which there is a hypointense zone corresponding to the articular cartilage. The white arrow indicates the median meningovertebral ligament and the triangle indicates the lateral meningovertebral ligament ($L5_1$, $L5_3$). The long arrows indicate the ligamenta flava. The black triangles at $L4\text{-}5_2$ level indicate linear structures, probably represented by the ligaments in the intervertebral foramen. L indicates the laminae of L4 (from $L4_2$ to $L4\text{-}5_1$), L5 ($L5_1$, $L5_2$) and S1 (S1). Note the signal hypointensity of the disc compared with that of the vertebral body; the areas showing lower signal intensity at L5-S1 and S1 correspond to portions of the disc.*

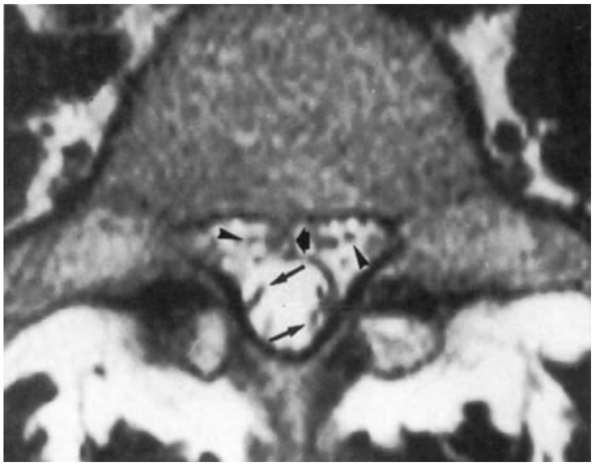


Fig. 9.40. *Turbo spin-echo T2-weighted MR image of L5 vertebra. The CSF in the thecal sac is hyperintense, whereas the nerve roots contained in the sac are hypointense (long arrows). The epidural fat is hyperintense. The epidural vessels (arrowheads) and the median meningovertebral ligament (short arrow) are clearly visible.*

sequences enhance the signal hyperintensity of the epidural vessels and CSF, in which the hypointense images of the spinal nerve roots may be easily identified (Fig. 9.40).

The conus medullaris, filum terminale and caudal nerve roots show an isointense signal on all sequences, thus making them easily distinguishable from the CSF in the thecal sac. On axial sections, the conus medullaris appears ovoid in shape and the anterior median fessure is clearly visible in its proximal portion. On sagittal and coronal sections, the conus medullaris displays the typical conic shape. The filum terminale cannot be distinguished from the caudal nerve roots, except at the level of its origin from the conus medullaris. The filum may be thickened and lipomatous or may contain a small lipoma (Fig. 9.41); this appears, on T1-weighted axial images, as a puntiform area of hypersignal in close proximity to the posterior wall of the sac on the midline (40). The cauda equina, on axial sections at L2 level, appears as a compact half moon, located in the posterior portion of the thecal sac. At L3 level, the individual roots are not easily distinguished, whereas at the levels below they appear as puntiform structures separated by CSF. On sagittal sections, particularly those in the paramedian planes, and on axial scans, the nerve roots are easily recognized as linear structures originating from the spinal cord.

On axial sections, the nerve roots in the extrathecal course are clearly visible on the sides of the thecal sac and in the intervertebral foramen; on T1-weighted images, they appear, compared with the surrounding fat, as hypointense structures (Fig. 9.39). As on CT scans, the shape of the nerve-root in the intraforaminal and extraforaminal areas depend on the inclination of the scanning plane. Coronal sections allow visualization of the entire root in a single image; occasionally, the dorsal root ganglion is also visible (40). On paramedian sagittal sections, the nerve roots are easily identified in the intervertebral foramen, where they appear as roundish structures, the signal intensity of which contrasts with that of the epidural fat and the surrounding venous plexus (Fig. 9.39).

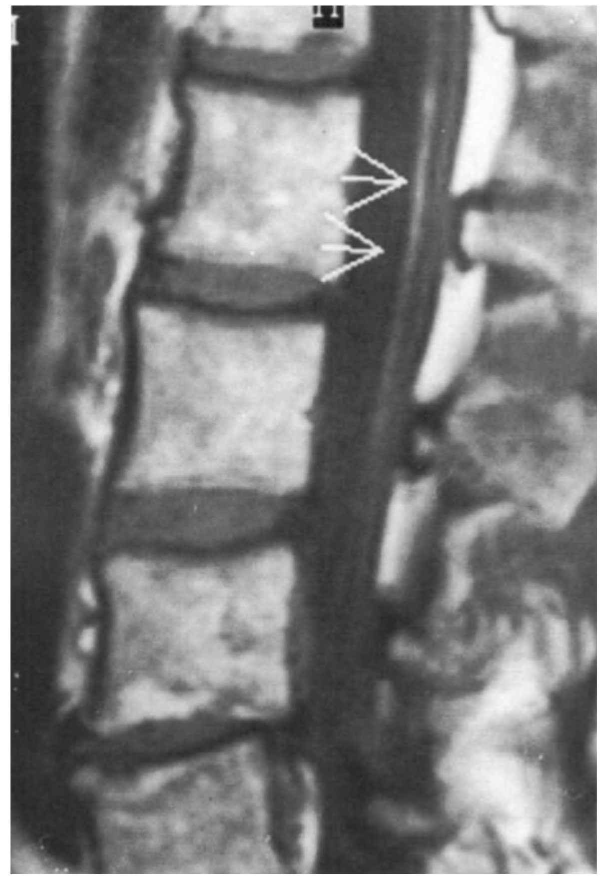


Fig. 9.41. *Spin-echo T2-weighted MR sagittal image. A hyperintense structure (arrows) represented by a lipoma of the filum terminale is visible within the thecal sac.*

Nerve-root anomalies may be recognized on axial and coronal images, whilst they are not usually seen on sagittal sequences. On axial scans, the anomalous roots show similar characteristics to those observed on axial CT scans. On coronal sections, they appear as on the posteroanterior myelogram.

Meningeal radicular cysts and cysts of the sac are clearly visible on T2-weighted images, appearing as roundish structures with the same signal intensity as the CSF (Fig. 9.42).

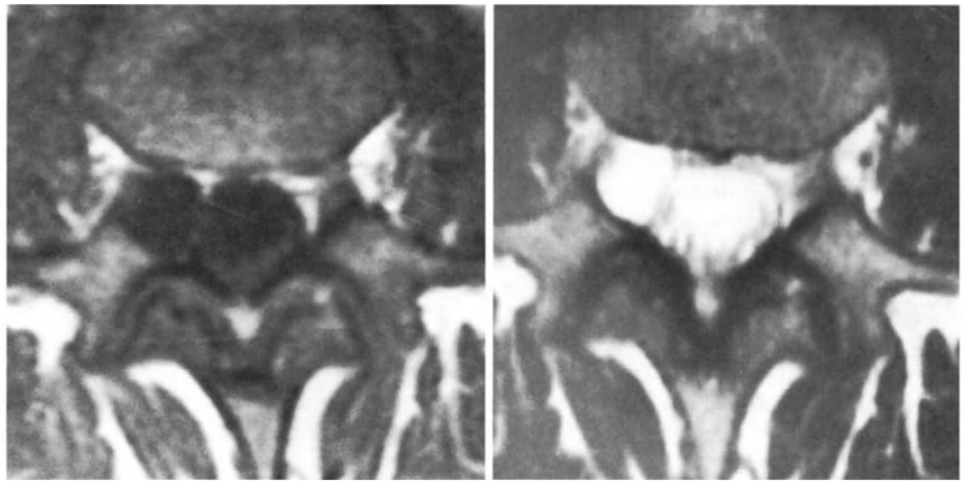


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Fig. 9.42. *Radicular meningeal cyst at L3 level on the right. The cyst has the same signal intensity as the thecal sac on the spin-echo T1-weighted axial image* (A) *and as the CSF on the spin-echo T2-weighted axial image* (B).

Disc degeneration

Degenerative changes of the disc present with a reduction in signal intensity on T2-weighted sequences. Numerous studies have shown that the decrease in signal intensity is related to loss of hydration and proteoglycan, typical of physiologic (age-related) and pathologic degeneration (22, 99, 109, 140, 155, 173, 205). Furthermore, several post-mortem and in vivo studies have demonstrated that intervertebral discs showing fissures in the annulus fibrosus or avulsions of the cartilage end-plate present a decrease in signal intensity (36, 189, 190, 238, 239).

In MRI studies on cadavers, circumferential and radial fissures in the annulus fibrosus have been visualized, on T2-weighted sequences, as areas of high signal intensity in the context of the hyposignal of the rest of the annulus (241). The high signal intensity appeared to be due to the presence of fluid or mucoid material in the fissures. In vivo, fissures have initially been identified, on T1-weighted images after intravenous injection of gadolinium (gadolinium-labeled diethylenetriamine pentacetate), as areas of hypersignal in the peripheral portion of the disc; the increased signal intensity would thus be due to the presence of granulation tissue in the fissures (178). On T2-weighted images, obtained in basal conditions, two types of hypersignal, corresponding to fissures in the annulus fibrosus, may be seen: puntiform areas of high signal intensity showing no communication with the nucleus pulposus and striae communicating with the nucleus (Figs. 9.43 and 9.44). The former may be observed in degenerated discs (signal hypointensity of the nucleus pulposus) or in otherwise normal discs. The latter result from penetration of the nucleus pulposus into the annulus fibrosus and are almost consistently associated with reduction in signal intensity of the nucleus pulposus. In the

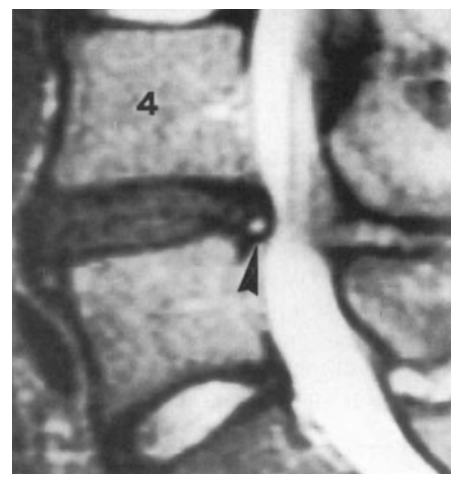

Fig. 9.43. *Spin-echo T2-weighted MR image. Puntiform hyperintense area in the annulus fibrosus of a disc showing a marked hyposignal due to degenerative changes.*

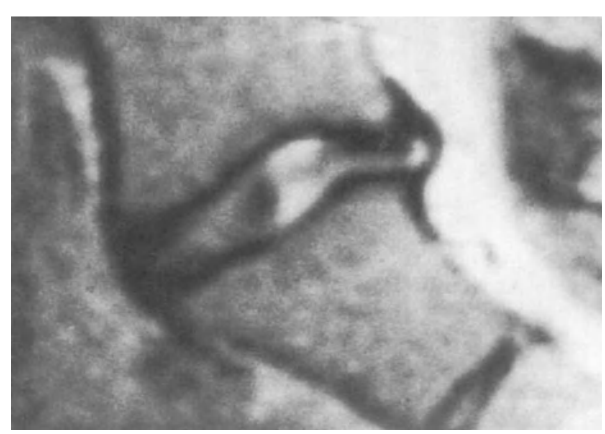

Fig. 9.44. *Spin-echo T2-weighted MR image. Hyperintense stria, which from the nucleus pulposus reaches the peripheral portion of the annulus fibrosus.*

presence of high-signal-intensity areas of the first type, discography may show an annular fissure and may give rise to pain (10). In a study (187), the pain provocation test was positive in 87% of cases in which the disc showed areas of high signal intensity in the annulus fibrosus, whereas it was negative or only mildly positive in 97% of cases showing no hyperintense areas; this suggests that the presence of high-signal-intensity areas is a reliable index of symptomatic degenerated disc. On the other hand, it is well known that a disc with annular fissures demonstrated at discography may appear normal at MRI (36, 116, 240, 242).

These findings indicate that a disc with normal features at MRI may not have necessarily a normal structure and that the decrease in signal intensity only demonstrates that the disc presents biochemical changes, which may not be associated with macroscopic or microscopic changes in the nucleus pulposus or the annulus fibrosus (205). This, however, is likely to be very uncommon when the disc shows a loss of height and is considerably hypointense at MRI. On the other hand, markedly degenerated discs may display an increase in signal intensity, probably due to replacement of fibrocartilaginous tissue with degenerated tissue presenting a high fluid content (238).

Scheibler et al. (189), using high TR/TE, have observed two types of changes both in otherwise normal discs and in degenerated discs. The changes consisted in curving of the inner annular lamellae and the presence of a hypointense puntiform area in the central zone of the disc. These abnormalities could represent very initial signs of disc degeneration, preceding the biochemical changes.

In the posterior annulus fibrosus, large areas of hypersignal on T2-weighted images are rarely visible (Fig. 9.45). The high signal intensity might result from ingrowth of vessels and granulation tissue in the peripheral portion of the disc.

In severely degenerated discs displaying a vacuum phenomenon, the gradient echo sequences are more sensitive than spin-echo sequences in demonstrating the intradiscal gas, which appears as an area of marked hyposignal (21, 83).

Bone marrow

Modic et al. (141), in the presence of degenerative disc changes, described three types of changes in the vertebral end-plates and bone marrow of the vertebral body. In Type I, the yellow marrow in the subchondral bone is replaced by fibrovascular tissue; this causes a decrease in signal intensity on T1-weighted images and an increase on T2-weighted sequences. In Type II, there is an increase in the amount of yellow marrow in the subchondral bone, wich results in signal hyperintensity on T1-weighted images and isointensity, or slight hyperintensity, on T2-weighted sequences (Fig. 9.46). Type III is characterized by thickening of the bone trabeculae in the subchondral region, resulting in a decreased signal intensity both on T1- and T2-weighted images. Only occasionally do these three types of change co-exist in

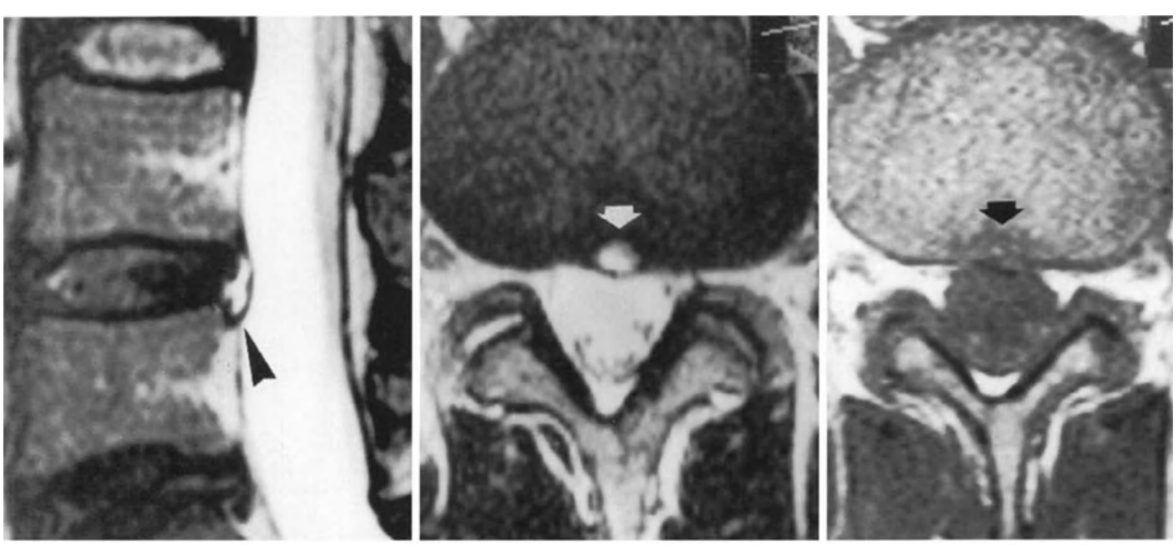

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Fig. 9.45. (A) *Spin-echo T2-weighted MR image. A large hyperintense area (arrowhead) is visible in the posterior portion of the annulus fibrosus of the L4-L5 disc, which shows a decreased signal intensity.* (B) *Turbo spin-echo T2-weighted MR image. The area of high signal intensity in the annulus fibrosus is roundish on axial section (arrow).* (C) *Spin-echo T1-weighted MR image. The posterior portion of the L4-L5 annulus fibrosus shows a zone of decreased signal intensity with puntiform hyperintense areas (arrow).*

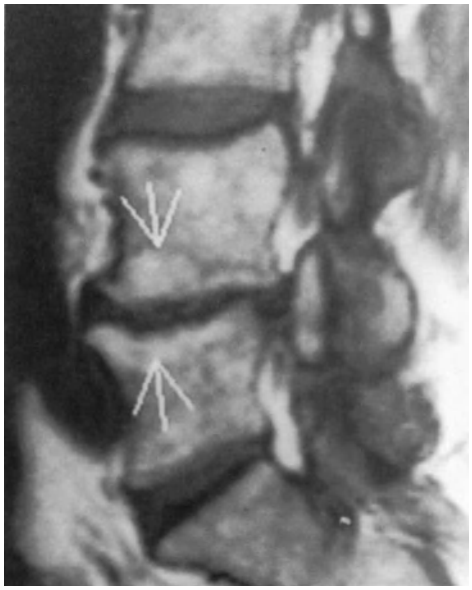

Fig. 9.46. *Spin-echo T1-weighted MR image. Hyperintensity of the subchondral bone of the L4 and L5 vertebral bodies (arrows) due to Modic's et al. (141) Type II changes of the subchondral bone marrow.*

the same subject (Fig. 9.47). With time, Type I may be transformed into Type II, whereas the contrary has never been reported to occur. Both types of change are unrelated to the severity of sclerosis in the subchondral bone visible on radiographs. Type I changes may occur following chymopapain chemonucleolysis (128, 201).

In another study (214), only two types of MRI changes were identified: Type A, including Type I and III described by Modic et al. (141), and Type B, corresponding to Type II. Type A lesions, which are characterized by a hyposignal on T1-weighted images, were associated with thickened bony trabeculae and fibrovascular bone marrow, indicating injury and repair of the vertebral end-plates. Most of the patients with Type A changes complained of back pain and showed segmental vertebral hypermobility, whereas Type B changes were common in patients with stable degenerative disc disease.

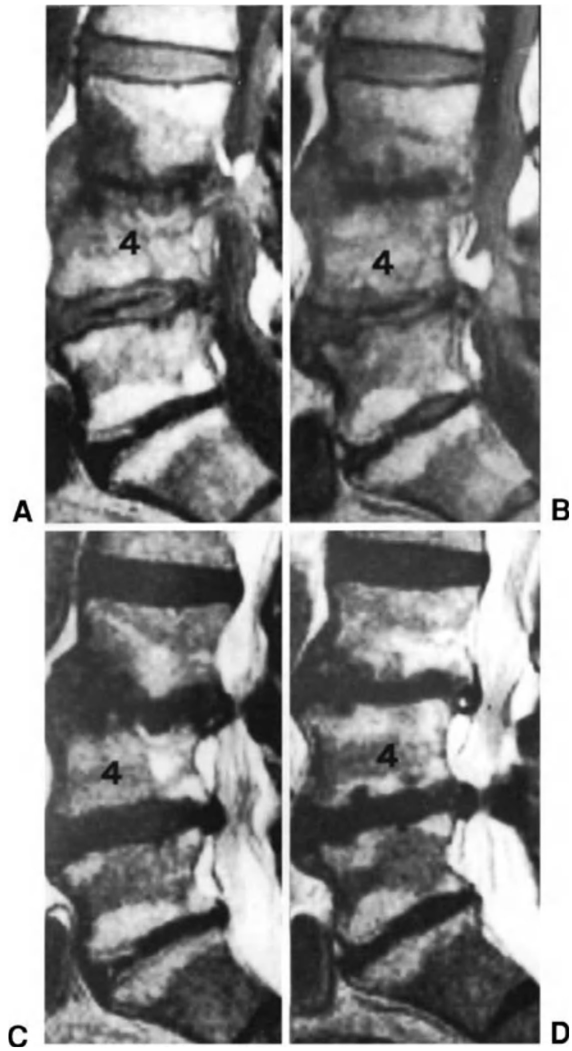

Fig. 9.47. *Simultaneous presence, in the same patient, of the three types of Modic's et al. (141) changes in the bone marrow of vertebral body.* (A) *and* (B) *Spin-echo T1-weighted MR images.* (C) *and* (D) *Turbo spin-echo T2-weighted MR images. At L4-L5 level, signal hypointensity on T1-weighted and signal hyperintensity on T2-weighted images due to Type I changes. At L5-S1 level, hyperintense signal on both T1- and T2-weighted sequences due to Type II changes. At L3-L4 level, signal hypointensity on both T1- and T2-weighted images, particularly in the anteroinferior portion of L3, due to type III changes.*

Bulging of annulus fibrosus

This condition appears as a uniform prominence of the entire posterior or posterolateral border of the disc, which usually displays a low signal intensity on T2-weighted sequences. The signal hypointensity is visible on sagittal sections, whereas the disc prominence is more clearly revealed on axial sections. After administration of gadolinium, it is possible, on T1-weighted images, to observe a high signal intensity in the posterior portion of the disc, in the presence of radial or circumferential fissures (239). However, areas of high signal intensity may also be seen, in basal conditions, on T2-weighted images.

The fifth lumbar disc often shows, in normal conditions, a mild posterior prominence, which should not be considered a pathologic bulging of the annulus fibrosus. Similarly, in the presence of spondylolisthesis or retrolisthesis, the intervertebral disc may display, on axial sections, a posterior prominence due to vertebral disalignment rather than pathologic disc conditions.

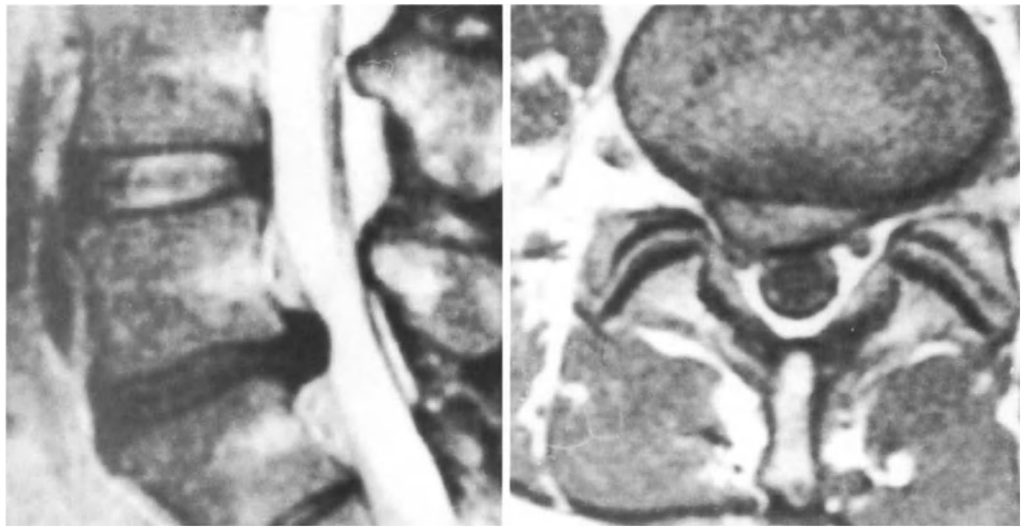

Fig. 9.48. *Right paramedian L5-S1 contained disc herniation. The turbo spin-echo T2-weighted MR sagittal image shows a marked hyposignal of the herniated disc. The spin-echo T1-weighted axial image shows a focal convexity of the posterior border of the disc, with a hypointense rim surrounding the herniated tissue.*

Furthermore, on lateral parasagittal sections, the lowermost intervertebral discs may show a non-pathologic posterior bulging, usually due to a decrease in disc height. During the day, posterior bulging of the annulus fibrosus may increase, whereas the signal intensity of the disc shows no significant change (195).

Disc herniation

The signal intensity of herniated tissue is similar to that of the disc from which it originates. On T1-weighted sequences, the herniated tissue is hypointense with respect to the epidural fat, whereas on T2-weighted scans the herniation shows a lower signal intensity than the CSF contained in the thecal sac and the nerve-root sleeves. When the disc of origin is severely degenerated or the herniation is long-standing, the herniated tissue may be markedly hypointense and, thus, be difficult to distinguish from osteophytes of the vertebral body.

A contained herniation is characterized by the presence of a peripheral hypointense rim, corresponding to the still intact portion of the annulus fibrosus (Fig. 9.48).

In extruded herniations, the hypointense rim typical of a contained herniation cannot be seen (82). In the extruded subligamentous herniation, the annulus fibro-

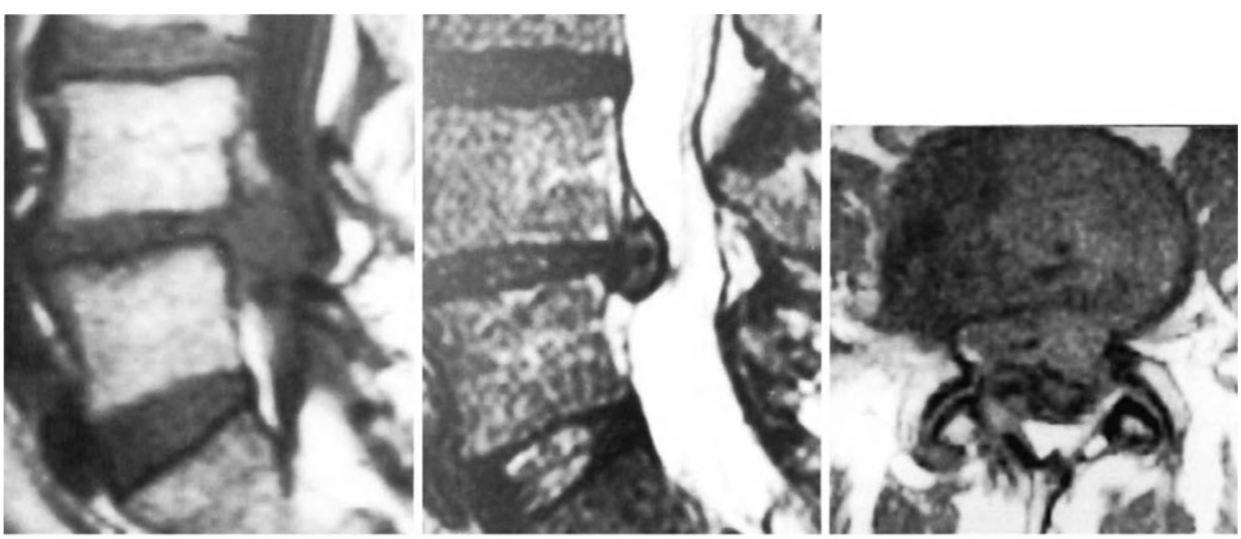

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Fig. 9.49. *Retroligamentous extruded L4-L5 disc herniation. Spin-echo T1-weighted sagittal image* (A), *turbo spin-echo T2-weighted sagittal image* (B) *and spin-echo T1-weighted axial image* (C). *A mass of disc tissue is visible in front of the disc and behind the posterior longitudinal ligament. A thin pedicle of tissue joins the mass to the parent disc.*

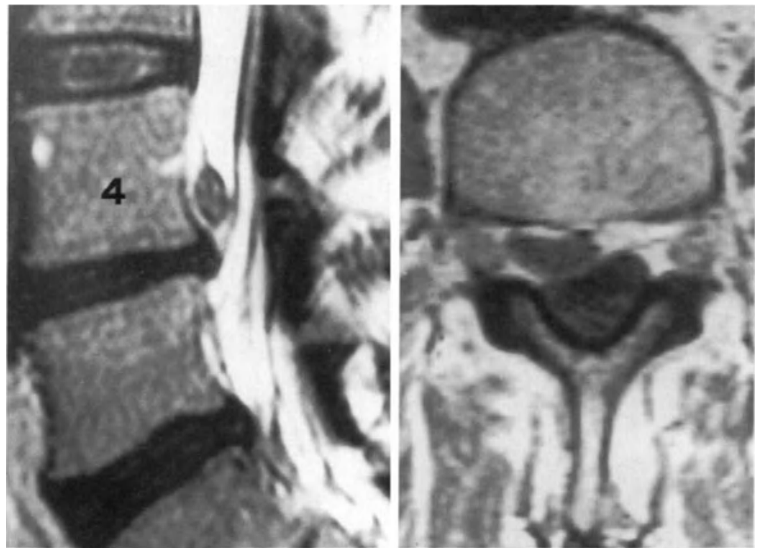


Fig. 9.50. *Turbo spin-echo T2-weighted sagittal, and spin-echo T1-weighted axial, images showing a migrated disc herniation originating from the L4-L5 disc. The disc fragment has migrated cranially on the right.*

sus is interrupted, whilst the posterior longitudinal ligament is intact. Occasionally, the ligament appears to be raised and displaced posteriorly by the extruded fragment. Instead, in transligamentous or retroligamentous extruded herniations, the ligament appears to be interrupted (Fig. 9.49). In extruded herniations of any type, a strand of disc tissue joining the extruded fragment to the intervertebral disc is almost always visible. The connecting strand is clearly visible on sagittal T2-weighted sections (129).

In migrated herniations, the disc fragment has no connection with the disc of origin (Fig. 9.50). On T2-weighted sequences, the migrated fragment usually shows a high signal intensity compared with the disc of origin (129). This occurs particularly when the fragment has only recently migrated from the disc. At long term, on the other hand, the signal becomes hypointense on T2-weighted sequences. It may, at times, be difficult to determine whether a herniated disc is extruded or migrated. This holds particularly when a large fragment has migrated at a distance from the disc, but still appears to have a thin strand of tissue connecting it to the parent disc (Fig. 9.51). In these cases, it is preferable to consider the herniation as migrated, at least for surgical purposes, since, when operating, the surgeon should look for the herniated tissue at a distance from

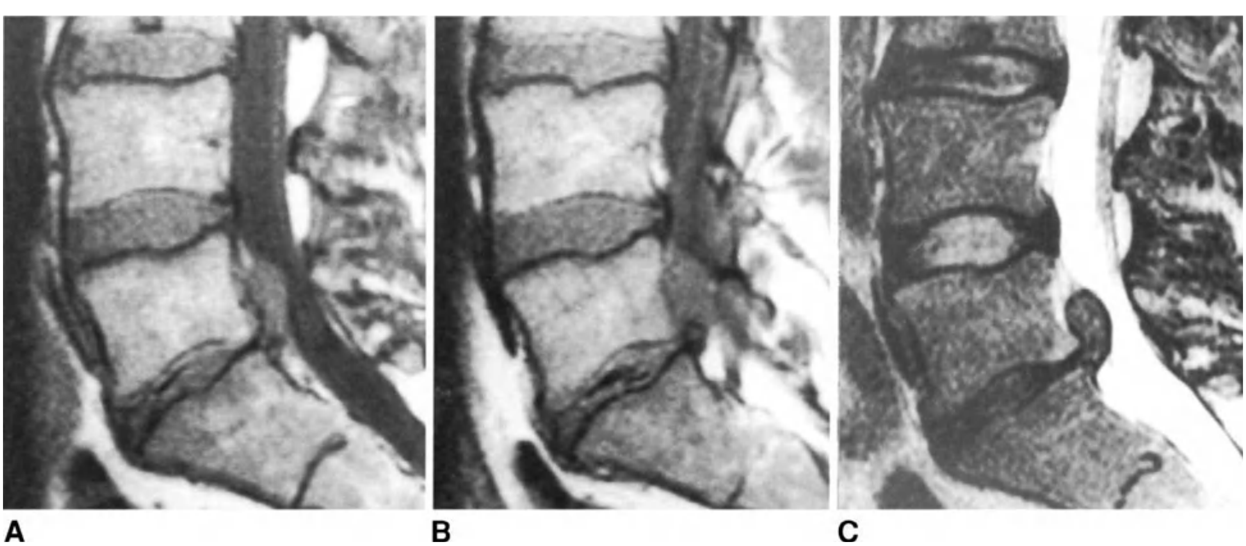


Fig. 9.51. *Retroligamentous extruded disc herniation, migrated proximally, at L5-S1 level. Spin-echo T1-weighted* (A) *and* (B), *and turbo spin-echo T2-weighted* (C) *sagittal images. The herniated disc fragment has migrated cranially as far as the proximal one third of L5, but it appears to be connected to the disc by a thin pedicle of tissue on the turbo T2-weighted image. This herniation may be classified as extruded or migrated. From the surgical viewpoint, it is preferable to classify it as migrated.*

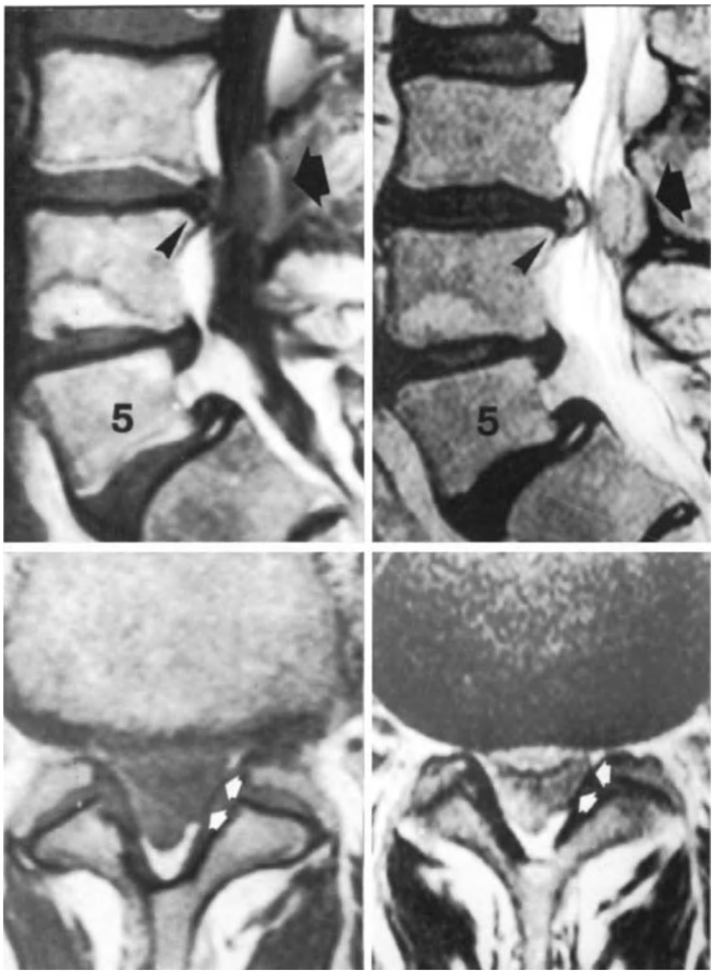


Fig. 9.52. *MR images showing a large disc fragment migrated dorsolaterally to the thecal sac. On spin-echo T1-weighted (left) and turbo T2-weighted (right) sagittal sequences, a moderately hyperintense structure is visible, impinging on the dorsal wall of the thecal sac (arrows) at the level of the L3-L4 disc, which presents a small extruded herniation (arrowheads). The T1-weighted (left) and turbo T2-weighted (right) axial sequences show the pathologic tissue dorsolaterally to the thecal sac (arrows). The histologic examination of the fragment excised at surgery demonstrated that it consisted of disc tissue.*

the disc. The disc fragment may migrate cranially or caudally. In some studies, the frequency of cranial migration was found to be comparable to (188), or only slightly greater than (46), that of caudal migration; in other studies, there was a definite predominance of cranial (68) or caudal (229) migration. In our experience, caudal migration is much more common, if migrated intraforaminal herniations are excluded. If these herniations, which almost always originate from the disc below, are included, cranial migration prevails. The disc fragment almost consistently migrates laterally to the midline. This is due to the presence of the median meningovertebral ligament; only when the latter is perforated or detached from the vertebra, will the herniated tissue migrate in the midline (188). Exceptionally, a disc fragment may migrate behind the thecal sac (Fig. 9.52).

Lateral herniations may be intraforaminal, extraforaminal or, more often, both intra- and extraforaminal. They represent 1% to 11% of all lumbar disc herniations (1, 150).

An intraforaminal herniation appears as disc tissue which occupies the intervertebral foramen and obliterates the fat that it contains. Often the herniation is better visible on sagittal paramedian sections than on axial scans. The herniated disc tissue may be clearly seen on T1-weighted sagittal sequences due to its considerably lower signal intensity compared with the epidural fat. Intraforaminal herniations frequently migrate behind the body of the vertebra above. Generally, the migrated fragment is clearly visible on T1-weighted axial sections, showing the disc tissue at the level of the inferolateral portion of the vertebra above the herniated disc (Fig. 9.53). On T1-weighted sagittal sections, the fragment may be barely recognizable, since its signal intensity is similar to that of the nerve root.

Extraforaminal herniations cannot generally be seen on sagittal sections, but are clearly visible on axial sequences (Fig. 9.54). In these sequences, the lateral margin of the disc shows a focal convexity, obliterating the paravertebral fat tissue and impinging on the nerve root in its extraforaminal portion (81). The herniated tissue is almost always in contact with the contents of

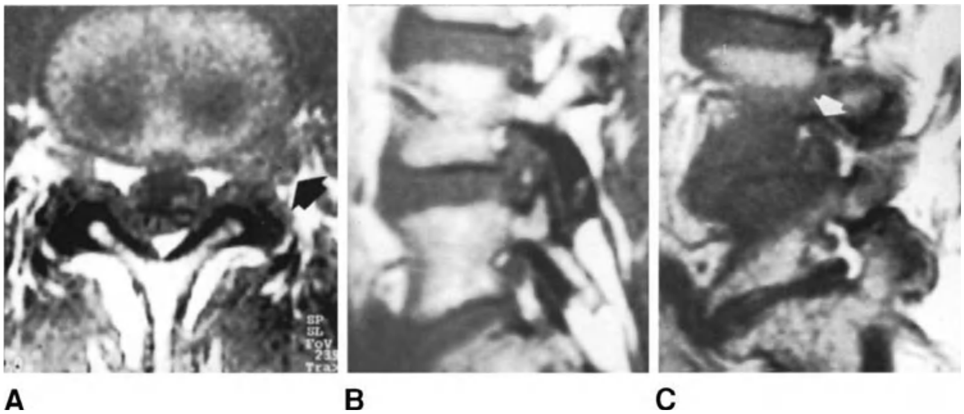


Fig. 9.53. *L4-L5 intraforaminal disc herniation on the left. The spin-echo T1-weighted axial image* (A) *shows a focal convexity in the left foraminal border of the disc which impinges on the L4 nerve root (arrow). The spin-echo T1-weighted sagittal images* (B) *and* (C) *show obliteration of the intraforaminal fat and compression of the L4 root* (C), *which is pushed against the pedicle (arrow). A free disc fragment, migrated into the intervertebral foramen, was detected at operation.*

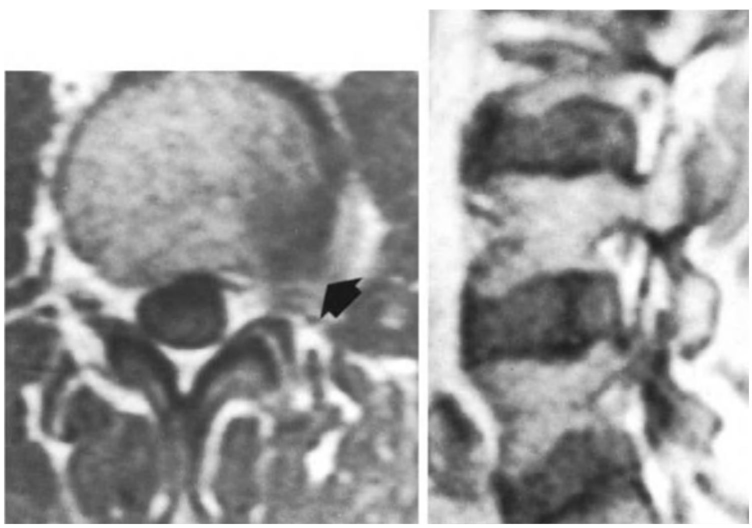


Fig. 9.54. *L3-L4 extraforaminal disc herniation on the left. The spin-echo T1-weighted axial image shows a focal convexity of the left lateral margin of the disc and obliteration of the paravertebral fat tissue (arrow). The spin-echo T1-weighted sagittal section through the intervertebral foramen does not show the disc herniation, since this is extraforaminal.*

the disc. In these herniations, the lateral portion of the vertebral end-plate may appear hypointense and display thin spurs resulting from avulsion of Sharpey's fibers.

Intraforaminal and extraforaminal herniations may be difficult to recognize at a superficial evaluation of MRI or CT scans; indeed, in the series of Osborn et al. (154), the herniation was not diagnosed at first evaluation in 15 out of 50 cases. Conversely, lateral bulging of annulus fibrosus, or the nerve root in the intra- or extraforaminal course, may be mistaken for a lateral herniation.

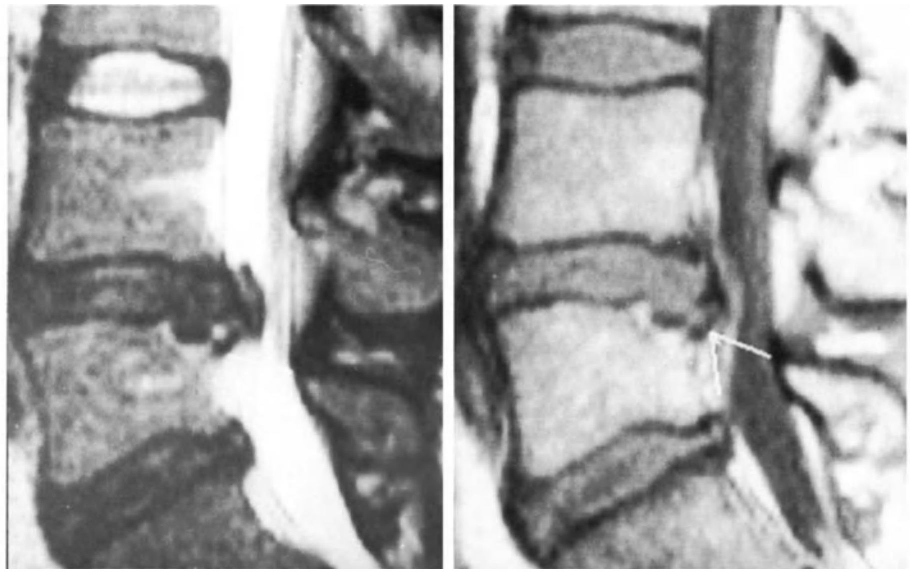
In intradural herniations, a tissue with the features of the intervertebral disc inside the thecal sac may be observed at MRI. In these cases, administration of gadolinium is necessary to exclude the condition to be an intradural tumor. It will be easier to make diagnosis if a strand of tissue is seen connecting the intradural portion of the herniation with the parent disc. Furthermore, T2-weighted images may show a hyperintense rim, indicating inflammatory processes (103).

In osteochondral avulsions of the posterior border of the vertebral end-plate, MRI shows a hypointense linear structure corresponding to Sharpey's fibers which have remained intact posteriorly to the herniation, and a structure showing the features of the cortical bone at the level of the posterior margin of the vertebral end-plate. The result, on sagittal scans, is a Y or 7 configuration at the level of the disc and the avulsed end-plate (15) (Fig. 9.55).

Usually, disc herniations can easily be differentiated from synovial cysts. These can be recognized by their lateral extradural location, adjacent to the apophyseal joint from which they originate, and the characteristics of the MRI signal, which is usually hyperintense on T2-weighted images and hypointense on T1-weighted scans due to the serous content of the cyst (106, 124, 174).

Gadolinium

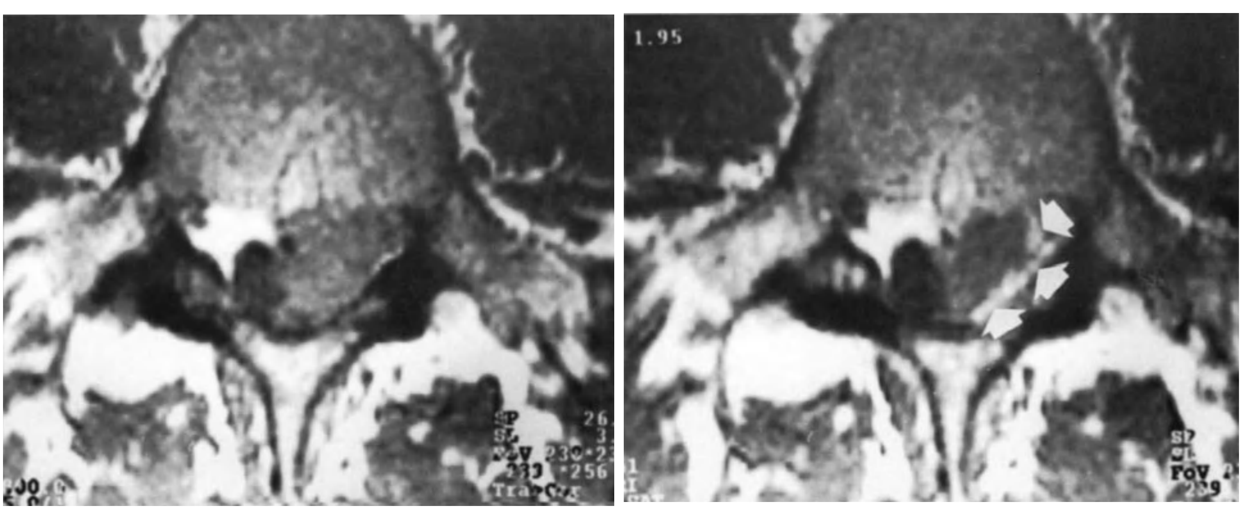
The use of gadolinium is not usually necessary in patients who have not previously undergone surgery,

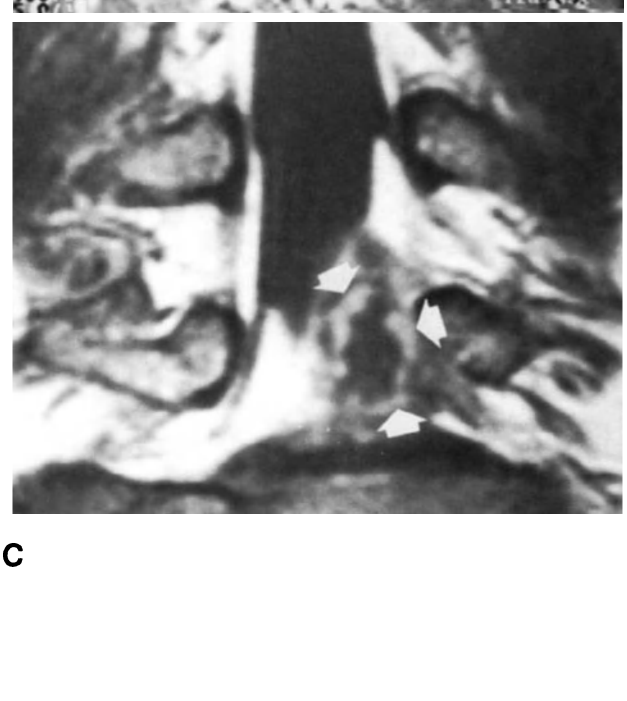


A B

Fig. 9.55. *L4-L5 disc herniation with osteochondral avulsion of the posterosuperior border of the L5 vertebral body (arrows).* (A) *Turbo spin-echo T2-weighted MR image showing hyposignal of the three lower lumbar discs.* (B) *Spin-echo T1-weighted image.*

A B





C

Fig. 9.56. *Large retroligamentous extruded L5-S1 disc herniation on the left. On the spin-echo T1-weighted axial image without contrast medium* (A), *the herniated tissue is hypointense. After administration of gadolinium* (B), *an increase in signal intensity is visible peripherally to the herniation (arrows). On the spin-echo T1-weighted image after injection of gadolinium* (C), *the central portion of the herniated tissue, showing no increase in signal intensity, and the peripheral hyperintense rim (arrows), which is due to the granulation tissue surrounding the herniation, are clearly visible.*

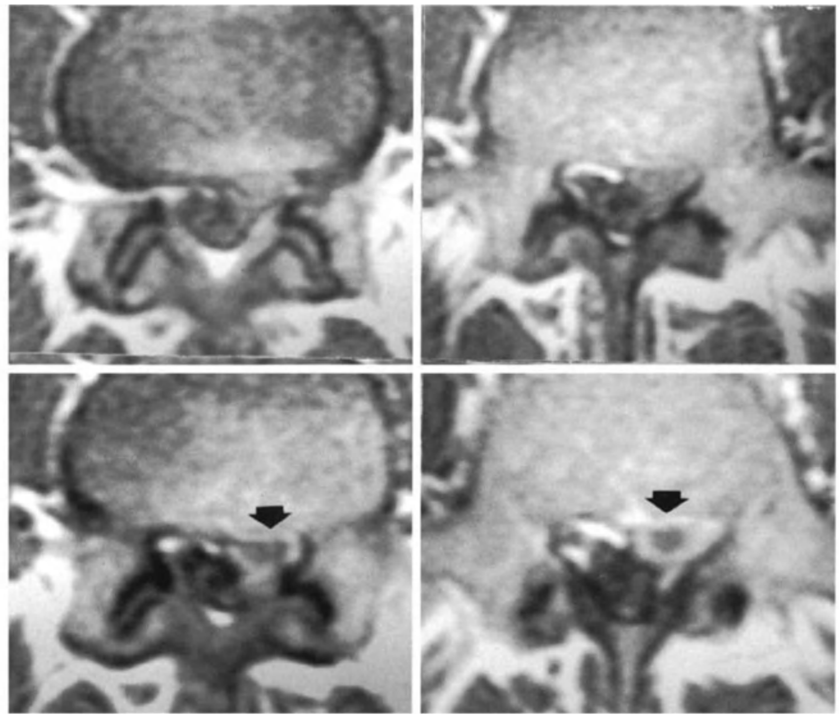


Fig. 9.57. *Left L4-L5 extruded disc herniation. Spin-echo T1-weighted MR images without contrast medium at the level of the disc* (A) *and the proximal portion of the L5 pedicle* (B) *and after administration of gadolinium* (C) *and* (D) *at the same levels. On the images obtained after injection of gadolinium, signal hyperintensity is observed around the herniated tissue (arrows), due to the presence of granulation tissue.*

unless differential diagnosis has to be made between a herniated disc and a neoplastic condition.

A disc herniation does not usually show an increase in signal intensity after administration of contrast medium. Occasionally, however, signal hyperintensity may be observed in the peripheral portion of the herniation, particularly in extruded forms, due to the presence of granulation tissue (175) (Fig. 9.56). An abundant fibrosis around the herniated disc may be predictive of a decrease in size or disappearance of the herniation with time. Similarly, the compressed nerve root, or sometimes even the contiguous roots, may appear hyperintense after gadolinium injection as a result of inflammatory processes; in some cases, the hyperintensity disappears with time (43).

Lumbar neurinoma or meningioma consistently show an increase in signal intensity after administration of gadolinium, which easily allows a disc herniation to be distinguished from tumoral conditions. Occasionally, also a herniated disc shows an increased signal intensity after gadolinium administration; however, unlike in tumors, the enhancement is dyshomogeneous because it occurs in the granulation tissue which surrounds the herniation, but not in the central portion of disc tissue (Fig. 9.57). Pseudoenhancement in signal intensity of a herniated disc may occur in the presence of hyperplasia of the venous epidural plexus which surrounds the herniation (12). Lateral disc herniations may simulate a neurinoma of the nerve root, since the herniated tissue may be difficult to distinguish from the compressed root. MRI may clearly demonstrate that the lesion has the features of a herniated disc, but, when there is any doubt, administration of contrast medium may solve the problem, due to enhancement of signal intensity by the tumor.

In the presence of a nerve-root anomaly, axial sections may show, in the site normally occupied by the nerve root, two contiguous halos of hyperintensity or a halo of periradicular increase in signal intensity larger than normal, which may allow the anatomic anomaly to be differentiated from a disc herniation.

Postoperative MRI

The changes in lamino-articular bony structures produced by surgery are similar to those visible on CT scans. A fat graft placed at the site of the surgical approach appears as a hypointense structure on T1-weighted sequences, which occupies the site of laminotomy or laminectomy (Fig. 9.58). Occasionally, in the site of surgical approach, images of decreased signal intensity are visible, which represent an artifact due to small residual metallic fragments, originating from surgical instruments (95) (Fig. 9.59).

In the immediate postoperative period, blood accumulates in the site of the surgical approach. The blood subsequently undergoes a process of organization and, in the next few months, the initial hematoma is replaced with fibrous tissue. The signal of the extravasated blood is isointense to the muscle tissue, on T1-weighted sequences, and markedly hyperintense, on T2-weighted

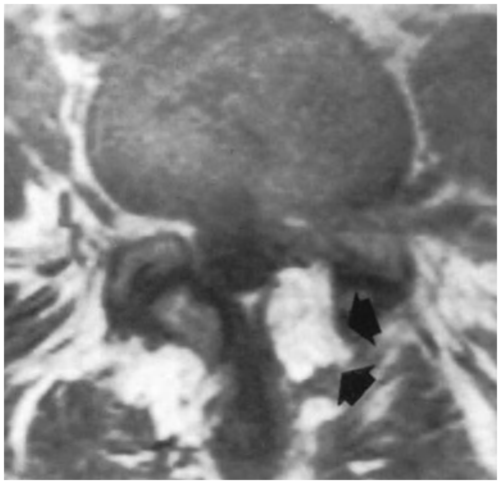


Fig. 9.58. *Spin-echo T1-weighted axial MR image showing a fat graft (arrows) in the site of laminotomy.*

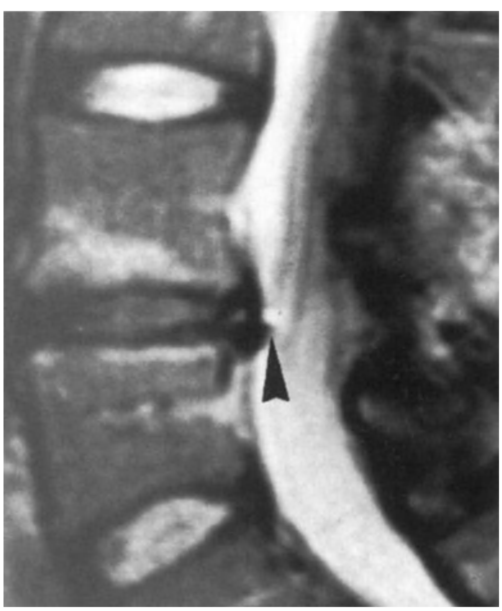


Fig. 9.59. *Turbo spin-echo T2-weighted MR image of a patient operated for disc herniation. Dorsally to the disc, a small hyperintense structure (arrowhead) is visible, presumably represented by a metallic fragment.*

images. The granulation tissue which develops during the first few weeks after surgery displays a higher signal intensity than disc tissue and may exert a mass effect on the thecal sac. Both the signal intensity and the mass effect tend to decrease in the first 3 months after surgery (Fig. 9.60). Between 3 and 6 months, the mass effect disappears and the scar tissue shows a further decrease in signal intensity. After 2 years, the scar tissue is generally hypointense on T2-weighted sequences (176, 197).

In a prospective study on patients successfully operated on for lumbar disc herniation, Boden et al. (26) observed a tissue that exerted a mass effect on the nervous structures and had an intermediate signal intensity with peripheral enhancement after administration of gadolinium in 38% of cases 3 weeks after surgery and in 12% after 3 months. Thus, in the first few months after surgery, and particularly in the first few weeks, MRI is of little diagnostic value as far as concerns the presence of herniated disc tissue responsible for the persistence or recurrence of radicular symptoms. Therefore, in the early postoperative period, the investigation should usually be carried out only when surgical complications are suspected, such as a large hematoma, pseudomeningocele or discitis, or the persistence of an extruded or migrated disc fragment.

When radical discectomy has been performed, the adjacent vertebral end-plates may show a focal or diffuse hyposignal on T1-weighted images in basal conditions and an increased signal intensity after administration of gadolinium (79). This change, which may simulate a discitis (27), is probably due to reactive processes in the bone marrow as a result of the surgical trauma.

Following chemonucleolysis, the disc decreases in height and, on T2-weighted images, displays a hyposignal that tends to persist over the time (112).

In a patient submitted to surgery for lumbar disc herniation in whom radicular symptoms reappear at some considerable time interval after operation, the differential diagnosis which should most frequently be made is between recurrent herniation and peridural fibrosis. In basal conditions, the two diseases may be differentiated by their morphologic features rather than the signal intensity (101). The main morphologic characteristics allowing for identification of the peridural scar tissue are the irregular configuration and unsharp margination, and the absence of mass effect on the thecal sac, which may appear as attracted by the fibrous tissue; the signal is of varying intensity, but it is generally hypointense with respect to the disc. In contrast, a recurrent herniation usually exerts a mass effect on the thecal sac, has curved or lobulated margins and generally presents the same signal intensity as the disc. In spite of these differences, it may be difficult to differentiate a recurrent herniation from postsurgical scar tissue; it is even more difficult to determine the clinical significance of scar tissue, which is normally present in operated patients.

The use of gadolinium considerably increases the ability of MRI to differentiate scar from disc tissue, thus making the diagnostic accuracy of the investigation very high.

After administration of gadolinium, the scar tissue displays a uniform enhancement of signal intensity (Fig. 9.61), whilst in the presence of a recurrent herniation, no enhancement is observed or the signal intensity increases only in the peripheral portion of the pathologic tissue (Fig. 9.62). The increase in signal intensity is

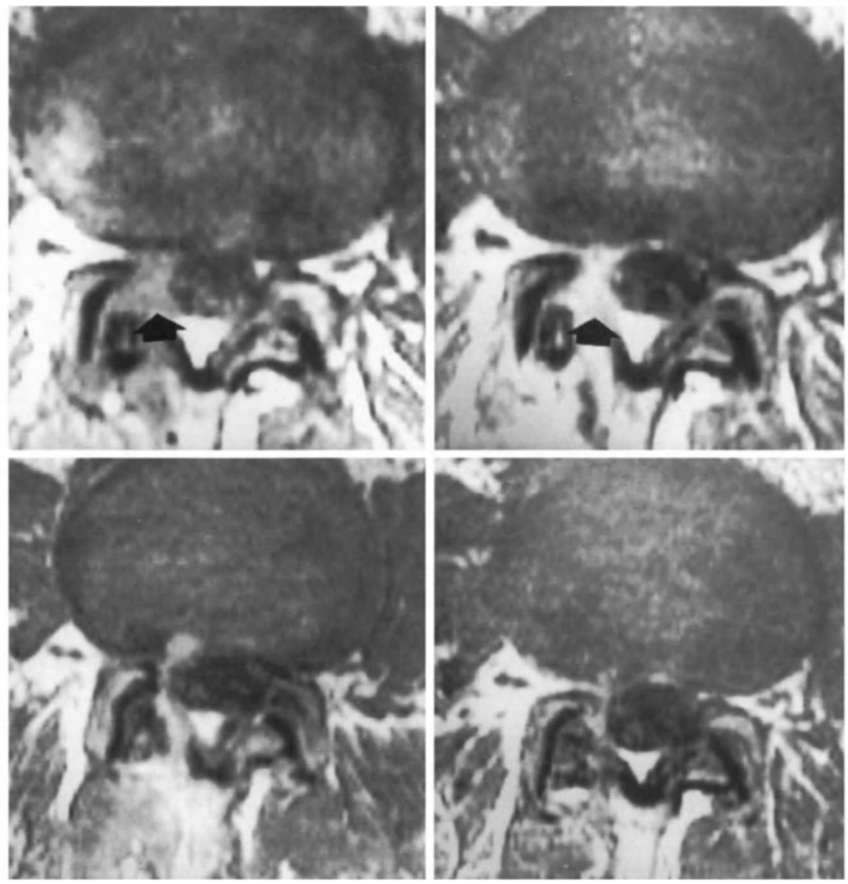


Fig. 9.60. *Spin-echo T1-weighted MR images without contrast* (A) *and after administration of gadolinium* (B) *obtained 7 days after discectomy on the right side, and images without contrast medium* (C) *and after injection of gadolinium* (D) *obtained 3 months after surgery. The decrease in amount of hyperintense tissue at the site of surgery (arrows) between 7 days and 3 months is due to normal postsurgical resorption of the tissue.*

related to the density of vessels in the tissue, permeability of the endothelium of the capillaries (characteristics of the tight junctions and pynocytotic vesicles of endothelial cells, and size of intercellular fissures) and the dimensions of the extracellular spaces (35, 177). The scar tissue takes up a relatively large amount of contrast, since it has a limited number of vessels, at least in a late phase, but has large intercellular spaces through which the contrast medium may diffuse. The signal intensity of the scar tissue increases about 1 min after administration of gadolinium, reaching the maximum values after 5 to 10 min (105, 177) and then slowly decreasing. MRI sequences should, therefore, be obtained within 10 min of injection of the contrast medium, preferably after 5 min. The increase in signal intensity of scar tissue after gadolinium may persist for years after surgery. Usually, however, the enhancement decreases or even disappears after the first postoperative year (75).

The herniated tissue displays an increased signal intensity after administration of gadolinium, but the enhancement is less than that of scar tissue and commences after 35 min (177). On the sequences obtained later, therefore, it may be difficult to differentiate the scar tissue from a possible recurrent herniation.

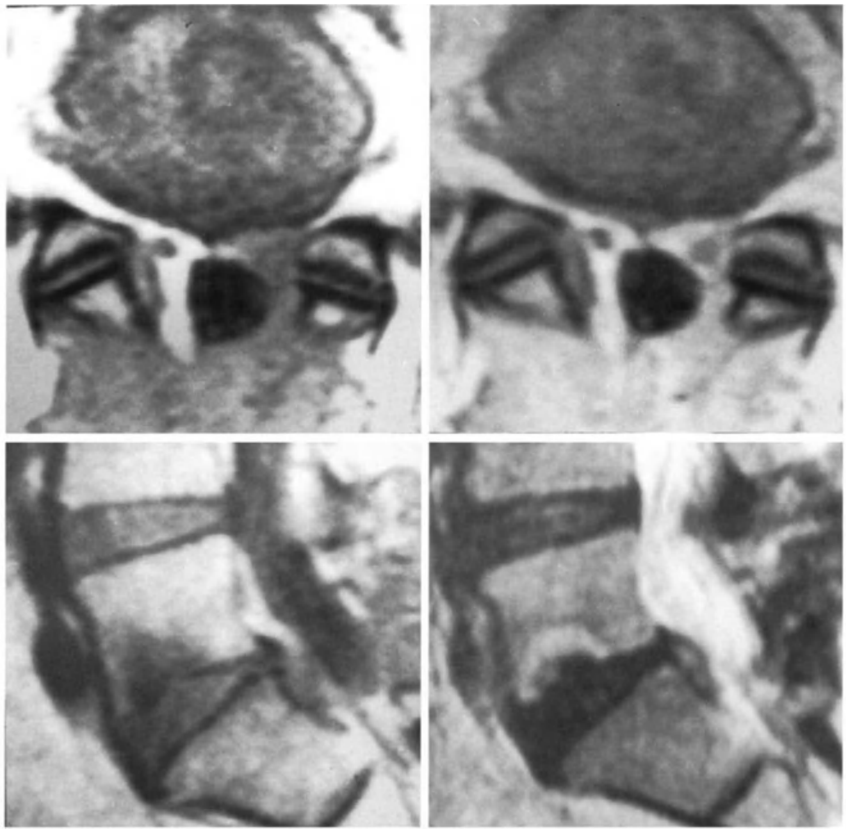
In the presence of a small recurrent herniation surrounded by abundant scar tissue, the effects of partial volume may mask the herniated tissue. Therefore, MRI should be carried out prior to, and following administration of, the contrast medium, in two spatial planes (sagittal and axial). The examination in basal conditions can be avoided if the fat suppression technique is employed (23, 138). In fact, with this technique, the increase in signal intensity of the scar tissue is more evident and the differentiation of the latter from the disc tissue is easier.

After administration of gadolinium, radicular hyperintensity may occasionally be observed, which may be due to chronic inflammation. This change tends to resolve spontaneously (Fig. 9.63).

Lumbar stenosis

Stenosis of spinal canal

MRI has many of the diagnostic potentialities of CT and myelography. Compared with the latter, MRI has two disadvantages: 1) dynamic examination cannot be performed; 2) in the presence of scoliosis, sagittal images



A B C D

Fig. 9.61. *Abundant postsurgical fibrosis in a patient submitted to L5-S1 discectomy on the left.* (A) *and* (B) *Spin-echo T1-weighted axial MR images, respectively, without contrast medium and after administration of gadolinium. The scar tissue at the site of previous surgery is hypointense on the image without contrast; after gadolinium, the tissue displays a uniform increase in signal intensity and the nerve root becomes clearly visible.* (C) *and* (D) *Turbo spin-echo T2-weighted sagittal images, before and after injection of gadolinium, respectively. After gadolinium, the scar tissue becomes slightly hyperintense.*

may provide false positive findings or findings of dubious interpretation due to the obliquity of the scanning plane with respect to the longitudinal axis of the spine in the scoliotic area (164). The latter inconvenience may be partially overcome by modifying the direction of the scanning plane when examining the various portions of the scoliotic curve.

In the presence of a narrow spinal canal (constitutional or achondroplasic), MRI shows short interpedicular and/or sagittal diameters of the spinal canal and short sagittal and transverse dimensions of the thecal sac.

In stenosis of the spinal canal, the T2-weighted sequences, simulating the myelographic images, are the most suggestive (Fig. 9.64 A). The latter, and even more the T2-star sequences, enhance the signal of the CSF and, thus, the severity of thecal sac compression.

Midsagittal and paramedian scans show constriction of the central portion of the spinal canal. Sagittal and axial T1-weighted images at the level of stenosis show a decrease in amount or complete lack of the epidural fat and a posterior indentation of the thecal sac. The indentation is produced by the posterior vertebral arch and/or thickened ligamenta flava encroaching on the spinal canal. Ventrally, the thecal sac may be compressed by the intervertebral disc, osteophytes of the vertebral end-plate or, in the presence of degenerative spondylolisthesis, the posterosuperior border of the vertebra below the slipped one (Fig. 9.65). On T2-weighted sequences, lateral sagittal sections reveal an interruption of the image of the sac at intervertebral level due to stenosis of the nerve-root canal.

T1-weighted axial scans show similar findings to those of CT: a decreased transverse area and/or deformation of the thecal sac, which may be compressed ventrally by a bulging annulus fibrosus or a disc herniation; a decrease in amount or disappearance of the epidural fat; a possible thickening of the ligamenta flava; lack of distinction of the spinal nerve roots in the radicular canal (Figs. 9.64 C and 9.65 C). In a study (90), a transverse area of the thecal sac less than 100 mm^2 was found to be indicative of a clinically symptomatic stenosis.

Compared with CT, MRI is better able to reveal the ligamentous structures and a disc herniation that may be associated with stenosis (Fig. 9.66). The osteophytes may be distinguished from the herniated disc tissue since they show a marked hyposignal in all sequences, both T1- and T2-weighted. However, it may be difficult, also with MRI, to obtain good visualization of the thecal sac when this is markedly constricted.

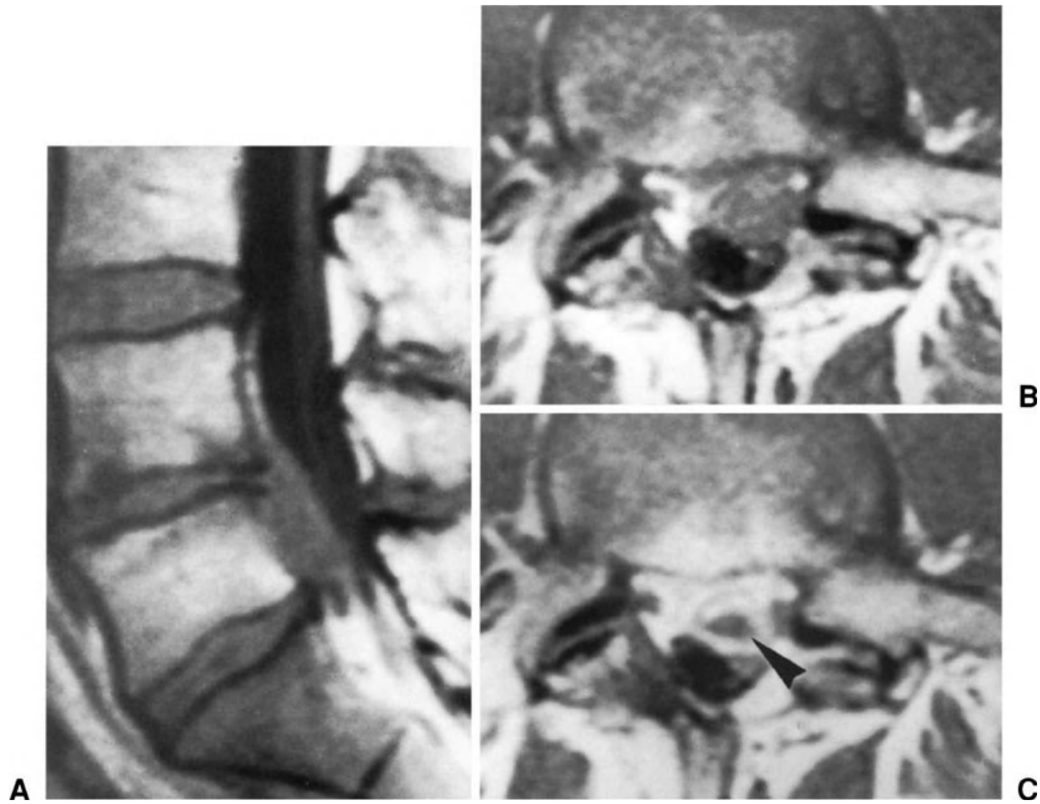


Fig. 9.62. *Recurrent L4-L5 disc herniation on the left.* (A) *and* (B) *Spin-echo T1-weighted MR sagittal image and spin-echo T1-weighted axial image showing pathologic tissue, isointense to the disc, anteriorly to the thecal sac.* (C) *Spin-echo T1-weighted axial image obtained after injection of gadolinium: the pathologic tissue shows signal enhancement in the peripheral, but not the central, portion (arrowhead). These findings indicate the presence of a recurrent disc herniation surrounded by scar tissue.*

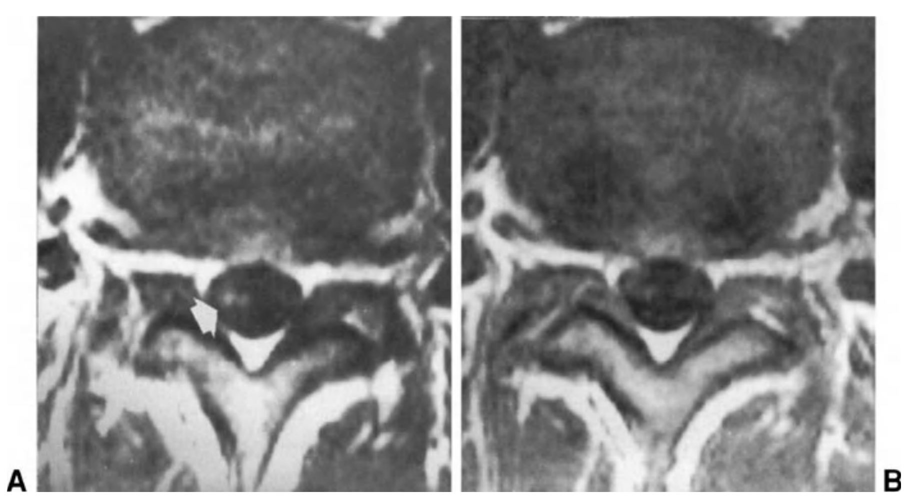
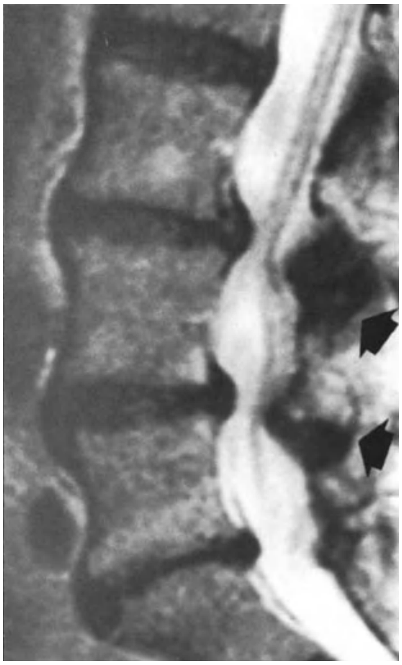
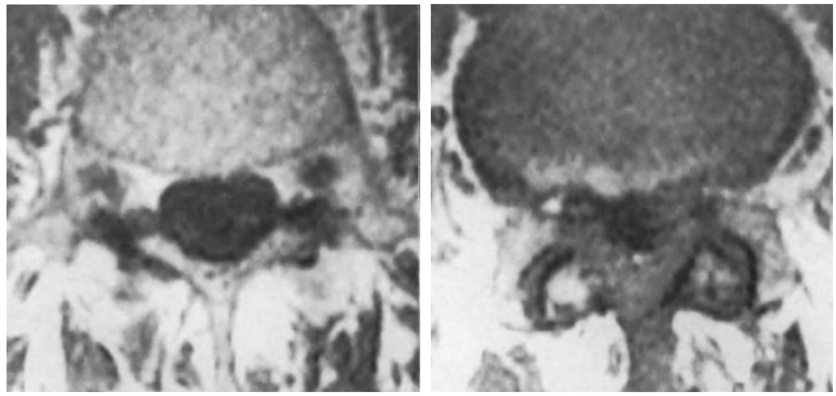


Fig. 9.63. *Spin-echo T1-weighted axial MR images after administration of gadolinium obtained 1 month* (A) *and 3 months* (B) *after discectomy. After 1 month of surgery, two hyperintense nerve roots are visible in the right portion of the thecal sac (arrow). The hyperintensity has disappeared after 3 months.*

Isolated nerve-root canal stenosis

This condition may be demonstrated both by axial T1-weighted scans and sagittal scans. The axial images show constitutional narrowing or degenerative constriction of only the lateral portion of the osteoligamentous spinal canal, to which a bulging annulus fibrosus or a contained disc herniation may be associated. Of the sagittal sections, the most diagnostic are the paramedian T2-weighted sections, showing constriction or inter-



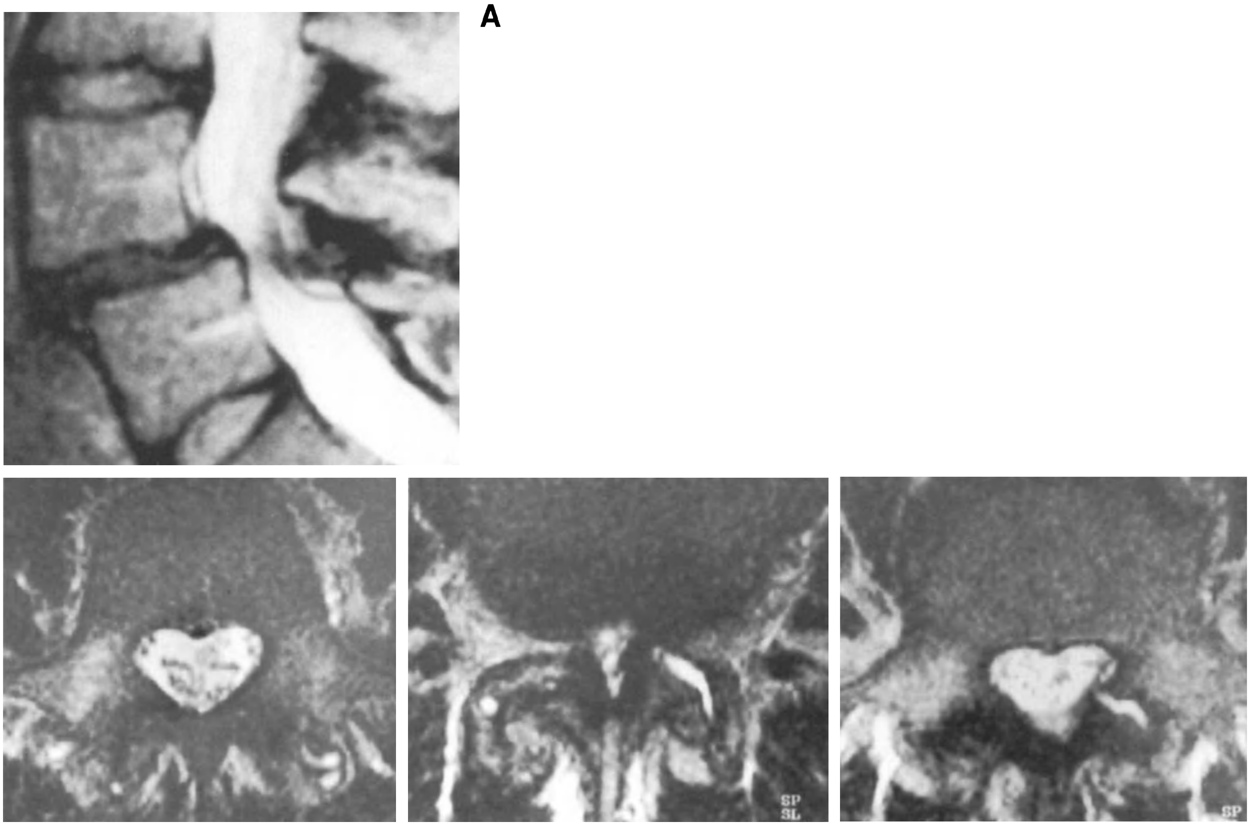


B C

A

Fig. 9.64. *Stenosis of the spinal canal at L3-L4 and L4-L5. The turbo spin-echo T2-weighted sagittal image* (A) *shows, at the stenotic levels, posterior compression of the thecal sac by thickened ligamenta flava (arrows), as well as anterior compression by the disc. The spin-echo T1-weighted axial image at the level of L4 pedicle* (B) *reveals the normal width of the spinal canal. By contrast, the spin-echo T1-weighted axial image at L4-L5 intervertebral level* (C) *shows constriction of the canal, thickening of the ligamenta flava, absence of the epidural fat and reduced diameters of the thecal sac.*

A



B C D

Fig. 9.65. *Stenosis of the spinal canal at L4-L5 level in the presence of degenerative spondylolisthesis of L4. The turbo spin-echo T2-weighted sagittal image* (A) *reveals marked compression of the thecal sac between the posterosuperior border of L5 and the posterior arch of L4. The spin-echo T2-weighted axial images at the level of the pedicle of L4* (B) *and L5* (D) *show a normal spinal canal, whereas that at L4-L5 intervertebral level* (C) *shows severe constriction of the canal.*

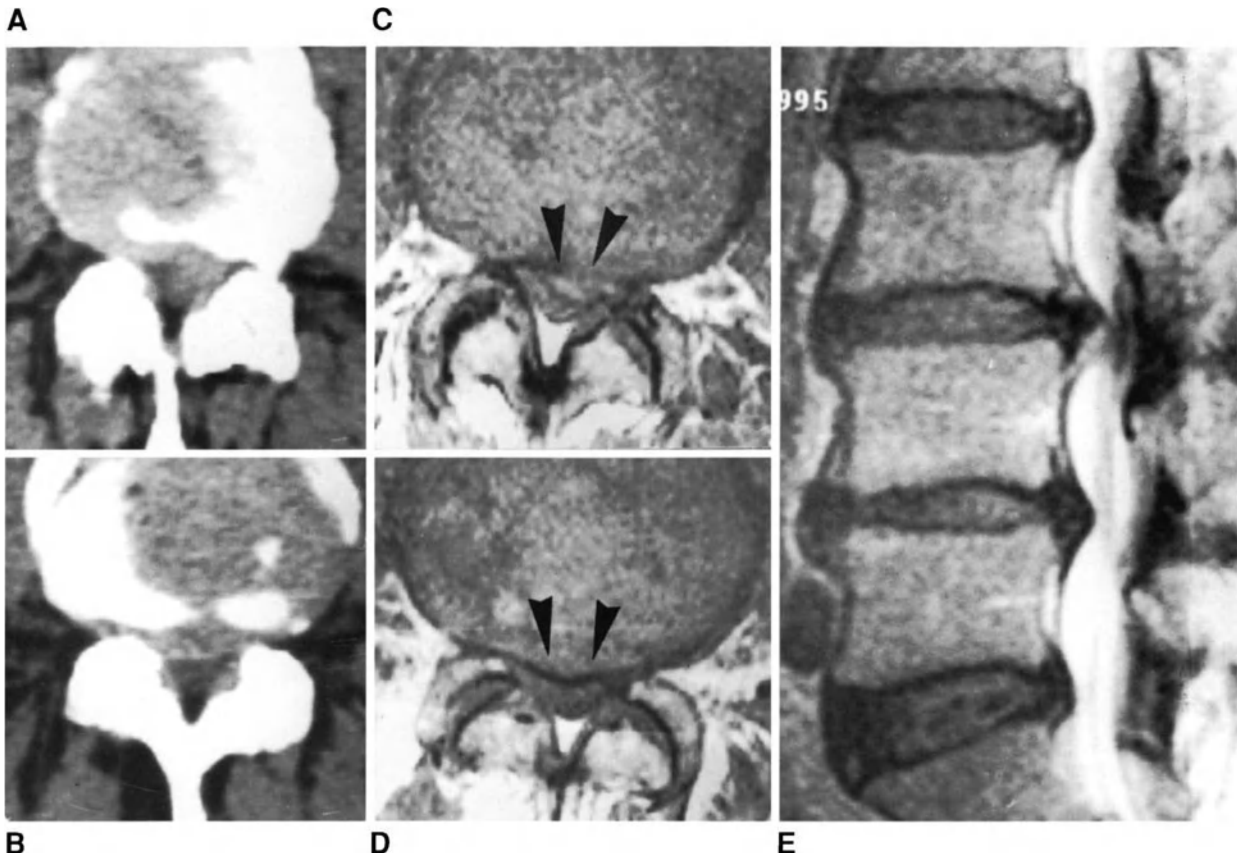


Fig. 9.66. *Multiple disc herniations in a patient with mild constitutional stenosis of the spinal canal. On CT scans at L3-L4 and L4-L5 levels* (A) *and* (B), *the image of the thecal sac is hardly distinguishable from that of the disc herniation. On the spin-echo T1-weighted axial MR images at the same levels* (C) *and* (D), *the thecal sac compressed by the disc herniations (arrowheads) and narrowing of the spinal canal are clearly visible. The pathologic conditions are even better evident on the turbo spin-echo T2-weighted sagittal image* (E).

ruption of the image of the CSF in the lateral portions of the spinal canal at intervertebral level; this holds both for pure forms of stenosis and those associated with a herniated disc (Fig. 9.67). Coronal sections may also be useful to demonstrate compression of the nerve root in a stenotic radicular canal.

Stenosis of intervertebral foramen

MRI is the most useful investigation in stenosis of the neuroforamen, since it allows both the osteoligamentous walls of the foramen and the nerve root surrounded by the periradicular fat tissue to be visualized. The bony degenerative changes are better seen on T2-weighted sequences, whereas the nerve root, periradicular fat and ligamentous structures are more clearly visible on T1-weighted sequences. In the presence of compression of the nerve root or the dorsal root ganglion, sagittal scans reveal narrowing of the foramen, generally due to spondylotic changes, disappearance of periradicular fat and a decreased transverse area of the nerve root. It should be stressed, however, that narrowing of the foramen is a frequent finding in patients with marked arthrotic changes, whilst an unequivocal compression of the nerve root by the bony structures or the ligamentum flavum covering the superior articular process is rarely observed.

In isthmic spondylolisthesis, the intervertebral foramen may appear stenotic and distorted on paramedian sagittal images. In these cases, an indication of stenosis is provided by the lack of the periradicular fat, which is clearly demonstrated by T1-weighted sagittal images (84).

Diagnostic accuracy: MRI compared with CT

Numerous studies have analyzed the diagnostic accuracy of MRI and CT in lumbar disc herniation, in patients submitted to only one of the two investigations or both. The reported percentages range from 76% to 96% for MRI (50, 53, 65, 92, 106, 108, 115, 139, 202) and

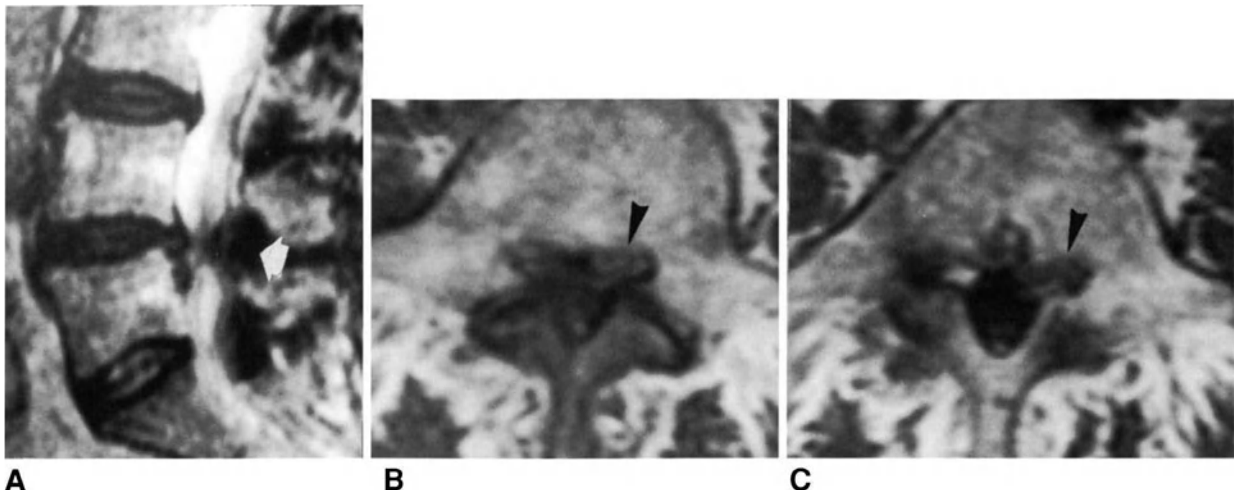


Fig. 9.67. *Left L4-L5 disc herniation associated with nerve-root canal stenosis.* (A) *Turbo spin-echo T2-weighted sagittal left paramedian image showing a subligamentous extruded L4-L5 disc herniation and posterior compression of the thecal sac by hypertrophic ligamentum flavum (arrow).* (B) *and* (C) *Spin-echo T1-weighted axial images showing the disc herniation on the left (arrowheads) and constriction of the nerve-root canal.*

from 72% to 93% for CT (19, 20, 30, 50, 62, 93, 106, 139, 145) (Table 9.1). In most studies, diagnostic accuracy both of MRI and CT was found to be approximately 80%–90%. The studies (50, 106, 139) in which both investigations were analyzed report similar diagnostic accuracy for the two modalities (Table 9.1). Even using the ROC (receiver operating characteristic) analysis, few differences have been found between the two types of investigation (209). In a study (4), in which the diagnostic ability of both investigations was evaluated by ER (expected regret) factor, the largest amount of diagnostic information was provided by CT. This, on the other hand, was found to provide more information than MRI in differentiating contained, from non-contained, herniations (50). The available data, therefore, indicate that the ability of MRI to identify the site and type of herniation is not significantly better than that of CT.

Table 9.1. *Diagnostic accuracy of CT and MRI in lumbar disc herniations.*

CT		MRI	
Haughton (1982)	88%	Edelman (1985)	90%
Berlin (1983)	80%	Modic (1986)	82%
Moufarrij (1983)	72%	Forristal (1988)	90%
Bell (1984)	72%	Szypryt (1988)	88%
Bosacco (1984)	92%	Jackson (1989)	76%
Firooznia (1984)	93%	Hashimoto (1990)	77%
Modic (1986)	83%	Kim (1993)	85%
Jackson (1989)	73%	Janssen (1994)	96%
Dullerud (1995)	87%	Dullerud (1995)	93%

The diagnostic ability of the two investigations seems to be comparable also in lumbar stenosis, isolated or associated with a herniated disc (113). In operated patients, instead, the diagnostic accuracy of MRI seems to be slightly higher than that of CT (page 586).

Studies on the accuracy of diagnostic methods in disc herniations or lumbar stenosis have several limitations which may affect the results. The evaluation of diagnostic accuracy is usually based on surgical findings. These, however, do not necessarily represent an accurate reference, since not only is surgery generally carried out only at the levels where the preoperative investigations show a pathologic condition, but also the detection and evaluation of the latter depend, to a large extent, on its characteristics and the experience of the surgeon. Furthermore, an important role is played by other factors, such as quality of the equipment used and improvements made over the years to their technical characteristics. Comparisons between CT and MRI made in the 80's may no longer be valid, since the actual CT equipment has not significantly changed, whereas the spatial resolution of MRI has considerably improved. Also the differences in the interpretation of images by different observers, related to the ability of the latter to correctly evaluate the investigations, may be important, and this holds more for a recently developed diagnostic modality, such as MRI, than for CT. In spite of these observations, CT still plays a primary role in the diagnosis of lumbar disc herniation and spinal stenosis. This does not hold, instead, for disc degeneration, in which MRI is definitely better than CT, since the latter provides no information on hydration of the disc or the presence of fissures in the annulus fibrosus.

Myelo-CT

This investigation consists in carrying out CT after opacification of the subarachnoid space with contrast medium injected by means of lumbar puncture. Myelo-CT may be performed after obtaining myelograms (secondary myelo-CT) or with no previous myelographic studies (primary myelo-CT). The main advantage with the former is that CT may be limited to the area in which the pathologic condition is located, when the latter, as usually occurs, has already been detected by myelography. Furthermore, the information obtained by means of both investigations may make diagnosis easier.

Technique

Opacification of the subarachnoid space is obtained with the same technical modalities as those described for lumbar myelography. For primary myelo-CT, 6–8 ml of contrast medium (200 or 300 mg I/ml) are generally used. However, in the presence of an intradural pathologic condition, it may be useful to inject a larger volume of contrast medium to obtain better diagnostic definition of the lesion.

After injection of the medium in the case of primary myelo-CT, or after obtaining myelograms in the case of a secondary investigation, the patient is invited to make several 360° rotations while lying on the bed of the CT equipment, which is inclined by about 10° to avoid the contrast medium spreading to the thoracic area. Rotations favor a homogeneous opacification of the subarachnoid space. Poor mixing of the contrast medium with the CSF causes a dorsal sedimentation of the opaque medium, resulting in inadequate definition of the interface between the thecal sac and the anterior epidural space, and insufficient filling of the nerve-root sleeves. At CT examination, the patient should initially be maintained with the lower limbs extended in order not to decrease lumbar lordosis. Subsequently, the thighs are flexed to obtain a slight flexion of the lumbar spine. Dynamic myelo-CT scans, like the dynamic myelograms, allow evaluation of the modifications of a bulging annulus fibrosus or a disc herniation in flexion-extension and the effects of the changes in size of the spinal canal on the nervous structures (Fig. 9.68). The dynamic study is, therefore, particularly useful in the presence of a narrow or stenotic spinal canal.

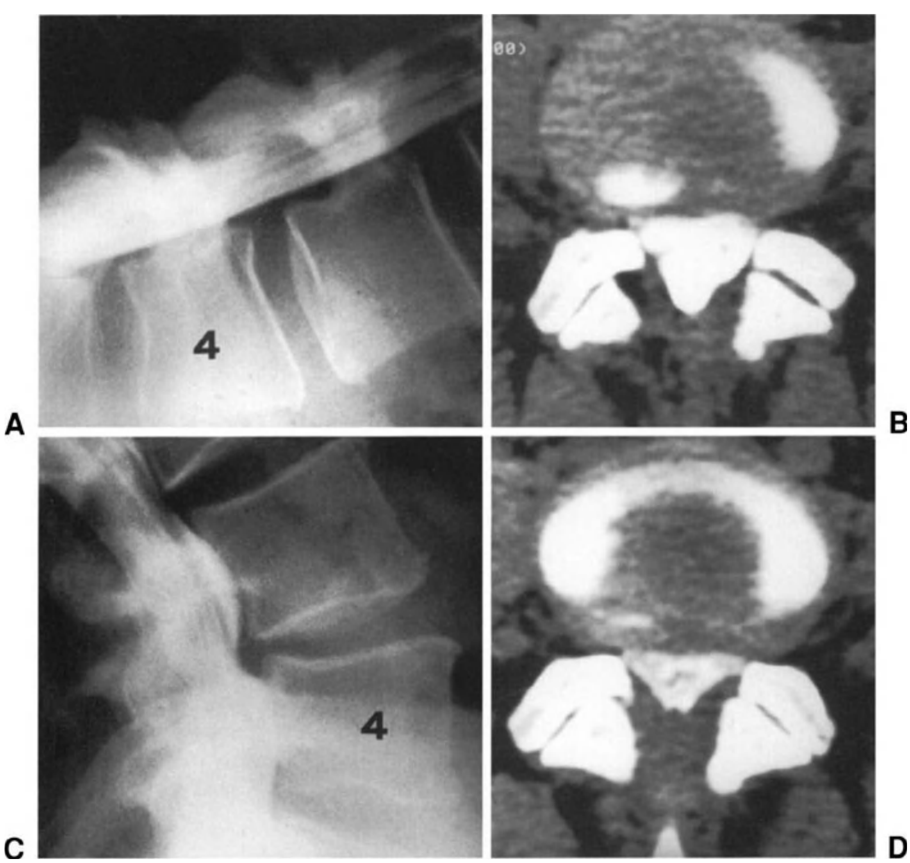


Fig. 9.68. *Myelograms and myelo-CT scans at L4-L5 level in flexion* (A) *and* (B), *and extension* (C) *and* (D). *Myelo-CT scans show a considerable decrease in size of the thecal sac in extension.*

Findings

The contrast medium uniformly opacifies the thecal sac and the sleeves of the emerging nerve roots, which appear, on axial sections, as roundish structures running on the sides of the thecal sac. On axial or coronal reconstructions, radiolucent striae, corresponding to intrathecal nerve roots, are often visible within the thecal sac. On axial sections, the profile of the individual nerve roots may be identified only when little intrathecal contrast medium is present or is poorly mixed with the CSF.

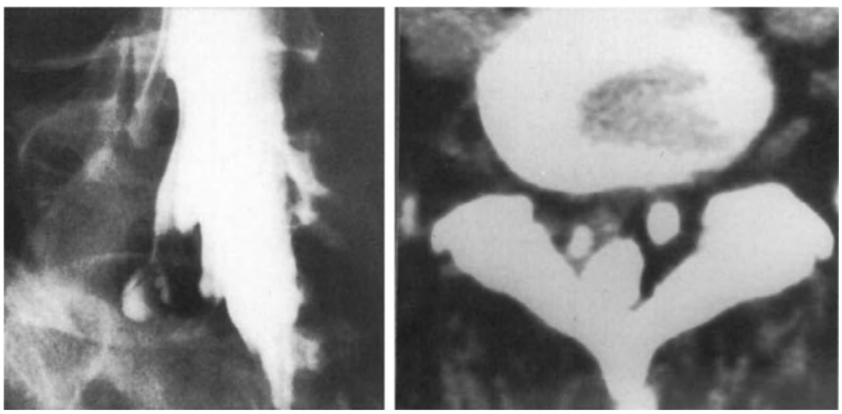
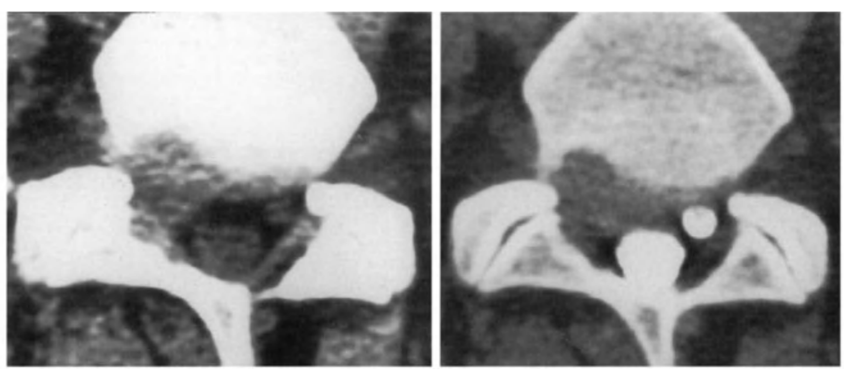
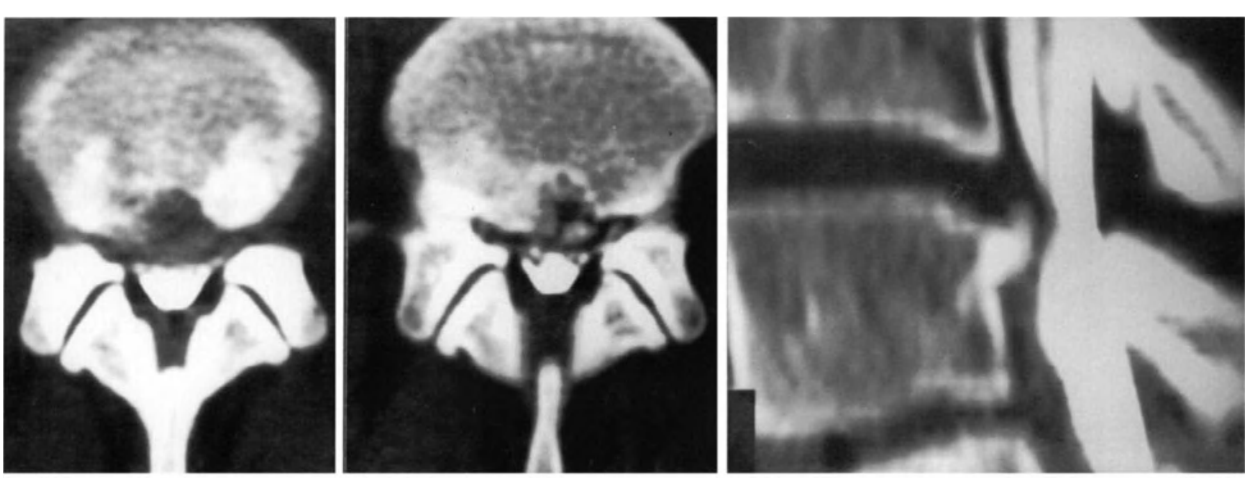


Fig. 9.69. *Migrated L5-S1 disc herniation on the right. The oblique myelogram shows cut-off of the right S1 nerve-root sleeve. The myelo-CT scan shows a decreased diameter of the right S1 root and intermediate density tissue between the root and the dural sac.*

Fig. 9.70. *Axial CT* (A) *and myelo-CT* (B) *scans at L5-S1 level. The CT scan shows a disc herniation on the right, but does not unequivocally demonstrate whether the S1 root is compressed. This is clearly demonstrated by the myelo-CT scan, in which the right S1 root is not visible.*

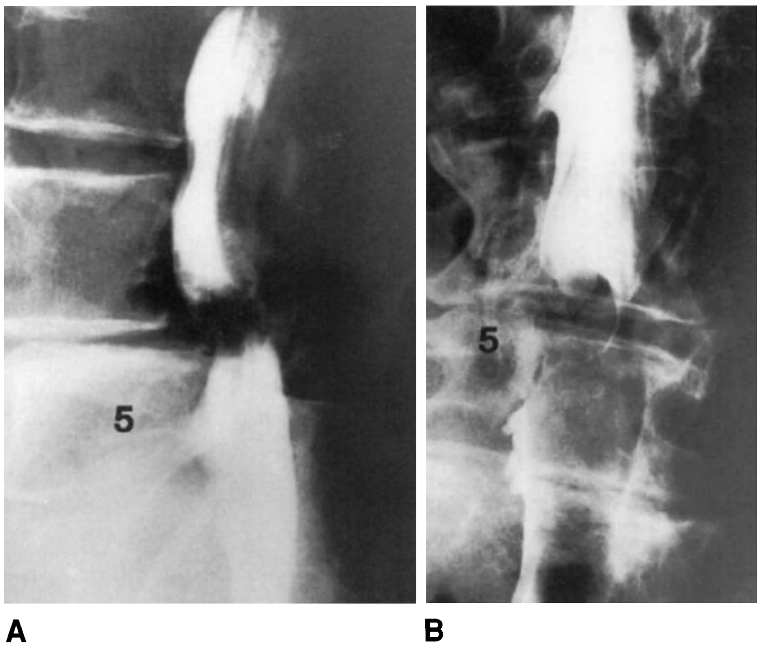


A B



A B C

Fig. 9.71. *Myelo-CT scans in a patient with an osteochondral avulsion of the posterosuperior border of the L5 vertebral body. The axial scans at L4-L5 level show a herniated disc and a defect in the posterior portion of the vertebral body* (A) *and* (B) *and a bony fragment impinging on the thecal sac* (B). *The osteochondral avulsion is clearly visible on the sagittal reconstruction* (C).



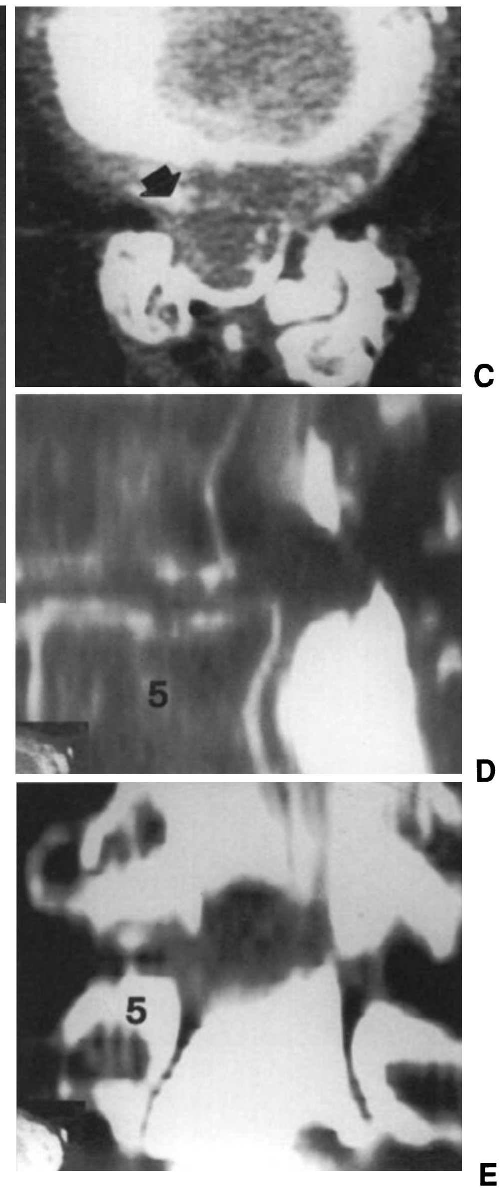


Fig. 9.72. *L4-L5 intradural disc herniation in the presence of spondylolisthesis of L4. The lateral myelogram* (A) *shows a complete block of the contrast medium, which, on the oblique view* (B), *has clear-cut, dome-like margins. On axial myelo-CT* (C), *the thecal sac appears almost completely occupied by a tissue with a similar density to the disc (arrow) and in continuity with it. Sagittal* (D) *and coronal* (E) *reconstructions confirm, respectively, that the block of contrast is due to disc herniation and that the block has dome-like margins as typically occurs in the presence of an intrathecal mass.*

In the presence of disc herniation, the thecal sac may show an indentation of its anterior or anterolateral aspect and / or the radiopaque image of the compressed nerve root is no longer visible or presents reduced transverse dimensions (Fig. 9.69). The advantage of myelo-CT, compared with CT and MRI, is that it enables us to demonstrate whether, and to what extent, the herniated tissue impinges on the emerging nerve root (Fig. 9.70).

Disc herniation associated with osteochondral avulsion of the posterior border of the vertebral end-plate is well demonstrated by myelo-CT, which shows the bony fragment, herniated disc tissue and compressed nervous structures (Fig. 9.71). In the presence of an intradural herniation, the thecal sac appears to be occupied by tissue showing a similar density to that of the disc and is surrounded by a posterior rim of contrast medium. In these cases, the differential diagnosis with an intradural tumor is based, as for myelography, on the features of the margins of the block of the dye column on sagittal and coronal reformatted images (Fig. 9.72). In stenosis of the spinal canal, the thecal sac is deformed and / or shows smaller dimensions on the scans through the intervertebral space compared with those through the adjacent vertebral bodies. Myelo-CT, with respect to CT, is better able to demonstrate a disc herniation associated with central spinal stenosis (Fig. 9.73). In isolated nerve-root canal stenosis, myelo-CT easily reveals both the compression of the emerging nerve root and the pathologic narrowing of the radicular canal (Fig. 9.74). In these cases, CT or MRI may not be diagnostic, whereas myelography may not allow us to determine whether the nerve-root compression is due to stenosis, disc herniation or both conditions. Myelo-CT may demonstrate stenosis of the intervertebral foramen and compression of the nerve root therein better than CT.

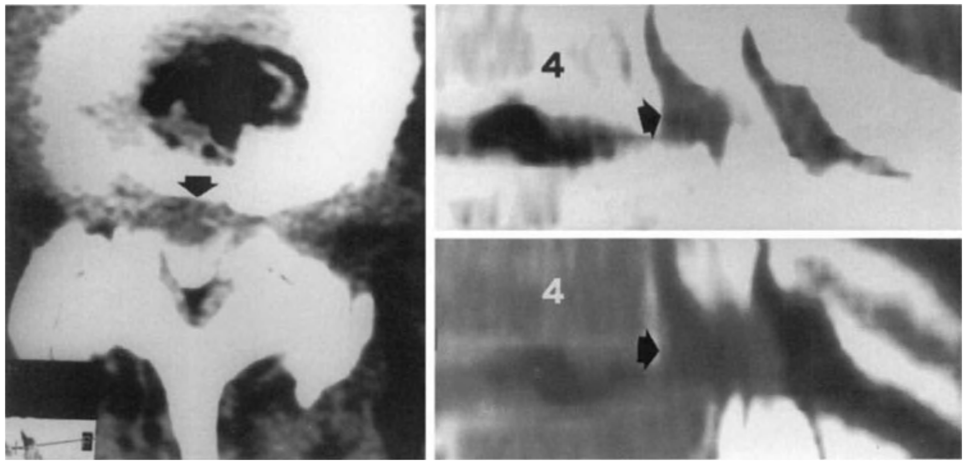


Fig. 9.73. *L4-L5 disc herniation in a patient with stenosis at this level and degenerative spondylolisthesis of L4. Myelo-CT scans show short transverse dimensions of the thecal sac due to stenosis of the spinal canal and a herniated disc (arrows) compressing the thecal sac anteriorly.*

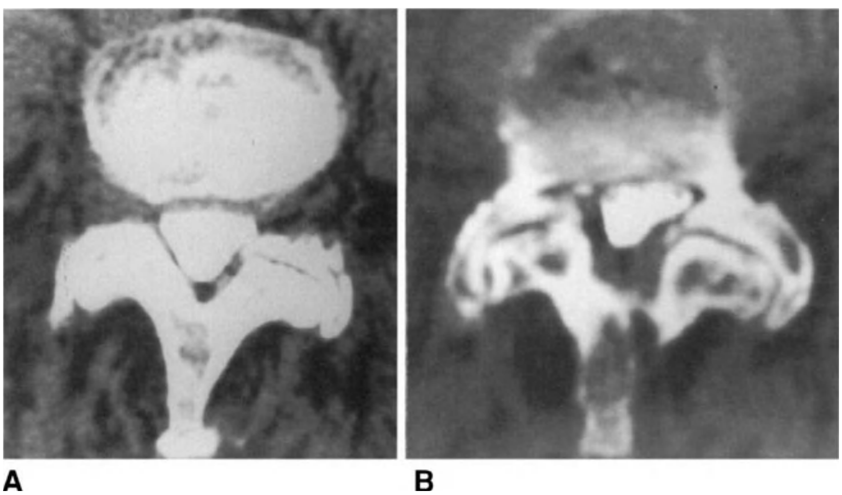


Fig. 9.74. *Myelo-CT scans in a patient with nerve-root canal stenosis at L4-L5 level on the right.* (A) *Section obtained proximally to the disc.* (B) *Section at the level of the proximal vertebral end-plate of L5. The L5 nerve root is not visible.*

Diagnostic accuracy and indications

The diagnostic accuracy of myelo-CT has been found to range from 57% to 89% (65, 106, 108, 139, 221), being approximately 80% in most studies. Myelo-CT was generally found to be more diagnostic than myelography and CT, and equally or less diagnostic than MRI. However, if myelo-CT and myelography are evaluated together, the proportion of cases correctly diagnosed increases considerably (221). In stenosis, myelo-CT has a higher diagnostic capacity than CT or MRI.

Secondary myelo-CT is indicated when myelography does not demonstrate adequately the pathologic condition. This may occur in the presence of a migrated disc herniation or, more often, of nerve-root canal stenosis or a block of the contrast medium of uncertain etiology. Primary myelo-CT may be useful to: 1) differentiate isolated central stenosis from stenosis associated with disc herniation, and to evaluate the severity of compression of the nervous structures, in patients who cannot undergo MRI; 2) demonstrate and/or evaluate the severity and cause of compression of the nerve root running in a stenotic radicular canal; and 3) demonstrate nerve-root compression by a small disc herniation. Also in these cases, however, myelograms should generally be obtained prior to myelo-CT scans.

In patients with suspected recurrent disc herniation, myelo-CT is rarely indicated, since it is no better than CT in differentiating scar tissue from recurrent herniation. One exception, however, concerns the patients with metallic vertebral implants, in whom MRI may not be carried out and the CT images may show artifacts making identification of the anatomic structures difficult. Usually, the presence of the contrast medium considerably improves the visalization of the nervous structures.

Discography

Discography, introduced into the clinical practice by Lindblom (123), consists in the injection of contrast medium into the area occupied by the nucleus pulposus. This investigation may provide two types of diagnostic information: 1) the fluoroscopic or radiographic image reveals the morphology of the nucleus pulposus and the possible presence of clefts in the annulus fibrosus; 2) distension of the annulus fibrosus by the contrast medium may provoke low back and / or radiated pain; this may allow differentiation of an asymptomatic degenerated disc from a degenerated disc responsible for back pain.

Technique

Patient positioning, instrumentation and approach to the intervertebral disc are similar to those described for chemonucleolysis. Usually a C arm fluoroscope is used, allowing ortogonal views to be obtained without moving the patient. However, discography may also be carried out using a routine radiographic apparatus equipped with a fluoroscope. In the latter instance, the needle is introduced with the patient in the lateral decubitus or, as suggested by Aprill (11), in the oblique position. The patient is then placed in the prone decubitus to check the needle position on the anteroposterior view and then he/she is again placed in the lateral decubitus during injection of the contrast agent.

In a normal disc, it is not possible to inject more than 1–2 ml of contrast medium. Gradually, as the liquid is injected, a progressively greater resistance is encountered, until the intradiscal pressure becomes so high as to hinder further instillation of the contrast medium. In a degenerated disc, on the other hand, several milliliters of contrast medium can be injected without excessive resistance. In general, the more degenerated the disc, the greater the volume of contrast agent that can be instilled, whereas the resistance encountered during injection is inversely related to the degree of disc degeneration. Occasionally, the disc will accept an indefinite volume of contrast medium, since this leaves the disc through fissures in the annulus fibrosus and flows into the epidural space; in this instance, the lateral fluoroscopic view reveals a radio-opaque stria, which extends proximally and / or distally to the disc, along the posterior aspect of the vertebral bodies. Gradually, as the contrast agent is injected, the disc image should be repeatedly evaluated by means of the fluoroscope. Injection of contrast medium should be stopped when the nucleus pulposus or the whole disc space are well opacified, or the contrast medium flows abundantly into the spinal canal. After removal of the needle, anteroposterior and lateral radiographs are obtained. In the presence of disc herniation, it may be useful to also obtain oblique views.

After discography, the patient is allowed to walk with no restriction, unless the pain caused by the procedure is unusually severe. Discography may, therefore, generally be carried out on an outpatient basis. Occasionally, the patient may experience asthenia, vertigo or nausea soon after the procedure. These disturbances are due to a decrease in blood pressure caused either by psychologic stress or by the local anesthetic, both of which are usually resolved within a few minutes.

Normal and pathologic discogram

Normal nucleus pulposus appears as a roundish or ovoid structure, occupying some one third of the disc space. In the center of the radio-opaque image, a thin, less opacified band is often visible, which gives the nucleus pulposus a bilobate appearance (Fig. 9.75). This shape is the expression of fibrotic changes in the central portion of the nucleus.

In the moderately degenerated disc, the contrast medium occupies more than one third of the area of the disc. The nucleus pulposus image is flattened and elongated transversely (Fig. 9.75) and may show irregular margins. In the peripheral portion of the disc, one or more radio-opaque striae, corresponding to clefts in the

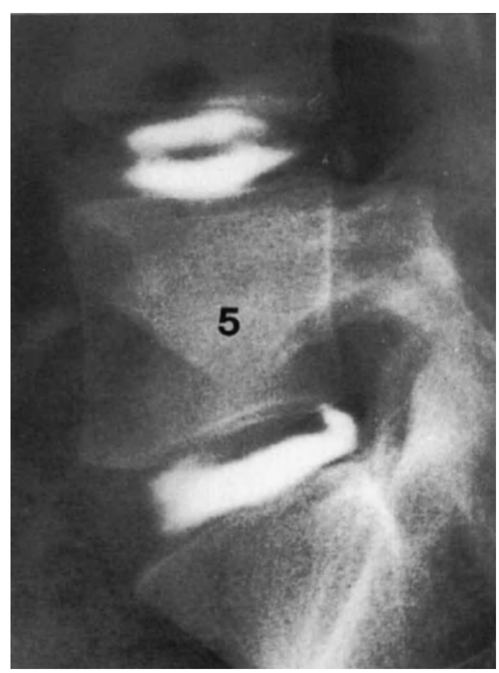


Fig. 9.75. *L4-L5 and L5-S1 discograms. At L4-L5 level, the disc is normal and shows a normal bilobate appearance of the nucleus pulposus. At L5-S1 level, the image of the contrast medium is flattened and elongated due to moderate degenerative changes of the disc.*

Fig. 9.76. *L3-L4 and L4-L5 discograms. The L3-L4 discogram shows a contained disc herniation. At the level below, the contrast medium almost entirely opacifies the markedly degenerated disc and protrudes into the spinal canal.*

annulus fibrosus, may be visible. In the severely degenerated disc, the contrast agent can completely or extensively opacify the disc. The image of the contrast medium may be either homogeneous or irregular due to opacified areas alternated with radiolucent zones.

A contained herniation is characterized by the presence of clefts in the annulus fibrosus and posterior protrusion of the contrast medium surpassing the border of the adjacent vertebral bodies (Fig. 9.76). In the presence of a subligamentous extruded herniation, the contrast medium exceeds beyond the vertebral end-plates and may spread for a short distance into the subligamentous retrosomatic space. Occasionally, the contrast medium engulfs the herniated disc fragment, which appears as a radiolucent islet surrounded by a radio-opaque rim. A retroligamentous extruded or migrated herniation is characterized by a degenerated appearance of the disc, which may protrude or not into the vertebral canal. At times, the contrast medium may flow, even massively, into the spinal canal; this, however, is not pathognomonic of a transligamentous, retroligamentous or migrated herniation, but only of the presence of a complete radial cleft in the annulus fibrosus (Fig. 9.77). These types of herniation may be demonstrated by discograms only when the herniated tissue is surrounded, and as if isolated, by a radio-opaque rim. In intraforaminal and extraforaminal herniations, the contrast medium opacifies the lateral region of the disc on the side of herniation; the pathologic image, therefore, is visible on the anteroposterior discogram (Fig. 9.78).

Pain provocation test

Injection of contrast medium into a normal disc usually causes no pain or produces only a feeling of painful tension. When injected into a degenerated disc, the contrast agent may produce no pain or the pain usually felt

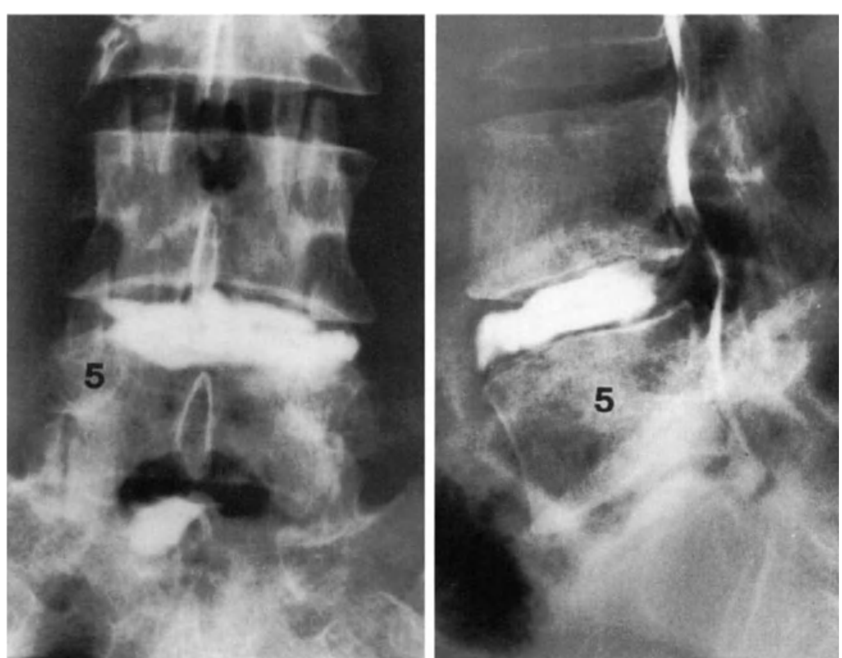


Fig. 9.77. *L4-L5 and L5-S1 discograms. The L4-L5 disc is uniformly opacified due to severe degenerative changes and protrudes into the spinal canal. The contrast medium injected into the L5-S1 disc has largely extravasated into the spinal canal and has risen as far as the L3 vertebra; this disc does not appear to be herniated.*

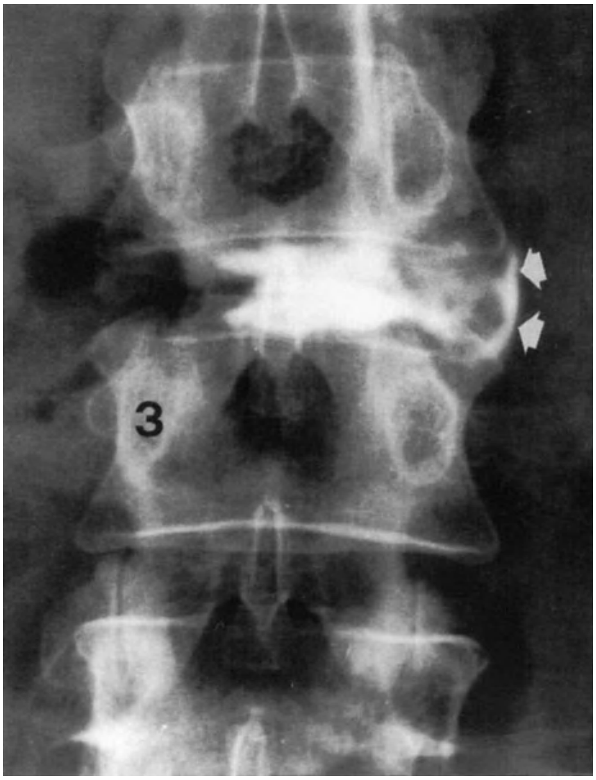


Fig. 9.78. *L2-L3 discogram showing a left intraforaminal disc herniation. The contrast medium opacifies the lateral region of the disc only on the left (arrows).*

by the patient. Provocation of the patient's typical pain is an important piece of diagnostic information, since it may allow us to determine whether the degenerated disc, or which of the degenerated discs, is responsible for the patient's symptoms. Pain is probably caused by mechanical stimulation of nociceptive fibers in the annulus fibrosus and the longitudinal ligaments as a result of an increase in intradiscal pressure caused by the injection of the contrast agent. A role, however, is likely to be played also by the nature of the medium injected, which may irritate, to a varying extent, the nerve endings due to its chemical characteristics.

In degenerative disc disease, discography may be considered as positive only when the radiologic image reveals degeneration of the disc and the patient – psychologically sound – experiences moderate to severe pain, similar to that usually felt (223). The sole abnormality of the discographic image, in fact, does not allow us to determine whether disc degeneration is physiologic or pathologic and, in the latter instance, whether it is responsible for low back pain. On the other hand, it is possible that distension of the annulus fibrosus may cause pain even in the absence of demonstrable structural changes in the disc (87, 106, 220).

In the presence of disc herniation, injection of contrast medium often causes low back and/or radicular pain. In our experience, this occurs more frequently in patients with a contained, or subligamentous extruded, disc herniation than in those with a retroligamentous or migrated herniation. Opposite findings, however, have been reported by Maezawa and Muro (126), who induced reproduction of the patient's typical pain more often in migrated, or retroligamentous extruded, herniations than in the other types of herniation.

Disco-CT

This investigation consists in performing CT scanning 2–4 hours after carrying out discography with 1–2 ml of contrast agent. In the time lapse between discography and CT, the patient is invited to walk around in order to obtain a homogeneous distribution of the contrast medium within the disc. Generally, 5 or 6 scans are performed at the center of the disc to avoid artifacts due to partial volume; in the presence of a migrated herniation, contiguous sections from one pedicle to the next, and possibly sagittal and/or coronal reconstructions, should be carried out (59).

In a normal disc, the contrast medium appears as a roundish radio-opaque area in the center of the disc. In the presence of degenerative changes, the whole disc appears irregularly opacified (Fig. 9.79). On CT scans, radial clefts in the annulus fibrosus may be clearly visible: they appear as radio-opaque striae, which originate from the center of the disc and penetrate into the annulus fibrosus for varying distances.

In a contained herniation, the contrast medium opacifies the cleft in the annulus fibrosus, through which the nuclear tissue has entered, and may saturate the herniated tissue protruding into the spinal canal. In a subligamentous extruded herniation, the contrast agent opacifies the annular cleft and the herniated tissue which is in continuity with the contents of the disc (Fig. 9.80). A retroligamentous extruded herniation may be demonstrated by disco-CT when the herniated fragment is in continuity with the disc by means of a tissue pedicle, or the contrast medium surrounds and isolates the herniated disc fragment. When the herniation has migrated at a distance from the disc, disco-CT shows the cleft in the annulus fibrosus, but may not be diagnostic if the contrast agent does not opacify or surround the herniated fragment.

Complications

These are represented by nerve-root lesions caused by the needle and disc infections.

Nerve-root lesions occur only when discography is performed under general anesthesia, since puncture of

Fig. 9.79. *Disco-CT scans. Irregular opacification of the disc due to marked degenerative changes.*

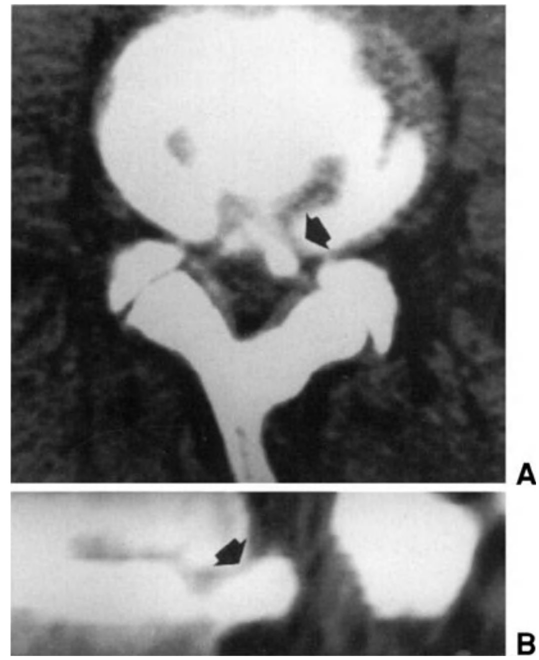


Fig. 9.80. *Disco-CT.* (A) *Axial scan.* (B) *Sagittal reconstruction. Subligamentous extruded herniation: the contrast medium opacifies the herniated tissue (arrows).*

the root when the patient is awake causes a sharp radicular pain, leading the operator to change the direction of the needle.

The frequency of spondylodiscitis, in clinical series including discographies of more than 1500 discs (11, 41, 196, 227, 234), ranges from 0.05 (41) to 0.6% (227). In contrast with these figures, Fraser et al. (66) found discitis in 2.3% of 432 patients submitted to discography. The prevalence of infectious complications was 2.7% when the procedure was carried out using a single needle with no stylet. In the patients in whom two needles with a stylet – a guiding needle and a needle, inserted in the former, to penetrate into the disc – the prevalence of complications decreased to 0.7%. This is probably due to the lower risk of contamination of the needle pricking the skin by the bacteria present on the cutaneous surface. The micro-organisms usually responsible for infection, are, in fact, stafilococcus aureus and epidermidis, and *E. coli.* (3, 88). The latter may originate from intestinal loops incidentally punctured by the needle during discography performed with an incorrect technique. Intravenous administration of antibiotics immediately before discography may have a prophylactic effect (67).

Diagnostic accuracy

Discography is highly accurate in identifying a degenerated disc responsible for low back pain, provided the radiographic image and the response to the pain provocation test are evaluated concomitantly (223). In studies based on the evaluation of both parameters, the proportion of false positives (1 / specificity) ranged from 0 to 13% (87, 220, 223). On the other hand, Vanharanta et al. (220) found that 93% of patients in whom the provoked pain was of similar intensity as the preprocedural pain had severely or moderately degenerated discs. However, in patients with chronic low back pain who have an abnormal discogram and a negative pain provocation test, no studies have demonstrated that the back pain cannot originate from the degenerated disc.

In a prospective study, the clinical success rate following spine fusion was found to be comparable in patients with, or without, typical provoked pain (58).

Numerous studies (61, 85, 86, 130, 131, 136, 215) have analyzed the diagnostic ability of discography and disco-CT in disc herniations. In a prospective study comparing several investigations (106), discography was found to have a greater sensitivity, but a lower specificity and a lower diagnostic accuracy (58%) than CT (73%) and myelography (70%); disco-CT, on the other hand, appeared to be the most sensitive and specific investigation, the diagnostic accuracy being 86%. In particular, disco-CT displayed a very high diagnostic accuracy in lateral herniations (91%) and in patients previously operated on (100%). The high diagnostic value of disco-CT is related to the ability of the investigation to demonstrate the route followed by the herniation (149) and to the greater capacity of the disc tissue to take up the contrast medium compared with the epidural tissue and, in operated patients, scar tissue (106, 107). The false negative results of discography might depend, at least in part, on the characteristics of the herniation. The investigation, in fact, may be negative in herniations of the annulus fibrosus when the annular cavity does not communicate with the nucleus pulposus (237).

In lateral herniations, reproduction of typical pain, which is obtained in about half the patients (126), has little diagnostic value, since it does not usually influence either the interpretation of the discographic images, or the therapeutic indications.

Indications

Discography, associated or not with CT, is indicated for the selection of patients with discogenic low back pain to be submitted to spine fusion. The alternative investigation is MRI, but this may be normal even in the presence of degenerative disc changes (36, 116, 242) and does not allow us to differentiate between a symptomatic, and an asymptomatic, degenerated disc.

In patients with a herniated disc, plain discography may be indicated only as an intraoperative investigation prior to chemonucleolysis or percutaneous discectomy. Disco-CT, which has a higher diagnostic ability than discography, has, like the latter, several disadvantages: it is invasive, implies a fairly high exposure to ionizing radiations, and involves the risk of discitis. This investigation cannot, therefore, represent a routine diagnostic modality. It is indicated when CT, MRI and/or myelography fail to provide conclusive diagnostic information; in particular, to differentiate a recurrent herniation from postoperative fibrosis and in patients with a lateral disc herniation.

However, disco-CT is useful in the selection of patients for chemonucleolysis, since the uptake of the contrast medium by the herniation indicates that the enzyme may reach the herniated fragment (54). The characteristics of the discogram, furthermore, were found to be useful in the selection of patients for automated percutaneous nucleotomy (37).

Radiculography and anesthetic nerve-root block

Radiculography consists in visualizing the spinal nerve root in the extrathecal course (radicular nerve) and the spinal nerve using contrast medium injected into the nerve-root sleeve. With anesthetic nerve-root block, dermatomal anesthesia is produced by injecting local anesthetic into the nerve-root sleeve. The two investigations may be carried out singly, but they are generally associated.

Technique

For radiculography of lumbar nerve roots, the patient is placed in the lateral decubitus, lying on the symptomatic side; to examine the S1 root, the patient is placed in the prone position with the symptomatic side raised by 15° from the radiologic table to align the anterior and posterior sacral foramens. Alternatively, the patient is placed, for examination of any root, in the oblique anterior position at 45° with the symptomatic side in contact with the radiologic table (219). An 18–22 G needle, 15 cm long, is used.

To examine the lumbar nerve roots, the needle is advanced under fluoroscopic control using the same technique as that for discography, but it is directed towards the pedicle under which the involved root runs. The needle is advanced until the tip is visible, on the lateral (or oblique) view, just below the pedicle and inside the intervertebral foramen and, on anteroposterior view, below the pedicle and laterally to the line joining the center of the two pedicles delimiting the intervertebral foramen. To examine the S1 nerve root, the needle is introduced vertically through the first posterior sacral foramen until it reaches the S1 root.

When the needle enters the nerve-root sleeve, the patient experiences a sharp pain in the lower limb and paresthesias in the distal portion of the dermatome. Then, 1 ml of contrast agent is very slowly injected under fluoroscopic control. When the needle is correctly positioned, the contrast medium surrounds the nerve root giving a tubular image, with rectilinear margins, within which the radiolucent outline of the root is often visible. If the needle is wrongly positioned, a striated image with irregular margins is observed laterally to the vertebra or an irregularly-shaped deposit of contrast medium is seen within the intervertebral foramen.

While injecting the contrast medium, the examiner asks the patient whether the pain elicited in the lower limb is in the same site as the pain usually felt. In the affermative answer, 0.5 ml of 1% carbocain are injected. This leads to immediate disappearance of the provoked pain and dermatomal hypoesthesia. Occasionally, a temporary myotomal muscle deficit may occur. After obtaining radiographs in the anteroposterior and oblique views, the patient is invited to walk or perform the physical activities which are usually painful, to confirm the disappearance of the preprocedural radicular pain.

Radiculography may be performed at one or more levels. In the latter case, the anesthetic block is generally carried out at only one level.

The only reported complication is temporary epidural anesthesia resulting from excessive medial advancement of the needle (219).

Diagnostic accuracy

Some authors (114, 203) believe that radiculography may allow detection of the site of the nerve-root compression. In most studies, however, no relationship has been found between radiculographic findings and the site of nerve-root compression or the nature of the compressive agent. This indicates that radiculography serves essentially to ascertain the correct position of the needle before nerve-root anesthetic block.

Several studies have analyzed the diagnostic accuracy of anesthetic nerve-root block as related to the surgical findings and the results of operative treatment. Krempen and Smith (117) performed an anesthetic block in 22 patients, almost all previously operated on. Of the 18 patients with a positive test, 16 underwent surgery, with satisfactory results in 12. In a retrospective study of 46 patients with a positive test submitted to surgery, it was found that, in all cases, a pathologic condition involving the tested nerve root had been detected at surgery (48). The pathologic condition was mostly represented by disc herniation or arachnoiditis. Excluding the patients with arachnoiditis, the results of surgery were satisfactory in 85% of cases. In a series of 24 patients with disc herniation and 18 with isolated nerve-root canal stenosis who underwent surgery, the predictive value of a positive test (true positive/true + false positive) was 100% and 95%, respectively (219). Stanley et al. (200) have compared the diagnostic value of anesthetic nerve-root block, myelography and CT in 19 operated patients; the anesthetic block was found to be much more reliable than the other two diagnostic modalities.

Indications

The nerve-root anesthetic block may be useful in several situations: 1) In previously operated patients, when the results of the routine investigations failed to provide a clear-cut diagnosis; this is the situation in which the test is more likely to be indicated. 2) In patients with persistent radicular symptoms, when CT, MRI and myelography are negative or show mild nerve-root compression not clearly correlated with the clinical features. 3) In the presence of nerve-root compression at two or more levels, of which only one is probably symptomatic; if one prefers to perform the operation at only one level, the anesthetic block may allow the symptomatic level to be detected. 4) In patients with pathologic conditions both in the hip and lumbar spine, in order to determine which condition is the main or only cause of symptoms.

On the whole, the indications for anesthetic nerve-root block are fairly rare. With the technologic improvements in CT and MRI equipment, it has become easier and easier to detect, in the non-operated patient, the cause of a radicular syndrome. When the other investigations are negative, there are high chances that the block will give a negative, or false positive, result. The anesthetic block, however, does not usually allow the cause of a radicular syndrome to be determined; in the operated patient, therefore, the test does not allow us to determine whether the radiated symptoms are due to extrinsic compression of the nerve root or intra-perineural fibrosis, i.e., a condition in which surgery has little chance of successful results. In both the virgin and operated patient, a positive test does not represent an indication for surgical treatment, but should be considered as one of the elements useful to establish the therapeutic protocol to be followed.

Bone scanning

This diagnostic modality has a low specificity, but is highly sensitive in various pathologic conditions, such as tumors, fractures or infections. In patients with lumbar disc herniation and/or stenosis, bone scans are usually negative. If positive, this is generally due to vertebral degenerative changes, causing a slight increase in the radioisotope uptake.

With planar scintigraphy, it is generally impossible to determine whether the increased radioisotope uptake in a vertebra is related to pathologic conditions of the vertebral body or the posterior arch, on account of the superimposition of the images of the various vertebral components. This limitation is overcome with Single Photon Emission Computerized Tomography (SPECT), which provides multiplanar images of the anatomical structures. This modality has shown an increased uptake of radioisotope in the articular processes of patients with persistent low back pain after unilateral or bilateral laminectomy (125). Positivity of the investigation has been interpreted as an expression of instability and / or functional overloading of the facet joints.

Suspected spondylodiscitis is one of the conditions for which bone scanning is most frequently performed in patients with low back pain. The investigation may be carried out using technetium-99-phosphonate (Tc-99) or Gallium-67-citrate (Ga-67), autologous white blood cells labeled with Indium-111 (In-111 WBC) or Tc-99 (Tc-99 WBC), or immunoglobulins labeled with Tc-99. This radioisotope, although non-specific for bone infections, may detect areas of increased blood flow or bone metabolism and may be used to exclude bone infection when scintigraphy is negative (7). Ga-67 is both highly sensitive and specific in detecting a tumor or a chronic inflammatory condition. In spondylodiscitis, its sensitivity is about 80% (2, 224); false negative results are usually observed in patients with chronic infection. In-111 WBC bone scanning, in spondylodiscitis, has revealed a low sensitivity, a high specificity and, approximately, a diagnostic accuracy of less than 30% (224, 236). The proportion of false negative results was found to reach 93% in patients who had undergone antibiotic treatment during the 6 months prior to the investigation (224). In patients with spondylodiscitis, therefore, bone scan should be done using Tc-99 and / or Ga-67, and only when the test is negative and the patient is not under antibiotic treatment might it be useful to use In-111 WBC or Tc-99 WBC. The latter seems to be more sensitive and specific than In-111. In both instances, however, the diagnostic ability is higher in acute than in chronic infections. Tc-99 labeled immunoglobulins may be useful in differentiating inflammatory processes from postsurgical or post-traumatic changes (127).

Echography

The diagnostic use of ultrasounds in the lumbar spine was introduced by Meire (134), but Porter (161, 162) was the first to apply the method on a large scale. He used ultrasounds to measure, with a probe placed on the back of the patient, the oblique sagittal dimensions of the spinal canal and, thus, detect a constitutionally narrow spinal canal or a stenotic condition. With the dorsoventral technique, the scanner is placed on the patient's back laterally to the midline and the ultrasonic beam, crossing the ligamentum flavum, is reflected at the interface between the ligamentum flavum and the spinal canal and at the interface between the spinal canal and the posterior longitudinal ligament or the vertebral body (104, 110); the distance between the two echos corresponds to the diameter of the canal. Several studies have analyzed, with conflicting conclusions, the diagnostic accuracy of echography and the reproduciblity of the measurements. In a few studies, measurements were found to be accurate and reproducible (57, 120), whilst in others they were found scarcely accurate and unreliable for use in the diagnosis of lumbar stenosis (14, 17, 104).

The possibility of visualizing a herniated disc by echography performed by a dorsal approach has been described by Engel et al. (57). In echographic studies carried out to measure the size of the spinal canal, they observed, in patients with a herniated lumbar disc, a third echo at the interface between the disc and the spinal canal. In patients with this "triple density", the sensitivity and specificity of echography was 89% and 100%, respectively. In a study (111) comparing the echographic, with the surgical, findings in 40 operated patients, the diagnostic accuracy of ultrasound reached 78%; of the 40 non-operated patients, 24 (60%) had a positive echographic diagnosis, which, in 13, was in keeping with the clinical diagnosis (which, however, had a sensitivity of only 50% in the operated patients).

With transabdominal echography, introduced as an alternative to the dorsoventral technique, the ultrasonic beam crosses the intervertebral disc and reaches the spinal canal, thus allowing visualization of the disc itself and the dural sac at intervertebral level (207, 211). With this technique, however, not all lower three lumbar discs can be visualized in one third, and the L5-S1 level in half, of patients examined, the reasons being: obesity, severe loss of disc height, spondylolisthesis and, for the L5-S1 level, marked obliquity of the disc. The dimensions of the thecal sac, on transabdominal ultrasonic scans, differ by ± 5 mm compared with those obtained by myelography (207).

In patients with a herniated disc (206, 208), the sensitivity of the investigation was as high as 91% in 23 operated patients; in 53 non-operated patients, the specificity of transabdominal echography was 85% and 88% as far as concerns myelography and CT, respectively.

Transabdominal echography may allow diagnosis also of degenerative disc disease. In a study comparing echography with disco-CT, the sensitivity of the former in diagnosing a degenerated disc painful at discography was as high as 95%, but the specificity was only 38%.

Echography may be used intraoperatively to detect residual disc fragments or stenotic areas non-adequately decompressed. A study (143) has shown that 41% of patients with disc herniation and 23% with lumbar stenosis had residual disc fragments or persistent stenotic compression of the nervous structures, detected intraoperatively with echography.

Conclusions. Echography by the dorsal approach, although able to detect a constitutionally narrow spinal canal, displays a low diagnostic capacity in lumbar stenosis. After the initial enthusiasm, therefore, this diagnostic modality has been less and less used in the screening of stenotic conditions. Similar considerations are valid for transabdominal echography, in which the margins of error in the measurement of thecal sac dimensions are too high to make it useful in clinical practice. With the transabdominal technique, furthermore, the bony walls of the spinal canal are not visualized and no information is thus obtained on the causes of the possible constriction of the thecal sac.

In patients with a herniated disc, sensitivity both of dorsoventral and transabdominal echography is approximately 85% and specificity is probably similar. However, with this diagnostic modality, a tissue fragment migrated behind the vertebral body cannot be visualized, since the ultrasonic beam is arrested by the lamina, in dorsoventral echography, and the vertebral body, in the transabdominal modality. The latter, furthermore, does not provide diagnostic information in a high proportion of patients. Echography may, therefore, be used in the screening of patients with a herniated disc, but its value is limited in clinical practice. In the presence of positive or negative findings, in fact, CT or MRI should generally be carried out to obtain a more reliable diagnosis.

Intraoperative echography is of little use in patients with disc herniation, since it may not be able to distinguish normal from pathologic tissues. Furthermore, this modality may be used only if an adequately large window is created in the posterior vertebral arch for the ultrasonic beam. Thus, it may not detect a disc fragment migrated at a distance from the disc if sufficient excision of lamino-articular structures is not performed.

Thermography

Thermography provides a map of the body surface temperature. The map may be obtained using an electronic infrared telethermograph camera or applying, on the region to be examined, liquid crystal sheets, which change color depending on the energy of the absorbed infrareds. The images obtained are photographed and compared with a scale of colors, each corresponding to a given temperature.

The surface temperature of the body is normally symmetrical. Lumbar radiculopathy may cause a decrease in skin temperature with a metameric distribution in the involved lower limb and an ipsilateral increase in the lumbosacral region. The decrease in the lower limb is due to reflex sympathetic vasoconstriction, whilst the increase in the lumbosacral region results from muscle spasm, metabolic changes and/or cutaneous vasodilation.

The first report on the use of this diagnostic modality in patients with lumboradicular syndrome appeared in 1964 (5). Since then, the use of thermography has become more and more widespread, at least in a few countries. Meanwhile, numerous studies have been carried out to establish the diagnostic ability of this technique in lumbar disc herniation and stenosis, when related to the clinical data, the findings of other investigations (EMG, myelography, CT, MRI) and/or the surgical findings (34, 38, 74, 77, 80, 137, 148, 158, 216).

In one of these studies (74), the sensitivity of thermography was 98% when related to the clinical data and 100% with respect to the surgical findings. In another study (34), the results of thermography agreed with surgical findings in 92% of cases. Chafetz et al. (38) found that the sensitivity of thermography was 100% in 19 patients with pathologic conditions of the disc demonstrated with CT. However, in the more carefully performed study from the methodological viewpoint (137), sensitivity and specificity of this diagnostic modality were approximately 50%.

In a meta-analysis of the diagnostic accuracy of thermography, Hoffman et al. (102) analyzed the results of 28 studies. Of these, only 5 were considered as methodologically good. In almost all studies, the sensitivity of thermography exceeded 80%, but in the majority, the proportion of false positives was over 40%. The predictive value of a negative test was 33% to 100% and that of a positive test was 26% to 100%. The data in the literature, therefore, indicate that thermography is positive in a large proportion of patients with lumbar radiculopathy, but also that a large proportion of positive patients have no radiculopathy.

It has been suggested that thermography could be used, in patients with little clinical evidence of radiculopathy, to decide whether CT or MRI should be obtained. The risk remains, however, of performing CT or MRI in many patients with a positive thermography, but no significant radiculopathy; on the other hand, since most of the studies carried out so far are clearly imperfect from a methodological viewpoint, the reported percentages of sensitivity cannot be considered totally reliable (102). At present, therefore, thermography does not appear to play a significant role in the diagnosis of lumbosacral radiculopathy.

Lumbosacral ascending flebography

This investigation is performed using a catheter inserted in the femoral vein and advanced under fluoroscopic control as far as the ascending lumbar vein on the symptomatic side. While the patient performs the Valsalva maneuver, 35–40 ml of contrast medium are injected and radiographs are then obtained. The catheter is then introduced into the ascending sacral vein on the same side and the procedure is repeated. In the presence of posterolateral disc herniation, the anterointernal epidural veins appear to be deviated, thinned or interrupted at the level of the disc. Similar flebographic changes, but bilateral, are produced by a midline herniation. A lateral herniation produces an interruption, albeit difficult to demonstrate, of the veins in the intervertebral foramen.

This investigation was quite popular in the 70's, but has been completely abandoned since then, as the flebographic images may be difficult to interpret and provide no information on the subarachnoid space. Furthermore, very little information can be obtained in previously operated patients. In non-operated patients, the accuracy of ascending flebography in diagnosing a herniated lumbar disc ranges, in most studies, from 78% to 98% (49, 133, 135, 153, 180). In a series of 1472 cases, accuracy was found to reach 84% (73).

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CHAPTER 10

ELECTROPHYSIOLOGIC INVESTIGATIONS

F. Postacchini, M. Pizzetti, D. Fredella

Electromyography

Electromyography (EMG) allows recording of the muscle action potentials, both spontaneous and elicited by muscle contraction. Although, in recent years, surface electrodes have also become available, recording of muscle potentials is usually performed by needle electrodes; thus, this technique is also termed needle EMG.

Needle electrodes are inserted into the muscle to be examined, whilst surface electrodes are applied on the skin overlying the muscle being studied. In general, needle electrodes are able to record the activity of a single motor unit or a few units, whereas the surface electrodes record the electric activity of numerous motor units. The electromyograph contains one or more systems of amplification, which can multiply the weak electric potentials recorded from the muscle. For instance, if the signal amplitude is 1 microV, 1000-fold amplification reproduces a potential, on the oscilloscope, which has an amplitude of 1 cm.

EMG allows evaluation of the contractile ability of a muscle by analyzing the amplitude and frequency of the action potentials. At rest, muscle tissue with a normal innervation does not present any electric activity, which, instead, is elicited by muscle contraction. Muscle contraction with a minimal force leads to activation of few motor units, that generates single action potentials of small amplitude and reduced frequency. By increasing the contractile effort, the EMG pattern is enriched due to progressive recruitment of motor units. After a transition phase (simple and reduced subinterference patterns), maximal recruitment is obtained, which produces the characteristic interference pattern, in which the individual motor units are no longer recognizable. Recruitment consists in the activation of motor units not yet involved in the muscle contraction and in a more frequent activation of already recruited units (Figs. 10.1–10.3).

Pathologic electromyogram

In the presence of total or partial impairment of muscle innervation (paralysis or paresis), there may be spontaneous activity at rest, which is an expression of the denervation process. This is characterized by fibrillation potentials, positive sharp waves or fasciculations. Their origin would be related to acetylcholine hypersensitivity of the denervated muscle fiber, which can thus be activated by subliminal stimuli. These potentials appear 2–3 weeks after the nerve lesion. The delay would be due to the fact the acetylcholine-like action would be exerted by products of degeneration of the denervated muscle fiber, which are progressively formed as a result of the loss of a normal nerve supply. The fibrillation potentials have a duration of 1–5 ms and an amplitude of 20–200 microV and, acustically, produce a short sharp sound. They persist a long time on the oscilloscope with a frequency of 1–30 per second (Fig. 10.4). The positive sharp waves are positive waves followed by a negative phase of long duration (Fig. 10.5). Fasciculation potentials correspond to spontaneous activity of one or multiple motor units and, at

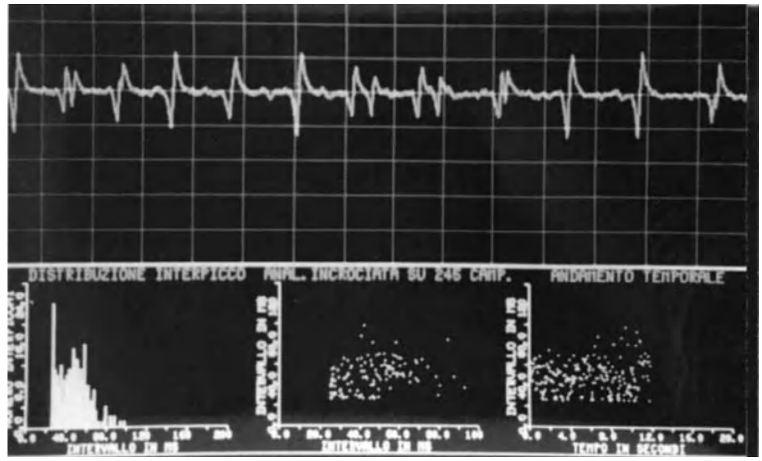


Fig. 10.1. *A slight muscle contraction leads to recruitment of few motor units, thus giving a trace with single deflections.*

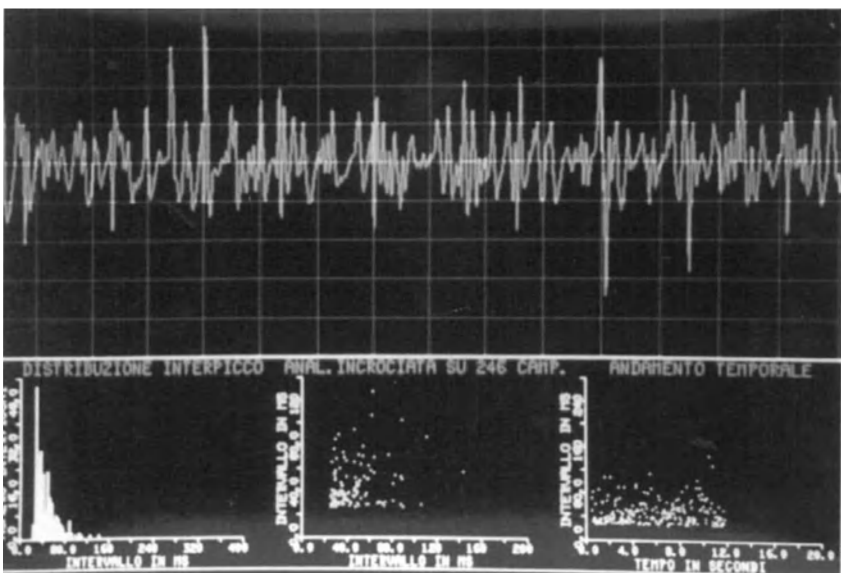


Fig. 10.2. *A greater intensity of contraction recruits an increasing number of motor units, thus giving the typical subinterference pattern.*

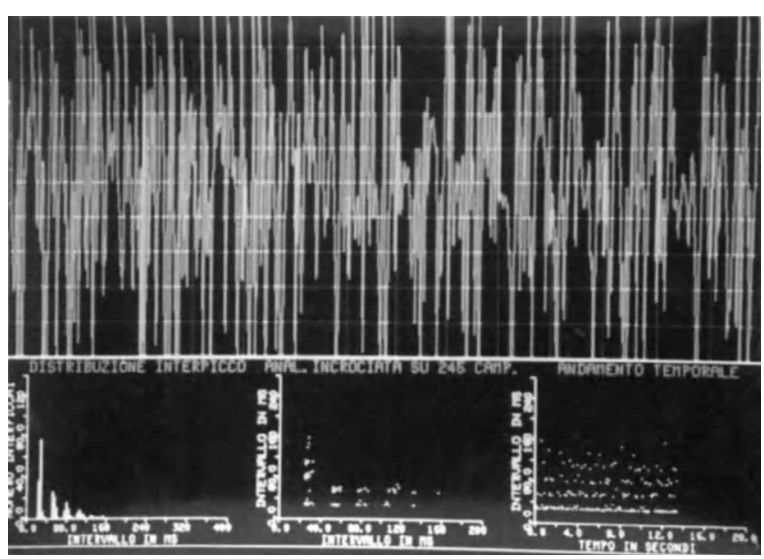


Fig. 10.3. *Maximal contraction of muscle fibers leads to recruitment of all the available motor units. The resulting summation of the action potentials generates an interference pattern.*

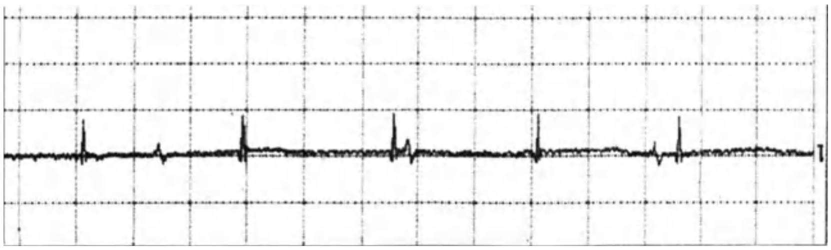


Fig. 10.4. *Fibrillation potentials. These are biphasic or triphasic potentials of short duration and varying amplitude. They indicate with certainty a state of denervation of the muscle fiber.*

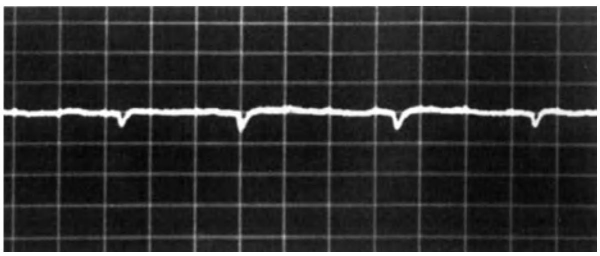


Fig. 10.5. *Positive sharp waves. Sharp positive monophasic deflections with an amplitude of 50 to 1000 microvolts. These have the same pathologic significance as the fibrillation potentials.*

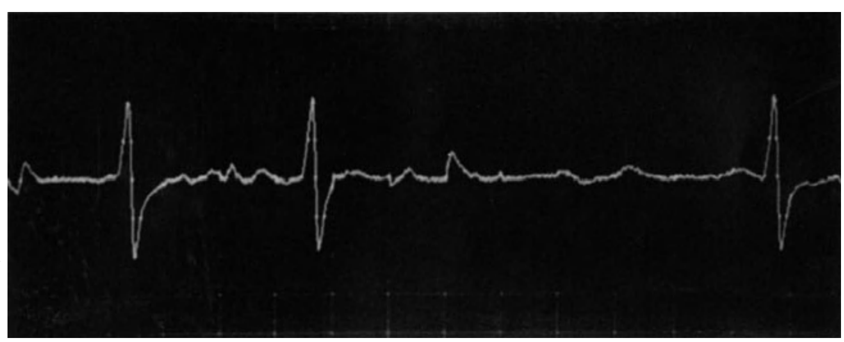


Fig. 10.6. *Fasciculation potentials. These are nonrepeatitive spontaneous potentials, showing an increase in frequency after a voluntary contraction of short duration.*

times, appear as vermicular skin contractions (Fig. 10.6).

Relatively mild motor neuron impairment manifests with a decrease in the activity of recruitment and possible presence of spontaneous potentials. This phenomenon is evaluated during the voluntary muscle contraction. A decrease in nerve conduction produces various changes in the normal EMG trace, particularly duration, amplitude, shape, number of phases of the potentials, area occupied by the deflections and number of positive-negative deflections. Quantitative evaluation of the neuromuscular impairment is made from the computerized analysis of the recruitment pattern. One method – spectral analysis – consists in selecting the potentials with an amplitude of more than 100 microV, obtained with a maximal contraction maintained over time, and transforming the elements of the trace into histograms. The area of the histograms is compared with that of the histograms obtained from the contralateral healthy muscle in order to calculate, in percentage, the functional deficit (Fig. 10.7). Another method – mathematical analysis – consists in analyzing the amplitude and number of the potentials greater than 100 microV and, particularly, the distance between the peaks, as well as the duration of the potentials of less than 20 microV. The data are compared, also in this case, with those obtained from the healthy side. On account of these computerized evaluations, the examination is considered highly reliable, since they exclude, to a large extent, the subjective component in the evaluation of the recruitment pattern.

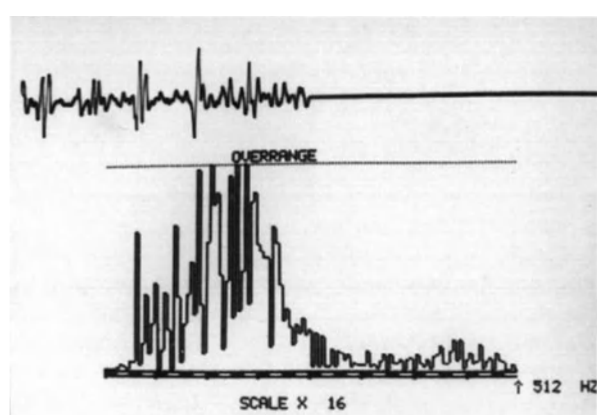


Fig. 10.7. *Spectral analysis. A computerized trace of voluntary activity, transformed into histogram, gives a more precise idea of the effective recruitment.*

In the presence of reinnervation processes, pathologic potentials are recorded, such as polyphasic potentials, giant potentials and polyphasic potentials of growing motor units, which are an indicator of functional recovery.

Radiculopathies

In radiculopathies due to disc herniation, EMG is the examination routinely performed and, in most cases, showing the highest diagnostic ability. In these pathologic conditions, only the muscles of the limb or also the paravertebral muscles may be studied.

EMG alterations of the paravertebral muscles appear only when these are denervated and, thus, in the presence of severe nerve-root compression. A milder radicular involvement causing no denervation produces no EMG changes. Denervation indicates a lesion of the posterior ramus of the spinal nerve, due to pathologic conditions involving the nerve root, the spinal nerve or the posterior branch of the latter. EMG examination of these muscles may be important, since the spontaneous potentials appear within 6–8 days of the injury, i.e., much earlier than in the limb muscles (16). However, compared with the latter, the paravertebral muscles undergo reinnervation much earlier and, thus, the recruitment pattern may be normal in the presence of a persistent radiculopathy. Furthermore, since several roots are involved in the innervation of these muscles, it is difficult to determine the level of the lesion in the absence of data obtained from the limb muscles. In previously operated patients, these may be found to be denervated due to lesions of the posterior ramus of the spinal nerve or prolonged ischemia induced by surgical retractors.

EMG of the muscles of the lower limbs may show muscle denervation, innervation abnormalities of varying entity, reinnervation potentials or no alterations. Denervation is a very rare finding, since most muscles, if not all, are supplied by multiple nerve roots. The chronicity of the lesion is demonstrated by the persistence of the same EMG changes (for instance, reduced subinterference pattern and fibrillation potentials) after a relatively short time interval (1 month).

Cauda equina syndrome is characterized by fibrillation potentials and giant potentials in multiple myotomes in the lower limbs, the paravertebral muscles and urethral sphincter. The recruitment pattern is similar to that observed in spinal cord compression, differing only in the asymmetry of changes on the two sides.

Lumbar stenosis may be characterized by a monoradiculopathy or a monolateral or bilateral pluriradiculopathy, with signs of denervation, in particular poor voluntary activity, intercalated by giant polyphasic potentials. A pluriradicular involvement may suggest lumbar stenosis, however, it is not possible with EMG to diagnose stenosis. Similarly, a spinal cord compression, a compressive neuropathy or a peripheral polyneuropathy do not cause peculiar EMG changes allowing etiologic diagnosis of the muscle innervation impairment.

Conduction velocity studies

These allow us to study the conduction of the nerve impulse along the axons of the motor or sensory neurons and to determine the velocity of diffusion of the impulse. These methods include various techniques, a few relatively simple, such as those studying the conduction velocity of the impulse in a peripheral nerve, and others which are more complex and in continuous evolution, such as those analyzing the somatosensory evoked potentials.

Stimulation techniques

Electric stimulation

The electric stimulators comprise an anode and a catode mounted on a handle. They emit exponential square wave currents with a duration of 0.05–1 ms and an intensity of 5–75 mA. Generally, electric stimulation is performed percutaneously at the points where the nerves to be examined are closest to the skin. When deep nerves are to be examined, needle electrodes can be used, which are inserted in close proximity to the nerve. The elicited nerve impulse is recorded from the muscle by means of surface or needle electrodes. The electric stimulus travels along the axonal pathways and generates, in the muscle, a contractile effect, which appears on the oscilloscope as a positive/negative deflection.

Electromagnetic stimulation

At the beginning of the 80's, the electromagnetic stimulation of the brain cortex was found to generate muscle contractions of short duration in the contralateral hemisoma due to activation of the axons with the fastest conduction of the corticospinal and peripheral nerve pathways. Over the next few years, the techniques of stimulation of the nervous pathways with electromagnetic fields were considerably improved, so that, at present, magnetic electrostimulation has almost replaced the traditional method in the studies of nerve

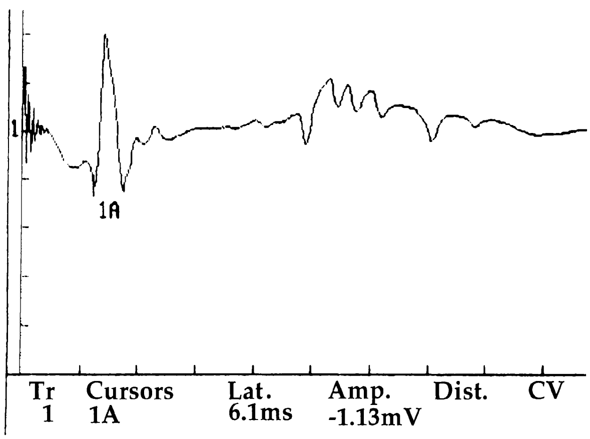


Fig. 10.8. *Electromagnetic stimulus-recording. At the level of the muscle recording, two distinct deflections of the isoelectric line are obtained: a positive deflection, followed by a negative deflection and a biphasic wave.*

conduction, except in patients with pace-makers. The presently available magnetic stimulators emit impulses equivalent to 1–2.5 tesla.

Magnetic electrostimulation, as electric stimulation, produces excitatory and inhibitory effects. The former generate the electric potential, whereas the latter are responsible for the subsequent silent period resulting from the temporary contractile inability of the muscle. At the level of muscle recording, two types of deflection of the isoelectric line are obtained: a monophasic positive wave, followed by a negative deflection; and a biphasic wave. The mean amplitude of the potential elicited is 0.2 mV, but giant potentials with an amplitude over 1 mV may also be recorded (Fig. 10.8).

The considerable ability of penetration of the electromagnetic pulse has allowed this stimulation technique to be employed in numerous body areas, such as the projections of the cortical areas on the scalp, the regions corresponding to the points where certain spinal nerves emerge or the motor points in the limbs.

Nerve conduction velocity

Motor conduction velocity

Motor conduction velocity (MCV) studies consist in stimulating a motor or mixed nerve in two sites, one proximal and the other distal, and then recording the responses elicited in a dependent muscle. Between the application of the stimulus and muscle contraction, there is a latency period of a few milliseconds. The conduction velocity is measured in meters per second (m / sec) by dividing the distance between the points of the proximal and distal stimulation by the difference of the latencies (Fig. 10.9). The mean conduction velocity of the peripheral motor nerves is 50 m / sec. The potentials evoked are of wide amplitude and are measured in millivolts. Usually, superficial nerves, such as the posterior tibial and the peroneal nerves, are examined, using an electric stimulus. With electromagnetic stimulation, even deep nerves, such as the sciatic nerve, may be studied. The potentials generated by stimulation of the posterior tibial nerve are recorded from the abductor hallucis muscle, which is supplied by the S1 and S2 nerve roots. The motor response to stimulation of the peroneal nerve is recorded from the extensor digitorum brevis muscle, which is innervated by the L5 and S1 nerve roots.

The motor conduction velocity reflects the ability of the motor fibers to conduct nervous impulses in the portion of the nerve trunk examined. It depends mainly on the integrity of the myelin sheath of the axon and is thus decreased in those peripheral neuropathies which lead to axonal demyelinization. The amplitude of the potentials may also be reduced as a result of axonal degeneration. The two pathologic conditions in which the conduction velocity is impaired are compressive neuropathies and polineuropathies.

In radiculopathies due to disc herniation, conduction velocity studies are routinely performed, but in most cases only to exclude peripheral neuropathies. In fact, in common disc herniations, the conduction velocity is normal, since the process of demyelinization and axonal degeneration is confined to the radicular, and thus intraspinal, portion of the nervous pathways. However, the amplitude of the potentials recorded

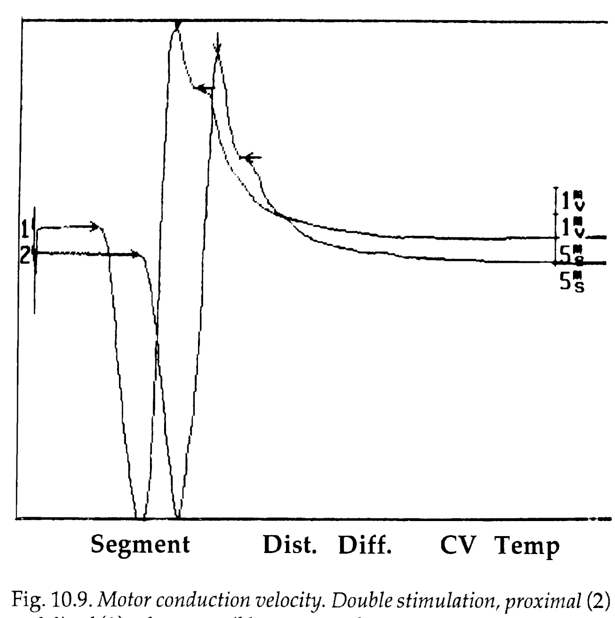


Fig. 10.9. *Motor conduction velocity. Double stimulation, proximal* (2) *and distal* (1), *of an accessible nerve trunk.*

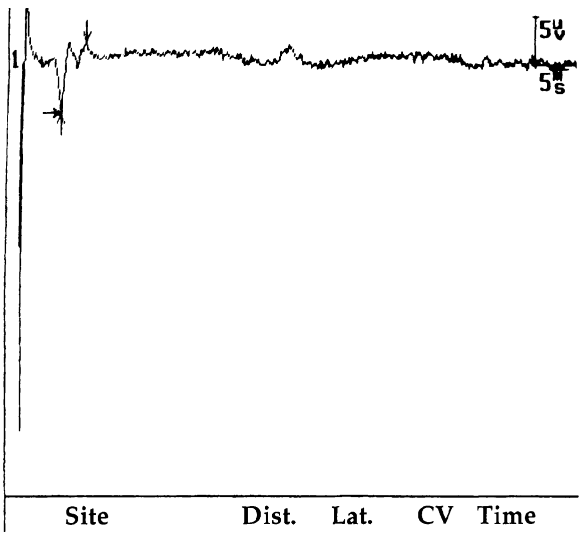


Fig. 10.10. *Sensory conduction velocity. The small amplitude of the response makes it necessary to use an averager, which calculates the mean amplitude of the responses recorded.*

from the muscle may be reduced. This rarely occurs, since usually only a part, mostly small, of the nerve-root fibers undergoes degenerative changes and, on the other hand, the pluriradicular composition of a peripheral nerve ensures that the deficit of the nerve fibers of a root is compensated by the normal function of the fiber derived from the non-compressed roots. This compensation mechanism may not be valid in the presence of a pluriradicular compressive syndrome, such as that possibly caused by a large disc herniation or lumbar stenosis. In the latter condition, there may be not only a decreased amplitude of the potentials, but also a moderate reduction of the MCV, particularly when nerve-root compression is severe (25). This indicates that a pluriradicular compression may affect, to some extent, the nerve conduction in the distal segments of the axon (43).

Sensory conduction velocity

Sensory conduction velocity (SCV) is evaluated by stimulating a sensory nerve and recording the action potential along the same nerve proximally or distally to the site of stimulation (Fig. 10.10). Usually the saphenous and sural nerves are studied. The sensory potentials are of much smaller amplitude than the motor potentials and, thus, need to be considerably amplified to be recorded. This is obtained by an averager, which, in the course of 20–30 stimulations, is able to isolate the potentials from the background noise of the equipment. The SCV is calculated in the same way as the MCV. The mean normal values are 50–60 m/sec.

The conduction velocity of a sensory nerve trunk has the same neurophysiologic significance as the MCV. In radiculopathies the SCV is normal, even in those cases in which the MCV or the amplitude of the recorded motor potentials may be reduced. This is due to the fact that the lesion is located proximally to the dorsal root ganglion, i.e., the body of the sensory cell, and cannot produce any effect on the peripheral nerve fiber. The SCV is impaired, on the other hand, in polyneuropathies, often earlier and more severely than MCV. Sensory potentials, in fact, are very sensitive – more so than the motor potentials – to axonal degeneration. However, they are also sensitive to the age-related changes; in elederly subjects, therefore, it may not be possible to evoke the sensory potentials on both sides (55).

H reflex

The H reflex is a sensory-motor monosynaptic reflex arc, which is evoked by stimulating the posterior tibial nerve in the poplitea fossa. The electric stimulus not only elicits a direct muscle contraction (M wave), but also activates the sensory fibers. Through the latter, the impulse reaches the spinal cord centers, travels to the motor fibers of the nerve root and then reaches the soleus and gastrocnemius muscles, where the impulse is recorded (Fig. 10.11). This electrophysiologic phenomenon provides information on the conduction of both the sensory and motor fibers of the S1 root and can thus be regarded as the equivalent of the Achilles tendon reflex. Unlike the EMG changes, the reflex becomes abnormal immediately or shortly after the onset of the nerve deficit. Furthermore, it may be altered due

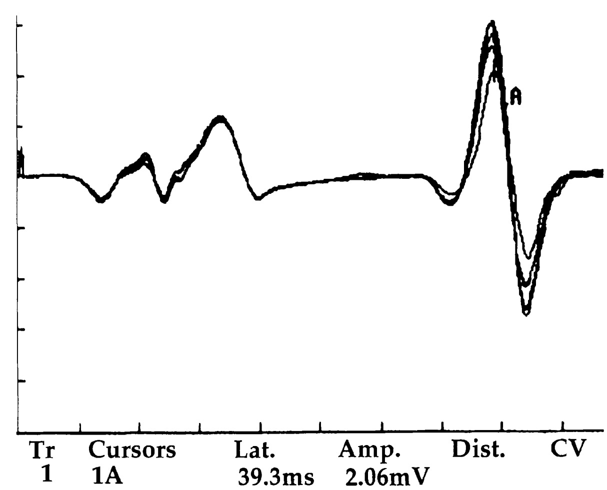


Fig. 10.11. *H reflex. The latency is measured on the second potential* (1A).

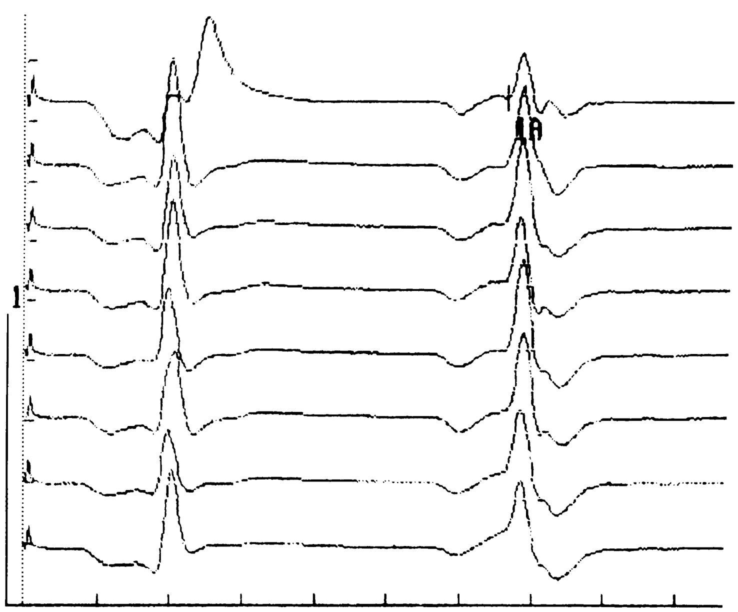
to impairment not only of the sensory, but also of the motor, pathways.

Recording of the latencies of the M and H waves allows evaluation of the conduction velocity of the afferent and efferent nerve fibers of the S1 root and of the peripheral nerves in which the fibers travel (sacral plexus, sciatic nerve, posterior tibial nerve). This may be done by dividing the distance between the T12 vertebra (where the S1 medullary center is located) and the popliteal fossa, by the difference of the H and M latencies. In clinical practice, however, the alterations of the reflex are evaluated by comparing the latency on the pathologic side with that on the opposite side, rather than by measuring the conduction velocity. The normal latency of the H wave is 29.5 ± 2.4 ms (29). A difference of more than 1.5 ms, or complete absence of the reflex, should be regarded as pathologic. The amplitude of the H response is an expression of the degree of excitability of the neurons of the reflex arc. The normal amplitude is 2.4 ± 1.4 mV (29). A comparative evaluation of the amplitude on the two sides is also made. In a series of 42 patients with clinical evidence of monolateral S1 radiculopathy, we found a mean latency time of the H reflex response of 38 ms on the affected side, compared with 32.5 ms on the opposite side; the amplitude of the response ranged from 1.7 and 11.7 mV, the mean values being 4.1 mV.

The H reflex is usually studied to diagnose an S1 nerve-root lesion and is considered an indicator of the function of this root. However, like the ankle jerk, it may be absent bilaterally in elderly subjects and usually remains indefinitely absent or abnormal in patients who have suffered from an S1 radiculopathy. The absence or alteration of the reflex, therefore, does not necessarily indicate radiculopathy. On the other hand, the H response may be present in patients not showing an Achilles tendon reflex. Alterations of the H reflex may result not only from a radiculopathy, but also from a functional deficit of the various nerve trunks in which the nerve impulses travel. However, when an electromagnetic stimulator, rather than an electric stimulus, is used, it is possible to apply the stimulus along the entire course of the sciatic nerve (58). This may allow the differential diagnosis to be made between radiculopathy and peripheral neuropathy of the sciatic nerve.

F response

A maximal electric stimulus applied to a motor nerve, after eliciting a direct contraction of the dependent muscle due to orthodromic diffusion (M wave), antidromically travels up along the nerve to the spinal cord centers and, through interneuronal circuits, again becomes an orthodromic impulse, which reaches the dependent muscle, where it is recorded after the M wave as a small amplitude potential (Fig. 10.12). The mean latency of the F response is on average 26 ms for the main nerve trunks. A normal latency of the M wave and an increased latency of the F response indicates that the orthodromic conduction along the stimulated nerve is normal, whilst the conduction between the



Tr	Cursors	Lat.	Amp.	Dist.	C.V.
1	1A	33.4ms	0.06mv		

Fig. 10.12. *F response. This corresponds to the second deflection* (1A) *in the trace (after the M response). The stimulus reaches the motor neuron and then travels back to the muscle, where the response is recorded.*

medullary centers and the site of nerve stimulation is impaired. An increased latency of the F response, therefore, is an expression of slowing of the conduction in that nerve root, the fibers of which run in the stimulated nerve. Usually, the F response is studied to evaluate the functional status of the L5 nerve root. Like the H reflex, the F wave presents an increase in latency immediately after the onset of the radicular deficit.

The abnormalities of the F response, such as the EMG alterations, indicate impairment of the motor nerve fibers. Since muscles have a pluriradicular innervation, the F response may be normal when a single nerve root is involved. Furthermore, it does not allow the degree of impairment of the root to be determined with adequate accuracy (14, 15). From this point of view, this test does not offer any advantage with respect to EMG. On the other hand, the F response, like the H reflex, may be abnormal if the nerve impulse is slowed in one of the nerve trunks in which it travels. For several reasons, therefore, the F response does not appear to play a relevant role in the diagnostic evaluation of patients with radiculopathy.

Somatosensory evoked potentials (SEPs)

The electrophysiologic process on which the somatosensory evoked potentials (SEPs) are based is that percutaneous stimulation of a cutaneous area elicits a nerve impulse which travels in the afferent fibers of a peripheral nerve, the dorsal nerve roots, the dorsal columns of the spinal cord and the thalamo-cortical projections, to reach the somatosensory brain cortex (8–10, 30, 33, 49). The impulse may be recorded from various sites along the nervous pathways, particularly the peripheral nerve, the spinal cord or the cortical area. With this electrophysiologic technique, therefore, one can evaluate the afferent nervous pathways situated proximally to the dorsal root ganglion, up until the sensory cortex (Fig. 10.13).

There are various types of evoked potentials. The four most used at present in the diagnosis of spinal pathologic conditions, particularly of radiculopathies, are: the mixed nerve SEPs, those of sensory nerves, dermatomal evoked potentials and pudendal evoked responses.

Technique

Electric stimulation is usually employed and the evoked potentials are recorded with surface electrodes. The intensity of the stimulus must be able to elicit a valid muscle contraction when a mixed nerve is stimulated and slightly exceed the sensory threshold if a sensory nerve being tested. Usually, the cortical potentials are studied and they are recorded from various areas of the scalp. For evaluation of a lumbar radiculopathy, recording may also be performed from the gluteal muscles and lumbar spinous processes, whilst for myelopathies the potentials may be recorded at more cranial vertebral levels. Due to the small ampli-

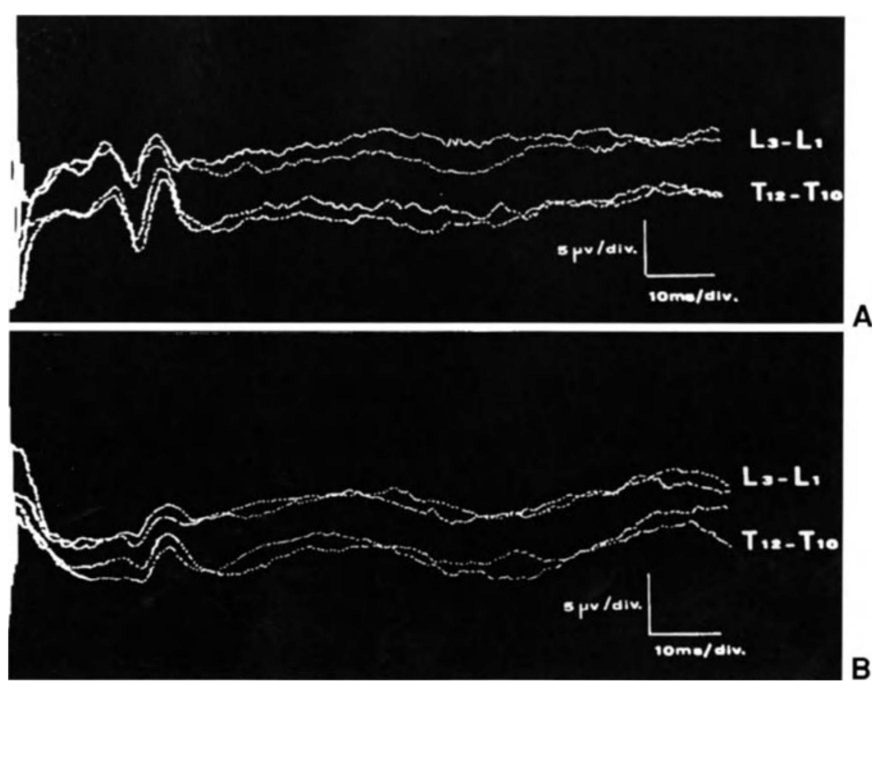


Fig. 10.13. *Somatosensory evoked potentials.* (A) *A trace recorded from the thoracic and lumbar complex.* (B) *Evoked potentials of small amplitude recorded from the same areas in a patient with* L4–L5 *disc herniation.*

tude of the evoked potentials (0.1–3 microV), an averager is used, which provides the mean of the evoked potentials by repeated stimulations (usually 100–300) and eliminates the background noises of the recording apparatus which do not have a constant temporal relationship with the stimulus. The characteristic mainly evaluated is the latency of the evoked potentials. This is considered as pathologic when it exceeds 2.5–3 points of standard deviation, as referred to subjects with the same height as the patient. Besides the latency, amplitude and morphology of the potentials may also be evaluated. However, it may be difficult to determine whether these parameters are pathologic, since they vary considerably even in normal conditions.

For intraoperative monitoring, the same techniques may be used as for clinical diagnosis, or subdermal electrodes may be employed to avoid their displacement and/or drying out during the operation, which can result in an increased resistance at the electrode skin interface and an altered impulse transmission. The intensity of the stimulus must be increased due to the neurodepressive effects produced by anesthesia.

Mixed nerve SEPs

Mixed nerve SEPs (MSEPs) are those most frequently studied. In lumbar radiculopathies, the tibialis posterior and common peroneal nerves are generally stimulated. The latency and amplitude of the recorded potentials may be decreased in the presence of a radiculopathy. It should not be forgotten, however, that the large mixed nerves contain fibers derived from multiple nerve roots: the MSEPs that are obtained by stimulating these nerves may, thus, be normal in the presence of a monoradiculopathy. Furthermore, slowing conduction in a short portion (nerve root at the level of compression) of the long pathway travelled by the nerve impulse from the site of peripheral stimulation to the site of recording of the potential may not significantly affect the velocity of conduction of the impulse (56). MSEPs, instead, are useful for evaluating the spinal cord pathways in patients with myelopathy, as well as for the intraoperative monitoring of patients undergoing surgery due to pathologic conditions of the thoracolumbar spine, or a lumbar herniated disc in the presence of thoracic cord conditions which may deteriorate on account of the operating position or the operation in the lumbar area.

Sensory nerve, dermatomal and pudendal SEPs

By stimulating exclusively the sensory nerves, such as the saphenous nerve (for L3 and L4 roots), the superficial peroneal nerve (for the L5 root) and the sural nerve (for the S1 root), Eisen and Hoirch (12) found abnormalities in the amplitude and shape of the potentials recorded from the scalp in patients with proven radiculopathy. Further studies, however, have shown that the sensory nerve SEPs (SSEPs) have a low sensitivity and specificity (47). The main reason for the poor diagnostic accuracy is likely related to the fact that also the sensory nerves contain nerve fibers of multiple nerve roots.

Dermatomal SEPs (DSEPs) are obtained by stimulating the skin of a specific dermatome; the recording is performed on the scalp. To examine the lumbar nerve roots, the areas usually stimulated are the lateral aspect of the foot (S1), the dorsum of the big toe and the second toe (L5), and the distal portion of the pretibial region (L4). There are conflicting opinions concerning the diagnostic value of the DSEPs in lumbar radiculopathies. A few authors (26, 34, 38, 45), in fact, believe that these evoked potentials are of high diagnostic value, whilst others (3, 40) consider these potentials less useful than needle EMG. The limitations of DSEPs are that the dermatomal areas are innervated by multiple roots and that these potentials, like the other SEPs, provide no information on the function of the motor pathways.

The pudendal evoked responses (PERs) are elicited by cutaneous stimulation of the dorsal nerve of the penis or clitoris. The impulses travel along the pudendal nerve, the S2-S4 sacral nerve roots and more proximal nervous pathways up to the cortical centers, where they are recorded (18). These potentials provide information on the function of the sensory fibers of the lower sacral roots, which are affected in the cauda equina syndrome. Stimulation of the dorsal nerve of the penis or clitoris can be performed even unilaterally, thus obtaining information on the function of the pudendal nerve or the nerve roots of only one side. If ring electrodes are used, the evoked responses can be recorded at vertebral level; this technique increases the diagnostic ability of the PERs in radiculopathies, since possible impairment of nerve conduction in the spinal cord is excluded.

Motor evoked potentials (MEPs)

Electric or electromagnetic stimulation at spine level can elicit motor responses in the muscles of the limbs. The evoked potentials have been recorded from the tibialis anterior and soleus muscles for the evaluation of the L5 and S1 nerve roots, respectively. In patients with compression of these roots, an increased latency and a reduced amplitude of the potentials compared with the opposite side have been observed, even in the absence of clinically evident muscle deficits (5, 53). Analysis of the motor potentials has also been used for intraoperative monitoring; stimulation may be cortical, electric or electromagnetic, or can be performed at cord level (33, 35). However, the study of these potentials for both diagnostic purposes and intraoperative monitoring is still in the experimental phase; therefore, they are not currently used in clinical practice.

Bulbocavernous reflex

The bulbocavernous reflex is studied by stimulating the dorsal nerve of the penis or the clitoris and recording the motor response from the bulbocavernous muscle or other muscles of the pelvic floor (50). Usually, it is elicited by applying a ring stimulating electrode around the glans of the penis or the clitoris and applying a single stimulus or successive stimuli with a frequency of less than 50 Hz (41). The reflex is recorded with electrodes inserted in the bulbocavernous or ischiocavernous muscles on both sides. The reflex may be elicited on only one side, as well as bilaterally. Normal latency is 30–35 ms (13). This reflex allows functional evaluation of the fibers of the pudendal nerve and the S2-S4 sacral nerve roots. Therefore, it may integrate the information provided by the pudendal SEPs. Like the latter, study of the bulbocavernous reflex may be useful in cauda equina syndrome to demonstrate a neurogenic bladder or impotence.

Two other reflexes have a similar functional significance to that of the bulbocavernous reflex. The first may be elicited by stimulating the perineal skin and recording the motor response from the anal sphincter with coaxial electrodes (42). The second is elicited by stimulation of the proximal urethra and is recorded from the anal sphincter (17).

Prerogatives and limitations

Only electrodiagnostic investigations allow evaluation of the functional integrity of the nerve roots and detection of even slight abnormalities in nerve function. Clinical examination may, in fact, demonstrate the presence of a radiculopathy only when the nerve root impairment causes such a decrease in muscle strength, sensibility or reflex activity that it can be appreciated by the examiner. Imaging studies show compression of the nervous structures or identify the cause of radiculopathy, but they do not detect the degree of nerve-root functional impairment; these investigations, on the other hand, may demonstrate a pathologic condition, such as disc herniation or lumbar stenosis, which causes no nerve-root compression or a significant functional impairment. Furthermore, electrophysiologic testing may demonstrate a deficit in the nerve root when other studies are negative, it may determine the entity of radicular functional impairment more precisely than the clinical examination and allow the evolution of radiculopathy over the time to be analyzed. A further prerogative of electrodiagnostic studies is that they may allow us to discriminate a recent radiculopathy from a long-standing radicular deficit. This information may be important both in the planning of treatment and for the prognostic evaluation.

Electrophysiologic investigations, however, have numerous limitations. They do not allow diagnosis of the quality, and often of the anatomic site of the pathologic condition responsible for radiculopathy. A few of these investigations, such as needle EMG, become positive only some time after the onset of the radicular deficit. Furthermore, with time, the EMG abnormalities may disappear as a result of muscle reinnervation processes; thus, it may not be possible to determine the presence, or the entity, of a chronic nerve-root compression. Due to the pluriradicular innervation of the muscles in the limbs and/or technical defects in carrying out the electrodiagnostic testing, errors may be made in identifying the level of the involved nerve root or, more often, it may be difficult to determine which one of two roots (for example L3 and L4) is impaired. At times, these investigations are negative even in the presence of nerve-root compression, particularly when chronic, as in compressions of stenotic origin. This may easily occur when only a part of the nerve-root fibers are compressed. On the other hand, electrodiagnostic studies may be positive even in the absence of significant radicular sypmtoms and signs. Even more often, they may indicate a moderate or severe radicular deficit in patients with mild radicular symptoms. This information may be useful for a purely diagnostic evaluation, but is of little use or may even hamper the clinician in his/her decision concerning the best approach to management, since he/she may be tempted to indicate unnecessary surgery.

SEPs studies are of considerable importance in the diagnosis of myelopathies, but have various limitations in the diagnostic evaluation of compressive radiculopathies. In this case, the somatosensory potentials become pathologic when there is a functional impairment of the sensory pathways, but not when only the motor pathways are impaired. Cortical recording of the potentials, which is that most commonly used, does not exclude that alterations in the medullary pathways, rather than radicular compression, may be responsible for the increase in latency. The radicular compression, on the other hand, may not cause a significant slowing of nerve conduction, particularly if of slight severity. Precise identification of the pathologic level may be difficult or impossible, since no peripheral nerve or dermatome is strictly monoradicular.

Diagnostic ability

In a prospective study (57), the diagnostic accuracy of needle EMG has been analyzed in 100 patients with L5 or S1 nerve-root compression due to disc herniation and / or nerve-root canal stenosis, submitted to surgical treatment. EMG identified the involved nerve root in 84% of the 95 patients with positive surgical findings; in the remaining five, the investigation was negative. No significant differences emerged between the L5 and S1 root as far as concerns the diagnostic ability of the investigation. However, in another prospective study (51), the EMG results agreed with the surgical findings in only 70% of 74 patients with disc herniation at the three lower lumbar levels.

Aiello et al. (1) have evaluated 25 patients with a clinical picture of compression of the L3 and / or L4 nerve roots. Needle EMG was positive in all 24 patients with positive surgical findings. However, in only two of them was the investigation able to identify the level of nerve-root compression. In the patient with negative surgical findings, EMG was also negative. The H reflex was abnormal in 96% of patients with positive surgical findings, but also in the patient with negative findings. In another study (2), the same authors examined 50 patients with a single, surgically confirmed, disc herniation at L3-L4, L4-L5 or L5-S1 level. The percentages of true positives were, respectively, 100%, 96% and 71%, and those of true negatives, 88%, 38% and 79%. Thus, the lowest diagnostic accuracy was found in the herniations located at L4-L5 level. The H reflex was found to be abnormal in all patients with an L5-S1 herniated disc and in some two thirds of those with L4-L5 (58%) or L3-L4 (71%) herniation. In contrast with these findings, however, Braddon and Johnson (4) found an increased latency of the H reflex in only two out of 16 patients with absence of the ankle jerk, whilst in the other 14, the reflex could not be elicited; in the same study, of the nine patients with preserved ankle jerk, seven were found to have an increased latency of the H response.

A series of patients with radicular pain underwent needle EMG and CT and were then submitted to surgery or treated conservatively (27). In 35 cases, EMG was pathologic and CT showed a herniated disc: at 1-year follow-up, the clinical picture had improved in 81% of the 16 operated patients and 47% of those not operated on. In 24 patients, EMG and CT were normal and none of the patients underwent surgery: at 1-year follow-up, 67% of patients had improved. This study suggests that the diagnostic accuracy of EMG is comparable to that of CT. In a prospective analysis of 100 patients with radicular pain of more than 6 months' duration (19), a correlation was made between symptoms, neurologic deficits, electrodiagnostic findings (EMG, H reflex and F response) and CT findings. The electrodiagnostic tests often demonstrated radiculopathy in patients with equivocal clinical signs. The results of CT did not allow the nature of the symptoms or the electrodiagnostic findings to be predicted. The latter, instead, showed the greatest ability to predict the CT findings.

In a study (32) of 50 patients operated upon for nerve-root compression due to zygoapophyseal degenerative changes, needle EMG, associated or not with recording of the H reflex, demonstrated 90% diagnostic accuracy, compared with 52% of water soluble myelography. In a series of patients with stenosis of the lumbar spinal canal (25), needle EMG showed neurogenic abnormalities in all 16 cases with a complete myelographic block, in 94% of the 48 with partial block, and in 54% of the 24 with intermittent claudication and normal myelograms. In most of the stenotic patients, neurogenic changes were bilateral and multisegmentary. EMG has also been found to be of high diagnostic value in other studies (24, 46). In stenotic patients, negative findings are likely to be obtained when the thecal sac is compressed but the emerging nerve roots are not affected to a significant extent (39).

DSEPs are the evoked potentials which appear to be of the greatest diagnostic value. In one study (44), 93% of 27 patients with herniation of the two lower lumbar discs showed abnormalities of the DSEPs evoked by electric stimulation of the L5 and S1 dermatomes. In a similar study (34), in which DSEPs were simultaneously evoked on both sides in 40 patients submitted to surgery, the electrodiagnostic findings were in keeping with the surgical findings in all cases but one. Using DSEPs, Dvonch et al. (11) identified the compressed nerve root in 86% of patients with lumbar radiculopathy. In contrast with these findings, Aminoff et al. (3) found that in patients with isolated compression of the L5 or S1 nerve roots, diagnosis was confirmed by DSEPs in 25% of cases and by needle EMG in 75%. In lumbar stenosis, abnormalities of the MSEPs and SSEPs (28) or DSEPs (52) were found in over 90% of cases.

Conclusions

In lumbar disc herniations, the sensitivity of needle EMG in identifying nerve-root impairment ranges, approximately, from 70% to 90% and specificity is only slightly lower. The diagnostic ability further increases in L5-S1 herniations, when the H reflex is recorded.

However, the electrodiagnostic tests are of little value in the identification of the pathologic disc, particularly when the L3 or L4 roots are involved. Probably, one of the reasons for this lack of success is that intraforaminal and extraforaminal herniations, which compress the root emerging from the thecal sac at the level above, usually occur at these lumbar levels. In lumbar stenosis, needle EMG, associated or not with the study of the F response and the H reflex, appears to have a high sensitivity, but a relatively low specificity. Even in this pathologic condition, and particularly in stenosis of the spinal canal, electrodiagnostic studies do not often allow identification of the vertebral level where the nervous structures are compressed. Data available seem to indicate that DSEPs are of high diagnostic value both in disc herniation and lumbar stenosis.

Indications

Diagnostic evaluation

In clinical practice, the investigations usually performed in patients with lumbar disc herniation are needle EMG and the study of H and F responses. The indications for these electrodiagnostic tests can be classified as absolute or relative.

The indication is absolute in patients with a severe motor deficit of one or multiple nerve roots and in those with a cauda equina syndrome. In these cases, the investigation may be carried out purely for diagnostic purposes, in the rare cases in which other investigations show no pathologic condition or a condition which appears to be unable to cause a severe radiculopathy. The most common aim of this investigation, however, is to document the severity of radicular impairment before surgical treatment, either for medico-legal reasons or for monitoring the postoperative recovery of nerve function. Furthermore, the indication is absolute when the clinical picture tends to suggest a peripheral neuropathy, partly or entirely responsible for the radicular syndrome. This occurs particularly in diabetic patients, who may have a neuropathy simulating the symptoms of disc herniation or lumbar stenosis (6, 22, 48). In these cases, the study of nerve conduction velocity is determinant, since this is generally decreased in the presence of diabetic neuropathy, whilst it is normally, or occasionally reduced to a mild extent, in patients with nerve-root compressive syndromes (6).

In the vast majority of patients with lumbar disc herniation, an accurate and correctly performed clinical examination is able to detect motor or sensory deficits, or decreased reflex activity, of even mild severity, which demonstrate the existence of a nerve-root compression syndrome and allow the degree of root involvement to be determined. In these cases, electrodiagnostic tests usually have a purely confirmatory role. These tests, however, may be useful, prior to surgical treatment, to establish whether the radicular deficit is recent or long-standing. It seems, in fact, that the surgical results tend to be less satisfactory in patients with a long-standing functional deficit compared to those with nerve-root compression of recent onset.

In patients with disc herniation who clinically present an irritative radicular syndrome, the electrodiagnostic tests may be useful to demonstrate the presence of nerve-root functional deficits and their severity. It should be stressed, however, that in these cases, the diagnosis and the indication for treatment, particularly surgical management, cannot be based on the results of the electrophysiologic investigations, but should stem from the overall evaluation of the clinical picture, imaging studies and electrophysiologic tests. In other words, the latter cannot represent the main laboratory tests on which the indication for surgery is based.

There is usually no indication for the study of MSEPs and SSEPs in patients with lumbar disc herniation, since these tests appear to have a low sensitivity and diagnostic accuracy in monoradiculopathies. The evaluation of SEPs may, at times, be indicated in the presence of concomitant lumbar stenosis to demonstrate a nerve-root compression not clearly detected by imaging studies. DSEPs, unlike the other evoked potentials, appear to have a high diagnostic ability also in monoradiculopathies. It should be borne in mind, however, that the study of these potentials is technically difficult and requires experience both in recording and interpreting the traces. For this reason, and the uncertainty still existing on their actual diagnostic ability, DSEPs are not usually studied in patients with simple lumbar disc herniation. Their evaluation may be indicated, however, when needle EMG does not provide reliable information due to the very short time which has elapsed from the onset of the clinical syndrome or when the H and/or F responses are negative or uninformative due to the level of radiculopathy.

Patients with a cauda equina syndrome usually appear for clinical observation a few hours or days after the onset of the syndrome, when needle EMG provides no diagnostic information. If there is a clinical or medico-legal need to document the neurologic deficits, the various types of SEPs should be studied. Study of the pudendal potentials, as well as the bulbocavernous reflex and the anal wink, may occasionally be useful to determine whether sphincteric or sexual disorders, possibly associated with a lumboradicular syndrome, are neurogenic in origin.

The somatosensory evoked potentials are abnormal in peripheral neuropathies and in the presence of cord compression or diseases, and may thus play an important role in the differential diagnosis between these conditions and a lumbar radicular syndrome.

Intraoperative monitoring

In patients undergoing lumbar spine fusion using pedicle screw fixation, intraoperative study of the EMG activity mechanically evoked (23, 37) by insertion of the screws or electrically evoked (36) by stimulation of the pedicle screws and the exposed nerve roots may be useful to avoid mistaken screw positioning, which may lead to nerve-root injury. In the event a screw breaks the cortex of the pedicle and irritates or compresses the adjacent nerve root, continuous neurotonic discharges originating from the involved root may be recorded.

Herron and Trippi (20) have proposed intraoperative monitoring of DSEPs in patients undergoing discectomy to evaluate the adequacy of nerve-root decompression; the procedure, however, is not in routine use, since it has not been demonstrated to improve the surgical outcomes in common disc herniations. Monitoring may, instead, be useful in particular conditions, such as a herniation of the first lumbar disc responsible for cord compression. Monitoring of MSEPs or SSEPs (28) or of DSEPs (7, 21) has also been performed during decompressive surgery for lumbar stenosis to make sure that complete decompression of the nerve roots is carried out; monitoring was found to be useful in this respect, however there is at present no convincing evidence that better clinical results are obtained in monitored patients than in those not monitored. Intraoperative DSEPs have recently been employed during operations of spinal fusion with pedicle screw fixation to detect nerve-root functional impairment resulting from malpositioning of screws (54). In these cases, however, the usefulness of DSEPs for preventing nerve-root lesions is very limited. In fact, they allow monitoring essentially of the spinal cord rather than the nerve roots and, then, only the sensory component of the latter. Furthermore, DSEPs may become abnormal only after the nerve root has been injured (37).

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·CHAPTER 11·

DIFFERENTIAL DIAGNOSIS. I. ORGANIC DISEASES

F. Postacchini, G. Trasimeni

Premise

Lumbar disc herniation may be responsible for low back pain alone, back pain and pseudoradicular pain, or low back and radicular pain, the latter being confined to the buttock and proximal part of the thigh or extended to the rest of the limb. Numerous pathologic conditions, other than disc herniation, may cause pure back pain and, on the other hand, a herniation is characterized clinically by the presence of radicular pain. We have, thus, limited the analysis of pathologic conditions which may simulate a lumbar disc herniation to the diseases that may be responsible for low back and/or leg pain. This does not imply that the conditions causing only low back pain or back and pseudoradicular pain – such as seronegative spondyloarthritis – cannot simulate a herniated lumbar disc producing only low back pain. However, in these cases, diagnostic confusion is extremely unlikely and, on the other hand, the association of the two conditions – rheumatic disease and disc herniation – may be only incidental, considering that a herniated disc is found in many asymptomatic subjects.

A few pathologic conditions, such as spondylitis, spondylodiscitis with marked radiographic changes, or isthmic spondylolisthesis, are not taken into consideration here, since it is extremely rare to encounter these in the differential diagnosis, and would, in any case, occur only in the clinical, i.e., the very initial, stage of the diagnostic evaluation.

Lumbar spinal stenosis has been analyzed only briefly because there is no clear-cut distinction between stenosis and disc herniation, as the two conditions may often be associated, thus representing a single pathologic entity, at least in clinical terms.

Vertebral conditions

Intraspinal tumors

Neurinoma

Some authors consider neurinoma and neurofibroma as a single pathologic entity, whereas others make a distinction between the two conditions and consider neurinoma much more common than neurofibroma (160). Some uncertainty also exists concerning the cells giving rise to these tumors and this has led to the use of various terms, such as neurilemmoma, schwannoma or peripheral glioma (138). Both tumors may be solitary or multiple (82). For our purposes, the two tumors may be considered as a single entity.

Neurinoma of the cauda equina is the most common tumor of the nervous structures in the lumbar region. In some 80% of cases, the neoplasm is entirely intrathecal, whilst in the remaining cases, it is entirely intrathecal or partly intrathecal and partly extrathecal. Usually, the tumor originates from a sensory rootlet and it is primarily located at L2 to L4 vertebral levels. Occasionally, the tumor may be completely asymptomatic for decades. More often, it causes clinical symptoms, which, however, are extremely variable in nature. The two extremes are represented by patients with monoradicular pain and no neurologic involvement and patients with multiradicular symptoms and marked neurologic deficits, associated or not with sphincteric disorders. The former condition is usually found when the tumor is small in size, whereas severe neurologic compromize, which is relatively uncommon, is observed in the presence of large tumors, unrecognized for a long time, or in those compressing the conus medullaris. Both types of clinical pattern may simulate a herniated disc (39, 113, 122, 127, 140, 193). However, the tumors most often mimicking a herniation are those responsible for unilateral symptoms, either monoradicular or biradicular (Fig. 11.1). When the tumor originates from a sensory rootlet, the initial symptoms are represented by pain, hypoesthesia and/or paresthesias, whilst motor deficits become apparent when the motor rootlets are compressed as a result of an increase in the size of the mass. The tumor often causes back pain and may produce cruralgia or sciatica, with positivity of nerve-root tension tests, as in lumbar disc herniations.

Case report

A 36-year-old female complained of vague symptoms of 1-year duration in the left lower limb, consisting in paresthesias and dysesthesias in the posterior and lateral aspect of the thigh and leg, and occasionally in the anterior aspect of the thigh. For 4 years she also had pain in the lower limb with the same distribution of sensory impairment. The pain appeared particularly in the prolonged upright position and during bed rest. An orthopedic surgeon, suspecting a lumbar disc herniation, requested a CT scan, that was performed from L2-3 to L5-S1. The investigation showed a mild annular bulging at L5-S1 level. Due to the mildness of the disc abnormality, conservative treatment was performed, which led to no improvement.

When seen by one of us, the patient had difficulty in maintaining the recumbent position due to exacerbation of the pain in the left lower limb. The nerve-root tension tests (straight leg raising test and femoral nerve stretch test) were slightly positive. Muscle strength was normal, but there was hypoesthesia in the L5 dermatome. The ankle jerk was slightly depressed. MRI studies showed a mass with the features of a neurinoma at the level of L1 vertebral body (Fig. 11.1). Surgical excision of the neurinoma led to disappearance of the symptoms.

Clinical diagnosis, or only the suspect, of neurinoma, is extremely difficult, at least in the initial stages of the disease. The clinical features that may generate the suspicion of the tumor are: the long duration of the radicular symptoms, which often last a few years at the time of diagnosis; the frequent involvement of multiple nerve roots, mostly the upper lumbar roots; the discrepancy between the severity of pain and the relative paucity of neurologic signs; and the characteristics of pain, which typically exacerbates in the recumbent position, particularly at night, and decreases in the sitting or upright position. However, posture-related changes occur only in a minority of patients, at least in the initial stages of

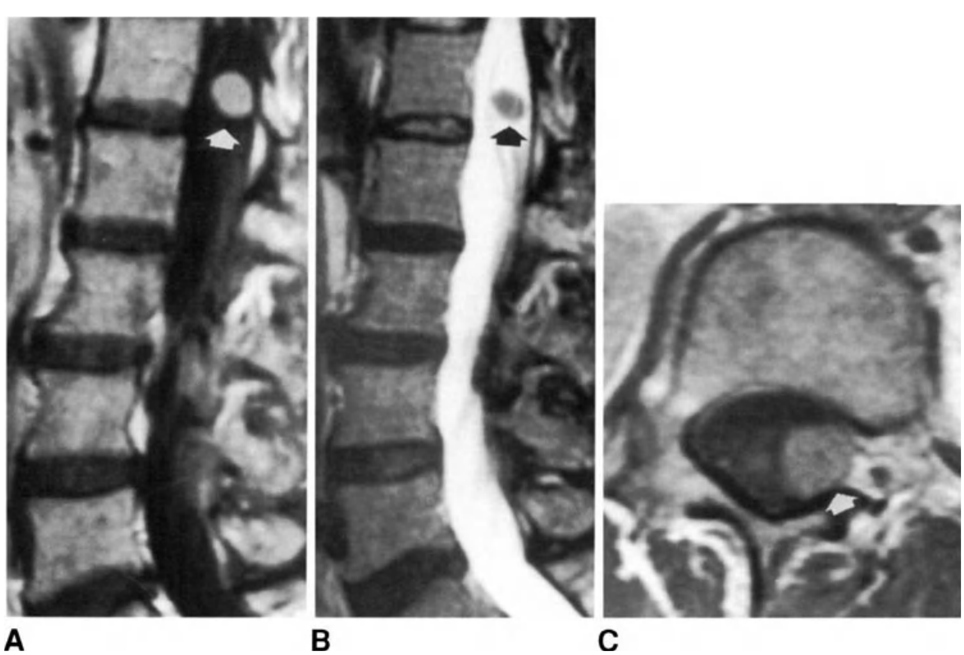


Fig. 11.1. *MR images of intrathecal neurinoma at L1 level.* (A) *Sagittal T1-weighted spin-echo image after administration of gadolinium.* (B) *Sagittal turbo T2-weighted image.* (C) *Axial T1-weighted spin-echo image after injection of gadolinium. A roundish lesion, showing a homogeneous increase in signal intensity, is visible within the thecal sac after administration of contrast medium. On the T2-weighted image, the lesion can be clearly differentiated from the CSF due to its lower signal intensity.*

the disease. Diagnosis may be easily suspected, instead, in the presence of multiple neurinomas or café au lait spots in the skin (Von Recklinghausen's disease).

Intrathecal neurinomas usually produce no radiographic changes, whereas the extrathecal masses may erode the pedicle and vertebral body. Neurinomas developing in the sacrum may reach giant dimensions and erode the anterior wall of the bone (1). On myelograms, the tumor causes a complete block, or a filling defect, of the dye column, with a typical dome-like shape of the margins.

CT scans may not show the tumor when it is located proximally to the scanned portion of the spine; this may easily occur for neurinomas situated at the level of L2 or L3 vertebral body, when CT studies are limited to L2-L3 or L3-L4 levels. On CT scans, the tumor shows a parenchimatous density, enhancing after administration of contrast medium. On axial images, neurinoma usually appears to occupy the whole width of the spinal canal. If the latter is occupied only partially by the hyperdense tissue, this is more likely to be a large disc herniation than a small neurinoma. The differential diagnosis can be made with the administration of contrast medium, because a herniation, unlike neurinoma, does not show an increase in density.

MRI usually allows the tumor to be easily diagnosed due to the marked difference in signal intensity between the CSF and the parenchimatous tissue of the tumor, which appears as a roundish or ovoid mass, occupying the thecal sac to a varying extent. Hour-glass neurinomas appear to be located only partly within the vertebral canal and extend in the paravertebral region through a narrower portion situated in the spinal canal or the intervertebral foramen (Fig. 11.2). On T1-weighted images, the tumor is isointense to the muscles and shows a marked enhancement after administration of gadolinium. Occasionally, an area of low signal intensity – called dot sign (74) – is visible within the tumor on the T1-weighted images after injection of gadolinium (Fig. 11.3). The dot sign has been attributed to tissue edema, presence of microcysts, hyalinization of vessels, previous hemorrhages or dystrophic calcifications. In addition to the main tumor, MRI may show other small satellite neurinomas, usually not visible on CT scans.

Meningioma, and dermoid and epidermoid cysts

Meningioma is uncommon in the lumbar region. Dermoid and epidermoid cysts, instead, are mainly located in the lumbar spine. The clinical features of these tumors are similar to those of neurofibroma: long duration of symptoms, prevalence of pain and sensory symptoms compared with motor deficits, and exacerbation of pain at night and in the recumbent position. A clinical diagnosis of disc herniation may often be made for these tumors as well (31). Radiographs are usually normal.

On CT scans, meningioma appears as a hyperdense mass within the spinal canal. On occasion, the lesion contains areas of greater hyperdensity, corresponding to calcified zones. After administration of contrat medium, density of the tumor shows a marked increase. MRI reveals an intraspinal mass, which, on T1-weighted images, is isointense to the muscle tissue, whilst on T2-weighted images it displays a high signal intensity, increasing homogeneously after administration of gadolinium. The latter is helpful in demonstrating the area of thickening and increased signal intensity of the meningeal surface at the site of origin of the tumor (144). Differential diagnosis with neurinoma is based on the signal intensity of the mass, which, in meningioma, is usually higher on T1- weighted, and lower on T2-weighted, images (118).

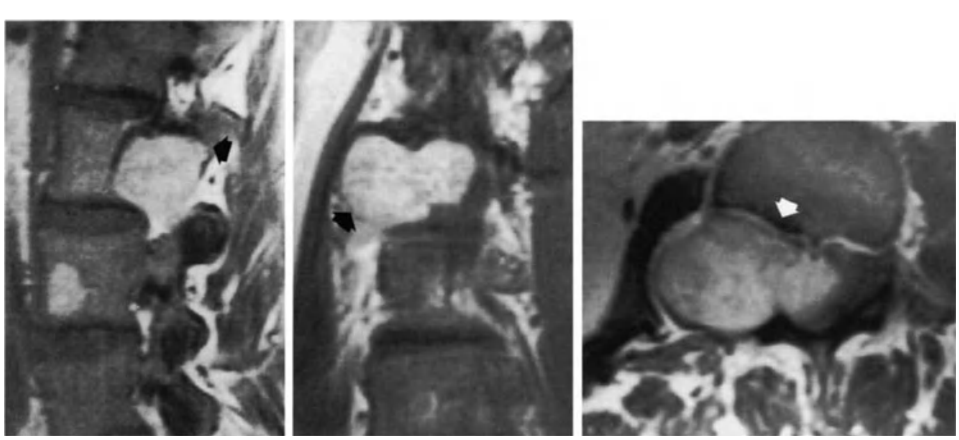


Fig. 11.2. *T1-weighted spin-echo MR images in three spatial planes obtained after gadolinium administration. A large hour-glass neurinoma occupying the spinal canal and the right intervertebral foramen is visible. The vertebral body is deformed and eroded, and the intervertebral foramen is enlarged. The lesion produces a reactive sclerosis in the adjacent portion of the vertebral body, responsible for the rim of hyposignal visible on the sagittal and axial images (arrows). The lesion displays a homogeneous enhancement after injection of gadolinium.*

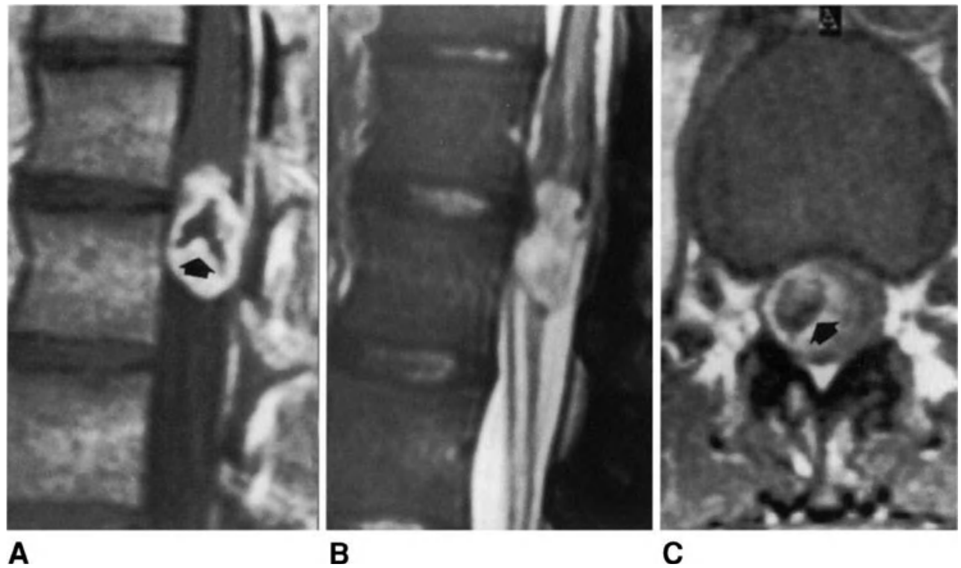


Fig. 11.3. *MR images of intrathecal neurinoma at T12-L1 level.* (A) *Sagittal T1-weighted spin-echo sequence after injection of gadolinium.* (B) *Sagittal turbo T2-weighted spin-echo image.* (C) *Axial T1-weighted spin-echo image after gadolinium injection. On the T1-weighted images, the lesion displays a dyshomogeneous enhancement after administration of gadolinium due to the presence of a hypointense central zone (dot sign). On the T2-weighted image, the lesion is weakly hyperintense.*

Dermoid cyst appears, on CT scans, as a hypodense mass due to the presence of colesterinic material. On T1-weighted MRI images, dermoid cyst is isointense or only slightly hyperintense due to the presence of abundant keratin, which decreases the high signal intensity of the adipose tissue. On T2-weighted images, the cyst appears as a hyperintense mass, containing areas of low signal intensity. The signal intensity of the epidermoid cyst may be similar to that of CSF and, thus, may not be easily visualized with MRI. In these cases, it may be useful to obtain proton density images, in which the cyst occasionally shows a high signal intensity with respect to the CSF.

Ependymoma

Ependymomas of the lumbar region originate principally from the filum terminale. Therefore, at least initially, they are extramedullary. They may also originate from the conus medullaris and, in this instance, they are primarily intramedullary. The increase in size of the tumor, which is usually benign, is slow and diagnosis is usually retarded. The clinical picture is initially characterized by pain and sensory disturbances in the lower limbs, and much later by motor deficits. Signs and symptoms may simulate a lumbar disc herniation, though this occurs less frequently than for neurinomas. This is related to the fact that the pain, even in the initial stages of the disease, usually has no dermatome distribution and the sensory disturbances, often dissociated, lead to suggest spinal cord diseases (30).

Plain radiographs often show enlargement of the spinal canal, erosion and thinning of the pedicles and scallopping of the vertebral bodies. Upon myelography, a complete block of the contrast medium is visible, showing irregular margins.

CT scans reveal an intraspinal mass with parenchymatous density, which increases dyshomogeneously after administration of contrast medium. Since the tumor usually spreads extensively in a vertical direction, sagittal and coronal reformatted images can be useful to determine the cranial and caudal limits of the mass.

MRI may allow characterization, as well as exact visualization of the limits, of the neoplasm. Ependimomas generally have the same signal intensity as the muscle tissue on the T1-weighted images; on T2-weighted images, instead, they are weakly hyperintense. After administration of gadolinium, the tumor shows a marked, though generally dyshomogeneous, enhancement (Fig. 11.4). In a recent study (60), the tumor was found, in most patients, to be located at L2 level and in no case did it extend cranially to T9.

Subarachnoid metastases

A few tumors of the central nervous system, such as medulloblastoma, ependymoma or germinoma, can metastasize to the subarachnoid space via the CSF. Less commonly, neoplasms of other organs or tissues, such as tumors of the lung or breast and melanomas, may lead to subarachnoid metastases. In these cases, CT can be diagnostic only after intravenous administration of contrast medium. With MRI, the diagnosis is

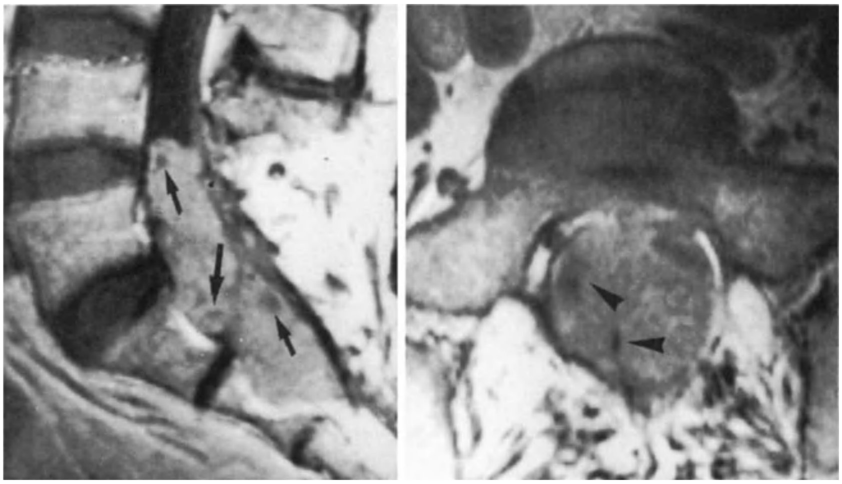


Fig. 11.4. *Lumbosacral ependymoma. Sagittal and axial T1-weighted spin-echo MR images after injection of gadolinium. A huge mass entirely fills the thecal sac from L5 to S3. The tumor shows marked enhancement after administration of gadolinium, except for small necrotic areas (arrows). The nerve roots of the cauda equina (arrowheads) appear to be absorbed in the lesion.*

Fig. 11.5. *MRI of a patient with intrathecal metastases of melanoma. Sagittal T1-weighted spin-echo image after injection of gadolinium* (A) *and sagittal turbo T2-weighted spin-echo sequence* (B). *Nodular lesions (arrow) are visible in the thecal sac, adherent to the caudal nerve roots. Metastases, located especially at the bottom of the thecal sac, are hyperintense after injection of gadolinium.*

usually easy, since it reveals nodules or masses of pathologic tissue within the thecal sac, which enhance after administration of gadolinium (Fig. 11.5).

Epidural tumors

The most common are lipomas, which are usually associated with spina bifida, and are often in continuity with subcutaneous lipomas; furthermore, these tumors often penetrate into the thecal sac (105, 114). Lymphomas, hemangiomas and sarcomas have seldom been described (131, 169). Metastatic localizations spreading into the epidural tissue without involvement of the bony structures are extremely rare. The clinical picture is that of a slow or rapid compression of the caudal nerve roots, easily simulating a herniated disc in the initial stages.

CT easily reveals lipomas, particularly those of large dimensions, due to the low density of fat tissue. In

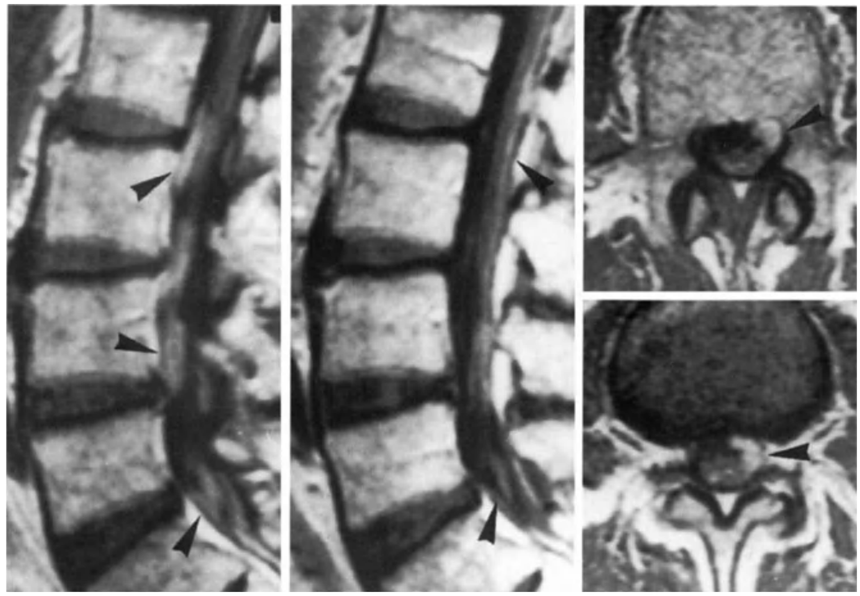


Fig. 11.6. *T1-weighted spin-echo MR images after injection of gadolinium in a patient with intrathecal metastases from lung cancer. On the sagittal images, the caudal nerve roots appear to be thickened and areas of signal hyperintensity are visible, corresponding to zones of neoplastic colonization (arrowheads). The axial images show hyperintense nodular masses within the thecal sac (arrowheads).*

lipomas with intrathecal spread, MRI allows visualization also of the intradural component of the tumor and the nerve roots coursing within the mass.

Lymphomas appear, on CT scans, as epidural lesions, generally extending along two vertebrae, showing an increased density after administration of contrast medium. On T1-weighted MR images, the pathologic tissue displays a low-signal intensity, which increases after administration of gadolinium. In epidural metastases CT, and particularly MRI, easily reveal the pathologic tissue (Fig. 11.6).

Lumbar subdural hematoma

This is a rare pathologic condition, that may have an acute or insidious clinical onset. In the former case, the hematoma may cause a cauda equina syndrome or progressive paraplegia, whilst in the latter, only neurologic deficits of multiple nerve roots can be present. Hemorrhage may occur following a trauma or a lumbar puncture, or may be spontaneous (117, 159). In both cases, the etiology can be related to coagulopathies or intradural vascular malformations.

CT rarely reveals a subdural hematoma, whereas MRI demonstrates a signal hyperintensity of the CSF on the T1-weighted images due to the presence of metahemoglobin, that has a paramagnetic activity. On T2-weighted images, instead, there are no changes in signal intensity.

Cysts

Intradural arachnoid cysts

Cysts or diverticula of the arachnoid membrane rarely develop in the subarachnoid space. They cause pain and sensory disturbances, and occasionally also motor deficits, in the lower limb. Symptoms may appear in the standing, and decrease in the recumbent, position (52, 198). Cysts of large dimensions may produce a deformation in the posterior aspect of the vertebral body (17, 175).

Extrathecal meningeal cysts and perineurial cysts

Lumbosacral radicular meningeal cysts are frequently observed and often are multiple in a single subject. They are usually of no pathologic significance and do not compress the nerve root. Occasionally, the cyst may reach a few centimeters in diameter and cause erosion of the pedicle and/or the vertebral body. In these exceedingly rare cases, the cyst may impinge, directly or indirectly, upon the nerve root or the thecal sac and require surgical treatment (11, 35). On CT scans, radicular cysts have the same density as CSF. On MR images, the signal intensity of the cyst is similar to, or greater than, that of CSF; the increased signal intensity is due to the larger quantity of proteins in the cystic liquid, particularly when communication with the subarachnoid space of the thecal sac is narrow.

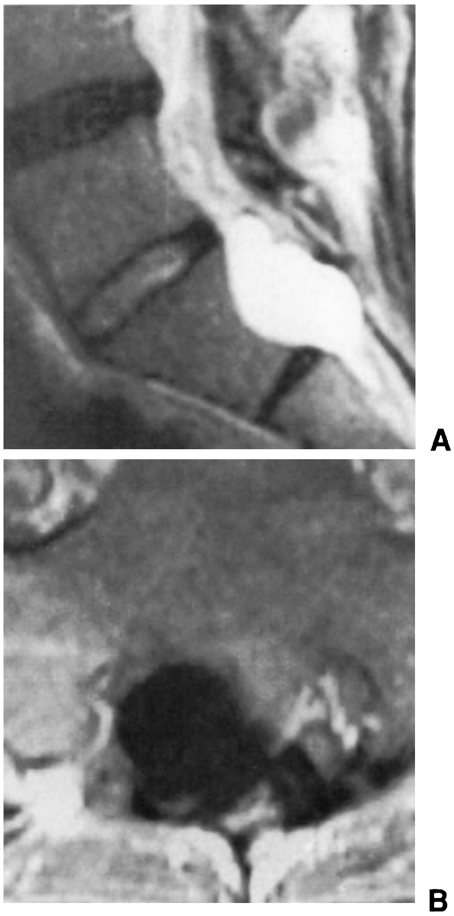


Fig. 11.7. *MRI appearance of large perineurial cyst at S2 level.* (A) *Sagittal turbo T2-weighted spin-echo image: the cyst displays a higher signal intensity than the CSF.* (B) *Axial T1-weighted spin-echo image: no nervous structures are visible within the cyst, which deforms the posterior wall of the thecal sac.*

Spontaneous meningeal cysts of the thecal sac in the lumbar region are rare and generally small in size. Less rarely, they can be observed in the site of a previous laminectomy, where the cyst presumably results from surgical injury to the dura mater. In both instances, the lesion is generally asymptomatic. Meningeal cysts of the sacral thecal sac are not particularly rare and vary considerably in size. A large cyst may stretch the extrathecal nerve roots or compress the roots against the walls of the sacrum (40); occasionally, the cyst may cause erosions of the anterolateral wall of the bone (Fig. 11.7). A cyst of small dimensions may impinge on the nerve root in the extrathecal course, particularly when it develops in close proximity to the root. The clinical features may be very difficult to distinguish from those of a disc herniation; however, an important distinctive feature is that the symptoms tend to decrease in the recumbent position. This may be due to partial emptying out of the cyst or decreased compression of the adjacent neural structures due to reduced hydrostatic pressure.

Case report

A 47-year-old female complained of pain in the lumbar and sacral regions, and the right lower limb of 8-month duration. The radicular pain was located in the buttock, the posterior aspect of the thigh and leg, and was associated with occasional paresthesias in the calf. Symptoms had appeared slowly and had gradually increased during the first few months of onset. The pain in the lower limb decreased gradually, until it disappeared, in the recumbent position, and exacerbated in the prolonged upright position and upon walking.

Physical examination revealed mild positivity of the straight leg raising test and an uncertain depression of the right ankle jerk. A lumbar disc herniation was suspected and MRI was performed, which revealed a decreased signal intensity of L4-L5 intervertebral disc on the T2-weighted images and small radicular meningeal cysts in a few right sacral roots. Physiotherapy, associated with anti-inflammatory drugs, led to an improvement of the symptoms, but only temporarily. Since the pain improved in the recumbent position, bed rest for some 20 hours a day for 2 weeks was advised. The radicular pain improved, but only for a few weeks. A myelogram was then carried out, which showed a cyst of the dural sac, located medially to the right S1 root at the level of the first sacral vertebra (Fig. 11.8). After a further unfruitful period of bed rest and medical therapy, and a psychometric test, which was normal, surgical treatment was carried out. Removal of the cyst, through resection of a limited portion of the thecal sac, led to disappearance of the radicular pain.

One should be extremely cautious in attributing lumboradicular symptoms to a sacral cyst, since even large cysts can often be observed in asymptomatic subjects. On the other hand, cases have been reported of a disc herniation and concomitant large sacral cysts, in which disc excision resolved the symptoms (14, 180).

Perineurial cysts, which are of uncertain origin and vary in structure (page 54), are analyzed together with the meningeal cysts, since they have similar characteristics to the latter. Whilst these cysts are very rare, they may cause symptoms of compression of the adjacent nerve root, which are indistinguishable from those caused by a herniated disc (44, 129, 149, 179). Perineurial cysts may occasionally reach large dimensions (172). Preoperative diagnosis can be made with CT, myelo-CT or MRI (124, 195). The latter may also show the nerve root at the periphery of the cyst and is, thus, the investigation of choice on account of the high diagnostic ability regarding the pathologic characteristics of the lesion.

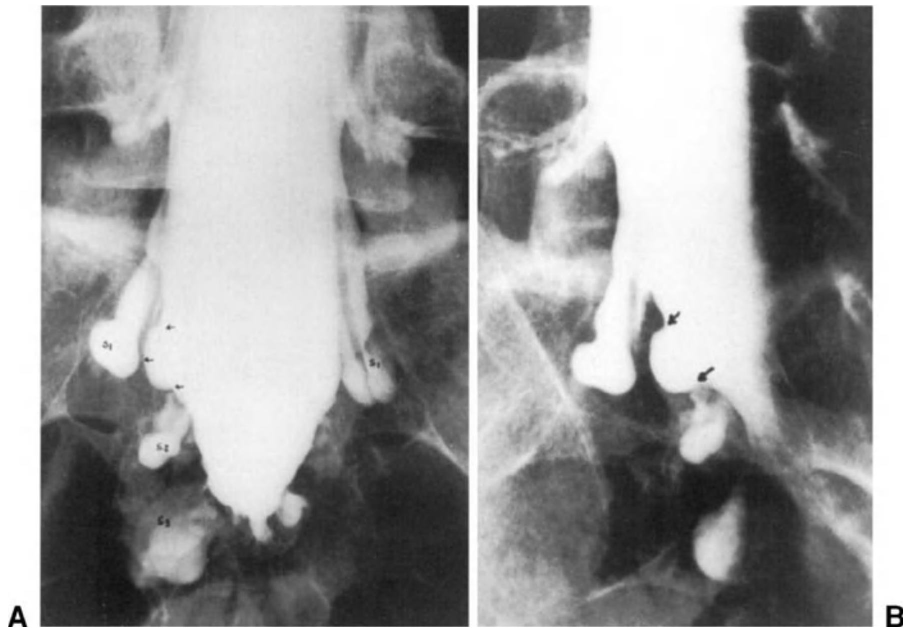


Fig. 11.8. *Meningeal cyst of the sacral thecal sac. Posteroanterior* (A) *and right oblique myelogram* (B) *obtained in moderate anti-Trendelemburg position show a cystic dilation of the wall of the thecal sac medially to the right S1 root. Both the latter and the right S2 and S3 roots show small radicular cysts.*

Arachnoiditis

This is now a rare condition, since the most common cause of arachnoiditis is myelography, which in recent years has been replaced almost completely by CT and MRI. Arachnoiditis may simulate a disc herniation particularly when the emergence of a single nerve root from the thecal sac is involved. The condition is analyzed in Chapter 22.

Cordonal sciatica

This form of sciatica is due to compression of cord columns by intrathecal or extrathecal tumors or a thoracic disc herniation, whereas only rarely is the cause a cervical cord compression (13, 24, 61, 78, 108, 166). The medullary component of the sciatic nerve has a very superficial location both in the posterior and anterolateral columns of the cord. This may explain its high vulnerability by a chronic expansive lesion and the fact that sciatica is the most common of the cordonal neuralgic syndromes. Symptoms are represented by a burning, continuous or fleeting, pain, paresthesias, coldness or electric shock sensations, disturbances of thermic sensitivity, and difficulty in the control of lower limb movements. The disturbances may have a fairly precise sciatic distribution or may also involve the anterior aspect of the limb, and may be monolateral or, more rarely, bilateral. Often the symptoms exacerbate at night. In the initial stages of cord compression, pyramidal signs may be absent or weakly positive; it is in this phase that the condition may easily mimic a lumbosacral radiculopathy. The main distinctive features are: atypical symptoms, involvement of multiple dermatomes, and negative nerve-root tension tests.

When the clinical features tend to suggest a lumbar disc herniation, but the symptoms are atypical, neurologic examination should include evaluation of pyramidal signs. If the latter are even weakly positive or uncertain, MRI studies extended also to the thoracic, or even cervical, spine should be carried out.

Non-tumoral epidural conditions

Lipomatosis

Epidural lipomatosis is characterized by the accumulation of a considerable amount of fat in the epidural space. The condition has almost consistently been observed in patients undergoing prolonged cortisone therapy. In the vast majority of the cases reported, lipomatosis involved the thoracic spine and was responsible for cord compression. In the lumbar spine, the condition is exceedingly uncommon and may be asymptomatic or cause monoradicular or multiradicular signs and symptoms (18, 29, 32, 145, 157, 177). It is possible, in these cases, that lipomatosis contributes to make a lumbar stenosis or a disc condition symptomatic.

Epidural hematoma

Epidural hematomas may cause acute or chronic neurologic syndromes. In the lumbar region, in which the condition seems to be rare, the clinical syndrome may easily be chronic, since the cauda equina bears compression better than the spinal cord and the subarachnoid space is larger than in the cervical or thoracic spine. The etiology of hemorrhage may be related to coagulopathy or anticoagulant treatments, vascular anomalies or neoplastic diseases. The condition is responsible for pain and / or multiradicular neurologic disorders, that may simulate a herniated disc or lumbar stenosis (126, 128).

Palmer et al. (134) reported on a case of sciatica subsequent to rupture of the ligamentum flavum at L4-L5 level after a physical effort; the ligament tear produced a cystic lesion probably subsequent to epidural hematoma. A similar case occurred in a basket player after a trauma during sport activity (80). CT scans revealed a laminar fracture of L5, responsible for a localized hematoma. This caused nerve root compression, which recovered spontaneously.

In contrast to the general belief, Heithtoff and Herzog (85) observed, on CT or MRI scans, a large number of spontaneous epidural hematomas in patients showing symptoms indistinguishable from those of a herniated disc. The symptoms usually disappeared within a few days or weeks and, in most cases, imaging studies performed after disappearance of the hematoma showed a small disc herniation or a cleft in the annulus fibrosus. The authors believe that the hematoma may result from tearing of epidural veins as a result of annular injuries or torsional instability. On CT scans, the hematoma appears as a retrosomatic extradural mass showing indistinct margins, density being only slightly more intense than that of the thecal sac; after intravenous administration of contrast medium, the density of the mass does not increase, unlike in the neoplastic tissue. On MRI, the lesion has the typical features of blood, i.e., increase in signal intensity on T1-weighted images and decreased or increased signal intensity on T2-weighted images, depending upon the concentration of hemosiderin and metahemoglobin and, thus, on the duration of the lesion.

Gas containing cysts

With the exception of synovial cysts of the posterior joint, gas collections can very rarely be observed in the vertebral canal, surrounded by a fibrous sheath. There are very few reports of this condition (23, 46, 56, 67, 79, 103, 110, 148), the gas being generally located in proximity to discs showing a vacuum phenomenon. Presumably the gas usually comes from within the disc through annular clefts. The gas bubble, located ventrally or ventrolaterally in the spinal canal, may impinge on the thecal sac and / or the emerging nerve root and cause similar symptoms to those of a disc herniation. CT easily shows the gas collection, whereas MRI seems to be unable to reveal it (56).

Epidural abscess

Epidural abscess caused by common bacteria may result from a spondylitis or discitis or be a primary condition. The latter, which is fairly uncommon, may originate from an infectious focus located at a distance from the spine, such as a dental abscess, a decubitus ulcer or urinary infection, but, in most cases, the origin is unknown (77). Sometimes, it is unclear whether the site of the primary infection is in the epidural space or in the vertebral structures, when the latter are invaded by the abscess. The course of the disease may be of a few days to several months (53). Predisposing factors are represented by diabetes and debilitating diseases. Usually, the initial symptoms are low back pain and decreased lumbar motion, to which monoradicular or multiradicular neurologic symptoms may later be associated. In the forms with an acute onset, there may often be high fever, involvement of general conditions and ingravescent neurologic deficits. When the clinical syndrome has an insidious onset, the condition may lead to the suspicion of a disc herniation or a tumor. Plain radiographs (when the bone structures are involved), CT and particularly MRI allow diagnosis to be made, whereas ESR, CRP and the leucocyte count may be normal in chronic cases.

Tuberculous abscesses or granulomas have a chronic course and can easily simulate a disc herniation when bone lesions are absent or very mild (9, 100, 139). Brucellar abscess or granuloma is exceedingly rare in the absence of concomitant vertebral involvement.

Hydatidosis

Echinococcus cysts usually involve primarily the vertebra. A primary epidural localization, which can be more difficult to diagnose than bone involvement, is very uncommon, but may cause a monoradicular or multiradicular syndrome easily mimicking a disc herniation radiculopathy (66).

Primary epidural adhesions

Revel et al. (147) reported on eight cases of epidural adhesions in previously non-operated patients. The patients had radicular syndromes suggesting a lumbar disc herniation, but neither myelograms nor CT scans revealed a herniated disc. These investigations and epidurography showed an atrophy of the epidural fat and suggested the presence of adhesions at the level of the involved roots. The patients were not submitted to surgery.

Varicosities

During operations for a herniated disc, dilated epidural veins, particularly those of the anterointernal plexus, are frequently observed, but only occasionally has the dilation the appearance of a true varicosity. Epidural varicosities have often been described and involved, in the past, in the etiology of lumbar radiculopathies (69, 197). This has occurred especially when the diagnosis was made essentially on clinical grounds and negative surgical explorations for disc herniations could easily lead to attributing an etiologic role to any abnormal intraspinal condition.

The so-called epidural varicosities are dilations of the epidural veins due to venous entrapment by a disc herniation or spinal stenosis and/or to abdominal compression related to the surgical position. In our experience, epidural varicosities play no role in the etiology of lumbar radicular symptoms and probably exist only in the presence of additional pathologic conditions.

Lumbar stenosis

The typical clinical features of lumbar stenosis are represented by mild low back pain, multiradicular pain in one or both legs, sensory disturbances in one or multiple dermatomes, intermittent claudication caused by asthenia, pain and/or hypoesthesia, and mild monoradicular or multiradicular motor deficits. In effect, this condition may cause very variable clinical syndromes, ranging from those characterized only by paresthesias on walking to syndromes dominated by acute monoradicular pain both at rest and on walking, or even only at rest. On the other hand, also a disc herniation may be responsible for very variable syndromes, including intermittent claudication. Based only on clinical signs and symptoms, therefore, it is usually easy to suspect one condition or the other, but it may be impossible to differentiate between disc herniation and spinal stenosis with certainty. This holds particularly for isolated nerve-root canal stenosis, that more easily causes similar clinical syndromes to those of a herniated disc. Furthermore, it should be taken into consideration that the two pathologic conditions may be associated and a single patient may present with the typical symptoms of both conditions

Similar considerations are valid for the radiographic features. The presence of severe arthrotic changes of the lumbar spine or degenerative spondylolisthesis are known to often be associated with stenosis, but it is also well known that no radiographic change allows the diagnosis of stenosis to be made with certainty.

Differential diagnosis between disc herniation and stenosis can be made only by means of neuroradiologic investigations.

Synovial cysts of facet joint

These cysts, almost unknown before the advent of CT and MRI, have frequently been described in the last decade (54, 89, 91, 101, 104, 107, 111). A prevalence of 0.5% has been reported in a series of 2000 spinal CTs (107). Histologically, a distinction has been made between synovial cysts and ganglions: the former, unlike the latter, have a synovial sheath and communicate with the joint. The so-called cysts of the ligamentum flavum (8, 187) may be included among the ganglions. The cysts usually originate from arthrotic joints and are, thus, frequently found in patients with degenerative stenosis, particularly those with degenerative spondylolisthesis. Ganglions are also usually observed in the presence of zygoapophyseal arthrotic changes. The most common site is the L4-L5 level and the cysts arise most frequently at the medial margin of the joint. They may have a calcified wall and a serous or jelly-like (ganglions) content, or may contain gas, particularly in the presence of vacuum phenomenon in the facet joint (15, 57, 107, 168).

The cyst can be asymptomatic or impinge on the thecal sac and/or the emerging nerve root. In this case, the clinical syndrome is generally indistinguishable from that caused by lumbar stenosis or disc herniation, which is occasionally associated with the cyst (163).

Case report

A 43-year-old female with a spastic paraparesis since childhood began to complain of radicular pain down the left lower limb in the L5 and S1 dermatomes. The pain appeared or exacerbated in the prolonged upright or sitting position and on walking.

After prolonged medical and physical therapy with no improvement in the symptoms, CT of the lumbar spine was carried out. An L5-S1 disc excision by conventional surgery was performed by a neurosurgeon, who reported finding a small contained herniation. Following surgery, the radicular symptoms remained unchanged and the patient was referred

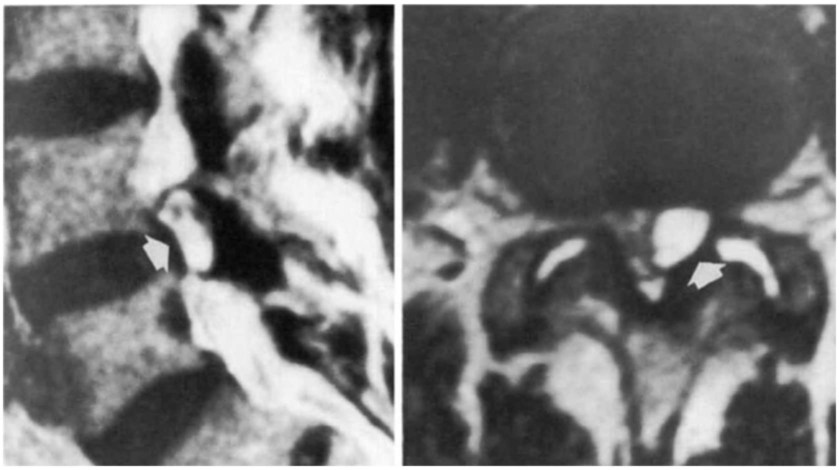


Fig. 11.9. *Turbo T2-weighted spin-echo MR images showing a synovial cyst of the left L4-L5 facet joint. An extrathecal lesion with a high signal intensity is visible (arrows), which is in contact with the anteromedial margin of the left facet joint and impinges on the thecal sac. Both zygoapophyseal joints show degenerative changes.*

to us 3 months later. Examination of the preoperative CT scans, which were of fairly low resolution, showed an L5-S1 disc protrusion, but also led to suspect the presence of a synovial cyst of the posterior joint at the same level and side as the herniation. MRI confirmed the presence of the cyst, impinging on the thecal sac and the L5 nerve root in the intervertebral foramen. Surgical excision of the cyst and the anteromedial portion of the zygoapophyseal joint, which was severely arthrotic, completely relieved the radicular symptoms.

Diagnosis can easily be made by CT or MRI, whereas myelography is aspecific, since it shows only a posterolateral compression of the thecal sac. On CT scans, the cyst appears as a roundish lesion, with a hyperdense wall with respect to the thecal sac. The lesion is located anteromedially to the facet joint, which consistently shows degenerative changes of varying severity. On MR images, synovial cysts have a characteristic appearance as far as concerns both the site and the flat base, which is in contact with the facet joint (111, 154). The signal intensity depends on the density of the fluid filling the cyst. The content is generally serous and the signal intensity is low on T1-weighted, and high on T2-weighted, images. (Fig. 11.9). The content may occasionally be hematic due to intracystic hemorrhage (91); in this instance, the cyst shows a high signal intensity also on T1-weighted images due to the presence of products of blood degradation.

Vertebral tumors

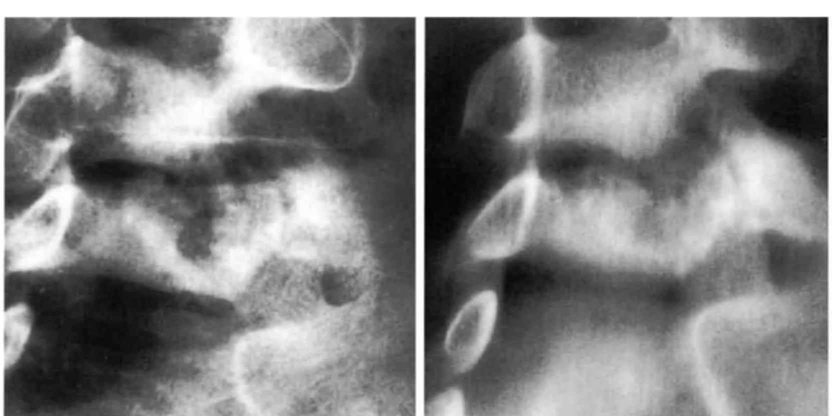
Benign primary tumors

The tumors most commonly encountered are hemangioma, osteoid osteoma and osteoblastoma, followed by osteochondroma, aneurysmatic bone cyst, giant cell tumor and eosinophilic granuloma.

Hemangiomas of the vertebral body are found in about 10% of subjects (190), however only exceedingly rarely do they deform the vertebral body and impinge on the neural structures.

Osteoid osteoma and osteoblastoma are very similar osteoblastic tumors, often occurring in the spine, mostly in the components of the posterior vertebral arch

A



B

Fig. 11.10. *Tomograms showing an osteoblastoma located in the right pars interarticularis and lamina of the L5 vertebra. The osteolytic lesion presents irregular margins and is surrounded by slightly sclerotic bone.*

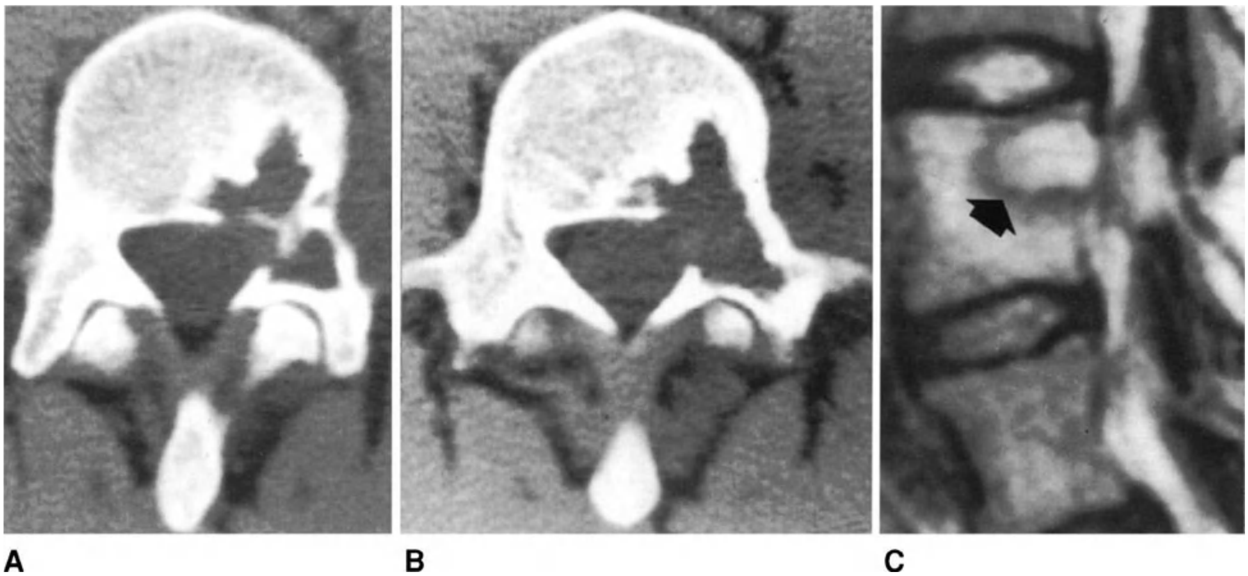


Fig. 11.11. *Eosinophilic granuloma in the vertebral body and left pedicle of L4. CT scans* (A) *and* (B) *show an osteolytic area interrupting the cortical bone delimiting the spinal canal anterolaterally. In the vertebral body, the lesion is surrounded by a rim of sclerotic bone. On the turbo T2-weighted image* (C), *the lesion appears hyperintense and encircled by a rim of low signal intensity resulting from bone sclerosis (arrow). The remainder of the vertebral body is hyperintense due to edema of the trabecular bone.*

(Fig. 11.10). These tumors may simulate a lumbar disc herniation when compressing one or, rarely, multiple nerve roots. This easily occurs when the lesion is located in the pedicle or the articular processes. A mistaken diagnosis of herniation is even easier in adolescents, in whom the tumor often gives rise to scoliosis, which can be interpreted as an antalgic scoliosis resulting from a herniation (116, 137). Differential diagnosis may be difficult particularly for osteoid osteoma, which may not be readily visible on plain radiographs due to its small size (75); this holds especially in the absence of the characteristic nocturnal exacerbation of pain and in the presence of neurologic radicular deficits. Bone scanning is consistently positive in these two pathologic conditions. CT and MRI may not demonstrate the tumor – particularly osteoid osteoma – if the investigation is not directed to disclose the lesion. Negative CT or MRI findings, therefore, do not exclude the presence of these lesions. In both tumors, there is an osteolytic zone surrounded by a sclerotic rim. In osteoblastoma, the osteolysis is larger, and the sclerotic rim thinner, than in osteoid osteoma; furthermore, in osteoblastoma MRI shows a marked inflammatory reaction of the surrounding soft tissues, which are hyperintense on the T2-weighted images (41).

Osteochondroma is very rarely found in the lumbar spine, but it can readily simulate a disc herniation (115, 185); the two conditions may also be associated (109). Aneurysmatic bone cysts, which are very uncommon in the spine, are usually located in the posterior arch of the lumbar vertebrae and may easily cause radicular signs and symptoms. Giant cell tumors are uncommon, locally aggressive, lesions that can be responsible for radicular pain and neurologic deficits (162). Eosinophilic granuloma usually develops in the vertebral body and occasionally spreads to the pedicle; the tumor may mimic the clinical features of a herniated disc when it erodes the cortical bone and encroaches upon the spinal canal (Fig. 11.11).

Primary malignant tumors

All primary malignant tumors of the lumbar spine – solitary and multiple myeloma, chordoma, osteosarcoma, chondrosarcoma, Ewing's and Paget's sarcomas – may give rise to clinical syndromes mimicking those of a lumbar disc herniation. However, chordoma is the tumor that can most often lead to making a diagnosis of disc herniation. Chordoma originates from residues of notochordal tissue in the sacrococcygeal region or the body of the lumbar vertebrae. It grows slowly and, when originating in the sacrococcygeal area, may give rise to sciatic symptoms resulting from compression of the sacral nerve roots, before eroding the sacrum and becoming visible on plain radiographs. When arising in the body of lumbar vertebrae, the tumor has to encroach upon the vertebral canal to cause radicular symptoms. In some one fifth of cases, the initial clinical presentation is paraparesis (22). On CT scans, the

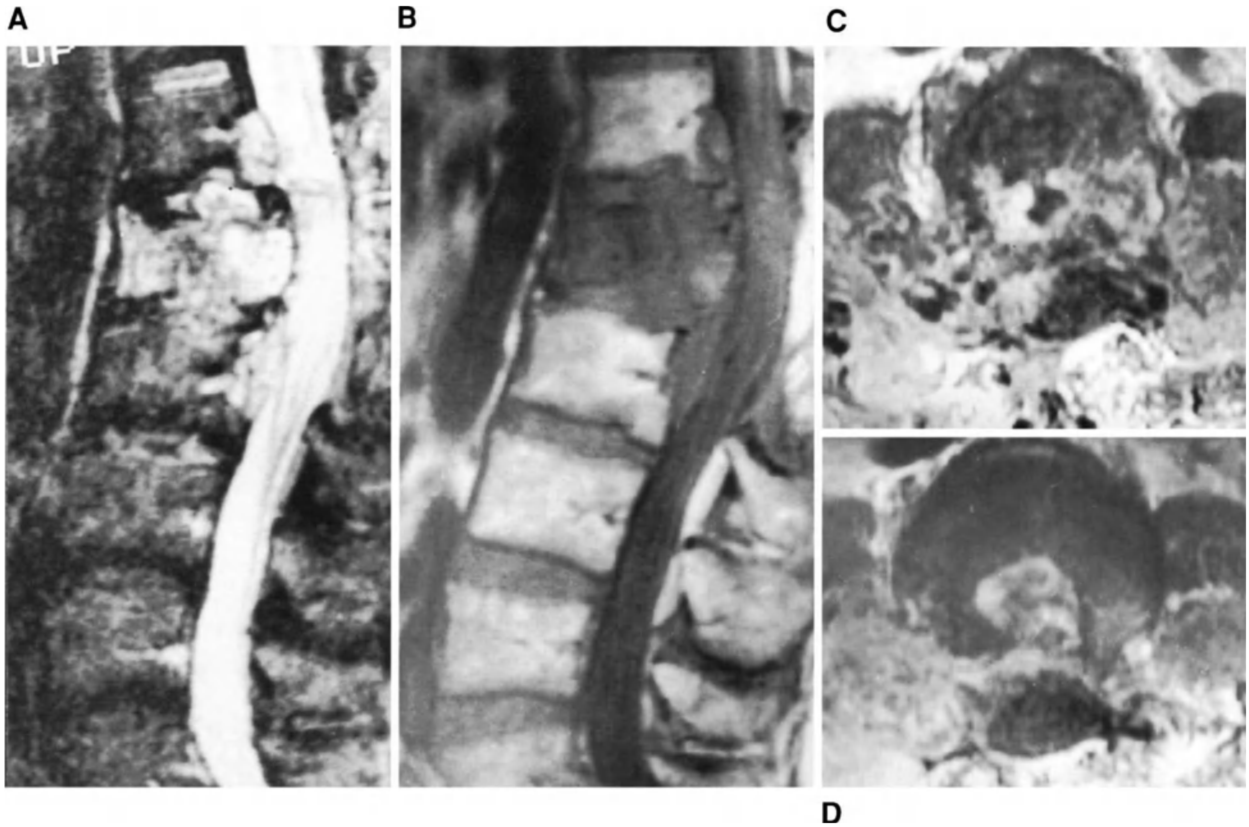


Fig. 11.12. *MR images showing a L2 chordoma.* (A) *Sagittal T2-weighted spin-echo image.* (B) *T1-weighted spin-echo image.* (C) *and* (D) *Axial T1-weighted spin-echo postgadolinium images. Large lesion, markedly hyperintense on the T2-weighted image, destroying the vertebral body. The thecal sac is compressed by the neoplasm, which invades extensively the anterior epidural space.*

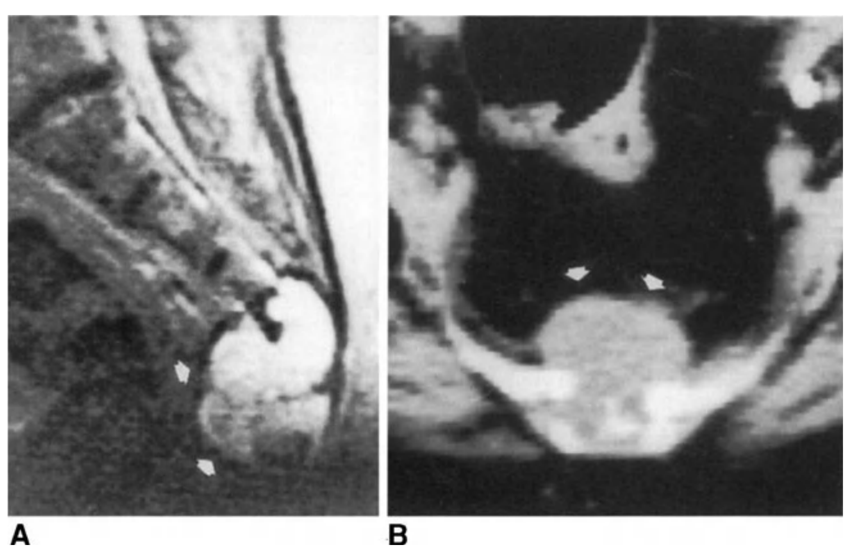


Fig. 11.13. *Chordoma in the sacrococcygeal region. The T2-weighted spin-echo MR image* (A) *shows a highly hyperintense lobulated lesion (arrows). On CT scan* (B)*, a mass with parenchymatous density (arrows) is visible, which has eroded the anterior cortical bone of the sacrum.*

neoplasm displays a uniform density, similar to that of muscle; after intravenous administration of contrast medium, a marked, however dyshomogeneous, increase in density is observed, dyshomogeneity being due to necrotic areas within the tumor. On MR images, chordoma displays a low signal intensity on T1-weighted, and a marked hypersignal on T2-weighted, images, the appearance being lobulated. After injection of gadolinium, there is a marked, but dyshomogeneous, enhancement (Fig. 11.12). Sacrococcygeal chordoma

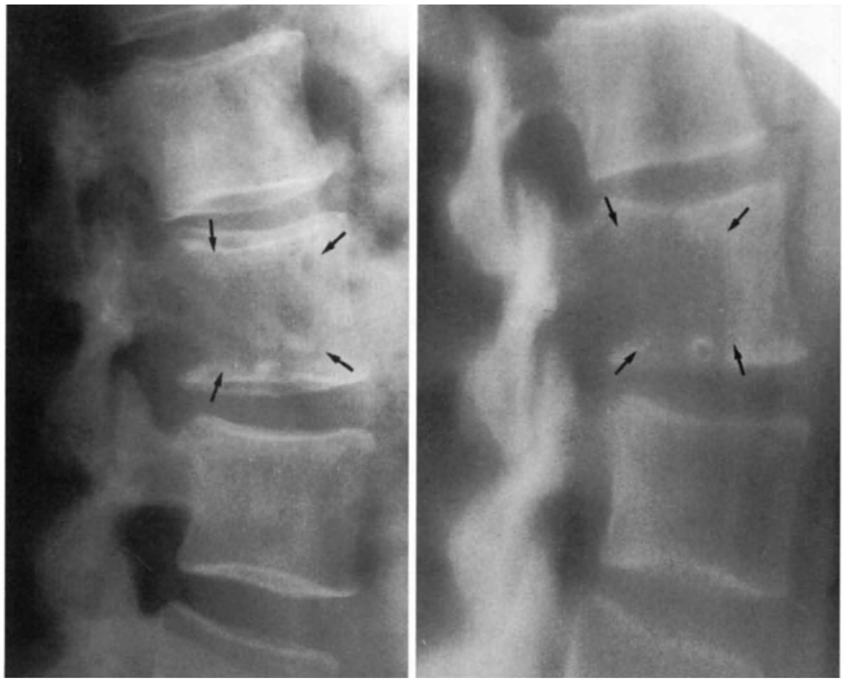


Fig. 11.14. *Metastasis of breast carcinoma in the L3 vertebra. The radiograph* (A) *shows an osteolytic lesion of the vertebral body (arrows), presenting a defect in the posterior cortical bone. The lesion is clearly visible on the tomogram* (B).

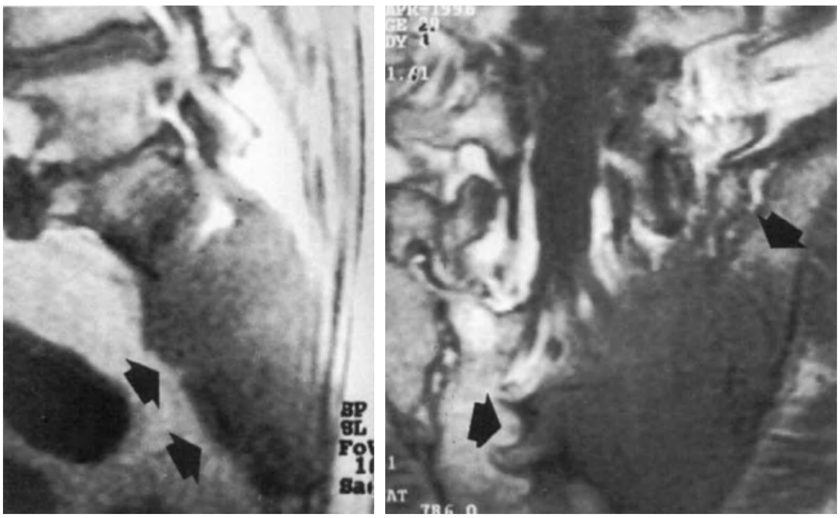
grows towards the pelvis and, at the time of diagnosis, is generally large in size (155, 192) (Fig. 11.13).

Metastatic tumors

In the skeleton, metastases are by far more common than primary tumors. This holds especially for the spine: of 1971 patients with neoplasms, only 1.5% had a primary tumor in the thoracolumbar spine (45). The tumors most often metastasizing to the spine are breast and lung cancer, followed, in most series, by prostate and kidney cancer, and lymphatic tumors (19, 50, 62, 65, 83, 136, 165, 194). The prevalence of metastases increases with advancing age, particularly after 50 years. The lesion is generally located in the vertebral body. An autopsy study showed that 36% of subjects dying as the result of a tumor had vertebral metastases and in 26% these were not visible on plain radiographs (194).

The initial symptom of lumbosacral spinal metastasis is almost consistently vertebral pain, but many patients with metastases have no back pain. The latter, when present, is usually insidious in onset, tends to increase with time and is often characterized by exacerbation at night. Symptoms in the lower limbs appear when the tumor deforms the vertebral body or the pedicle and narrows the spinal canal or the intervertebral foramen, or when it erodes the cortical bone and invades the epidural space. In a few cases, lumboradicular symptoms become apparent following a pathologic fracture. Pain may be associated with neurologic deficits, but these are often mild or absent, at least in the initial stages of the radicular syndrome. The clinical features may be indistinguishable from those of a herniated disc, but a few elements may lead to the suspicion of a different pathologic condition: age over 50 years, marked severity of pain, multiradicular distribution of symptoms, mildness or absense of neurologic deficits, poor general conditions, and a previous history of neoplastic disease. Metastatic lesions of the L1 vertebra can impinge on the conus medullaris and produce a cauda equina syndrome of acute onset, with rapid deterioration of the neurologic status, as often occurs in cervicothoracic metastases (36).

In the presence of a lumboradicular syndrome, radiographs usually show at least one bone lesion, generally osteolytic in nature (Fig. 11.14). In the initial stages of metastatic invasion, however, radiographs may be negative; in fact, for the lesion to be radiographically evident, destruction of bone trabeculae has to reach 30%–40%. Three investigations are indicated in these cases: bone scanning, which, however, has the drawback of being aspecific; CT, that has a high diagnostic ability (188), since it demonstrates the lesion when the latter has destroyed only 10%–15% of the bone trabeculae, but may not provide evidence of a discrete encroachment on the epidural space; and MRI. This is the investigation with the highest diagnostic ability, since it can reveal the tumor before destruction of bone structure, i.e., in the stage of inva-



A B

Fig. 11.15. *Sagittal* (A) *and coronal* (B) *T1-weighted spin-echo MR images showing a voluminous lesion with low signal intensity, located in the left half of the sacrum and extending to the adjacent portion of the ilium. The low signal intensity and the widespread bone destruction indicate a metastatic lesion.*

sion of bone marrow; furthermore, MRI may show compression of the neural structures better than CT and allows the whole spine to be visualized.

Case report

A 64-year-old male had been complaining of pain in the left lower limb for 4 months. Pain was located in the posterior aspect of the thigh and leg, and was not affected by walking or rest. No low back pain was present; pain in the lower limb had considerably exacerbated in the last month, in spite of antalgic and anti-inflammatory drugs. No radiographs of the lumbosacral spine had been obtained. CT scan performed a few weeks earlier showed moderate spinal stenosis at L4-L5 level and an intraforaminal protrusion of the L3-L4 disc on the left. Upon physical examination, a mild positivity of the SLRT was found, as well as absence of the ankle jerk on both sides and mild weakness of the triceps surae on the left. Radiographs of the lumbar spine revealed an uncertain osteolytic lesion of the left sacral ala. The latter was not visible on the CT scans, since the lowermost scan had been obtained at the level of the caudal border of the L5-S1 disc. MRI showed a massive invasion of neoplastic tissue in the left half of the sacrum (Fig. 11.15), but no other spine lesions. Total body CT demonstrated a lung cancer.

On MRI, metastatic lesions appear as areas of low signal intensity on T1-weighted images due to replacement of bone marrow, rich in fat, with pathologic tissue. Occasionally, MRI shows metastatic invasion before bone scanning becomes positive.

In patients with a clinical history of primary extravertebral tumor, a lumboradicular syndrome should lead us to suspect a metastatic lesion. This, however, may coexist with a disc herniation, in which case it is the herniation that may simulate the neoplasm (71).

Extravertebral diseases

Abdominopelvic organs and retroperitoneum

Tumors of various pelvic organs – ovaries, uterus, colon, rectum – may swarm upon the retroperitoneal space and infiltrate the lumbar or sacral plexus, or the spine itself, and give rise to lumboradicular syndromes simulating radiculopathy. In these cases, however, there is seldom a problem of differential diagnosis with a herniated disc, since usually visceral disturbances coexist, and pain is dull, nocturnal, independent of physical activity and multiradicular in distribution.

An abscess in the pelvic organs may invade the retroperitoneal space and irritate or encroach upon the nervous plexuses or the sciatic nerve and give rise to radicular symptoms (5).

Neoplasms in the retroperitoneal space, such as lymphomas or sarcomas, may infiltrate the neural structures and the spine, causing lumboradicular syndromes (120). The same holds for masses of extramedullary hemopoietic tissue located in front of the lumbar spine or the sacrum (73). These pathologic conditions, once of difficult diagnosis, are now easily demonstrated with CT or MRI.

Vessels

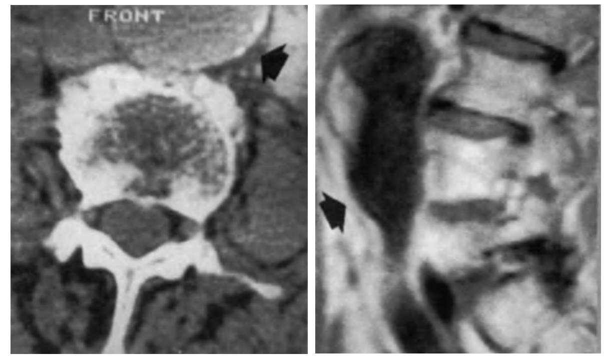
It is well known that an aneurysm of the abdominal aorta may manifest with low back pain, associated or not with abdominal pain. There is seldom pain also in the lower limb. In a series of 51 patients with aneurysmatic rupture, six complained of abdominal pain radiating to the thigh (10). However, in two large series, including 951 patients with aneurysms of the abdominal vessels, no cases of radiation of pain to the lower limb were found (43, 59). Exceptionally, an aneurysm of the aorta or iliac arteries causes pain in the lower limb only of the cruralgic or sciatic type (6, 20, 81, 161, 184).

Case report

A 72-year-old female had been complaining, for 6 months, of continuous low back pain, which had increased in severity and become associated with right thigh pain, over the last few weeks. The patient had not previously experienced low back pain. Leg pain was mild and mainly located in the groin. Radiographs of the lumbar spine, carried out after the onset of symptoms, had shown a mild decrease in height of the three lower lumbar discs. Physical examination revealed a mild positivity of the femoral nerve stretch test on the right, but no neurologic defcits. CT scan from L2-L3 to L5-S1 was obtained, which showed a mild bulging of the annulus fibrosus at L4-L5 level. A marked dilation of the abdominal aorta, suggesting an aneurysm, was incidentally observed, and later demonstrated by MRI (Fig. 11.16). Retrospective analysis of the radiographs of the lumbar spine indicated that the aneurysm could easily be suspected from the calcifications in the aortic wall, demonstrating ectasia of the vessel. Surgical treatment of the aortic aneurysm resolved the lumboradicular symptoms.

A few patients also present with muscle weakness or even a paraplegia (156). Pain and neurologic deficits may become apparent before or after rupture of the aneurysm. The disturbances in the lower limbs can be caused by an irritation of the periavventitial nervous branches, hemorrhage in the iliopsoas muscle or compression of the lumbosacral plexus. This latter pathogenetic mechanism may be involved in particular in the aneurysms of the common, or internal, iliac arteries (68, 191), running in close proximity to the lumbosacral plexus. However, in the rare aneurysms of the internal iliac artery, an important role may be played by ischemia of the nervous trunks, which are supplied by branches of this artery.

In patients with an aneurysm of the abdominal or pelvic vessels, the disturbances in the lower limbs do not show any features allowing them to be distinguished from the symptoms caused by a lumbar disc herniation. An aneurysm of the aorta or common iliac arteries should be suspected, in a middle-aged or elderly patient, in the presence of a pulsatile abdominal mass, occasionally associated with arterial bruit, particularly in the presence of abdominal pain and/or absence of peripheral pulses. An aneurysm of the



A B

Fig. 11.16. *Aneurysm of the abdominal aorta responsible for a cruralgic syndrome. CT* (A) *performed for suspected lumbar disc herniation shows marked dilation of the abdominal aorta (arrow). The sagittal MR image* (B) *clearly demonstrates the aneurysm (arrow).*

hypogastric artery may cause urinary tract and rectal disorders, as well as lower limb edema; on rectal or vaginal exploration, a pulsatile mass can be felt. Rupture of the aneurysm produces hypovolemic shock and a drop in hematocrit values, frequent abdominal pain with ileum, alterations of the peripheral pulses and other visceral disorders related to the site of the aneurysm. In those rare cases in which pain and neurologic symptoms in the lower limbs preceed the circulatory and visceral symptoms, rupture of the aneurysm may simulate a lumbar disc herniation.

Plain radiographs can lead to the suspicion of an aneurysm due to the position of the calcification in the vessel wall or in the presence of anterolateral erosion of the body of a lumbar vertebra. Diagnosis can be made by CT or MRI, showing the vessel dilation, or by arteriography.

Aneurysms of the superior (141) or inferior (151) gluteal artery may impinge on the sciatic nerve leading to pain and neurologic deficits in the lower limb. In most cases, these are pseudoaneurysms, caused by open injuries or traumas to the gluteal region. When the cause is a contusive trauma, symptoms can appear even after a few years, during which the gluteal mass slowly increases in size. Clinical diagnosis is easily suspected when a pulsatile mass is palpated in the gluteal region.

Nerves

Lumbar and sacral plexuses

The nervous trunks of the lumbar and sacral plexuses are rarely the site of neurinomas, which can easily simulate a radiculopathy due to disc herniation (94).

Diagnosis may be very difficult, particularly when the tumor is small in size.

The plexuses, besides being directly infiltrated by abdominopelvic or retroperitoneal tumors, can be compressed by lymph node metastases originating from tumors of the pelvic organs, such as uterus, prostate, bladder or rectum (120). The clinical picture is characterized by constant pain in the hip or posterolateral aspect of the thigh, with possible wasting of the glutei and thigh muscles.

Sciatic nerve

Piriformis syndrome

This syndrome is due to entrapment of the sciatic nerve, at the level of the sciatic notch, by the piriformis muscle. The nerve, in normal conditions, leaves the pelvis below the muscle, but in a minority of subjects it passes through the musculotendinous portion of the piriformis (135). The latter or other anomalies – course of the nerve anteriorly to the muscle (2, 164), fibrous bands (164, 186), perineural hypertrophic venous plexus (2) – may represent predisposing conditions to compression of the nerve by the muscle, if this is fibrotic or inflamed.

Robinson (152) described six clinical characteristics of this syndrome: 1) history of trauma to the buttock; 2) pain in the region of the sciatic notch, with radiation to the lower limb; 3) exacerbation of pain in lifting weights or trunk flexion; 4) palpation of a fusiform mass, painful on pressure, in the area of the piriformis muscle; 5) positivity of the straight leg raising test; 6) wasting of glutei muscles in long-standing cases. Pain may be elicited or aggravated by resisted abduction-external rotation of the thigh (Pace and Freiberg's maneuver) (133), forced internal rotation of the extended thigh (Freiberg's maneuver) (63) and active abduction-external rotation of the thigh in the patient lying on lateral decubitus on the asymptomatic side (Beatty's maneuver) (16). Electrodiagnostic investigations are usually negative. Occasionally, injection of local anesthetic in the area of the piriformis muscle may lead to temporary disappearance of pain, thus being of diagnostic value.

Diagnosis of this syndrome is based on clinical data and is made by exclusion, when investigations show no other lumbar or pelvic pathologic conditions. In the reported cases, the most constant, and very often the only, clinical element was pain upon pressure in the region of the sciatic notch, with radiation along the lower limb. Since this clinical sign is highly aspecific, one should be extremely cautious not only in making the diagnosis, but also in establishing the indication for surgical treatment, of a piriformis muscle syndrome.

Hamstring syndrome

This syndrome, first described by Puranen and Orava (143), is characterized by pain in the area of the ischial tuberosity, radiating down the posterior aspect of the thigh. Pain is typically felt on stretching of the posterior thigh muscles while running or exercising and, often, even in the sitting position. The syndrome has generally been observed in athletes, particularly sprinters, and rarely in non-athletes. It would result from entrapment of the sciatic nerve laterally to the ischial tuberosity by tendinous fibrotic bands situated along the muscle belly of the biceps femoris, in proximity to the bone insertion. Diagnosis is entirely clinical. The main differential diagnosis is with the piriformis muscle syndrome, in which the pain is felt more proximally and the maneuvers of Pace and Freiberg are often positive, unlike in the syndrome described by Puranen and Orava. These authors operated on 59 patients with hamstring syndrome, but few reports have since appeared in support of their observations.

Tumors

Few cases of neurinoma (neurilemmoma or schwannoma) of the sciatic nerve have been described (42, 48, 55, 88, 99, 123, 142, 182). In only one case was the tumor located in the short intrapelvic portion of the nerve, in proximity to the greater ischiatic foramen (99). Symptoms consisted, in all cases, of pain and paresthesias in the lower limb, but only in a few patients were there neurologic deficits, similar to those produced by a disc herniation responsible for compression of one or two (L5 and S1) nerve roots. When the tumor occurs in the thigh and is fairly large, a mass can be palpated along the course of the sciatic nerve; pressure on the mass usually elicits pain and paresthesias radiating distally. Tumors located in the most proximal portion of the nerve may easily be mistaken for a pyriformis syndrome or a neoplastic compression of the nerve or the lumbosacral plexus. Diagnosis may be made with CT or MRI (Fig. 11.17). EMG studies may be helpful for tumors occurring in the thigh.

Desmoid tumors are benign neoplasms, fibroblastic in nature, highly invasive and tending to recur. When occurring in the gluteal region or the posterior aspect of the thigh, these tumors may impinge or encroach on the sciatic nerve and cause symptoms, which, at least initially, can simulate a lumbar disc herniation (26, 119). Diagnosis is made, often in the advanced stages of the disease, with CT or MRI.

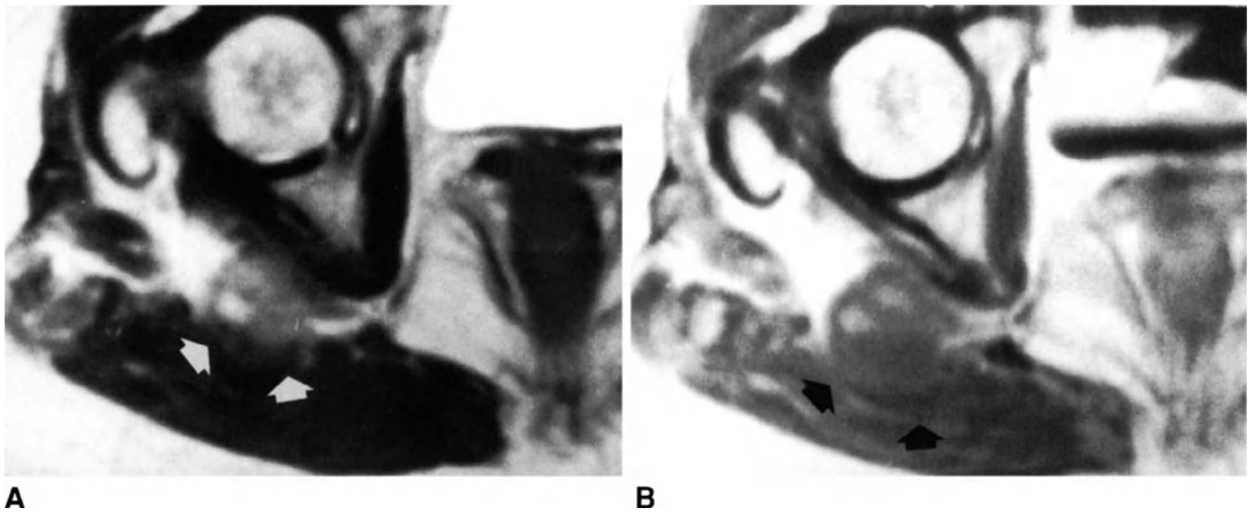


Fig. 11.17. *Neurinoma of the right sciatic nerve. Axial turbo T2-weighted spin-echo MR image* (A) *and axial T1-weighted spin-echo image after injection of gadolinium* (B). *Between the gluteus maximus and internal obturator muscles, a mass is visible, which is weakly hyperintense on both images (arrows). Histologic examination of the excised tumor revealed a neurinoma.*

Endometriosis

This condition consists in the presence of ectopic islets of growing and functioning, hormone-dependent, endometrial tissue. Endometriosis is a fairly common gynecologic disease, but the formation of an endometrioma in close proximity to, or within, a nerve is exceedingly rare. Some 20 cases of histologically proven endometriosis of the sciatic nerve have been reported (7, 47, 47a, 49, 84, 86, 150, 178, 183). Generally, endometriosis is located in the pelvis, at the level of, or proximally to, the sciatic notch. Symptoms are typical, since sciatic pain appears just before the menstrual cycle and prolongs for a few days after the end of the flow. With time, the free interval tends to become progressively shorter and, occasionlly, the pain becomes constant. The right side is almost consistently involved, probably because the sigmoid colon hinders implantation of the endometrioma on the left. The clinical features are similar to those of an irritative or, more often, compressive syndrome of the L5 and/or S1 roots. Diagnosis can be made with CT or MRI of the pelvis, showing an intra- or perineural mass with a cystic or solid texture. In some cases, EMG would demonstrate the typical changes of the peripheral nerve, rather than the nerve root, involvement (7, 84).

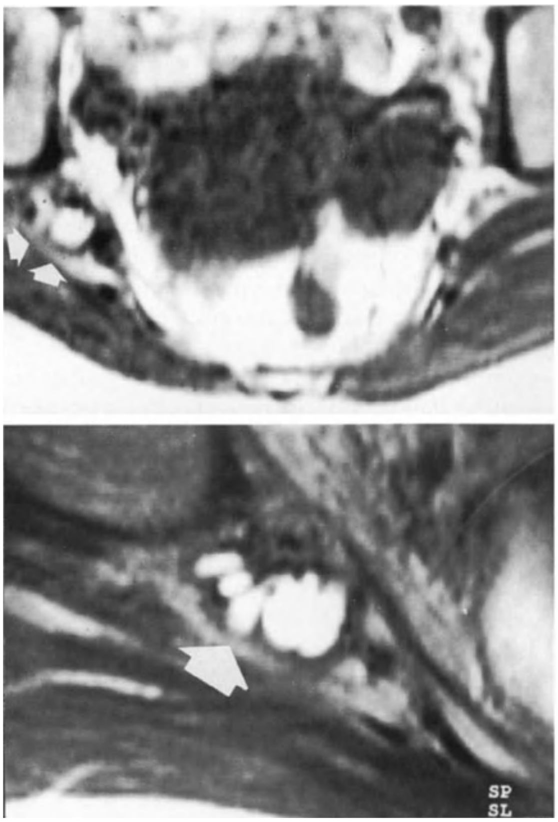
Case report

A 28-year-old female had been complaining of pain in the buttock and along the posterior aspect of the right thigh and leg for 1 year. The radiated pain, which was not associated with back discomfort, was constant, but exacerbated considerably during the menstrual cycle. Upon physical exmination in the intermenstrual period, straight leg raising was limited to 60°, and pain was felt upon pressure to the gluteal region and the posterior aspect of the thigh, and a moderate depression was observed of the ankle jerk, on the right side. MRI of the lumbar spine was normal. Since the pain was more severe during the menstrual period, MRI of the pelvic region was performed, which revealed a mass about 2 cm in diameter with the features of endometriosis, in the right sciatic notch (Fig. 11.18). The patient preferred to undergo hormonal suppression of the menstrual cycle, which led to disappearance of the pain after 2 months of treatment. Endometriosis will be excised surgically if the pain will recur after 6 months of treatment.

Other causes of compression

Very few reports have appeared in the literature concerning compression of the sciatic nerve by ectopic bone (64, 95, 96, 102, 146, 181). In all cases, the metaplastic bone had appeared following trauma – pelvic fracture or fracture-disclocation of the hip, or open or closed trauma to soft tissues – and symptoms of entrapment of the sciatic nerve had commenced months or years after the trauma. In three cases, the nerve was surrounded by a bone sheath of varying length; in two of them, sciatic signs and symptoms had appeared following fracture of the bone sheath (96, 181).

Very occasionally, sciatic nerve compression may be caused by a fracture-avulsion of the ischial tuberosity, initially unrecognized (121), migration of greater trochanteric osteotomy wire following hip prosthesis



A

B

Fig. 11.18. *Endometriosis of the sciatic nerve.* (A) *Axial T2-weighted spin-echo MRI image after injection of gadolinium. A hyperintense mass, 2 cm in diameter, is present at the level of the right sciatic notch (arrow).* (B) *Axial T2-weighted MRI image at higher magnification. The arrow indicates the endometriosis.*

(70) or lipomas, abscesses or coagulopathy-dependent hematomas of the gluteal region (51, 106, 167).

Other nerves in the lower limb

The common peroneal nerve may show functional impairment due to numerous conditions, ranging from cysts of the proximal tibio-peroneal joint (171) to gastrocnemius muscle herniation (4), or long-standing compression of the lateral aspect of the knee (176). The clinical features are those of sensory-motor paresis or paralysis, often not associated with pain.

The femoral nerve can be compressed by hematomas, tumors or inguinal hernias (25, 130, 176). The clinical picture can mimic an irritative or compressive syndrome of high lumbar nerve roots. The tibial nerve may be compressed by the gastrocnemius and the saphenous nerve can be entrapped in the adductor canal (153) or between the tendons of the gracilis and semitendinosus muscles proximally to the pes anserinus (158).

In a series of 4000 patients examined for suspected lumbar radiculopathy, Saal et al. (158) found 36 cases of lower limb nerve entrapment masquerading as radiculopathy. The nerve most frequently involved was the common peroneal and those less commonly entrapped were the femoral and saphenous nerves. Almost half of the patients had low back pain, decreased lumbar motion and / or positivity of nerve-root tension tests. A possible explanation for these findings is that activation of the dorsal root ganglions could give rise to a radiated pain similar to that of primary lumbar syndromes (3). In most patients in this study, idiopathic perineural fibrosis was responsible for nerve compression, as shown by electrodiagnostic studies.

In our experience, entrapment syndromes of these nerves of the lower extremity can readily lead us to initially suspect a lumbar radicular syndrome, particularly when the patient also complains, incidentally, of low back pain. Only rarely, however, does the diagnostic doubt persist after accurate evaluation of the clinical history and physical findings, and electrodiagnostic and neuroradiologic studies. If doubt persists, it may be helpful to carry out, in the presence of a painful condition, an anesthetic block of the peripheral nerve and / or the nerve root. However, idiopathic perineural fibrosis, as described by Saal et al. (158), is an extremely uncommon occurrence, if indeed it exists.

Peripheral neuropathies

Diabetic neuropathy

This is the most common neuropathy in the lower limbs and that most easily mimicking lumbar radiculopathy. Neuropathy is present in some one third of diabetics, is more frequent in patients who are not insulin-dependent and increases with the duration of diabetes.

There are two main types of diabetic neuropathy: 1) sensory or symmetric sensorymotor polyneuropathy and 2) polyradiculopathy or radiculopathy (also called femoral diabetic neuropathy or diabetic amyotrophy).

The first type, which is the most common, is dominated by sensory dysfunction, generally bilateral and symmetrical, which appears in the lowermost parts of the limbs and progresses proximally with a stocking pattern. Clinical signs and symptoms vary depending on the classes of involved nerve fibers (76); the most common consist of tactile and thermic hypoesthesia, paresthesias and dysesthesias, disturbances of proprioceptive sensitivity, loss of reflexes, and weakness in the sensorymotor forms; pain is seldom present. This type of neuropathy, usually insidious in onset, is found as a clinical or subclinical form in over 50% of subjects over 60 years with non-insulin-dependent diabetes (196). It usually does not give rise to problems of differential diagnosis with a herniated lumbar disc. Occasionally, neuropathy simulates lumbar spinal stenosis, particularly in the presence of diabetic microangiopathy responsible for intermittent claudication. However, the clinical symptoms of diabetic neuropathy, particularly the sensory disorders, are usually so typical (burning or electric shock sensations, diffuse pains, painful feeling of coldness, contact dysesthesia, frequent aggravation of symptoms at night) to infer diagnosis. The latter can be confirmed by EMG studies, which, in patients with diabetic neuropathy, show a considerably greater decrease in the nerve conduction velocity than in patients whose symptoms are caused by stenosis (34).

By contrast, radiculopathy (12, 37, 174, 189), which is relatively rare, may easily simulate a lumbar disc herniation syndrome (87, 125). Generally, the onset is acute and only one limb is involved. Clinical features include pain, weakness and muscle wasting, absense of reflexes, and mild disturbances of superficial sensitivity. The pain, often exceedingly severe, is usually located on the anterior aspect of the thigh and may have neuropathic characteristics (burning sensation, paresthesias). The muscles mainly involved are those of the anterior aspect of the lower extremity. Often multiple myotomes are involved, but occasionally the disease is more focal, only L4 or L5 myotomes being affected. In a few cases, bilateral, but asymmetric, involvement may be observed. Sphinteric disturbances are rarely present. Marked weight loss is occasionally found. In most cases, there is also clinical and EMG evidence of symmetric polyneuropathy. Radiculopathy usually occurs in elderly subjects and is independent of the duration of diabetes. The condition generally improves or resolves spontaneously; the pain usually disappears over the course of a few weeks or months, whereas the muscle wasting and weakness may take more than 1 year to improve and often resolves only partially. Diagnosis is achieved with EMG, which allows easy differentiation both of polyneuropathy from polyradiculopathy and of the latter from nerve-root compression syndromes.

In elderly diabetic patients with a clinical syndrome suggesting lumbar disc herniation, diabetic radiculopathy should always be considered when the high lumbar roots appear to be involved. On the other hand, the presence of a herniated disc, demonstrated by neuroradiologic studies, does not exclude that the patient's signs and symptoms are caused, entirely, or to a large extent, by a concomitant diabetic radiculopathy. In these instances, surgical discectomy may only partially improve or leave unchanged the clinical syndrome (87, 170). Whenever diabetic radiculopathy is suspected, electrodiagnostic studies should always be performed.

Guillain-Barré syndrome

This is a syndrome of unknown etiology, characterized by involvement of nerve roots, dorsal root ganglions and spinal nerves as well as cranial nerves, and by an increased rate of CSF proteins. The pathogenesis, which is probably of an autoimmune type, seems to be related to sensitization of lymphocytes to protein components of the nervous tissue. The syndrome occurs at all ages, but particularly in young or middle-aged adults, and usually has an acute onset, often following an infectious disease.

The condition generally begins as a paresthetic sensation in the hands and/or the feet, often associated with pain (vertebral or muscle pain, headache), to which motor deficits are later associated. In most cases, the latter commence in the lower extremities and extend, in a few days or weeks, to the upper limbs, the trunk and often the cranial nerves. Motor dysfunction generally consists of flaccid paralysis in the lower limbs and paresis in the upper extremities, particularly the shoulder girdle, with a symmetric pattern. Occasionally, sphinteric disorders are present, usually in the form of urinary retention or stipsis. Deep reflexes are abolished and the abdominal and plantar reflexes are depressed or absent. In the initial stages, the syndrome can simulate a lumbar disc herniation, in the presence of paresthesias in the feet, vertebral pain, paresis or paralysis in the lower limbs and sphinteric disorders, which can lead to the suspecion of a cauda equina syndrome.

Alcoholic neuropathy

This condition occurs in some 5% of alcoholic subjects and seems to be essentially related to deficiency of B complex vitamins. The initial clinical manifestations are intermittent paresthesias and pain at the extremities. The symptoms later become permanent and are associated with pain upon pressure to the muscles, stocking or glove hypoesthesia or anesthesia, loss of deep reflexes, and weakness, particularly of the extensor muscles of the foot and hand. This neuropathy can readily masquerade as a lumbar disc herniation, especially when the lower limbs are primarily or exclusively involved, and no prominent psychiatric disturbances (mental deterioration, confusional psychoses) are present.

Multineuropathies

These are characterized by simultaneous or sequential involvement of multiple nerve trunks, in the form of successive multiple neuropathies or symmetric polyneuropathy. The etiology is multiple and may include some collagen diseases, rheumatoid arthritis and acute porphyria.

The form most commonly encountered is that associated with polyarthritis nodosa, characterized by the onset of peripheral neuropathy concomitantly with sistemic symptoms (fever, visceral, articular, cutaneous and central nervous system disorders). In this condition, neuropathy is due to vasculitis of vasa nervorum, resulting in infarctions of limited zones of the nerve. The nerves most frequently involved are the peroneal, tibialis and sciatic nerves and the branches of the brachial plexus. Symptoms are represented by pain, often severe, paresthesias, and subsequently by motor deficits of a peripheral nature and neurovegetative dysfunction in the distal portions of the limbs. The disease may simulate a herniated lumbar disc in the initial stages, when neuropathy is the first clinical manifestation and particularly when only one lower limb is involved. In the advanced stages, the presence of systemic disturbances easily allows a disc disease to be ruled out.

Herpes zoster

Herpes zoster is due to reactivation of a latent varicella zoster virus. The virus, in the course of the infection, colonizes the dorsal root ganglion, where it remains in a quiescent status. In the presence of deficient immunological resistance, the virus is reactivated and proliferates in the ganglion, the sensory nerve root and/or a sensory peripheral nerve or the sensory component of a mixed nerve. The virus reaches the skin, where it proliferates in the deep portion of the epidermidis, thus giving rise to the typical cutaneous rash.

The clinical syndrome is characterized by general symptoms and successively by pain along a peripheral nerve with a dermatomal pattern; pain is often associated with paresthesias, dysesthesia and hypoesthesia, and seldom with weakness and wasting of muscles supplied by a specific nerve root (173). Within 1 week of the onset of pain, cutaneous lesions become apparent. At times, the cutaneous rash is represented by minimal eriyhema or is absent (28). The disease may mimic a disc herniation radiculopathy in the pre-eruptive stage and in the rare cases of slight or no cutaneous papulovesicular rash, particularly if the patient also complains of back pain (21, 27, 92). The same holds for the cases in which a postherpetic neuralgia persists, occasionally for months or years; this rarely occurs in young or middle-aged patients, but occurs in 75% of patients older than 60 years (98). Thus, in an elderly patient with an atypical lumboradicular syndrome, every attempt should be made to detect a recent herpetic episode. Diagnosis of varicella zoster virus infection in the absence of cutaneous rash is based on the increase in anti-zoster virus antibodies; diagnosis of postherpetic neuralgia may be impossible in the absence of a history of herpetic rash, since electrodiagnostic studies are aspecific and the anti-zoster antibodies may be within the normal limits.

Sacroiliac joint

Infectious sacroiliitis

This rare pathologic condition may be of tuberculous etiology or result from a pyogenic infection. In both events, but particularly in tuberculous sacroiliitis, diagnosis is often delayed, since the symptoms may be vague for a long time and ill localized, or referred to the pelvic region or the abdomen (38, 72, 132). The condition may manifest with symptoms of irritation or compression of the sciatic nerve, which runs in close proximity to the sacroiliac joint. Neural compression can be caused by a joint abscess spreading to the pelvic floor or a retroperitoneal synovial cyst resulting from the intra-articular infectious process (33, 112). The syndrome is generally characterized by buttock pain, difficulty in walking and a positive (pain and resistance to motion) straight leg raising test, as well as possible systemic signs and symptoms of infection. The condition may be suspected on the basis of the positivity of the maneuver of lateral compression of the pelvis and the specific tests for sacroiliac joint (Gaenslen's and Patrick's tests). Bone scanning, CT and aspiration of the joint fluid with subsequent bacterial cultures will lead to the diagnosis.

Hip

Pathologic conditions of the hip, such as aseptic necrosis of the femoral head, osteoarthrosis or synovitis, may mimic a high lumbar disc herniation, particularly when they cause thigh pain. Even in the absence of the latter, these conditions can simulate a lumbar disease when the patient complains of buttock pain. Discomfort in the gluteal region, in fact, is typical of a pathologic lumbar condition, but may also be present in patients with a hip disease, in whom, however, it is generally associated with pain in the groin. The following symptoms and signs refer to the hip: appearance or aggravation of buttock and/or inguinocrural pain on standing or walking, limping, decrease in hip motion, pain upon passive rotation of the hip, particularly internal rotation, and absence of back pain and neurologic deficits.

The femoral nerve stretch test may be positive even in patients with a hip condition, but positivity is consistently slight.

Radiographs of the hip may be of little diagnostic help in patients with aseptic necrosis in Ficat's stage I (58) or synovitis, in whom the radiographic picture can be negative. In this event, MRI of the hip or, alternatively, bone scanning should be carried out. If these investigations are negative, MRI of the lumbar spine should be performed.

Osteoid osteoma of the femoral neck may occasionally simulate a high lumbar disc herniation (90), as indeed other tumors of the proximal end of the femur.

Peritrochanteric region

This region may be the site of various diseases: trochanteric or subgluteal bursitis, insertional tendinopathy of the glutei muscles, and bursal or tendinous calcium deposits (97). These conditions give rise to pain at the tip of the greater trochanter, often located on its posterior portion. Pain may radiate to the groin or more often to the lateral aspect of the thigh. Particularly in these cases, the condition can mimic an L4 or L5 radiculopathy. The main clinical feature on which the diagnosis of peritrochanteric disease is based, is the reproduction or aggravation of pain upon pressure on the tip of the greater trocanter; at times, the pain aggravates upon resisted abduction of the hip. Both these clinical signs are usually negative in the presence of radiculopathy. Diagnosis of peritrochanteric disease can be confirmed by the presence of peritrochanteric calcium deposits on radiographs and by the improvement of symptoms with local injections of corticosteroids.

Knee

Knee pain may simulate a high lumbar disc herniation, particularly when the patient also complains, incidentally, of low back pain. Compression of the L2, L3, or more rarely L4, roots, in fact, can occasionally cause knee pain and mild or no anterior thigh pain. The clinical data that should lead to the suspicion of a lumbar spine condition are as follows: absence of pain on palpation of the knee and upon forced flexion of the joint in the supine position; presence of pain and/or hypoesthesia in the pretibial region; depression of adductor or patellar reflex and/or weakness of the quadriceps or adductor muscles; and positivity of the femoral nerve stretch test performed with the knee extended.

In the presence of osteoarthrosis of the lateral compartment of the knee or a cyst of the external meniscus, there may be radiation of pain towards the lateral aspect of the leg, which can mimic compression of the L5 nerve root. In these instances, the possible diagnostic doubt is generally solved by examination of the knee, nerve-root tension tests and neurologic evaluation.

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·CHAPTER 12·

DIFFERENTIAL DIAGNOSIS. II. PSYCHOGENIC PAIN

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Introduction

Knowledge of the influence of the psychologic factors on low back or lumboradicular pain have considerably improved in the last 50 years (48). In the 50's and 60's, a dichotomous opinion prevailed, according to which low back pain was purely organic or psychologic in nature. Clinical studies, in that period, were mainly aimed at identifying the psychologic factors which might predict the results of surgery. However, many of these studies had methodological defects and the results were often conflicting. In the 70's, the clinical studies were carried out on patient populations, mostly small and selected, often consisting of "difficult" cases unresponsive to various treatments, using different criteria for the diagnosis of psychologic disorders. This led to obtain extremely different percentages of prevalence of the psychologic disorders in patients with low back pain. In recent years, the evaluation methods have attained a higher level of standardization and many studies have been epidemiological in nature, with the aim of clarifying the relationships between low back pain and the patient's psychologic traits. These studies clearly show that the prevalence of neurotic or psycotic disorders, or behavioral abnormalities, is higher in patients with low back pain, particularly if chronic, than in the general population. Meanwhile, the analysis of the demographic, social and psychosocial factors has revealed that some factors may play a relevant role in the etiology of pain and the results of management.

The available knowledge on the role of the psychologic factors was mainly obtained from patients with only low back pain of the chronic type, and often idiopathic in nature, i.e., not due to a demonstrable organic condition. Only few studies have analyzed also patients with acute low back pain, and an even smaller number have been focused on patients with lumboradicular pain or disc herniation diagnosed with imaging studies. The presence of psychologic disorders may play an important role in the genesis and persistence of pain in the latter group of patients as well. Such role, however, is likely to be less relevant than in patients with idiopathic chronic low back pain. Nevertheless, the assessment of the psychologic factors is of considerable importance also in patients with suspected or demonstrated disc herniation, either from the diagnostic point of view or, particularly, in the choice of treatment, since numerous evidences indicate that the results of surgery are related to the patient's personality and psychosocial factors. On the other hand, the clinical picture of lumbar disc herniation varies considerably and also includes syndromes characterized by only chronic low back pain, continuous or intermittent in nature.

Psychologic disorders related to low back pain

Depression

This is a psychopathologic state characterized by depressed mood and alteration of affectivity and the feelings related to it (92). The most typical symptoms are sadness, feeling inefficient and useless, loss of affection, reduced interest, pessimism, anxiety, hopelessness, somatic disorders, such as asthenia, insomnia, and neurovegetative disorders, often painful, such as headache. Many types of depression have been identified, which differ as far as concerns quality and severity of the clinical presentation. One of the mildest forms is the so-called masked depression, in which the patient tends to have an hypochondriac behavior, which conceals the typical depressive symptoms, that he often denies to suffer from. This type of depression is usually dominated by somatic disorders.

Depression is one of the most frequent neurotic syndromes associated with low back pain (1, 24, 45, 58, 96, 98, 120, 125). Depressive symptoms have been identified in proportions ranging from 60% to 100% of patients with chronic low back pain (6, 54); a study on 80 patients (31) revealed that 21% had a major depression, 54% presented intermittent depressive disorders, 5% had minor depressive symptoms and 20% showed no evidence of depression. However, these studies were carried out on selected patient populations. An epidemiologic psychiatric survey of 220 Finnish patients complaining of low back pain who were identified by the responses to a questionnaire and of 101 control subjects has shown that 31% of patients had psychologic disorders (including depression), compared with 20% in the control group (48). Conversely, in the epidemiologic study of Westrin (132), no significant differences in the prevalence of neurosis were found between the patients with low back pain and the controls. According to a few authors, low back pain, similarly to headache, vertigo and gastroenteric disturbances, can be a somatic expression of a masked depression (60, 118) or a variant of the depressive disease (12).

An abnormal prevalence of affective disorders, including depression and alcoholism, has been found in both the first-degree relatives of patients with low back pain or sciatica, and in the relatives of patients with depression (1, 76). In a study (32), the prevalence of major depression was found to be significantly higher in the relatives of patients with low back pain and major depression than in the relatives of patients with low back pain and no evidence of depression, whilst the familial prevalence of alcoholism was similar in the two groups. These findings suggest that major depression in patients with chronic low back pain may be related to a genetic predisposition to depression. In effect, the etiologic relationship between chronic back pain and depression, particularly the minor forms of depression, is still unclear. It is possible that depression is a result of somatic pain (54, 117) or that the latter represents a form of somatization in subjects with primary depressive disorders (6, 50). A further possibility (72) is that pain may have a multifactorial etiology: in some cases the somatic component prevails; in others, overt or masked depression is the dominant factor; in still others, the component "role" given to pain is prevalent, i.e., pain is incorporated by the patient (usually after an illness) and used to justify behaviors that ensure him certain privileges.

Anxious neurosis

This psychoneurosis is characterized by an abnormally high level of anxiety, which is manifested by alarming reactions and worries absolutely out of proportion to the anxiety-inducing event. Certain events, or even any event, provoke sensations of existential insecurity and emotional instability or, at times, of danger, threaten or persecution. At times, anxiety may also, or only, be lived as a somatic disorder (such as vertigo or lipothimic crisis), which may become stable with time.

This condition has often been observed in patients with chronic low back or lumboradicular pain, frequently in association with symptoms of depressive neurosis (34, 55, 71, 100). However, in a psychiatric epidemiologic study by Youkamaa (48), the prevalence of anxious neurosis was found to be slightly greater in patients with chronic low back pain than in the controls, however only in males.

Hypochondriasis

This is a neurotic syndrome characterized by an excessive worry for ones own health or for the integrity of some parts of the body or mind, anxiety and depression, unpleasant somatic feelings, morbid attachment to doctors and medication, and apathy for what does not affect ones own disorder. The hypochondriasis syndrome should be distinguished from the hypochondriasis symptom, which may be present in many other neurotic or psycotic syndromes.

Hypochondriac symptoms are often observed in patients with chronic low back pain, however usually as an expression of anxious-depressive or hysteric syndromes, rather than as a specific syndrome.

Hysteria

The hysteric syndrome is a combination of various symptoms, of even opposite nature to one another, of which the common denominator, according to the classic theory, is that they do not have a demonstrable organic pathologic substratum. The hysteric subject has abnormal modalities in seeing himself in relation to reality, the others and himself (22). The hysteric personality is extremely vulnerable in facing external reality and reacts to it in a distorted way and to an exaggerated extent, with pathologic psychologic states (psychologic conversion) or organic symptoms, ranging from neurovegetative disorders to functional motor paralysis (somatic conversion). The hysteric personality is abnormally unstable and easily influenced, and it is inclined to use the repression mechanism in a pathologic measure in order to avoid psychologic conflicts. Furthermore, the hysteric subject tends to victimism and autodevaluation, as well as to mythomania and exhibitionism, of which dramatization of feelings and actions, and hystrionism, are an expression.

In the past, conversion hysteria was believed to be present in all patients with chronic low back pain (83, 97, 104). More recently, many authors have denied a close relationship between hysteria and low back pain (11, 48, 62). Hysteric traits may, at times, appear evident at a superficial analysis, however not in a thorough psychiatric evaluation. Maruta et al. (62) initially diagnosed a conversion hysteria or an hysteric personality in 48% of patients with chronic low back pain who were hospitalized for psychiatric assessment, but during the hospital stay many patients showed an anxious-depressive, rather than, hysteric syndrome.

Alexithymia

This term was coined by Sifneus to indicate a psychologic dysfunction characterized by difficulty in expressing feelings and emotional distress, particularly hostility and anger (101). Patients with this disorder have an extremely poor imagination, rarely dream, use actions to avoid inner conflicts and concentrate on irrelevant details and trivial somatic symptoms. In these patients, pain would be a kind of physical language to communicate feelings they do not know how to express in other ways. This disorder can be present alone or be one of the symptoms of depression; it has also been hypothesized that alexithymia may be the cause of masked depression. Several studies point out that alexithymia is present in a high proportion of patients with chronic pain (3, 70, 108), but can be difficult to measure by questionnaires or psychiatric interview (84, 114).

Somatization

Diagnosis of somatization is based, according to the DSM III of the American Psychiatric Association (2), on a lifetime history of at least 12 – from a list of 37 – medically unexplained somatic complaints reflecting disturbances in multiple organ systems. So defined, this condition is rarely observed (51, 94). More recent definitions imply that a spectrum of severity exists in somatization disorders, which includes, at the one end, an overt syndrome and, at the opposite end, forms of mild severity with less than 12 somatic complaints (20, 27). Patients with chronic low back or lumboradicular pain often complain of multiple symptoms (30, 86). In a study on chronic low back pain patients (7), it was found that, during lifetime, 25% of subjects had 12 or more of the symptoms in DSM III list, 51% had experienced only seven to 11 symptoms and the 22% had none to six symptoms; in the controls, the percentages in the three groups were 4%, 8% and 87%, respectively.

Epidemiologic studies have revealed that high degrees of somatization are associated with psychiatric disorders, including depressive syndromes. On the other hand, chronic pain is often associated with depression as well. It has therefore been hypothesized that the mechanism of somatization may, in these patients, represent the link between pain and depression (7). That is, the depressed patient tends to be a somatizer and low back pain may be one of the somatization symptoms through which he manifests psychologic or psychosocial disorders.

Abnormal illness behavior

Parson (82) first analyzed the social role of the illness condition and identified the privileges and obligations related to the role. For instance, the rights are that the individual is not considered responsible for his / her illness and that the social obligations change proportionally to the severity of illness; the obligations are to aknowledge that it is not desirable to be ill, and to accept in part the responsability for one's own illness and cooperate with those who are in charge of restoring the health state (129). The normal role of the illness condition may, in certain circumstances, become abnormal, particularly in chronic illness, since the patient does not adequately adapt to it.

The expression "illness behavior" was coined by Mechanic (68), who initially used it to indicate the way some symptoms can be perceived, assessed and turned into action in different ways by different personality types. The successive evolution of the concept of illness behavior has led to the use of the expression to indicate the different perceptions, thoughts, feelings and actions, which influence the personal and social meaning of symptom, illness, disability and their consequences (67). Pilowsky (87, 88) integrated the concept of illness behavior with that of hypochondriasis and transferred it into a sociological context, thus identifying a normal and an abnormal behavior. In the former case, the sick role put on by the patient is proportionate to the objective pathologic condition and it is congruous with the role assigned to him. In the latter, the behavior is out of proportion to the objective findings and the patient obstinately keeps an inappropriate role of sick person, despite the physician's reassurance on his state of health. Waddell et al. (126) recognized that an abnormal illness behavior is an expression of cognitive and affective disorders and defined, on a clinical basis, the illness behavior as a complex of actions and behaviors which express and communicate the individual's perception of an altered health condition, and the abnormal illness behavior as a behavior correlated to a physical disease, which is manifestly maladjusted and disproportionate to the disease and attributable to cognitive and affective disorders, rather than to an objectively demonstrable pathologic condition. This behavioral disturbance, like hypochondriasis and somatization disorders, can be isolated (in patients with cognitive disorders represented by an excessive attention to somatic symptoms and affective disorders consisting in an increased somatic awareness) or it can be one of the pathologic features in various neurotic syndromes.

Passive coping strategies

Patients with chronic low back pain, like those with other chronic painful conditions, may use active strategies (i.e., minimizing, "gritting" one's teeths, insisting in physical activities) or passive strategies (i.e., praying, hoping, groaning, avoiding social life and physical activities) to cope with pain. The passive-avoidant coping strategies have been interpreted as an expression of psychologic dysfunction and maladjustment to pain, which favor development of chronicity of the symptoms and disability (52, 93, 113). Furthermore, decrease in physical activity may have deconditioning effects on the musculoskeletal structures, thus favoring development of chronic pain (42). On the other hand, passive strategies are often adopted by depressed patients presenting no painful pathologic condition (10, 28). These strategies, therefore, might be due to dysfunctions of the emotional sphere rather than to pain. This hypothesis is supported by a controlled study on depressed or non-depressed patients, complaining of chronic low back pain: an increased rate of passive-avoidant coping responses was found to be associated with the combination of chronic low back pain and depressed mood, rather than with chronic back pain alone (130).

Psychosocial factors

Numerous studies have shown that various psychosocial factors may be associated with chronic low back pain. They are mainly represented by domestic conflicts, general or marital in nature, and by psychologic conflicts in the workplace, correlated to work dissatisfaction, excessive stress or professional responsability, conflictual relationships with the colleagues or superiors.

The prevalence of domestic conflicts, especially marital, and libido disorders was found to be higher in patients with chronic low back pain than in those complaining of no back pain (5, 29, 75, 102); on the other hand, there seem to be an increased prevalence of painful syndromes in relatives and consorts of patients with chronic low back pain (12, 26, 50). This might be due to a greater sensibility to pain or to behavioral disorders involving the whole domestic group, possibly related to educational or socioeconomic factors (26, 123). It has been found, for instance, that a high proportion of patients with chronic low back pain belong to large families (36, 48, 63) and that the patient's cultural level plays a primary role in the quality of the results of treatments for chronic low back pain (23). Similar results have been obtained in the evaluation of psychosocial disorders related to the work environment, which have been observed more frequently in patients with, than in those without, low back pain (29, 75, 111). Heaton et al. (44), however, found an abnormal prevalence of psychosocial dysfunctions also in patients with chronic low back pain considered as organic in nature.

Psychometric tests

Facing a patient with low back or lumboradicular pain, the physician often wonders: who is this patient? That is, has he/she psychologic dysfunctions or is he/she psychologically stable ? Are the complaints that he/she reports entirely organic, or partially or entirely functional ? What is the real severity of pain and functional impairment ? If both a psychologic disorder and a demonstrated organic disease are present, what will be the outcome of the conservative or surgical treatment ? The psychometric tests are the instruments developed to answer these questions, before asking a psychiatric consultation or in addition to this.

Three categories of psychometric tests can be distinguished: the questionnaires, the pain drawing test and the inappropriate physical symptoms and signs test. Numerous questionnaires have been developed, some of which are very similar; those described herein are some of the most frequently employed.

Minnesota Multiphasic Personality Inventory (MMPI)

The Minnesota Multiphasic Personality Inventory is one of the oldest and most utilized psychometric instruments in patients with low back or lumboradicular pain. The questionnaire, consisting of 566 statements to which the patient is asked to respond "true" or "false", has three validity scales and 10 clinical scales. The questionnaire requires 90 minutes or even more to complete, as well as a cultural level at least of secondary school.

Sternbach et al. (109, 110), who first employed the test in patients with low back pain, found elevations on the scales measuring Hysteria (Hy), Depression (D) and Hypochondriasis (Hs). At the same time, Gentry et al. (36) observed that, in many patients, the scales corresponding to hypochondriasis and hysteria were higher than the depression scale. Since in the test histogram, the D scale is in between the two others and the profile thus displayed a "V" pattern, the authors labeled this profile conversion "V" and considered it as typical of patients with chronic low back pain (Fig. 12.1). Later on, many studies have been performed to determine the validity of the MMPI and its clinical usefulness in the assessment of patients with low back or lumboradicular pain. This has been done in two ways: by evaluating the results of the test in patients with organic disorders compared with patients considered as functional; and by correlating the results of conservative or surgical treatments to the psychometric characteristics emerged from the test.

The studies in the first group have provided conflicting results. Hanvic (40) developed a low back pain (LB) scale, which was supposed to correctly identify cases of psychogenic pain. However, this ability has not been confirmed by other studies (6, 16, 33, 57, 116, 133). Another scale, developed by Pichot and called Dorsal (DOR) scale (16), was also found to be unable to identify subjects with psychogenic pain (33, 115). Multivariate cluster analysis (13) of the MMPI results in patients with low back pain have led to identify three homogeneous subgroups of patients (and a fourth in females): one group with elevations on the Hs, D and Hy scales; one with very slight elevations on the three scales and an elevated K-scale (correction scale); and one, clearly psychopathologic, with elevations on the three scales as well as on that of Schizophrenia. Several investigations have later validated this subgroup model (4, 41, 66, 103). Furthermore, two studies (41, 66) found the four-group model to be valid for both sexes. In conclusion, it is now clear that a unique type of personality correlated to low back pain does not exist and that MMPI does not allow us to distinguish organic, from functional, patients. The available data indicate that, among the low back pain patients, at least four subtypes of personality exist, which show various differences in the affective, cognitive and behavioral characteristics, or distortions, regarding pain.

The correlations between the MMPI profiles and treatment outcomes have usually been analyzed in operated patients. In many studies (25, 46, 47, 56, 59, 79, 80, 85, 119), a correlation was found between a few MMPI scales and the results of discectomy: in all studies, it was noted that patients with poor results had high scores on the Hs scale; in the majority of investigations, the Hy scale was elevated as well; and in a few studies, the poor outcomes were related to an elevated D-scale. Sorensen (105–107) has evaluated the scores on the MMPI scales at short, medium (2 years) and long term (5 years) after discectomy for lumbar disc herniation. Elevations on the D scale were found only at short term; the Admission of Symptom scale (which measures the degree of somatizzation) was that showing the highest predictive value for both the good and poor results, either at short or long term. In a retrospective study (133), fair or poor results of spinal fusion were found to be associated with high postoperative scores on the conversion-V scale. In addition, Wiltse and Rocchio (135), found a significant correlation between the scores on the Hy and Hs scales and the clinical response to chemonucleolysis. Therefore, the scores on the conversion-V scale of the MMPI appear to

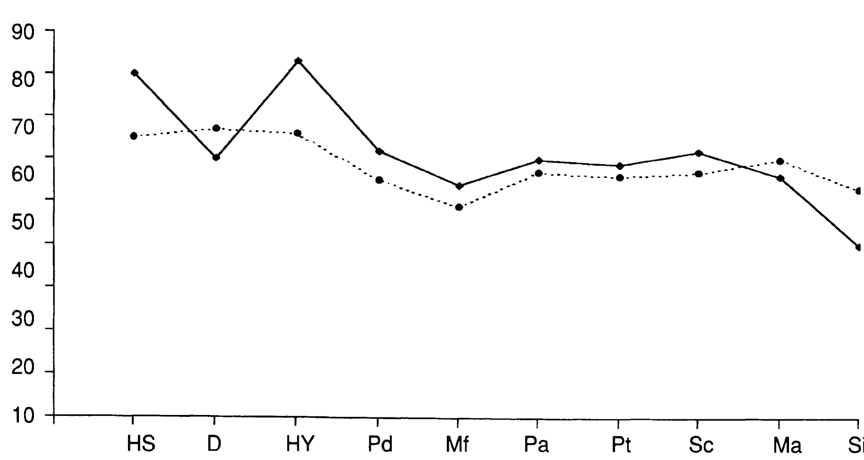

Fig. 12.1. *MMPI profile of two patients with chronic lumboradicular pain. One patient (dotted line) has a normal profile, with slight elevations in the scales of Hysteria, Depression and Hypochondriasis. In the other patient (continuous line) the higher scores in the scales of Hysteria and Hypochondriasis compared with that of Depression give the profile a V shape (conversion V).*

be good predictors of the surgical results, at least as far as concerns the poor outcomes. However, it should be taken into account that the examiners have usually assessed the results of surgery in a subjective and empiric way, and this may partially decrease the validity of the correlations with the MMPI scores. The latter may probably predict also the responses to conservative treatments, but the available data do not allow definite conclusions to be drawn. The outcomes of the conservative treatments seem to be related to the scores on the conversion-V scale (64, 65), but the correlation is less certain than for the surgical outcomes. The results of the anesthetic block of spinal nerves (15, 19) and the application of epidural stimulators (14), were not found to be related to the MMPI profile. Only few studies, however, have analyzed patients submitted to conservative treatments.

Beck Depression Inventory (BDI) and Zung self-rating depression scale

The BDI (9) consists of 21 items pertaining to cognitive, affective, behavioral and somatic symptoms. The Zung (136) scale is structured in 20 statements, to each of which the patient is asked to give a score of 1 to 4, based on how he believes it truthful. Both questionnaires are designed to identify patients with depressive symptoms. Crisson et al. (21) have shown that, in patients with low back or lumboradicular pain, the BDI is not influenced by the organic condition: in patients with a clear organic pathology, such as disc herniation, in fact, they observed similar depressive patterns to those in patients with little or no evidence of organic disease. The Zung scale was found to have a high sensitivity and specificity in identifying psychologic disorders in patients with low back pain, particularly when it is combined with the Modified Somatic Perception Questionnaire and the combined test was not found to be affected by pain or socioeconomic and cultural factors (37).

Millon Behavioral Health Inventory (MBHI)

This questionnaire (73) consists of 150 statements that the patient has to judge as "true" or "false" and 20 clinical scales (such as, Introverted, Cooperative, Respectful, Pessimism, Pain Treatment Responsivity, Chronic Tension, Somatic Anxiety) which reflect psychologic features or behaviors related to medical aspects. In one study (74), the questionnaire allowed four types of personality to be identified in chronic low back pain patients attending a rehabilitation program: introvert, denying/minimizing, prone to adapting (with potential psychosomatic disorders), and with psychopathologic disorders.

In two studies, the MBHI was found to be predictive of the results of rehabilitation programs (35) or surgical treatment (78). Barnes et al. (8) observed that only a few scales are predictive of the results of a functional rehabilitation program. Sweet et al. (112), however, found no significant differences between the MBHI and the MMPI in the ability to predict the treatment outcome.

McGill Pain Questionnaire (MPQ)

This questionnaire has been developed by Melzak (69) to assess the quality and intensity of pain. It consists of 20 sets of adjectives, which describe the sensorial, emotional and cognitive components of pain. The patient is asked to choose the adjectives which best describe his/her pain. In addition, a Present Pain Intensity scale is present, which is aimed at measuring the severity of current pain.

The MPQ can detect affective and cognitive disorders in pain perception in patients with low back pain (100), but it does not seem to be effective in differentiating patients with organic, from those with partially or entirely functional, pain.

Illness Behavior Questionnaire (IBQ)

This questionnaire (89, 90) assesses the illness behavior under various aspects. It includes seven first-order scales: General Hypochondriasis, Disease Convinction, Psychological vs Somatic Perception of Illness, Affective Disturbance, Affective Inhibition, Denial, Irritability. Some of these scales reflect attitudes and feelings regarding the illness, whilst others evaluate the degree of the dysphoria (Affective Inhibition), difficulty in communicating feelings (Affective Disturbance) and interpersonal irritability (Irritability). Combining these scales, two second-order scales have been obtained: Affective State and Disease Affirmation. Various studies (17, 49, 53) have found the first-order scale Disease Convinction to have a high ability to identify an abnormal illness behavior. Waddell et al. (129) have compared, in patients with chronic low back pain, the results of IBQ with the objective clinical signs of pain and physical disability, with psychometric measures of psychologic dysfunction and with the inappropriate physical symptoms and signs of illness, and have analized the predictive value of these symptoms and IBQ pattern regarding the results of the surgical treatment. The IBQ scores (particularly those on the second-order scale Disease Affirmation, which includes the first-order scales Disease Convinction and Psychological vs Somatic Perception of Illness) were found to be strictly related to affective disorders and psychologic dysfunction, and both the questionnaire scores and the inappropriate symptoms and clinical signs were found to be predictive of the surgical results.

Coping Strategies Questionnaire (CSQ)

The CSQ has been developed by Rosenstiel and Keefe (95) to evaluate the active or passive strategies used by the patient to cope with pain. Administration of the questionnaire to patients with chronic low back pain has revealed that high scores on the Cognitive Coping and Suppresion scales indicate, on the one hand, the use of active strategies to get over pain, and, on the other hand, low levels of pain and depression and high levels of disability. High scores on the Helplessness scale indicate poor ability of coping with pain and limited efficacy of the strategies used, as well as high levels of depression and anxiety. High scores on the Diverting Attention and Praying scale indicate that the patient uses mechanisms of diversion of attention from pain and the strategies of prayer and hope to face the symptomatology; these patients have a high level of pain and functional impairment. The use of the questionnaire was found to be predictive of the surgical outcome in patients submitted to decompressive surgery on the lumbar spine (38).

Pain drawing test

This simple test makes use of an outline drawing of the human body on which patients indicate the site of their pain and its characteristics, i.e., pins and needles, burning, stabbing or deep pain. The patient with an organic condition tends to describe only one of the four types of pain and this has an anatomic distribution, which is in keeping with the organic diagnosis. In the presence of psychogenic components, the patient tends to describe various types of pain located in multiple sites showing no precise anatomic distribution (Fig. 12.2).

Various scoring systems have been developed to evaluate this test. Ransford et al. (91) have developed a

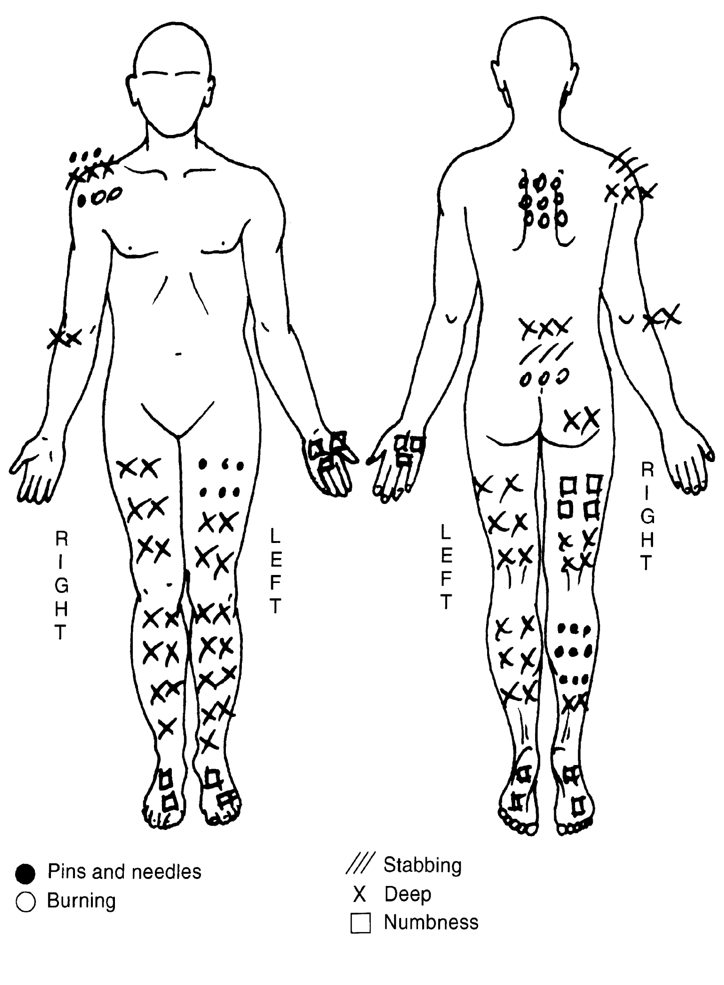

Fig. 12.2. *Typical pain drawing of a patient with functional symptoms. The pain is of various types, is located in different sites and shows a nonanatomic distribution in the lower limbs.*

penalty point system of scoring, based on the assumption that patients with psychogenic pain tend to 1) describe pain in anatomically unrelated sites, 2) expand or magnify pain (for example, symbols outside the body outline), 3) emphasize pain (for example, using arrows), 4) indicate pain all over the body. These authors found a correlation between their evaluation system and the MMPI scales of Hysteria and Depression, and concluded that the pain drawing test can be used to screen 93% of patients with poor psychometrics, who could be referred for more detailed psychologic assessment. Other authors (124), however, found the sensitivity of Ransford's system to be only 44%, whilst the specificity reached 80%.

Margolis et al. (61) have described a method of quantitative assessment of the test, based on the extension of the body area where pain is located. The drawing is divided in 45 anatomic areas, to each of which a score is assigned based on the extension of the area. The results of this method partially agree with those obtained with Ransford's method (91). Udén et al. (122), using a system based on the general impression given by the drawing, distinguished four categories of pain : organic, possibly organic, possibly nonorganic, and nonorganic.

Parker et al. (81) have developed three evaluation scoring systems (a modified Ransford's system, a Body Map system aimed at distinguishing organic from functional pain and a Pain Sites system, similar to that of Margolis, designed to evaluate psychologic dysfunctions). The first system was found to be a poor predictor of distress; the second also proved to be ineffective; the third was found to be a more accurate predictor than the first, but nevertheless produced high percentages of false positives or false negatives. In contrast with these findings, a study (77) found a positive correlation between the pain drawing test and pain provocation at discography; another investigation (18) has revealed a close relationship between the results of the pain drawing test and the nonorganic physical signs of Waddell et al. (128). A similar correlation, however, had not been found in a previous investigation (37).

In conclusion, the majority of the available data seem to indicate that the pain drawing test has considerable limitations in identifying psychologic dysfunctions or distinguishing organic from functional pain. However, the simplicity of the test and the approval met with the patients, make it a useful tool for a preliminary psychometric evaluation, even if the impression of the clinical examiner may often anticipate the results of the test.

Inappropriate physical symptoms and signs

Waddel et al. (127, 128) have described a series of complaints and clinical signs, that they considered as inappropriate descriptions of symptoms and inappropriate responses to examination, since they clearly do not fit general clinical experience (Table 12.1) (Fig. 12.3–12.6). They represent a magnified and emphasized presentation of the symptoms as far as concerns the anatomic location, severity and duration. As such, they are a clear clinical expression of cognitive and affective dysfunctions, and are used by the patient to communicate to the physician that he / she has a severe physical illness which entirely occupies his / her attention, overwhelms him / her and produce severe psychologic distress. These symptoms and signs, also defined nonorganic or

Table 12.1. *Inappropriate (nonorganic) physical symptoms and signs.*

Inappropriate symptoms	Inappropriate sign
Tailbone pain	Superficial tenderness
Whole leg pain	Nonanatomic tenderness
Whole leg numbness	Pain on axial loading
Whole-leg giving way	Pain on simulated trunk rotation
No pain-free periods in last year	Improvement of SLR when distracting the patient
Intolerance or reactions to previous treatments	Regional (nonmyotomal) weakness
Emergency admissions for low back pain	Overreaction to examination

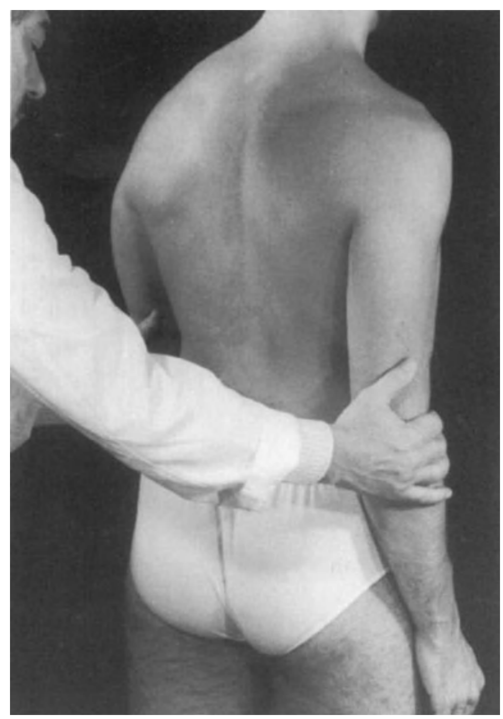

Fig. 12.3. *Simulated trunk rotation. This clinical sign is positive if the patient reports to feel pain.*

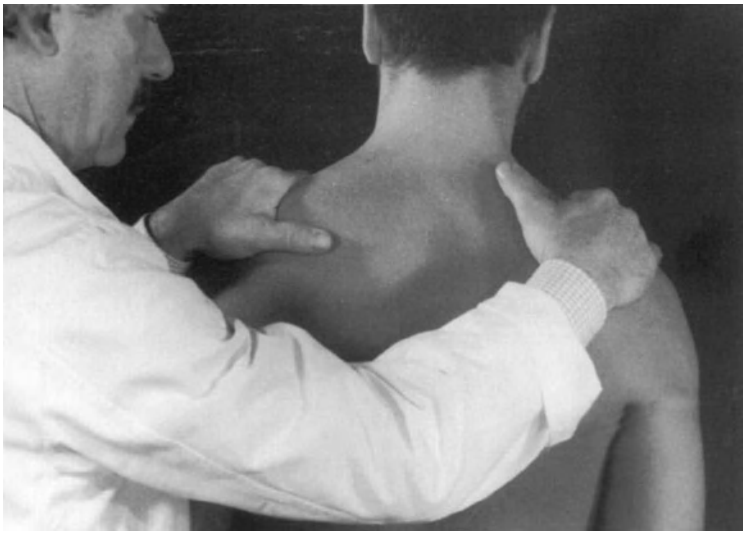

Fig. 12.4. *Axial compression. This maneuver may cause pain in the patient with abnormal illness behavior.*

behavioral, were found to be an expression of abnormal illness behavior, although they are not sufficient, in themselves, for such a diagnosis to be made (129). In addition, it is necessary that the majority of the inappropriate physical symptoms and/or signs are present for an abnormal illness behavior to be suspected.

Several clinical studies by Waddell (127–129) have demonstrated the validity of this psychometric test in both detecting psychologic dysfunctions in patients with chronic low back pain and predicting the outcome of surgery. These results have been confirmed by independent studies. In a study (18), a large proportion of patients with high scores in the inappropriate symptoms and signs test also had a pain drawing which was collectively scored as nonorganic. Another study (131) has analyzed the score changes in the inappropriate signs test after a functional rehabilitation program for chronic low back pain: the scores were found to be decreased in those patients who had returned to work, but not in those who had not. However, Greenough and Fraser (37) found the inappropriate symptoms test to have a low sensitivity and specificity compared with some questionnaires, such as the Zung's and the Modified Somatic Perception Questionnaire; the inappropriate signs test presented a low sensitivity as well, since only 30% of patients with psychologic disorders scored more than one.

In conclusion, the main prerogatives of the inappropriate symptoms and signs psychometric test are its simplicity and the rapidity with which it can be carried out. A high positivity of the test should lead to suspect behavioral disorders. This is particularly true for the clinical signs; many of the inappropriate symptoms, in fact, may also be present in patients with organic pathologic conditions. For the diagnosis of psychologic dysfunction to be made, the test positivity needs to be confirmed by additional psychometric tests.

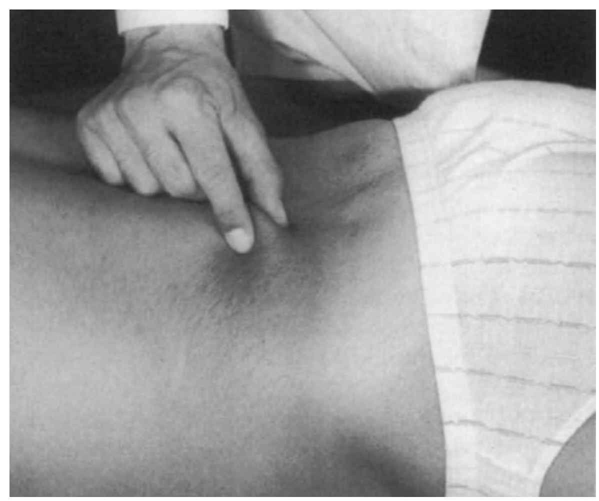

Fig. 12.5. *Light pinch on the skin of the lumbar region: the patient is asked whether he feels pain. An affirmative answer indicates an abnormal illness behavior.*

Fig. 12.6. *Pressure on the sacrum. Generally, this does not provoke pain in the patient with low back or lumboradicular pain who has no psychologic disorders.*

Psychiatric evaluation

Clinical diagnosis, in patients with suspected disc herniation or chronic low back pain, is usually based on the patient interview and objective examination, during which the inappropriate behavioral signs are often assessed and / or the patient is asked to undergo a pain drawing test. In the presence of symptoms and signs of abnormal illness behavior, or when the pain drawing test and / or the interview detect overt distress, the patient is often asked to undergo a psychometric test using a questionnaire, the results of which are evaluated by an orthopaedic surgeon, a physiotherapist or a neurosurgeon, or less frequently a psychologist. When clearly neurotic or psychotic traits emerge or are suspected, the patient is sent to the psychiatric consultant for a thorough evaluation of the nature and severity of the psychopathologic disorder. The general psychiatrist, however, tends to give little importance to mild personality disorders or non-prominent neurotic traits and, in these cases, he considers the patient psychiatrically normal or only in need for antidepressants. Furthermore, many general psychiatrists only marginally know the relationships between the so-called minor psychologic disorders, abnormal illness behavior or poor coping mechanisms and the results of conservative or surgical intervention, and do not, therefore, provide the treating physician precise opinions on the indication or contraindication for surgery or for physical, rather than psychotherapeutic, rehabilitation programs.

In effect, the complexity of the problems correlated to the influence of psychologic disorders on low back or lumboradicular pain and to the possible failure of surgical treatment in patients in whom the psychogenic component of pain prevails on the organic component, makes it necessary, in many cases, to perform multimodal diagnostic approaches and a thorough evaluation of the role of the psychologic and psychosocial factors in both the genesis of pain and disability, and the possible evolution of the acute disease into a chronic condition. A psychiatrist who is experienced in the interactions between personality disorders and spinal pain should not only be precociously involved in the diagnostic evaluation and management of patients with low back or lumboradicular pain, particularly if chronic (39), but also be an integral part of a multidisciplinary team, including an "orthopaedic surgeon, a psychiatrist or a psychologist, a physiotherapist, an occupational therapist, an anesthesiologist and, occasionally, a neurosurgeon" (99). The psychiatrist should be immediately consulted when the specialist whom the patient was referred to, has an even vague impression that psychologic implications are present in the low back or lumboradicular pain, or when the clinical syndrome does not unexpectedly respond to conventional management within a few weeks. At present, this is likely to be the best way to early identify patients in whom there is the risk of physical treatment failure, and to prevent the development of chronicity of the disease. On the other hand, a more frequent involvement of the psychiatrist in the diagnostic phase, as well as in the treatment, should with time lead to a better acceptance of the psychiatric intervention on the part of the patients, many of whom, at present, strongly resist the intervention even of the psychologist, since they refuse the idea that a psychogenic component may have a role in their illness.

Nomogenic disorders

The expression "nomogenic disorder" was coined by Tyndel and Tyndel (121) to describe those psychopathologic disorders originating from the law and its application, namely the complaints of pain and disability in which an etiologic role is played by legal controversies aimed at obtaining benefits, usually financial in nature. These disorders constitute a chronic benign pain syndrome, wherein symptoms are maintained by social reinforcement, such as increased attention, care, socially acceptable reasons for failure in work or relationships, avoidance of unpleasant social responsibilities, and / or financial compensation (134). The latter is a necessary, but not sufficient, component for diagnosing a nomogenic disorder; diagnosis can be made only in the presence of additional elements, such as the absence of objective findings of a disease and inconsistencies in reporting both pain and the limitations that it causes in daily activities (43).

Hayes et al. (43) have evaluated the responses to various psychometric questionnaires and the Waddel's inappropriate signs test in a group of 97 patients anticipating or receiving financial compensation (Group I) and a group of 134 patients not receiving or anticipating compensation (Group II). The questionnaires were administered twice within 4 hours and an inconsistency score was assigned by comparing the responses given in the two administrations. The patients in Group I obtained significantly higher scores than those in Group II both on the inconsistency measures and the Waddell's nonorganic signs. The nonorganic score alone correctly classified 90% of cases, whilst the predictive value of the inconsistency scores was 78%; the combination of the two raised the predictive value to 93%. The authors conclude that the results of the psychometric tests are unreliable and thus invalid in Group I patients, given the high inconsistency scores obtained by these patients.

Nomogenic disorders cannot be identified with simulation. This, in fact, represents an intentionally deviant behavior, whilst the behavioral abnormalities of the nomogenic syndrome are largely, or even entirely, unconscious. However, it may not be possible to distinguish simulators from patients with nomogenic psychologic disorders based on psychometric testing, since the results tend to be similar in the two categories of subjects.

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believe that MRI is the investigation with the greatest ability of diagnosing lumbar disc herniation and, indeed, any pathologic condition of the spine. In effect, MRI is not, in any patients, of greater diagnostic ability than other less technologically sophisticated investigations. Occasionally, high resolution CT is better able to demonstrate a herniated disc than MRI. This holds particularly for intraforaminal and extraforaminal herniations. On the other hand, in a very few cases, neither CT nor MRI will demonstrate a herniated disc or will reveal it in such a way that it is completely convincing for the surgeon, whilst myelography can be diagnostic. In other words, no investigation is absolutely better than the others in demonstrating a herniated disc and, at times, diagnosis may stem only from information obtained with a variety of imaging studies.

One limitation of some investigations is the high prevalence of positivity in asymptomatic subjects. A study on 52 asymptomatic subjects submitted to CT of the lumbar spine has shown disc herniation in 19.5% of subjects under 40 years of age and in 27% of those over 40 (16). A similar MRI study demonstrated a herniated disc in 22% of subjects under 60 years and in 36% of those over 60 (2). These percentages are in keeping with those obtained at myelography, which was found to be positive in 25% of asymptomatic subjects (6). In our experience – based on the analysis of discs adjacent to herniation in patients successfully operated only at the level of the herniated disc – the percentage of true disc herniations causing no symptoms is considerably lower than the reported data. However, the message stemming from these studies is that the presence of disc herniation on CT or MRI scans may not be of clinical significance if the findings are not consistent with the patient's signs and symptoms.

When deciding which diagnostic test is to be made, four factors should be taken into consideration: diagnostic ability, invasivity, rate of complications and potential damage related to the use of ionizing radiation, and cost of the investigation. A few investigations, such as sonography, are completely innocuous and of low cost, but their sensitivity and/or specificity are so low that they are not suitable for routine use. Other investigations, such as myelography or myelo-CT, have a high diagnostic ability, but also the defect of being invasive and presenting a relatively high rate of adverse effects; these investigations cannot be excluded from the diagnostic armamentarium, since they may occasionally be able to demonstrate a pathologic condition better than non-invasive investigations, but they should be performed only when the latter have unexpectedly provided negative or uncertain results. CT exposes the patient to ionizing radiations and may not reveal a few pathologic conditions of the nervous structures, but does have the advantage of being less expensive than MRI and is comparable from the diagnostic point of view, at least as far as concerns disc herniation. Due to these prerogative, CT is very often the investigation of first choice in a patient with suspected disc herniation. Finally, a few investigations, such as EMG, are often of little use in patients with a simple disc herniation either because they are of limited diagnostic significance or because they do not allow a definite decision, such as the surgical one, to be made in the absence of imaging studies; these investigations should, therefore, be used only in particular circumstances, for instance to document a neurologic impairment or for differential diagnosis with other pathologic conditions.

Usefulness of diagnostic algorithm

A diagnostic algorithm is a procedure protocol, structured in several consecutive steps, each of which requires a decision to proceed in the diagnostic pathway. The protocol is based on: 1) the information obtained from the literature regarding the diagnostic ability and the usefulness, in given circumstances, of performing one investigation rather than others, and 2) the prerogatives and limitations, for instance invasivity and costs, of a given investigation. A protocol with these characteristics should theoretically represent a diagnostic standard, able to lead us to correct identification of the pathologic condition and the characteristics of the latter which may be relevant from the therapeutic viewpoint. In effect, the situations which may be encountered in clinical practice are so numerous and variable, that no algorithm will ever be able to resolve all the items that may arise in the single case. Any diagnostic algorithm, therefore, necessarily represents a mere guide to approach a diagnostic problem not only as efficiently and rapidly as possible, but also with as little inconvenience as possible to the patient and society.

An algorithm has the merit of indicating the sequence of the diagnostic decisions, which are, to a certain extent, automated. Use of the protocol, therefore, avoids initiating the diagnostic iter, or to proceed in it, employing investigations of little usefulness or inadequate with respect to the clinical picture. However, the single decisions, at the various stages of the algorithm, are taken by the clinician on the basis of his professional experience, particularly the ability to correctly interpret a diagnostic test and to relate it to the characteristics of the clinical picture. For instance, judging the negativity or positivity of a diagnostic test, from which the need for prescribing further tests may stem, relies upon the ability of the clinician to interpret the test, as well as his experience or clinical intuition. In the absence of these requisites, the algorithm is of no significant usefulness in helping to make the diagnosis.

Diagnostic algorithms for lumbar disc herniation

Our diagnostic algorithms are based on data from the literature and clinical experience. The protocols are, necessarily, not rigid, since they cannot take into account the many situations that may be encountered in clinical practice. The proposed algorithms, therefore, represent only guides, which indicate the shorter and less expensive diagnostic pathways to reach a diagnosis of lumbar disc herniation or pathologic conditions mimicking a herniated disc.

Lumboradicular or radicular syndromes

Lumboradicular syndromes due to suspected disc herniation – in the absence of clear-cut evidence of psychogenic pain and significant radiographic changes – should be identified as typical or atypical. The typical syndromes, in turn, should be classified into one of five groups, depending on the characteristics of the signs and symptoms (Fig. 13.1).

In patients with a lumboradicular syndrome, which, although suggesting disc herniation, is characterized by rather vague symptoms and no neurologic deficits, lumbar MRI is indicated, since the whole lumbar spine should be visualized to exclude non-discal pathologic conditions. The same holds when multiple nerve roots are involved. Occasionally, whatever the clinical syndrome, it may be necessary to confirm or better define the MRI findings by means of CT scan of a given disc or vertebra.

In the presence of precise radicular symptoms – for instance, pain with dermatome distribution – associated or not to monoradicular or biradicular deficits, CT should be preferred, because of its low cost and efficacy, comparable to that of MRI in demonstrating disc herniation and / or lumbar stenosis. If CT scans are normal or difficult to interpret, MRI should be carried out.

In patients with a cauda equina syndrome, MRI should be performed, in addition to neurophysiologic

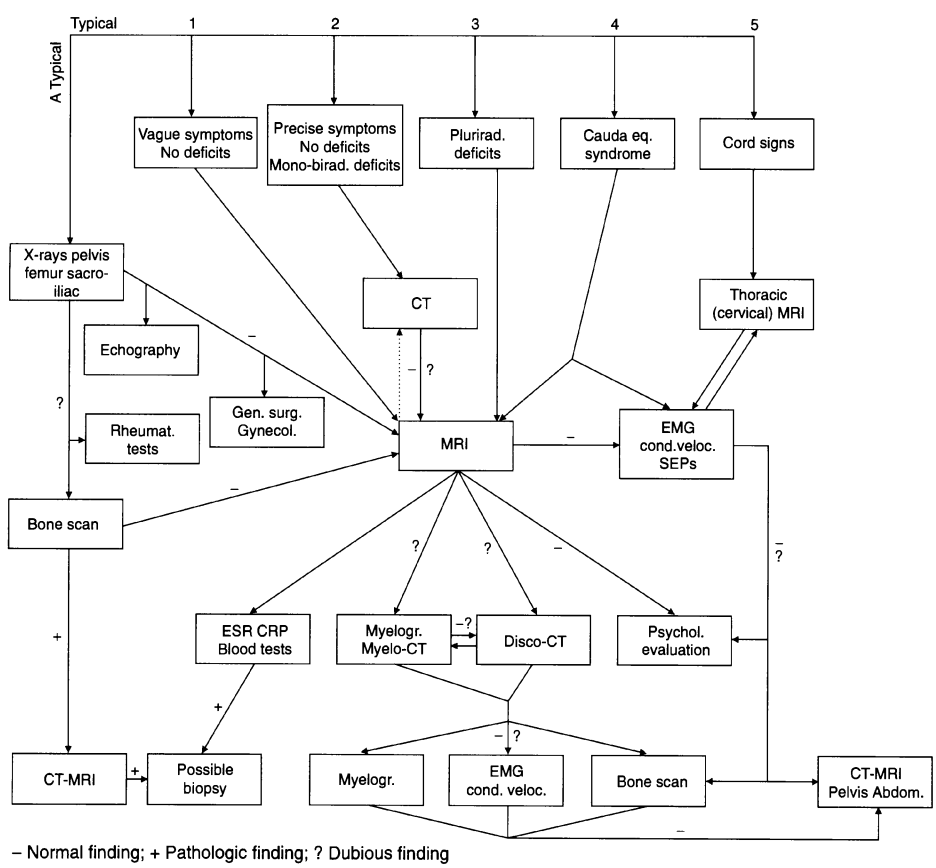


Fig. 13.1. *Diagnostic algorithm for lumboradicular, or only radicular, syndromes.*

investigations in order to document impairment both of the voluntary and autonomic nervous system. In the presence of clinical signs of even mild cord involvement (slight hyperreflexia, a positive Babinski test, absence of abdominal reflexes), MRI should be extended to the thoracic, and if necessary the cervical, spine; in these cases, furthermore, it may be necessary to carry out one or more neurophysiologic investigations.

In patients with a type 1, 2 or 3 syndrome, in whom CT and / or MRI are normal or of uncertain interpretation, several successive diagnostic pathways should be taken into consideration. One possibility is to perform myelography and, if indicated, myelo-CT; this holds particularly when radicular pain prevails on low back pain or when the latter is absent. Although only rarely, myelography may be more diagnostic than CT or MRI, due to its ability to demonstrate or exclude compression of the nerve root in the extrathecal course (Fig. 13.2). Furthermore, myelography is often indicated in patients with associated spinal stenosis, particularly in

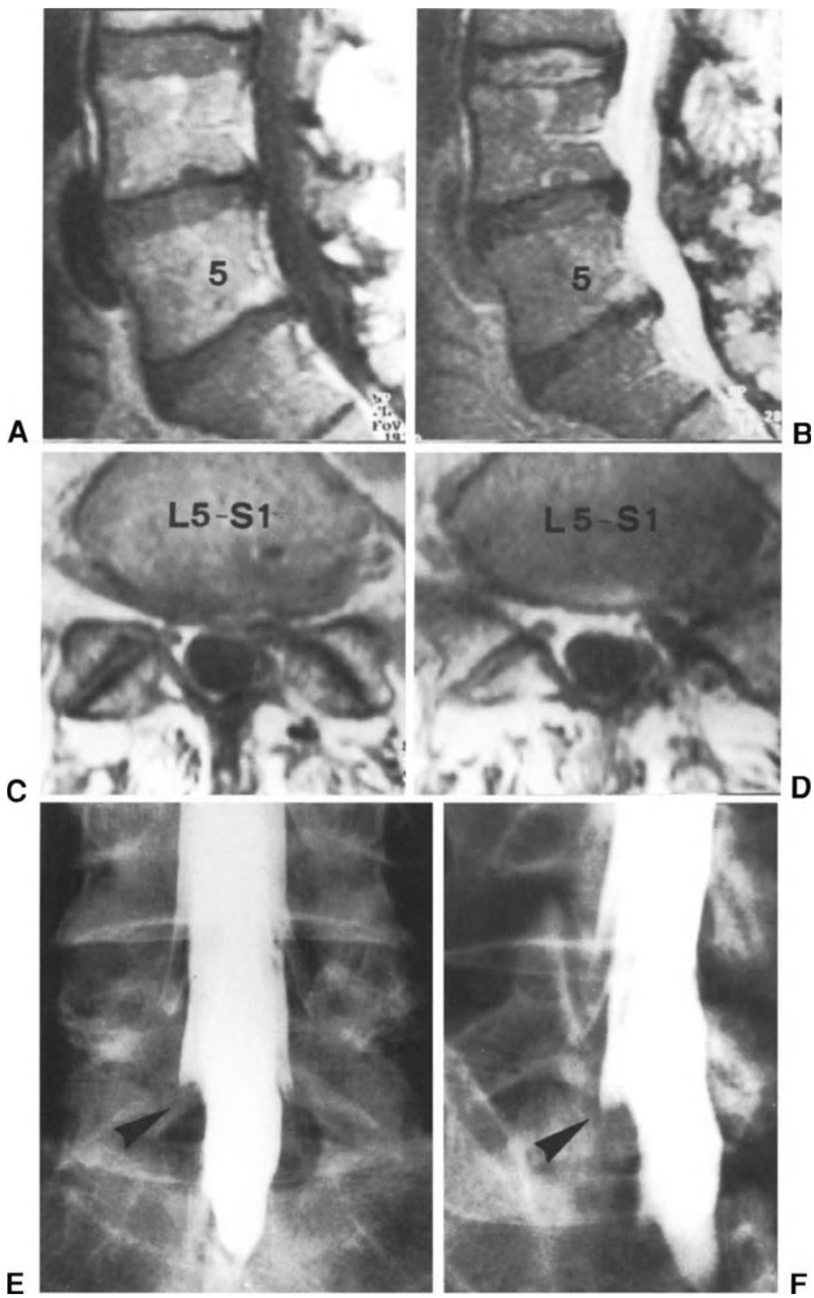
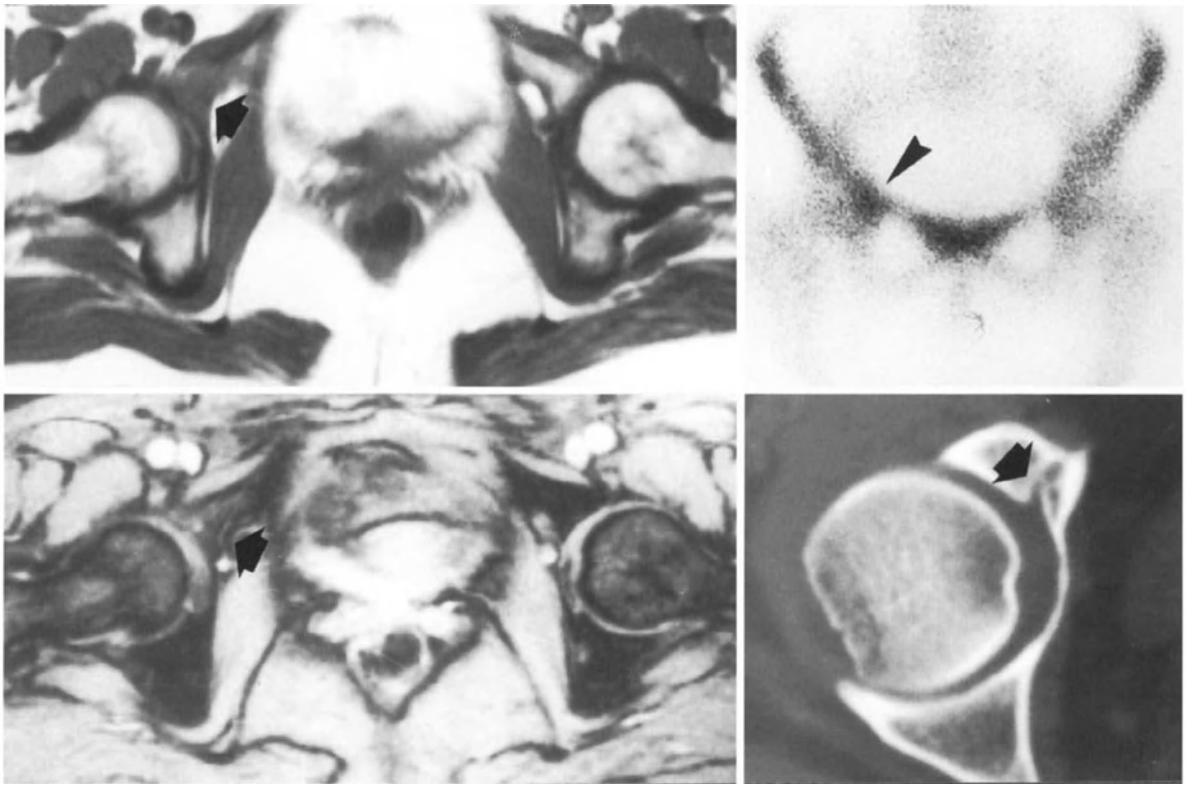


Fig. 13.2. *This 62-year-old male had undergone excision of L5-S1 disc herniation on the left in 1982 and ipsilateral L4-L5 intraforaminal herniation in 1994. In 1996, sciatic pain, not associated with low back pain, appeared quite suddenly on the right side. The pain, extremely severe, was located in the S1 dermatome, but particularly in the buttock and thigh. Physical examination revealed limitation of SLR at 60° and bilateral absence of the ankle jerk, but no loss of power of the triceps surae. Corticosteroids were administered for 1 week. The severity of the pain, however, led to the need for CT, which did not reveal any pathologic condition on the right side. After 4 days, the patient was admitted to our hospital due to persistence of severe pain, despite high doses of analgesics. MRI revealed mild annular bulging at the two lowermost lumbar levels on T1- and T2-weighted sagittal images* (A) *and* (B) *and abnormalities resulting from the previous surgical treatments on the right side on T1-weighted axial scans; at L5-S1 level, axial sections* (C) *and* (D) *showed no significant pathologic conditions on the right. After 2 days, myelography* (E) *and* (F) *was performed, which showed non-filling of the right S1 nerve-root sleeve (arrowhead). At surgery, a small contained L5-S1 disc herniation and slight S1 nerve-root canal stenosis was found on the right. Soon after surgery, the radicular symptoms disappeared almost completely. The result was satisfactory at the 3-month follow-up evaluation.*



A B C D

Fig. 13.3. *This 44-year-old female fell down the stairs and sustained trauma to the lumbar region and right buttock. After a few days, plain radiographs of the lumbar spine were obtained due to persistence of pain in the lower lumbar region, as well as in the right buttock and groin. Since the radiographs were normal, disc herniation was suspected and the patient was referred to a neurosurgeon, who requested CT scan of the lumbar spine, which showed no abnormalities. Sixteen days after the trauma, the patient was examined by another neurosurgeon, who requested MRI studies of the lumbar spine; since even the latter were normal, bed rest and anti-inflammatory therapy were prescribed. After 1 week of bed rest, the patient still complained of pain in the buttock and groin, particularly in the upright position and on walking. When examined by an orthopaedic surgeon, 26 days after the trauma, the patient presented slight limping due to groin pain, radiating to the upper portion of the anterior aspect of the right thigh. Neurologic examination was normal. Hip rotations and flexion were limited and painful. Plain radiographs of the hip were normal. MRI of the hip –* (A) *and* (B) *– showed abnormal signal intensity in the region of the right acetabulum on T1- and T2-wighted images (arrows). Bone scan* (C) *showed increased uptake in the right acetabulum (arrowhead), and the subsequent CT* (D) *revealed a fracture of the acetabulum (arrow). In this case, scrupulous physical examination should have led the examiner to suspect a pathologic condition of the hip, soon after the trauma.*

the presence of lumbar scoliosis. Another pathway consists in carrying out discography and disco-CT, if low back pain prevails. However, if one of the two types of investigation (myelography and/or myelo-CT, and discography and disco-CT) is negative or dubious, the other type may be indicated. A further option is to submit the patient to psychologic evaluation (psychometric tests and possibly psychiatric examination), straight away or after performing the appropriate neurophysiologic tests. Another diagnostic pathway, if MRI suggests or demonstrates discitis, is aimed at evaluating the blood tests for infection and the possible indications for biopsy. Apart from the latter, the last step of the algorithm includes: anesthetic nerve-root block and/or myelography, at least in patients with a monoradicular, or at the most biradicular, syndrome; bone scan; neurophysiologic investigations, if not already performed; and CT and/or MRI of the pelvis and abdomen.

In the presence of atypical lumboradicular or radicular-like symptoms, plain radiographs of the pelvis and femur may be indicated. If the latter are normal or of uncertain interpretation, lumbar MRI or bone scan, respectively, should be obtained. In these cases, however, it is of paramount importance to accurately take the clinical history and examine the patient (3, 15), to avoid missing the diagnosis or performing long and tortuous pathways (Fig. 13.3). Occasionally, before carrying out lumbar MRI, it may be useful to perform doppler examination or have the patient seen by a general surgeon, urologist or gynecologist, if inguinal hernia or diseases of the retroperitoneal organs or the genitourinary

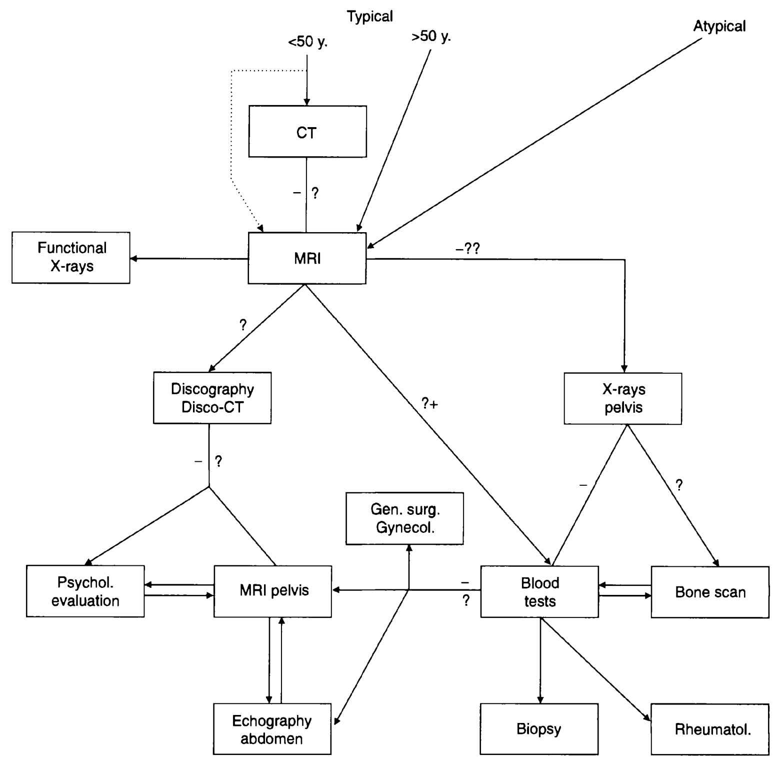


Fig. 13.4. *Diagnostic algorithm for pure low back pain syndromes.*

apparatus are suspected. In the event of radiographic changes of the sacroiliac joint, rheumatic tests should be performed, prior to or after bone scan.

Prevalently lumbar syndromes

In patients complaining prevalently of low back pain – for instance, acute or subacute back pain and mild pseudoradicular pain – diagnosis may not be as easy as in those with lumboradicular or only radicular pain, due to the multiplicity of the vertebral or extravertebral pathologic conditions producing the syndrome. It is thus more difficult to schematize the diagnostic pathways, which, on the other hand, are less rigid than in the lumboradicular syndromes.

Also the prevalently lumbar syndromes can be classified into two groups: syndromes with clinical characteristics typical of a pathologic condition of the disc and atypical syndromes from this point of view (Fig. 13. 4).

In typical syndromes of young or middle-aged patients, CT is indicated and, if this is negative or of uncertain interpretation, lumbar MRI should be carried out. In older patients, MRI should be preferred because of the better chances to find annular bulging or disc degeneration at multiple levels, or non-discal pathologic conditions (tumors, inflammatory or hematologic diseases, osteoporotic fractures), which are better demonstrated by MRI. If the latter is of uncertain interpretation, discography or disco-CT may be indicated and, if diagnosis still remains uncertain, a thorough psychologic evaluation of the patient or MRI of the pelvis, before or after abdominal echography, should be carried out. If MRI is negative or of extremely dubious interpretation, a further diagnostic pathway includes radiographs of the pelvis, hematologic blood tests and/or bone scan, and evaluation of the patient by other specialists, such as the general surgeon, gynecologist or rheumatologist. In patients with isthmic or degenerative spondylolisthesis, flexion-extension radiographs may be indicated after lumbar CT and/or MRI studies. When the latter suggest or demonstrate discitis, blood tests and possible biopsy should be performed.

In atypical syndromes, the investigation of choice, after plain radiographs, is generally lumbar MRI, since the syndrome may easily be caused by pathologic conditions not related to the disc.

Computerized algorithms

Most computer-aided diagnostic systems are of two types (5, 13). A few calculate the likelihood of different diagnoses, using the probability theory, in particular, the Bayesan theorem (1). Other protocols make use of systems of artificial intelligence to imitate the human reasoning process (10, 11, 14). In both cases, most computerized programs include a diagnostic algorithm and a therapeutic algorithm strictly related to the former.

An example of a diagnostic-therapeutic algorithm based on the calculation of probability is LOBAK (8,9). With this protocol, the patient with a suspected disc herniation is first assigned to one of seven clinical groups, which have a pre-test probability of 98% ("good" neurologic and mechanical signs) to 10% (only low back pain, no neurologic and mechanical signs). The program then analyzes the clinical signs and symptoms and indicates the interspace where disc herniation is most likely to be located. If the signs and symptoms suggest a stenotic condition, spondylolisthesis, spinal tumor or inflammatory disease, the program makes recommendations for diagnostic testing or treatments. If these conditions are excluded, the anamnestic data, clinical signs and the results of investigations are analyzed to detect possible conflicting data. In the absence of the latter, the program analyzes the results of diagnostic tests and lists the tests to be performed. Finally, it calculates the post-test probability for disc herniation using the Bayesan analysis. Based on the value of probability calculated, the program recommends further diagnostic tests or specific types of treatment.

Mathew et al. (11) have developed an "expert" computerized system for the differential diagnosis of pathologic conditions of the lumbar spine. The system uses the mathematical theory termed inductive learning, which mimics the human ability to learn from example patients. These are first assigned to one of four diagnostic categories: simple low back pain, radicular pain, spine pathologies (infections, tumors, inflammatory diseases), and abnormal illness behavior (psycogenic pain). The expert system uses two diagnostic methods: without and with dialogue. With the former method, all the data are entered and a diagnosis computed. With the latter, the computer imitates the focusing skills of a human expert and engages in an intelligent dialogue during which it requests specific items of information. The dialogue is interrupted by the system itself when it has gathered sufficient information to be certain of its diagnosis. In a prospective study of 200 patients – 50 in each of the four diagnostic categories – the authors found that the computer outperformed a large number of clinicians, specialists and non-specialists, even though its patient data base was relatively small.

A diagnostic and therapeutic algorithm for lumbar disc disease (7), developed in the 70's and continuously updated with the advent of new investigations and methods of treatment, has been computerized for use as a monitoring system in a large population (17). A prospective study has demonstrated the practicality of the computerized system and its validity in the diagnostic and therapeutic monitoring of workers in industry.

Computerized programs of diagnostic algorithm, despite the considerable enthusiasm evoked in the 80's, have never been widely used. One of the main reasons is that the data are introduced into the computer by man, who has to interpret and catalogue a clinical sign or the result of a diagnostic test; in this process, man may make mistakes, thus negatively affecting the elaboration of the data by the computer. For instance, the clinician has to interpret whether CT or MRI studies are negative or positive, and, in the latter instance, whether a disc prominence into the spinal canal should be considered as annular bulging or disc herniation, and whether the latter is midline, posterolateral or lateral herniation. Depending on the interpretation of the clinician, the diagnostic pathway followed by the computer may be considerably different. Other reasons for the lack of use are the risk of excessive simplification of the clinical problems, when the system of probability is used (4, 5), or the complexity and inadequacy of the mathematical models employed in some expert systems (11, 12).

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·CHAPTER 14·

CONSERVATIVE TREATMENTS

F. Postacchini, I. Caruso, V. M. Saraceni

Natural history of lumbar disc herniation

The natural history of a pathologic condition may be analyzed from two different points of view: natural evolution of clinical signs and symptoms, and natural evolution of the pathomorphologic changes. In either case, the patients under study should not be submitted to any treatment. However, whilst the clinical natural history may be, to some extent, affected by any conservative treatment, the pathomorphologic natural evolution is not presumably influenced by most conservative treatments currently carried out in patients with disc herniation. Regarding the latter aspect, therefore, also clinical studies including patients submitted to treatments with no known effects on the pathologic changes of the disc may be reliable.

Clinical evolution

In the Western world, it is extremely difficult, at present, to study the clinical natural history of a pathologic condition causing pain, since patients almost inevitably undergo some form of treatment. This may explain the paucity of information on the natural evolution of clinical signs and symptoms of disc herniation.

In a multicenter prospective study, Weber et al. (196) have analyzed 208 patients with a mean age of 48 years, presenting the clinical features of lumbar radiculopathy probably due to disc herniation. In no case was herniation (or the pathologic condition responsible for radiculopathy) diagnosed by means of imaging studies. All patients were examined within 2 weeks, and at 4 weeks, of the onset of symptoms, whilst a questionnaire was used to evaluate the clinical status at 3 and 12 months. All patients were instructed to observe complete bed rest for 1 week and some were treated with Piroxicam, whilst the others were given a placebo. No significant differences in the evolution of signs and symptoms were observed between the Piroxicam, and the placebo, group. During the first 4 weeks after the onset of symptoms, some 70% of patients had a considerable decrease in pain and almost 60% resumed work. After 1 year, some 30% of patients complained of back pain, decreased working ability and limitations in recreational activities, and 19.5% had not resumed work. Four patients had been treated surgically.

In a prospective randomized double-blind study carried out by Fraser (60), 30 patients underwent chymopapain chemonucleolysis and 30 were injected with the same volume of saline. Disc herniation was diagnosed by myelography in all patients. At 6 weeks, only 37% of patients in the placebo group had a satisfactory clinical result. The proportion of satisfactory outcomes reached 57% at 6 months and decreased to 47% at 2 years (61). Surgery had been performed in 40% of patients. The results of this study are not consistent with those reported by Weber (196). A possible explanation is that, in Weber's study, diagnosis of disc herniation was made solely on clinical grounds, by non-specialists. In Fraser's study (60), on the other hand, the clinical material was more selected, since the patients had been referred to a specialist center, probably after failure of conservative management, and the clinical diagnosis of disc herniation had been confirmed by myelography.

Pathomorphologic evolution

In recent years, numerous studies (17, 23, 119, 169, 182, 183) have shown that disc herniation may decrease in

Fig. 14.1. *T1-weighted spin-echo right paramedian MR images.* (A) *Small disc fragment migrated distally to the L4-L5 disc (arrowhead) in a patient with a right lumboradicular syndrome.* (B) *On MRI performed 8 months after the previous examination, the migrated disc fragment is no longer visible; the patient had undergone conservative treatment with complete resolution of radicular symptoms.*

size or disappear in the course of a few months. The process may occur in contained, extruded or migrated herniations of either small or large size (Figs. 14.1–14.3). In a prospective study (23), 111 patients with disc herniation or annular bulging diagnosed by CT underwent a second CT study 1 year later, following one or more epidural injections of steroids. Of the patients with disc herniation (contained, extruded or migrated), 76% showed a decrease in size (four fifths of cases) or disappearance of the herniation (one fifth) on control CT scans. Similar findings were observed only in 29% of patients with bulging annulus fibrosus. In only four (5%) patients with disc herniation, did the control CT show deterioration in the pathomorphologic picture. Similar results were reported by Maigne et al. (119): of 48 patients treated conservatively and submitted to CT studies 1 to 48 months after the initial CT study, 64% showed a decrease of over 75% in the size of the herniation on the control CT and 17% presented a decrease in size of 50% to 75%.

Large herniations tend to decrease in size to a larger extent (37, 119, 169). By contrast, extruded herniations of small size seem to show less tendency to spontaneous resolution. A decrease in size may occur even in the course of a few weeks, before complete resolution of the symptoms. A retrospective study (98) has shown that, after a mean period of 262 days, the vast majority of extruded herniations had decreased in size or disappeared following conservative management. Almost none of the contained herniations, on the other hand, showed any significant change. All those patients with a decrease in size or disappearance of the herniation presented excellent or good clinical results.

Little is known about the mechanisms leading to a decrease in size or disappearance of the herniation. In contained herniations, the main mechanism is likely to be represented by dehydration of the herniated nucleus pulposus. This may account for the higher frequency with which young subjects, who tend to have greater hydration of the nucleus pulposus, present a decrease in size of their herniation (23). In extruded or migrated herniations, phagocytosis of herniated tissue by macrophages probably also plays a primary role (page 125).

Modalities of conservative treatment

Bed rest

Bed rest is the oldest and simplest of conservative treatments for lumbar disc herniation. Its effects are related to a decrease in intradiscal pressure, spine motion and lumbar lordosis as well as to relaxation of the paraspinal muscles.

Bed rest may be particularly useful during the first few days after onset of lumboradicular symptoms. The bed should be hard and the position to be preferred is that which most reduces lumboradicular pain. This is usually the supine position with the hips and knees slightly flexed or the lateral decubitus in the fetal position. The prone position should be avoided if, as usually occurs, it exacerbates lumboradicular pain.

In effect, it is not known whether this therapeutic modality is really effective and what should be considered the optimal duration of bed rest. Two studies have analyzed the therapeutic efficacy of bed rest in patients with only low back pain in the acute phase. The patients were randomly assigned to two groups: no bed rest or

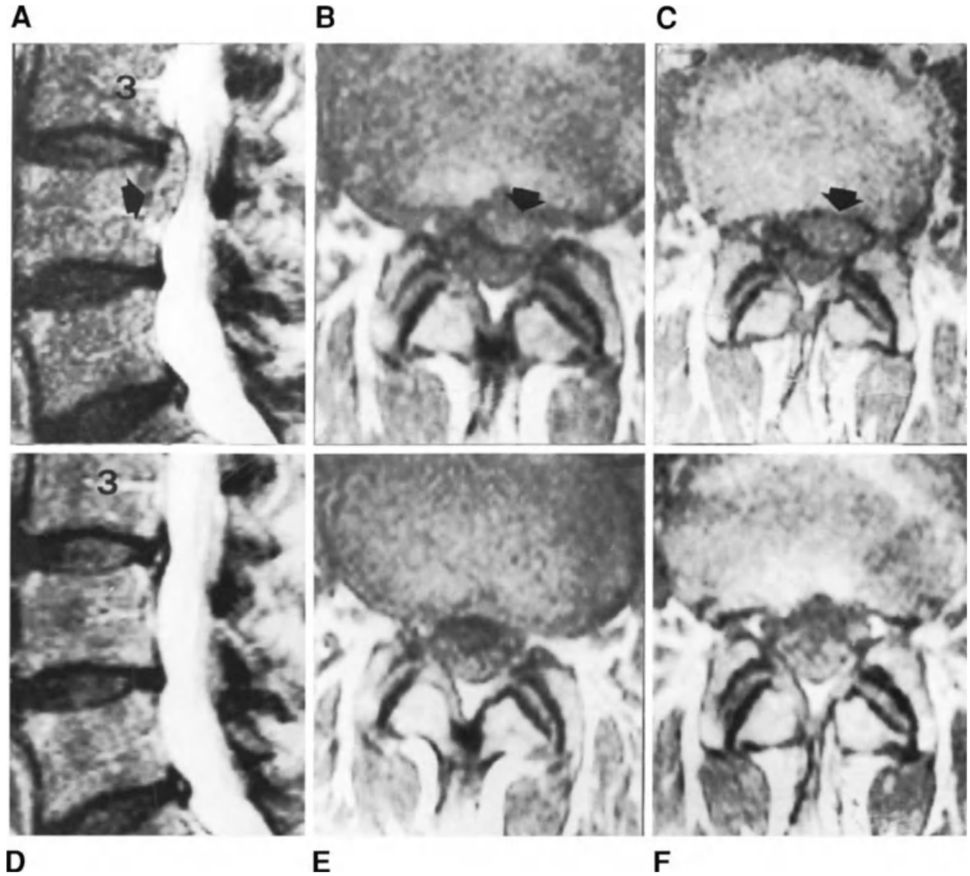


Fig. 14.2. (A)–(C) *Sagittal T2-weighted spin-echo MR image* (A) *and axial T1-weighted spin-echo* (B) *and* (C) *images at L3-L4 level in a patient with anterior thigh pain on the left. A large retroligamentous extruded herniation is visible at L3-L4 level on the left (arrows).* (D)–(F) *MR images obtained 5 months after the previous examination: complete disappearance of disc herniation after conservative treatment (medical and physical therapy for 4 weeks).*

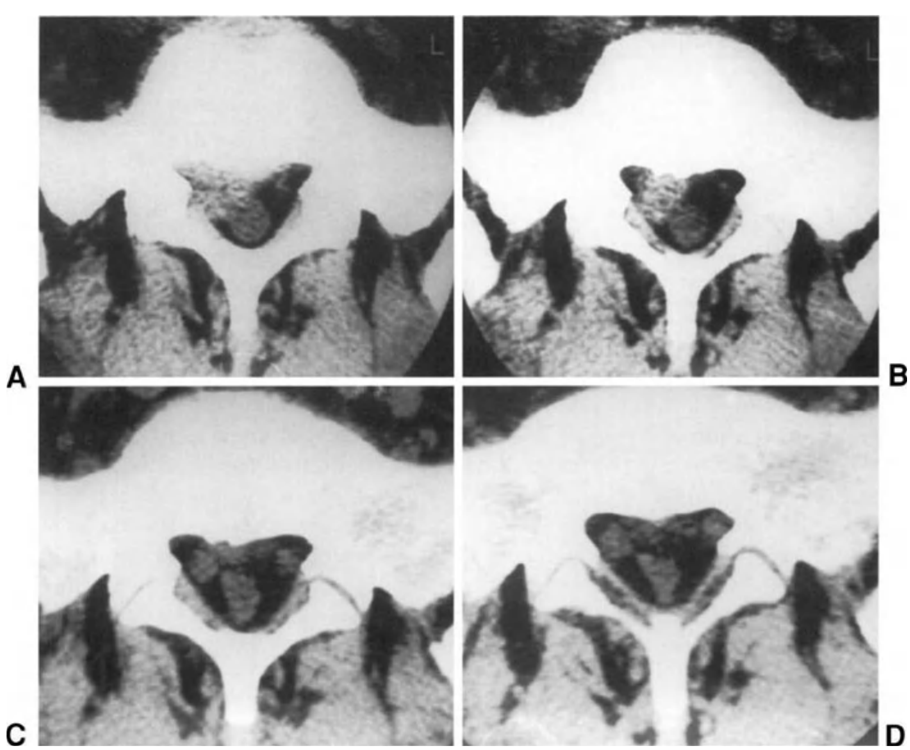


Fig. 14.3. (A) *and* (B) *Axial CT scans of a patient with disc herniation migrated distally to the L5-S1 disc on the right.* (C) *and* (D) *CT scans at the same levels obtained 1 year after the previous examination. Complete disappearance of the migrated fragment. Only a slight paramedian bulging of the L5-S1 disc is visible on the right.*

complete bed rest for 4 days in one trial (67), and bed rest for 2 or 7 days in the other (40). No significant differences were found, in either study, between the two study groups in terms of pain resolution and recovery of function. However, patients who remained ambulatory or stayed in bed for a shorter period of time had a significantly faster return to work.

In only one study (196), the therapeutic efficacy of only bed rest (associated with a placebo) has been analyzed in patients with disc herniation diagnosed from imaging studies. Patients were asked to observe complete bed rest at home for 1 week and then to proceed with gradual mobilization over the next few weeks. Some 70% of them obtained a considerable decrease in pain in the first month after the onset of symptoms. The possible evolution of symptoms in patients confined to bed for a shorter or longer period of time is, however, unknown.

Our experience indicates that, in patients with acute lumboradicular pain due to disc herniation, bed rest favors resolution of pain in the first few days after the onset of symptoms. We usually recommend bed rest for 3 to 7 days. After the first week, symptoms do not usually show a progressive improvement with increasing time of bed rest. On the other hand, prolonged bed rest may have adverse psychologic, physical (muscle atrophy, cardiorespiratory deconditioning) and financial effects.

After the first few days of absolute bed rest, the patient should be encouraged to get up several times a day for progressively longer periods of time. A few authors advise against the sitting position in the presence of acute lumboradicular pain, since this position involves an increase in intradiscal pressure and lumboradicular symptoms. In effect, this occurs in only a few patients and only in these should the sitting position be avoided.

Medical therapy

Medical therapy is based on various types of medication: analgesics, anti-inflammatory drugs, muscle relaxants, sedatives and neurotrophic medications.

Analgesics may be non-narcotic or narcotic. Non-narcotics, such as acetaminophen and ketoralac, have analgesic but not anti-inflammatory effects, since they inhibit prostaglandin production in the central nervous system, but not in the peripheral organs. Narcotic analgesics include codeine, meperidine and morphine. The advantage of pure analgesics is that they have little or no gastrointestinal side effects; one of the main disadvantages is the short duration of their action. These drugs may be particularly useful in patients with acute lumboradicular pain complaining of gastrointestinal disturbances and who do not tolerate anti-inflammatory medications, to which, however, analgesics may be associated.

Anti-inflammatory drugs include nonsteroidal agents and corticosteroids. Nonsteroidal anti-inflammatory drugs (NSAIDs) have both anti-inflammatory and analgesic effects. The latter are obtained with lower doses of the drug, but the effects usually last considerably less than those of the anti-inflammatory drugs. Unlike pure analgesics, NSAIDs inhibit prostaglandin synthesis in the peripheral organs. Furthermore, they act on other components of the inflammatory response, such as the oxidative phosphorylation and cell activation. The most recent NSAIDs rapidly initiate their action (1–2 h) and they have a long half-life (18–72 h). All are metabolized by the liver and excreted by the kidney.

Several clinical trials have shown that NSAIDs are effective on acute low back pain. By contrast, in patients with lumboradicular pain, these drugs have failed to display any therapeutic efficacy (71, 196). Even in our experience, NSAIDs are more efficacious on low back, than radicular, pain. They are indicated in patients with prevalently low back pain in the acute phase and in those with subacute lumboradicular pain. In the acute phase, these drugs should be administered via the parenteral route, once or twice a day. In the subacute phase, oral administration should be preferred from the beginning or following a period of parenteral administration. In chronic syndromes, there is generally no indication for these medications.

Corticosteroids have purely anti-inflammatory effects. They are of little efficacy on low back pain, but are highly effective in reducing radicular inflammatory changes and, thus, the radiated pain (72). These drugs are indicated in patients with severe radicular pain of recent onset. In these cases, they should be administered in high doses (4–8 mg a day of betamethasone or equivalent doses of other corticosteroids) for 2–4 days and then in decreasing doses for 4–8 days. This therapeutic regimen may be able to reduce severe radicular pain, even dramatically. Occasionally, corticosteroids are also indicated, in lower doses, in patients with radicular pain of moderate severity.

Anti-inflammatory drugs, considering their side effects, should be avoided in patients with pathologic conditions likely to be negatively affected by the medication. This is particularly true for corticosteroids, which should not be used, or should be administered with extreme caution, in patients with diabetes, hypertension or infectious diseases, as well as in those with gastritis or ulcerative disease. Furthermore, corticosteroids are known to cause avascular bone necrosis, even when administered for short periods of time (56). However, the likelihood of this complication occurring after administration of moderate doses is so low as to make cortisone treatment justified, when the clinical advantages are such to make it indicated.

Muscle relaxants act by decreasing muscle tone and, thus, paraspinal muscle spasm. Two groups of drugs may be identified: pure muscle relaxants and medications with a concomitant sedative or anxiolytic effects.

The drugs in the first group include pyridol and thiocolchicoside. Pyridol has an atropin-like mechanism of action. Thiocolchicoside is a semisynthetic derivative of colchicoside, a glycoside contained in the meadow-saffron, which has spasmolytic effects. Thiocolchicoside appears to have an agonist effect upon GABA (gamma aminobutyric acid) receptors. Neurons with these receptors inhibit tonic facilitatory impulses reaching the α and γ motor neurons from supraspinal centers. The advantage of pure muscle relaxants is that they have negligible side effects.

The best known drug in the second group is diazepam, which decreases anxiety and favors sleep by acting on the brain structures, such as the lymbic system and the hypothalamus. Furthermore, it exerts relaxation of the skeletal musculature, probably by decreasing monosynaptic and polysynaptic spinal reflex activity. Studies on the efficacy of these medications as muscle relaxants, in patients with low back pain, indicate that most of them are better than placebo in decreasing muscle spasm, particularly in the acute stage (11, 19, 33, 35). The main side effect is sleepiness, which, however, may be useful in patients with acute syndromes, when bed rest is advised.

Muscle relaxants may be useful in acute low back pain, particularly in the presence of clear spasm of the paraspinal muscles. In subacute or chronic back pain, in which there is little or no muscle spasm, indications for these drugs are little or nil. In patients with only radicular pain, pure muscle relaxants are not indicated; the others may be useful only for their sedative effects and relief of anxiety. In lumboradicular syndromes, these medications are indicated in the acute phase to decrease low back, but not radicular, pain.

Phospholipids may activate neuronal metabolism, normalize membrane enzymatic activities and increase the turnover of neurotransmitters and endogenous phospholipids. Cyanocobalamin exerts a generic trophic action on neurons. These substances have no effect on pain, but they might favor, in some way, the functional recovery of damaged neurons. However, there is no proof that phospholipids and cyanocobalamin can be effective in favoring the functional recovery of impaired nerve roots in patients with disc herniation or other pathologic lumboradicular conditions.

Tricyclic antidepressants (amitriptyline, imipramina, doxepin) have long since been used. Their effects have not yet been completely elucidated, however multiple mechanisms of action might be involved. The main mechanism is probably related to the inhibitory effect of these drugs on the uptake of serotonin at nerve ending level and, thus, to an increase in the concentration of this substance in the synapses. Serotonin, being a neurotransmitter, might affect the mechanisms of transmission of pain stimuli. Sternbach (180) hypothesized that chronic pain produces depletion of serotonin in the brain, thus causing depression. Antidepressants, by increasing serotonin levels, would be effective in both conditions. In addition to the serotonergic effect, other mechanisms of action have been hypothesized: antidepressants might directly or indirectly affect the synthesis of endorphins (6) or might act by reducing anxiety and muscle tension (101) or masked depression (14). Pain, in fact, may be one of the multiple symptoms of masked or overt depression.

Several studies have shown that tricyclic antidepressants are more effective than placebo in patients with chronic low back pain (1, 81, 160). Some 60% of these patients obtain pain relief after 3–4 weeks of treatment (189). The therapeutic efficacy is likely to be similar in patients with chronic lumboradicular pain due to a herniated disc or other conditions causing nerve-root compression. However, there is no clear-cut clinical evidence in this respect.

Physical therapy

Electrotherapy

Continuous (galvanic) current

Continuous, or galvanic, current is used to perform iontophoresis, which consists in percutaneous administration of medications with a positive or negative polarity. The substance, placed at the homologous pole, would enter the body surface due to the electric field, which attracts it towards the opposite pole. In superficial tissues, the medication would be linked to ions with an opposite charge, thus forming a depot, and would be carried to the surrounding tissues by local blood circulation. Of the anti-inflammatory drugs, lysine salicylate, corticosteroids, lidocaine and other local anesthetics appear to penetrate the cutaneous barrier, whilst for many other medications there is no evidence that this occurs. In patients with low back, or lumboradicular, pain, the electrodes may be placed on the lumbar region on either side of the midline or arranged longitudinally on the lower limb or, again, one electrode may be placed on the lumbar region and the other on the upper portion of the thigh.

Although iontophoresis is widely used, considerable doubts exist on the pharmacodynamics of the medication ions (25, 27), as well as the efficacy of this therapeutic modality, particularly when the target organ is situated at a considerable distance from the skin, as in the case of the lumbar spine.

Alternating low-frequency or medium-frequency currents

These include the diadynamic currents, which are of low frequency, the interferential currents, which are of medium frequency, and the currents used for Transcutaneous Electric Nerve Stimulation (TENS). All these currents are employed for the so-called analgesic electrotherapy.

Diadynamic currents, introduced by Bernard, are modulated 50 or 100 Hz currents in phase opposition, but of the same sign. To avoid the habit forming which occurs with constant currents, four modalities of current delivery are mixed. Each treatment lasts 3 minutes, or double, if the polarity of the current is inverted, and may be performed several times a day. Diadynamic currents are still widely used, however much less than in the past. Interferential currents are used very little in clinical practice, mainly since delivery is not very practical.

TENS is performed by currents with a frequency of up 200 Hz, a voltage of about 80 mA and pulses lasting 50–400 microseconds, emitted at a rate of 2–150 per second. Pocket pulse generators are generally used (Fig. 14.4), which have two channels delivering single or groups of pulses, at a constant current flow. These parameters may be changed depending on the clinical features and patient's sensitivity. The treatment is generally performed with two modalities: using high-frequency and low-intensity, or low-frequency and high-intensity, currents. The first modality, which has rapid effects, but is of short duration, acts with the mechanism of the "gate control". The second modality, which has more lasting effects, would act by increasing endorphin synthesis (29), as suggested by the fact that administration of naloxone reduces the analgesic effect of the therapy (188). With the former, treatment may be carried out for several hours, whilst with the second, which is less well tolerated, the session usually lasts 1 hour. In patients with low back pain, the electrodes are usually placed transversely on the lumbosacral area. In lumboradicular syndromes, two electrodes are placed on the sides of the spinous processes at the level of nerve-root compression and other two are applied longitudinally on the lower limb, along the sciatic, or the femoral, nerve. However, for the treatment to be successful, the position of the electrodes appears to be less important (199) than the selection of the stimulation parameters (187) and adequate patient instruction.

Fig. 14.4. *Pocket equipment for TENS.*

Although TENS is the electric current therapy which has been most widely studied and with the most rigorous methods, its efficacy in patients with low back, or lumboradicular, pain is still debated. In acute low back pain, TENS is held to be less effective than exercise therapy protracted for 1 month (85). Of the studies on patients with chronic low back pain, a few reported a high success rate only at short term (8, 115), others found that the initial improvement was maintained at long term in about half the cases (49), and still others revealed no significant therapeutic efficacy of TENS, which was found to be less effective than exercise therapy in relieving pain (41). In patients with disc herniation, this treatment may be effective in alleviating radicular pain (2), but the available data in this respect are fewer than for low back pain and even more conflicting.

Yet another form of electroanalgesia uses monophasic currents of short duration and high amplitude, which would be able to reduce muscle spasm and delay muscle fatigue. This form of treatment may be useful only when associated with exercise therapy.

High-frequency alternating currents

Both shortwave (length 7–22 meters) and microwave (length 12.5 centimeters) currents produce deep thermogenic effects. Shortwaves penetrate into the body structures to an inversely proportional extent to the resistence of tissues and produce fairly deep and homogeneous tissue heating. Microwaves generate heat with the mechanism of dielectric losses. Their ability to penetrate, and the thermic effects, are high in the superficial structures, such as muscles, but poor or absent in deeper tissues. The therapeutic action of these currents is related to the ability of heat to increase the blood flow, to decrease γ nerve fiber activity and muscle spindle excitability and to inhibit the transmission of nociceptive impulses. Therefore, they can decrease muscle spasm and pain caused by muscle ischemia resulting from spastic contraction, and can raise the pain threshold by acting on nociceptive fibers. These therapeutic effects, however, remain to be fully demonstrated and little is known concerning the clinical results in articular and periarticular degenerative conditions.

In pathologic conditions of the lumbar spine, shortwave diathermy may be indicated for chronic low back pain due to facet joint osteoarthrosis, but not for discogenic low back pain and, in particular, for lumboradicular syndromes due to disc herniation, since in these cases deep heat may increase the inflammatory processes in the compressed nerve root. Microwaves are poorly indicated due to their poor ability to penetrate into soft tissues.

Over the last few years, hyperthermia, originally employed for oncologic treatments, has been also used in patients with traumatic or degenerative pathologic conditions of the locomotor apparatus. The advantage of this form of thermotherapy compared with the conventional modalities is that it allows us to more precisely quantify the heat delivered and to administer it at a predetermined depth and body surface (15). The available data on the therapeutic effects are still fragmentary and poorly documented.

Low-frequency magnetic fields

This form of treatment consists in exposing a body segment to a magnetic field. The latter can be generated by two types of current: one type, consisting of square waves, produces an electromotor force, which is able to stimulate the bone formation processes; and another type, consisting of sinusoidal waves, which would polarize the cells along the force lines of the magnetic field. In both cases, the frequency of generated currents is about 100 Hz. Little is as yet known about the mechanism of action of the low-frequency magnetic fields. The hypotheses so far advanced include: magnetoelectric and magneto-mechanical effects, enzymatic modifications, action on the partial tension of oxygen, molecular orientation and changes in cell permeability (13, 21, 161, 190).

One of the advantages of magnetic field therapy is that it does not produce thermic effects. It is thus suitable in patients with acute lumboradicular pain. However, there is no clear-cut evidence that magnetic fields have therapeutic effects in low back, or lumboradicular, pain syndromes.

Ultrasounds

Ultrasounds are sound waves with a greater frequency than that normally detected by the human ear (> 20.000 Hz), which travel in a material means on account of the successive compressions and decompressions of the structures that they cross. Thus, these enter in vibration producing thermic energy. Besides this effect, ultrasounds produce a micromassage and have a chemical action, consisting in processes of molecular oxidation, polymerization and depolymerization, related to the phenomenon of cavitation. Ultrasounds with 1 MHz frequency better penetrate the tissues, whereas those with 3 MHz frequency produce more superficial tissue heating (43). The emission may be continuous or pulsed and the application of the transducer on the skin may be massage-like or fixed; the latter modality is less used. The duration of treatment sessions is generally 5–10 minutes. In patients with lumboradicular pain, the treatment is carried out along the paraspinal muscles or on the side of the radiated pain. Ultrasounds, as the other forms of endogenous thermotherapy, are not indicated in the acute phase of pain, since they may stimulate the local inflammatory processes. In the subacute or chronic phase, the treatment may be carried out to relieve low back, rather than radicular, pain.

There are conflicting opinions regarding the therapeutic efficacy of ultrasounds in lumboradicular syndromes (69, 106, 153, 159). A meta-analysis of the literature over the last 40 years (87) revealed that, even in the most reliable studies, the methodology was not sufficiently rigorous due to incorrect use of double blind evaluation or deficiencies in the statistical analysis. Ultrasounds, despite the still existing doubts on their therapeutic efficacy, are among the most commonly used forms of physical therapy in patients with low back, or even lumboradicular, pain.

Phototherapy

This includes those forms of therapy employing sources of natural (heliotherapy) or artificial light.

Infrared, ultraviolet and Bier thermotherapy are forms of exogenous heat therapy, which produce an increase in temperature of the skin and superficial layers of the subcutaneous tissue. These may be indicated in patients with low back pain, preparing for massage of the lumbosacral area.

Laser (light amplification by stimulated emission of radiation) is employed since a few years in physical therapy, in addition to the dermatologic (mid laser) and surgical (power laser) use. Generators of soft laser generally consist of diode semi-conductors (Ga-As), occasionally associated with generators of mid laser (He-Ne). The determining parameter for the therapeutic action is the pulse frequency: low frequencies (less than 2000 Hz/sec) have analgesic and anti-inflammatory effects, whereas higher frequencies have a hyperhemic and biostimulating action. Tissue penetration, however, is low. There are conflicting opinions regarding the therapeutic efficacy of laser therapy on inflammatory or degenerative pathologic conditions of the locomotor apparatus (45, 108, 116). In a double-blind study of patients with chronic low back pain, the therapeutic effects of laser were similar to those of exercises (97). There is no clinical evidence indicating that this therapeutic modality may be effective in lumboradicular syndromes due to disc herniation.

Cryotherapy

Cold has various biological effects, such as capillary vasoconstriction followed by vasodilation, reduction in muscle spasm and conduction velocity of the nerve impulses, and hyperstimulation of large-diameter sensory nerve fibers. Two modalities of cryotherapy may be used: an extreme form, reaching −180°, and a mild form reaching −20°. Cryotherapy is usually performed by means of cold packs, ice massage, massage with jets of air, or cryogenic apparatuses programmed for temperature and duration of treatment. It is probably not necessary to reach temperatures much below zero to obtain therapeutic effects, which, instead, appear to depend, to a large extent, on the adaptability of the cryogenic means to the anatomic region to be treated and the duration of treatment (66).

In a study on patients with chronic low back pain, a 33% reduction in pain following ice massage was obtained in over two thirds (134). The therapeutic effects of this treatment in patients with lumbar disc herniation is still unknown, but the efficacy is likely to be very limited, even if present, at least on radicular pain. On the other hand, it should be taken into account that cryotherapy is often performed with considerable empiricism and may have adverse effects (burns, reactive edema) and contraindications (cryoglobulinemia).

Conclusions

The paucity of studies using rigorous scientific methodology to determine the mechanism of action and efficacy of physical therapy justifies the belief of those expressing skepticism on the validity of these forms of treatment. However, it should be underlined that, in this field, clinical experimentation is difficult due to the variability of the physics parameters employed in the various forms of treatment, poor knowledge of their biological effects and frequent association of other, even spontaneous, forms of treatment, such as drug uptake. Furthermore, these forms of treatment are essentially effective on pain and it may, thus, be difficult to discriminate between organic, and placebo, effects of the therapy. However, whatever the type of therapeutic action, physical therapies seems to be effective in relieving, or contributing to the relief of, pain in numerous patients with a low back, or lumboradicular, syndrome. In addition, these agents may replace medications or contribute to limit their uptake, and thus may be particularly useful in patients with gastric, hepatic or kidney disorders. The use of these forms of treatment is, therefore, fully justified, at least for those with less aleatory clinical effects, when there is a correct clinical indication and little or no risk of biological damage. It is, nevertheless, generally advisable to carry out these forms of treatment in association with other conservative methods to better the chances of a more rapid clinical recovery.

Manual therapies

Massage

Massage of back muscles has several biological effects: it enhances the skin temperature as a result of an increase in blood circulation; favors relaxation of paraspinal muscles and decrease in muscle spasm; improves muscle trophism; and has an analgesic action which might be related to a mechanism of hyperstimulation or direct or indirect effects on the synthesis of endogenous opiates. There is no scientific evidence that low back pain is significantly improved by massage either in the classic Western variants, including connective massage and lymphodrainage, or in the forms of Oriental origin (shiatsu). Most patients, however, report feeling a benefit from a correctly performed massage. This holds particularly for those with only low back pain. In those with lumboradicular symptoms due to disc herniation, massage may be effective mainly on back pain. A few of these patients, on the other hand, are unable to maintain the prone position in the acute stage of pain.

In patients with a herniated disc, massage should usually only be performed in the presence of low back pain and 2–3 weeks after the onset of symptoms, since in the first few days it may exacerbate the lumboradicular symptoms. In patients with buttock pain, it is useful to extend the massage to include the upper part of the buttock.

Manipulation

Chiropraxis, osteopathy and manual medicine are often erroneously considered as a single mode of treatment. Chiropraxis and osteopathy, although they have considerably contributed to the popularity of manual treatments, are based on concepts that do not lie within the criteria of traditional medicine. Chiropraxis is based on the concept of vertebral subluxation, which would be cured by manipulation, whilst osteopathy is founded on the principle of an indefinite "osteopathic lesion" and foresees maneuvers to mobilize numerous joints, including those between the cranial bones. Manipulation therapy has been brought within the scope of traditional medicine by Mennell (140) and Cyriax (34). More recently, Maigne has defined the principles of manual medicine directed to the vertebral column: it is indicated only in the presence of a minor intervertebral disturbance (MID) and consists in mobilization of the painful vertebral region and subsequent manipulation, according to the rule of non-pain and the contrary movement, i.e., in the opposite direction to that of limitation of movement. Mobilization, which is a less brusque maneuver than manipulation, starts where the active range of motion ends at the extreme of the physiologic motion of the anatomic structure. Manipulation is a quick passive movement of a spine segment beyond the limits of active joint motion, with immediate recovery of normal joint relationships (120).

There are few reliable scientific data on the effects of manipulation on a herniated lumbar disc. Mathews and Yates (126) reported two cases in which disc herniation diagnosed by epidurography was reduced following spinal manipulation. Chrisman et al. (28), on the other hand, failed to demonstrate any changes in the myelograms of patients with disc herniation after manipulation, and Wilson and Ilfeld (198) found no modification in the myelographic filling defect after manipulation carried out under general anesthesia. Nevertheless, a large number of patients, throughout the world, undergo manipulation therapy with results ranging from lack of any benefit to complete resolution of the pain. The still unsolved problems, therefore, are whether manipulation is effective in patients with disc herniation, whether it is dangerous and when there is an indication for manipulation therapy.

Efficacy

Many studies indicate that a large proportion of patients with lumboradicular pain submitted to manipulation do show improvement both in low back and radiated pain (47, 125, 162, 164). In none of the reported trials, however, was a precise diagnosis made regarding the etiology of the pain. On the other hand, in no investigation were the results of manipulation analyzed in a large series of patients with a herniated disc diagnosed by imaging studies. Although it has often been reported that manipulation may lead to a reduction in the protrusion of the nucleus pulposus, this has never been convincingly demonstrated in a statistically significant number of patients. It is still unclear, therefore, whether manipulation is effective, at least from the clinical viewpoint, in patients with disc herniation, or whether it may be effective in some pathologic types of herniation and ineffective in others. It is feasible to presume, however, that manipulation cannot be effective in patients with transligamentous extruded, or migrated, herniations.

In many cases, other treatments, such as massage, heat, traction, muscle stretching, exercises or prolonged talk with the patient, are associated with manipulation. It is possible that the therapeutic efficacy of manipulation may be partly due to the associated treatments or may be enhanced by them.

The therapeutic effects of manipulation were found to be better when evaluated at short intervals after treatment (157, 174). These findings concern patients with generic low back pain, but it is unknown whether they are valid also in patients with radicular pain due to disc disease.

Complications

Lumbar manipulation, particularly chiropraxis, involves the risk of even severe complications, regardless of the skill with which it is performed. This holds particularly for patients with disc herniation. Numerous cases have been reported of a cauda equina syndrome occurring after manipulation in patients with disc herniation, which certainly or presumably was preexistent to the treatment. Most of the complications were observed in patients undergoing manipulation under general anesthesia (a practice now abandoned), but 14 cases occurred after manipulation performed in outpatients (63, 78) and, even if in many cases no definite etiologic relationship could be demonstrated between manipulation and the cauda equina syndrome, in most patients there was a close temporal relationship between the treatment and the complication (78). On the other hand, we have observed several patients with disc herniation in whom radicular symptoms became more severe following manipulation and similar occurrences have been reported by others (63, 195). In two patients coming to our attention with contained herniation who presented an exacerbation of symptoms after manipulation, CT revealed extrusion of the herniation (Fig. 14.5).

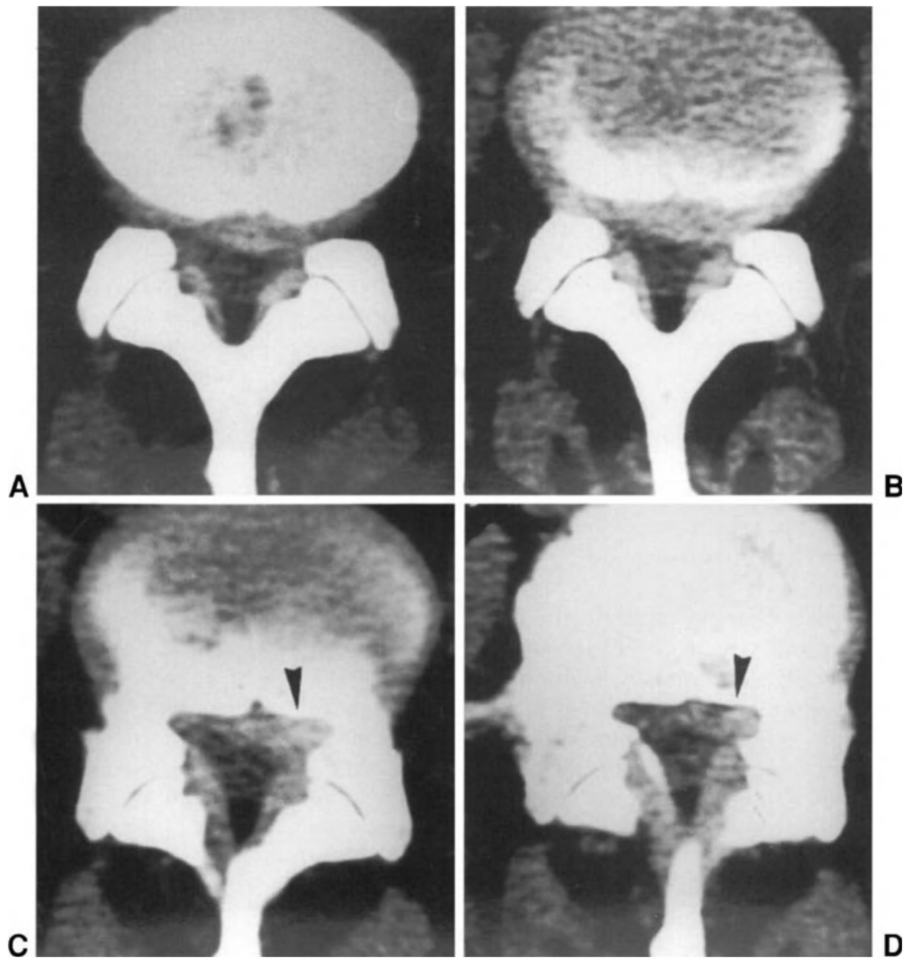


Fig. 14.5. *CT scans of a female with contained paramedian disc herniation who underwent manipulation* (A) *and* (B). *After four manipulations, radicular symptoms became more severe with onset of a L5 motor deficit. The patient withdrew from treatment. CT scans performed after the last manipulation* (C) *and* (D) *showed subligamentous extruded herniated disc (arrowheads).*

The rate of complications is certainly very low compared with the large number of patients undergoing manipulation therapy. However, the risk of severe complications should make us very cautious in the indication for this type of treatment in patients with disc herniation. Furthermore, manipulators should be well aware that the possibility exists of causing or increasing compression of the nervous structures when they treat patients with herniation or suspected herniation.

Indications

Manipulation therapy may be indicated in patients with only low back pain, particularly in acute syndromes, in which manipulation may provide even better results than other forms of conservative treatment (51, 68, 162, 166). Similarly, patients with predominantly low back pain and referred discomfort in the lower limb may be good candidates for manipulation therapy (158). In the presence of radicular or lumboradicular pain, manipulation may be indicated or contraindicated. The presence of neurologic deficits is usually considered the discriminating factor in this respect. In our opinion, other factors should also be evaluated before deciding upon the indication for manipulation therapy.

In acute or subacute lumboradicular syndromes, manipulation is generally contraindicated: 1) In the presence of motor or sensory deficits, or depression of pertinent reflexes (for instance, the ankle jerk in a S1 radicular syndrome). This form of treatment is also contraindicated both in patients in whom CT or MRI have demonstrated disc herniation, and in those who have not yet undergone diagnostic tests; on the other hand, clinical evidence indicates that most patients with neurologic deficits tend to have poor results with manipulation (96, 144, 164). 2) In patients with no neurologic deficits not submitted to CT or MRI, when nerve-root tension tests are moderately or markedly positive; in these cases there may be even a large midline disc herniation, or extruded herniation, which may increase in size or undergo transformation into an extruded or migrated herniation after manipulation. 3) In those patients with no neurologic deficits in whom diagnostic tests show a contained middle-size or large herniation, an extruded or migrated herniation, or lumbar stenosis.

In addition to these specific contraindications, there is a long series of generic contraindications, such as severe osteoporosis, vertebral fractures or tumors, rheumatoid arthritis or ankylosing spondylitis.

Of the patients with acute lumboradicular syndrome, good candidates for manipulation therapy are: 1) Those not submitted to CT or MRI, who show no neurologic deficit and slightly positive nerve-root tension tests; in these cases, however, a neuroradiologic imaging study is recommended before performing manipulation. 2) Those patients showing no neurologic deficit, in whom CT or MRI have demonstrated a bulging annulus fibrosus or small contained disc herniation. In the latter case, manipulation, particularly forced or brusque rotations, should be stopped if they produce or exacerbate radicular pain (158).

In subacute or chronic lumboradicular syndromes, the indications may be extended to those patients in whom a middle-sized contained herniation has been present for a few months at least, provided radicular pain has considerably decreased or disappeared over the time, or CT or MRI show that the pathologic condition has not changed or the disc protrusion has decreased in size. In these cases, structural changes occurring over time in the herniated disc make it very unlikely that disc protrusion will increase following manipulation. The absence of a pertinent reflex (which often does not return once it has disappeared, even if the nerve root is not significantly compressed) does not represent a contraindication to manipulation. However, also in chronic syndromes, the presence of neurologic deficits considerably decreases the chances of a satisfactory result (96).

In previously operated patients, the indications for manipulation are similar to those outlined for nonoperated subjects. In those operated on, however, the presence of neurologic deficits, particularly of reflexes, may not represent a contraindication even in acute syndromes.

Traction

Traction of the lumbar spine can be performed in various ways. Usually, beds with electric traction able to generate forces of up to 100 kg are used. The patient is placed on the bed in the supine position and the direction of the traction force is parallel to the longitudinal axis of the body. Traction may be continuous or intermittent. Continuous traction is usually employed, applying forces as high as 25%–50% of the patient's body weight, for periods of a few minutes to more than 1 hour. In intermittent traction, the application of the force lasts a few seconds and is followed by a resting period of comparable duration.

Autotraction, first proposed by Lind and then improved by Natchev, is performed by the patient himself/herself, who pulls, for few seconds at intervals of 30–60 seconds, on a harness located at the head of the bed. The most modern beds consist of two parts operated electrically independently from one another; the patient generates traction by pulling on bars placed at the head of the bed (Fig. 14.6). The duration of each autotraction is 3–6 seconds and the session lasts 30–40 minutes. With a few beds, only longitudinal traction is possible, whereas others allow also flexion, extension and rotation of the lumbar spine. Beds of the latter type

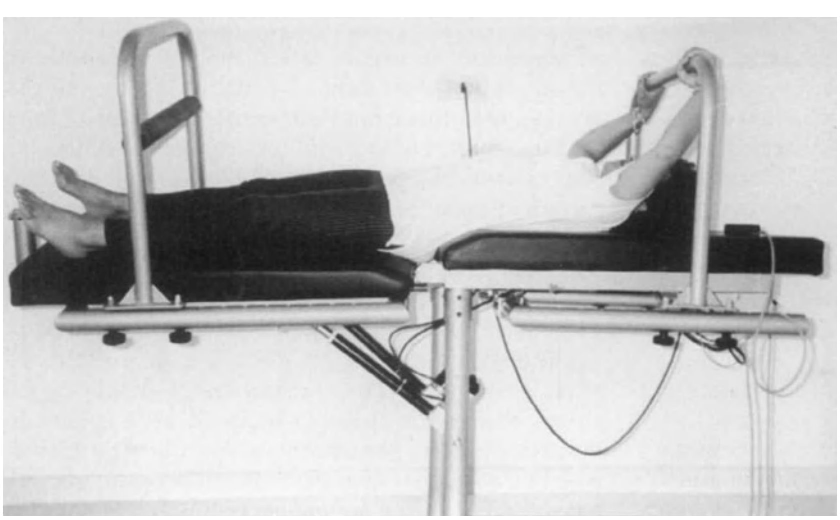


Fig. 14.6. *Apparatus for autotraction with electrically operated movement.*

are inclined and rotated so that the patient passes from a position of little pain to one of less tolerable and, for each position, autotraction is carried out.

Gravity traction is performed by suspending the patient vertically on a support in the inverted position (head down) for a few minutes. Manual traction is that performed during the sessions of spinal manipulation.

Passive traction produces intervertebral distraction, reduces intradiscal pressure, although not more than 20%–30% (148), and may lead to reduction of contained disc herniation (76, 124, 156). The latter effect has been observed (156) more often in midline (78%), than posterolateral (66%) or lateral (57%), herniations. Mathews (122), however, found that a few minutes after the end of traction, herniation returns to the original size. Intermittent passive traction would favor the inflow of nutrients into the disc and facet joints. Autotraction, unlike passive traction, does not decrease intradiscal pressure (3). It has been hypothesized that the treatment may act by modifying the interface between the disc and the peridiscal nerve endings and / or by decongesting the epidural venous plexus (184).

The therapeutic efficacy of passive traction in patients with disc herniation is still controversial. In some studies (88, 156), a significant clinical improvement has been observed in patients undergoing traction, but in other trials (31, 125), the treatment was not found to be significantly effective or more effective than other forms of conservative management, such as thermotherapy, corsets or an exercise program. In a controlled study analyzing patients submitted to effective traction (one third of body weight for 20 minutes) or placebo traction, no significant differences were found between the two groups (193). Most of the studies on the therapeutic effects of autotraction indicate that this mode of treatment is effective in reducing low back or lumboradicular pain in a large proportion of patients (105, 109, 114). Tesio et al. (185), in a randomized study on patients complaining of subacute or chronic low back or lumboradicular pain, obtained satisfactory results in 75% of cases. Some of these studies, however, have not used rigorous criteria in the evaluation of efficacy of the treatment, the mechanisms of action of which still remain unclear.

In the case of gravity traction, the patient is exposed to various side effects, including cardiocirculatory, visive and gastrointestinal involvement, for which this mode of treatment is often contraindicated.

Biofeedback

This technique reveals otherwise undetectable events by means of a proportional change in a visual or auditory signal. The patient may thus modify these events depending upon the signals that he/she perceives. Electromyographic biofeedback is the technique currently used to affect muscle contractile activity. The electric activity of the muscles involved is recorded by means of surface electrodes and the EMG signals are shown to the patient who has previously been instructed as how to interpret their significance. The patients is then taught to relax or contract the involved muscles by evaluating the effects of his/her attempts on the electromyograph. Treatment is carried out over a 3-week period.

The use of biofeedback in patients with chronic low back pain is based on the assumption that these patients have high muscle tension, particularly of the paraspinal muscles. The treatment may teach the patient to relax these muscles or, more in general, to attain a state of psychomotor relaxation. Studies aimed at determining the efficacy of the treatment have led to controversial results. In a few trials, the treatment was found to be effective (59, 135), whereas in others (22, 100, 151), results were comparable to those following placebo or demonstrated a decrease in EMG activity of the paraspinal muscles, but not a significant relief of pain. Biofeedback, however, may be of value in modifying the perception of pain in patients with chronic low back pain. In patients treated with this technique, there may be a better self-control and greater reliance upon the medical approach resulting in pain relief. To our knowledge, no specific analysis has been made of patients with lumboradicular pain caused by disc herniation or other pathologic conditions responsible for chronic compression of lumbar nerve roots. Presumably, this mode of treatment can lead to relief of radicular pain only as a result of changes in pain perception.

Acupuncture

Acupuncture consists in introducing 30 G needles in the cutaneous areas situated along the chinese meridians, i.e., hypothetic force lines crossing the body from the head to the big toe. After insertion, the needles are slowly twisted and removed after 20–40 minutes. Electric stimulation with currents of varying frequency and voltage can be performed through the needles (electroacupuncture). Most of the points in which acupuncture is performed are close to the site of the pain, however a few are located at a distance from it.

The mechanism of action of acupuncture seems to be of at least two types. Acupuncture stimulates the release of endogenous opiates, i.e., of endorphins. In fact, the effects of the treatment may be, in part, abolished by administration of opiate antagonists, such as naloxone (128). The second mechanism concerns the "hyperstimulation analgesia", which is based on the Melzack and Wall, gate theory (136). According to this theory, the perception of a sensory stimulus at brain level may be inhibited by another stimulus, of different nature and intensity. In the case of acupuncture, stimulation of cutaneous mechanoreceptors depending on large myelinated fibers would close the gate in the spinal cord, thus preventing the nociceptive stimuli transmitted through small unmyelynated fibers from reaching the cortex centers. Cutaneous injection of procain before acupuncture, in fact, abolishes the analgesic effect of the treatment.

The effects of acupuncture have been studied, almost exclusively, in patients with chronic low back pain. Prospective randomized studies comparing the therapeutic effects of acupuncture performed with a correct technique along the body meridians with the effects produced by insertion of needles in areas located outside the meridians, indicate that acupuncture does not provide significantly better results than non-orthodox application of needles (46, 65, 70). In a double-blind study (137), in which control patients received superficial injections of lidocain, acupuncture was found to be slightly, but not significantly, more effective than the injections of the anesthetic. However, acupuncture, compared with physiotherapy and occupational therapy or placebo TENS, has provided significantly better results (75, 129).

Many acupuncturists treat patients with lumboradicular pain caused by a herniated disc and a few have reported a large proportion of satisfactory results. These results, however, have not been corroborated by prospective randomized studies including control groups treated with placebo. It is, thus, unclear as to what extent the satisfactory results are due to the natural history of the disease, rather than to the effects of the actual treatment. Whilst available data indicate that, in patients with low back or lumboradicular pain, acupuncture may be effective, the efficacy does not seem to be significantly greater than that of other conservative treatments.

Injection therapy

Injections of pharmacologic agents may be given in: 1) the derma of the lumbar region or the thigh (mesotherapy); 2) the paravertebral muscles in proximity to the facet joints (paraspinal injection); 3) the area of the intervertebral foramen (paraforaminal injection); 4) the articular space of the facet joints (articular injection); 5) the epidural space (epidural injection); 6) the thecal sac (intrathecal injection); 7) the intervertebral disc to produce chemonucleolysis; this modality is analyzed in chapter 15.

Mesotherapy (Mésotherapie)

With this technique, small amounts of the medication are introduced in the derma by means of Lebel needles (length 4 mm, caliber 27 G) inserted into a conventional syringe or in a round plate. If a syringe is used, multiple injections are necessary, whereas when plates, which contain multiple needles, are employed, the injection occurs simultaneously through all the needles. One or more agents may be injected; usually a local anesthetic is associated with a NSAID and/or a vasoactive drug. The therapeutic effects would depend on the reflexogenic action of the needle and the injected medications. The treatment is performed weekly and is stopped if pain does not improve after 3–4 sessions.

In patients with low back or lumboradicular syndromes, the injections are made in the lumbar paravertebral regions and/or along the course of the sciatic nerve. This therapeutic modalty is indicated, as an

Fig. 14.7. *Schematic drawing of paraspinal injection.*

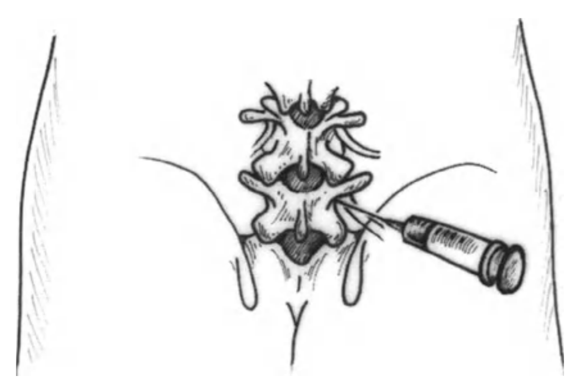


Fig. 14.8. *Paraforaminal injection. The needle reaches the area of the intervertebral foramen.*

initial form of treatment, in patients with lumbar disc herniation (64), but there are no unequivocal scientific data demonstrating the efficacy of the treatment in relieving low back or radicular pain.

Paraspinal injection

Paraspinal injections are made 2–3 cm from the spinous processes using a 20 G or 22 G spinal needle, which is advanced until the bone surface is reached (Fig. 14.7). At this point, injection of the pharmacologic agent begins. The direction of the needle is then changed to inject the medication above and below the initial site of inoculation. Finally, while withdrawing, the remainder of the drug is injected into the paraspinal muscles. The injection is made either on one or both sides. Fluoroscopic guidance is not needed. The medications currently used are slowly absorbable corticosteroids diluted in 10 ml of local anesthetic.

The pharmacologic agents may act on the facet joints and the paraspinal muscles either directly or indirectly through the posterior branch of the spinal nerve. The medications may decrease the muscle spasm and articular and periarticular inflammatory processes in patients with acute low back pain. Although some patients undergoing paraspinal injections obtain relief of low back pain, there is no evidence that these injections are more effective than systemic administration of anti-inflammatory drugs or analgesics. Paraspinal injections do not relieve radicular pain produced by disc herniation. Thus, they are usually not indicated in patients with clinical evidence of nerve-root compression.

Paraforaminal injection

The medication is injected in the area surrounding the exit of the intervertebral foramen (Fig. 14.8). The injection may or may not be performed under fluoroscopic guidance. The injection under fluoroscopic vision is carried out with the patient in the sitting position. To reach the L4 or L5 nerve root (radicular nerve), the spinal needle (22 G) is introduced 6–8 cm from the midline, in close proximity to the iliac crest, and is advanced medially with an angulation of some 60°, until the area of the L5 transverse process is reached (or, possibly, the transverse process is touched). The needle is then advanced, proximally to reach the L4 nerve root or distally to reach the L5 root, at a depth of 1–2 cm. To reach the S1 nerve root, the needle should be inclined by about 45° in the cranio-caudal direction until the tip is seen in proximity to the first sacral foramen. If, whilst advancing the needle, the nerve root is punctured, the patient feels acute radicular pain, which diminishes or disappears by withdrawing the needle a few millimeters. This technique is simple, but not precise, since one has the certainty that the tip of the needle is in close proximity to the nerve root only if this is punctured. With the use of the fluoroscope, the technique is the same as that for radiculography (page 269).

A few clinicians inject only a local anesthetic with normal or slowly absorbable characteristics, the effects of which, however, last only a few hours (99). The addition of a slowly absorbable corticosteroid may prolong the effects due to a decrease in the inflammatory reaction which may be induced by the drug.

After the injection, the patient should be under surveillance for 30–60 minutes, particularly if the nerve root has been punctured and the anesthetic may, thus, have entered the thecal sac. In this event, motor or sensory deficits may be produced, which however disappear in a few hours.

If the injection is not performed under fluoroscopic guidance, the procedure can be repeated several times, even daily; in this instance, 4 days should be allowed to elapse before adding the corticosteroid again to the anesthetic. If the fluoroscope is used, the number of injections should be limited to 2 or 3 in order to avoid excessive exposure of the patient to ionizing radiation.

The greatest therapeutic effect is reported to be obtained after six injections (99). However, also for this technique, there is no evidence that it is more effective than placebo or other conservative therapies, if the temporary pain relief produced by the anesthetic is excluded. This form of treatment may be indicated in patients with nerve-root irritation syndrome after failure of epidural injection, when there is no indication for more aggressive invasive treatments (23).

Epidural injection

The epidural injection of local anesthetics in patients with lumboradicular pain is a therapeutic procedure already practiced in the 1920's (186). Over the last few decades, a slowly absorbable corticosteroid has usually been associated with the anesthetic. Injections merely of anesthetic agents may be used for anesthetic purposes (179).

Technique

The injection may be made in the lumbar region or through the sacral hiatus.

The injection in the lumbar spine is usually performed at L3-L4 level, using a 22 G or 25 G spinal needle, connected to a syringe containing saline or

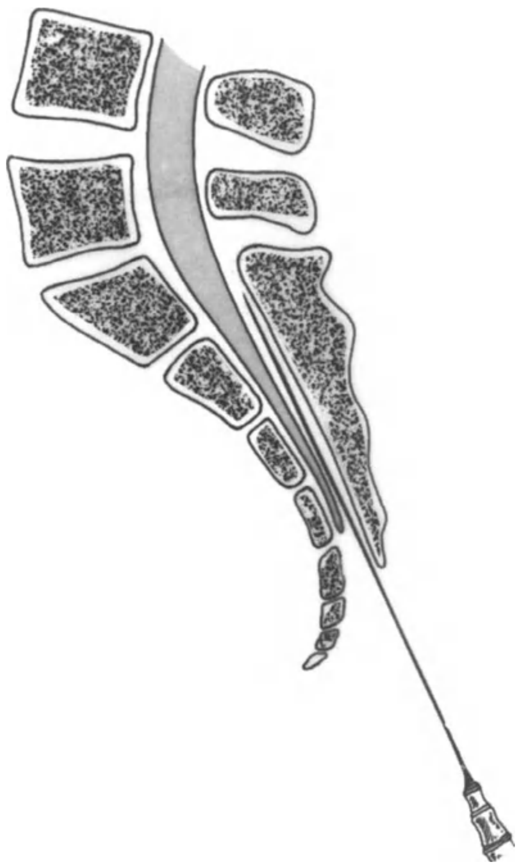


Fig. 14.9. *Epidural injection performed through the sacral hiatus.*

air. The needle is very slowly introduced through the interspinous ligament, while simultaneously pushing the syringe plunger, until a sudden decrease in resistance is felt when the epidural space is reached. The syringe plunger is withdrawn to make sure that the needle has not penetrated the subarachnoid space. Then, a small amount of air or saline is injected: if no resistance is encountered, the tip of the needle is situated, in all probability, in the epidural space. An alternative technique employs the hanging drop test (18). For further confirmation of needle positioning, 1 ml of contrast medium may be injected, while checking with the fluoroscope that it is inoculated into the epidural space. In a large series of cases (197), an initial error in needle positioning occurred in 20% of patients. The corticosteroid (80 mg methylprednisolone acetate or 50 mg triamcinolone diacetate), diluted in 5 ml of saline or 3 ml of 0.5% marcaine, is then injected. The patient is left in the supine position and checked for 15 min, and then allowed to go home.

If the caudal route is used, the needle is pointed, with or without fluoroscopic guidance, towards the sacral hiatus, proceeding until decreased resistance is felt and the needle is then advanced for a few millimeters (Fig. 14.9). The same steps as those described for the lumbar injection are then performed.

Provided one does not penetrate the thecal sac, no complications can occur, except for possible infections (26).

Therapeutic effects

A prospective randomized double-blind study (32) has compared the effects of an epidural injection of 80 mg of methylprednisolone acetate combined with 5 ml of procaine with those produced by the same volume of saline and procaine, in patients with disc herniation or lumbar stenosis diagnosed by neuroradiologic studies. The results were evaluated 24 hours and at least once every 3 months after injection for a mean period of 20 months. The result was considered as positive when pain had decreased by 75% or more. In the group of patients with disc herniation, the result was positive in 32% of cases treated with the steroid and in 35% of those receiving placebo. Even at long term, the epidural injection of steroid was not found to be more effective than placebo. The results of this study confirm those of a previous trial (176), in which very similar methods had been used. The criticisms raised regarding these two studies concern the evaluation of the short-term results, which was made only 1–2 days after treatment. It has been, in fact, observed that a few days are usually necessary for the steroid to produce relief of lumboradicular symptoms (42, 73). Furthermore, in many cases a satisfactory result is obtained only after the second injection: in one series (191), this occurred in 58% of 144 cases.

In contrast to these two investigations which failed to demonstrate any therapeutic efficacy of the steroids, there are many others indicating that the epidural injection of steroids is indeed effective in patients with disc herniation (7, 16, 20, 24, 181, 197). A few of these are prospective randomized double-blind studies, in which the steroid was compared with a placebo. Dilke et al. (42) have added the steroid to 10 ml of saline, evaluating the results after 8 days and then repeated the injection in one third of their patients who showed little improvement in symptoms after the first injection: the outcome was satisfactory in 60% of cases treated with the steroid, compared with 31% of those who had received the placebo. Similar results were obtained in a study (167) performed on outpatients using similar methodologic criteria to those in Dilke's trial. In a recent study (24), corticosteroids injected through the sacral hiatus were found to be significantly more effective than placebo. The criticisms that can be raised concerning the studies in which epidual injection of steroids was reported to have good therapeutic efficacy are that: many of them are not prospective randomized double-blind trials; a few included a small number of patients; in the majority, the clinical diagnosis of disc herniation had not been confirmed by neuroradiologic studies. Moreover, in some of these studies (42) the satisfactory results at short term did not deteriorate with time, whilst in other series (197) most of the short-term successes turned to failures within a few months.

Indications

The clinical data available so far fail to resolve the issue concerning the therapeutic efficacy of epidural injection of corticosteroids. This, however, is certainly the only type of spinal injection indicated in patients with lumbar disc herniation.

In our opinion, the most elective indication for epidural injections is small disc herniation responsible for radicular symptoms of recent onset (3–6 weeks), if pain is refractory to systemic anti-inflammatory therapy and physiotherapy, or when systemic therapy is contraindicated on account of the presence of gastrointestinal disorders. At the opposite extreme are those patients with a large disc herniation, severe radicular pain and marked radicular deficits, in whom there is usually little indication for epidural injections due to the poor chances of a significant improvement in the clinical syndrome. In the intermediate situations, the indication is considerably influenced by the habits of the clinician and the willingness of the patient to undergo injection therapy, the severity and duration of radicular symptoms, the severity of nerve-root compression, and the coexistence or not of stenosis (which, unlike disc herniation, shows no tendency to spontaneous regression with time). A successful outcome is certainly more likely in patients with only disc herniation, acute radicular inflammation, mild nerve-root compression and psychologic resistance to undergo surgery.

The number of injections to be performed will depend on the result of the first injection. If this has provided little relief of radicular pain (less than 30%) or a considerable relief (more than 70%), there is no indication for a second injection. If the first has provided mild improvement, it may be useful to repeat the injection after 2 weeks and, if improvement increases, to perform a third injection after 2–4 weeks.

Intrathecal injection

Injection of a corticosteroid, associated or not with a local anesthetic, into the subarachnoid space is probably more effective than epidural injection, since the medications act directly on the nerve roots in their intrathecal course. This procedure, however, involves risks of complications due to lumbar puncture (headache, nausea, vomiting), the anesthetic (hypotension, spinal anesthesia) or the steroid. The latter, or its vehicle, might lead to the risk of adhesive arachnoiditis (9, 165). Due to the possibility of this complication, there is little indication for intrathecal injection of corticosteroids.

Facet joint injection

The therapeutic efficacy of these injections in patients with proven or presumable pathologic conditions of the articular facets is highly uncertain (91, 141, 155). In patients with disc herniation or, more in general, with pain caused by disc disease, there is no indication for performing injections into the zygoapophyseal joints.

Oxygen-ozone therapy

Oxygen and ozone, after their use in the treatment of arteriopathies, bed sores and lipodystrophy, have been employed in the management of lumbar disc herniations.

A mixture of 30–40 ml of O_2–O_3 at concentrations of 20–30 micromole/ml are injected in the paraspinal muscles at the level of the herniated disc. The treatment is performed twice a week for some 2 months. It has recently been proposed to directly inject the two gases into the intervertebral disc. In this instance, the volume of gas injected is about 3 ml at a concentration of 10 micromole/ml and 2–3 injections are given. Very little is known concerning the mechanism of action of paravertebral injections: it would appear to be related to increased oxygenation and improved tissue metabolism, as well as to the anti-inflammatory effects of the oxygen itself. As far as concerns the intradiscal injection, it has been hypothesized that oxygen and/or ozone may produce oxidation of the mucopolysaccharides in the nucleus pulposus resulting in a decrease in size of the herniation. At present, there is no reliable scientific data demonstrating the efficacy of oxygen-ozone in producing pain relief in patients with disc herniation and certainly no evidence of a possible decrease in size of the herniation.

Re-education

Exercise therapy

Of the numerous techniques proposed for exercise therapy, three represent the cornerstones in the rehabilitation of patients with low back or lumboradicular pain.

Flexion exercises

Flexion exercises, which are, even today, the most frequently performed, are designed to open the intervertebral foramens, to mobilize the posterior joints, to lengthen the extensor muscles of the trunk, and, in particular, to strengthen the abdominal muscles. The aim is to increase intra-abdominal pressure, thus stabilizing the lumbar spine, and to reduce lumbar lordosis by activating the abdominal and gluteal muscles. The criticism addressed to these exercises is that they may be harmful in patients with discogenic pain, since those activating the recti abdomini muscles increase intradiscal pressure, whilst those designed to flex the trunk, particularly when performed in the standing position, may lead to an increase in posterior protrusion of the disc.

These drawbacks are partly overcome by isometric exercises, performed in the supine or upright positions, and carried out in a single session for few minutes several times a day (95).

Mézières's method

In 1949 Françoise Mézières presented her program of re-education of the spine in a small volume entitled "Révolution en gymnastique orthopédique" (139): "Spinal muscles should be elongated in all their length rather than toned up and shortened by backward flexion of the trunk and the head against the resistance...". A true revolution, therefore, with respect to the conception predominating at that time and still today strongly held in consideration, according to which, strengthening of the extensor muscles of the trunk plays a pivotal role in re-education of patients with back pain.

Mézières based her method on six principles: 1) The back muscles behave as a single functional unit. Thus, the spastic contraction of even one single muscle in the kinetic chain leads to shortening of all the muscles in that chain. 2) The muscles of the posterior kinetic chain are always in a condition of shortening and increased tone, whereas the anterior muscles are always hypotonic. 3) Any action finalized to shorten or lengthen one element of the kinetic chain leads to shortening of the whole system. 4) The attempt to resist shortening, immediately produces lateral bending or rotation of the spine and the lower limbs. 5) Hypertone of the muscles in the lower limb consistently produces internal rotation of the limb. 6) Any elongation implies a respiratory block in expiration.

The methodology of postural re-education stemming from these principles is based on postures in eccentric isometric contraction, which, during expiration, produce muscle stretching and a decrease in muscle hypertone. According to this method, isotonic contractions, which tend to shorten muscles, should be strictly avoided.

McKenzie's method

This method is based on the concept that the application of mechanical forces by mobilization of the lumbar spine in flexion-extension or lateral bending up to end-range motion makes it possible to better determine the pathogenesis of low back pain by referring to three main categories in the spectrum of nonspecific pain: the postural, dysfunction and derangement syndromes (130, 131). Furthermore, it is possible to determine the nature of the mechanical disorder responsible for low back pain and to identify the direction and intensity of the mechanical forces to be applied in order to obtain pain relief. In the derangement syndrome, for instance, there may be posterolateral protrusion of the intervertebral disc needing mobilization in lateral bending or a condition of anterior protrusion in which pain will be diminished or abolished by flexion.

A characteristic phenomenon described by McKenzie is centralization of pain, i.e., the change in location of pain from a peripheral area, for instance the calf, to a more central area, such as the buttock, when taking up a certain posture or performing an end-range movement. Centralization of pain has a favorable prognostic significance and the postures or end-range movements which have produced it are used in the treatment. However, although the criteria described by McKenzie allow a detailed classification of the different forms of nonspecific low back pain and a rational therapeutic planning, the modalities of treatment are in effect dictated by pain. Thus, a painful syndrome which should in theory be treated with mobilization in extension, may improve in effect with flexion treatment.

The mechanical force can be produced in a static way by assuming specific postures or in a dynamic way by active exercises. Postures generate lower mechanical forces and should be reserved for conditions characterized by severe pain. In other conditions, a single exercise should be performed several times a day: as a rule, 10–15 repetitions every 2 hours. The criterion for judging whether the treatment is correct is the modification in pain. If pain centralizes or decreases, the treatment is continued, whilst an increase or change in location of pain to a more pheripheral area of the body indicates that treatment needs to be modified. Once the method has been taught, the patients, guided by pain, rapidly learn the modalities of prevention and self-treatment.

There is little indication for the extension exercises of the McKenzie technique in patients with osteoarthrosis of the facet joints or lumbar stenosis. Furthermore, these exercises may easily lead to an exacerbation of symptoms in patients with an acute lumboradicular syndrome due to disc herniation.

Low back schools

The first low back school was developed in Sweden by Zachrisson-Forsell in 1969 (200). The inspiring concept was to transform the patient with low back pain from a passive subject in the fruition of the most disparate therapies to an active and responsible subject able to manage his pathologic condition. This therapeutic modality was aimed at instructing the patient about the static and dynamic mechanisms responsible for low back pain in order to prevent it and at educating him to the daily routine of exercises for the maintenance of normal tone, strength and elasticity of the muscles.

Modalities

The Swedish back school program consists of four 45-minute lessons held by a physiotherapist teaching 6–8 patients, in a 2-week course (200). In the first lesson, the patients are taught about the anatomy and function of the spine, the clinical features and natural history of low back pain, as well as the modes of treatment of the disease. In the second lesson, the mechanical strain occurring in different positions and in the course of various movements is discussed, and the relationship between the center of gravity and strain on the back is explained. The function of the muscles and their influence on the back is demonstrated and some relaxation exercises are taught. The third lesson consists in the practical application of this theoretical knowledge. The patients are also taught isometric abdominal muscle training and advised to continue the exercises at home. The fourth lesson consists mainly in encouraging the patients to increase their level of physical activity and to take part in sports to improve their psychophysical tolerance to pain and stress. This lesson is concluded by seeing how much the patients have assimilated during the course.

Many other low back schools have since been set up, which have been structured either like or differently from the original Swedish school.

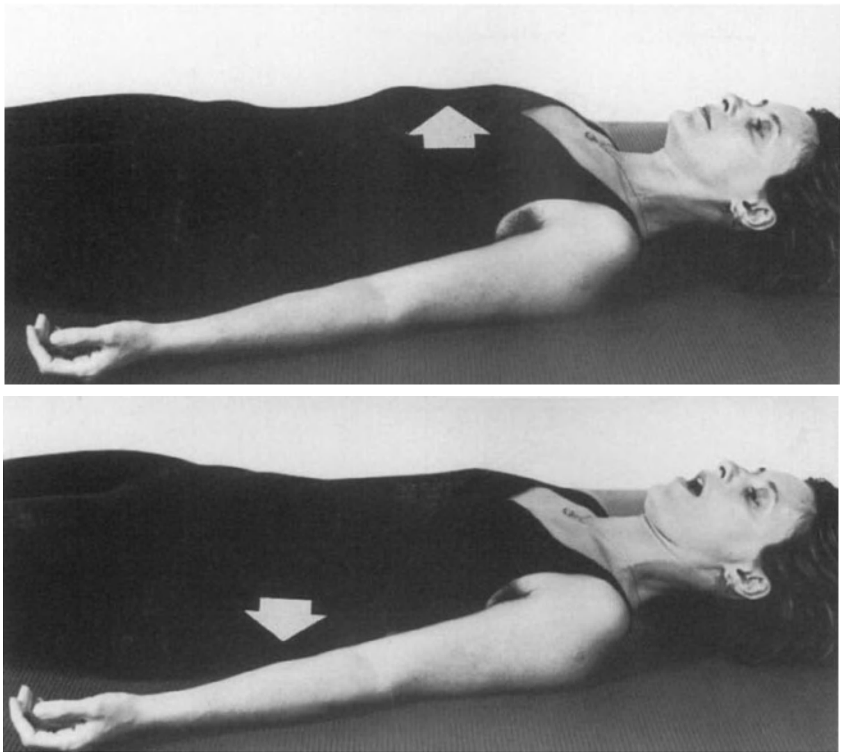
The Canadian back education units, set up in 1974, have stressed the importance of the psychologic aspects in the therapeutic control of low back pain, by including, in the teaching group, a psychiatrist and a psychologist in addition to an orthopaedic surgeon and a physiotherapist (79, 80). The program consists of four 90-minute lessons held at weekly intervals for classes of 15–25 patients. The first session covers anatomy, physiology and pathophysiology of back pain. In the second, discussion is focused on the basis of physiotherapy and the effectiveness of back care. The third describes the place of emotion in chronic pain and the psychiatric aspects of back trouble. The fourth lesson is a practical demonstration of relaxation methods and exercise therapy.

The California back school, developed in 1976, has strictly ergonomic and more individualistic characteristics than previous schools (127). It consists of three 90-minute lessons held for a maximum of four patients at weekly intervals. At the end of the program, the patients are taught exercises to reinforce body mechanics. A unique element of this program is the use of an obstacle course to evaluate physical performance skills.

A few low back schools include individual tuition, as well as group, programs (54, 127). In a few schools (86), in addition to 4-hour courses, 12-hour programs have been developed to make teaching more gradual and analytic. In others (so-called mini-back schools), teaching is concentrated into a single 4-hour course (12) or a 45-minute lesson, in which no exercises are taught (177).

In Italy, the first low back schools were set up between the end of 1970's and the beginning of 1980's (149, 163). Postacchini's school (163) consisted of four 90-minute sessions, for two consecutive days, held by an orthopaedic surgeon, a physiatrist, a psychiatrist and a physiotherapist. This school had intermediate characteristics between the Swedish and Canadian schools. In fact, it was aimed at: providing adequate information on the anatomy and physiology, as well as on the diseases of the lumbar spine (orthopaedic surgeon); explaining the fundamentals of ergonomy and biomechanics of the vertebral column, and the objectives and methodology of exercise therapy (physiatrist); clarifying the role of psychologic factors in the genesis of pain (psychiatrist); and practical teaching of the exercises that the patients were encouraged to perform every day at home (physiotherapist).

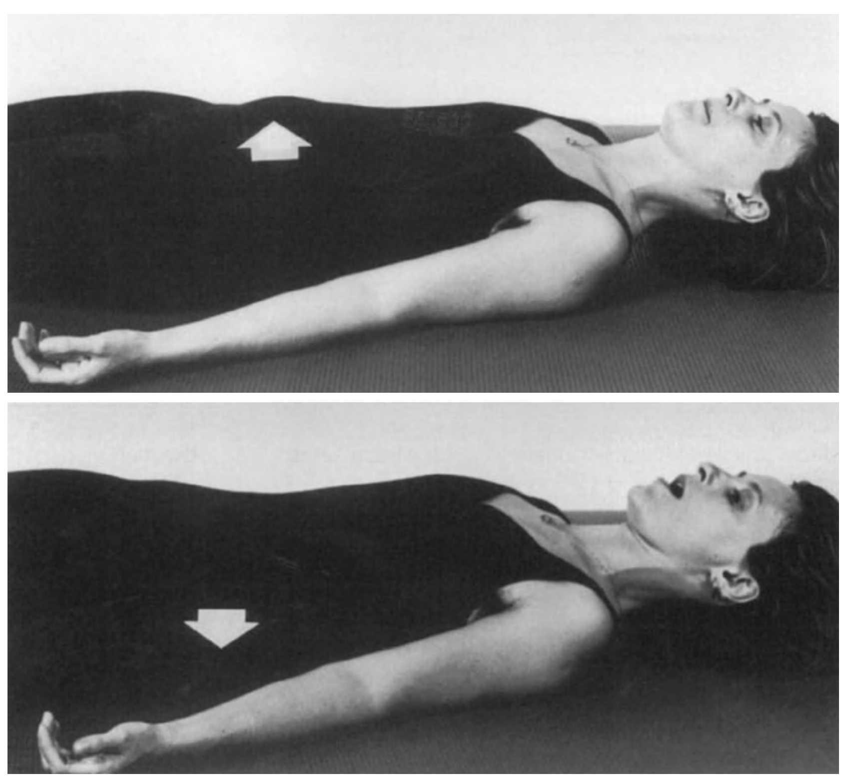
The low back school set-up by Saraceni and collaborators was started in 1987 and later developed to reach the present-day form (58, 171). It includes an initial 2-hour lesson on theory, held for classes of six patients, the contents of which are much the same as those of the other schools. The program then continues with 1-hour lessons twice weekly for 8 weeks, during which the patients are taught some 20 postural gymnastics exercises, of increasing difficulty, a few of which are shown in Figs. 14.10–14.17. The methodologic approach is summarized in the following principles: 1) all exercises, aimed at reducing lumbar lordosis, are carried out in the supine position; 2) the exercises are performed simultaneously with breathing, according to two different modalities, the active movements being always carried out in the expiratory phase; 3) the primary



A

B

Fig. 14.10. *Slow thoracic inspiration* (A) *and expiration with mouth open expanding the abdomen and decreasing lumbar lordosis* (B).



A

B

Fig. 14.11. *Abdominal inspiration with mouth closed* (A) *and then expiration until the lumbar spine is completely extended on the floor* (B).

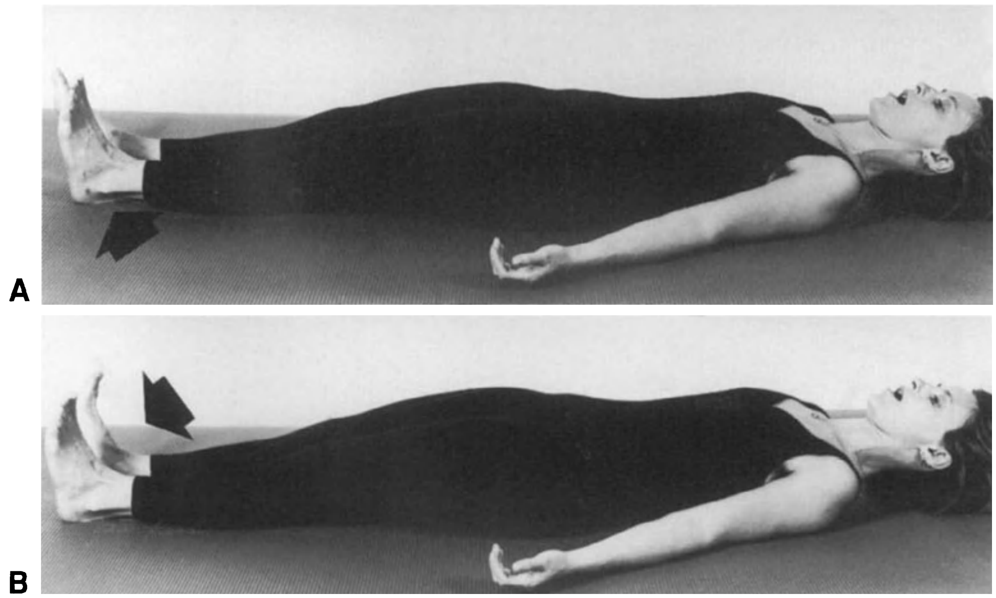


Fig. 14.12. *Dorsiflexion of one foot* (A) *and both feet* (B) *during expiration.*

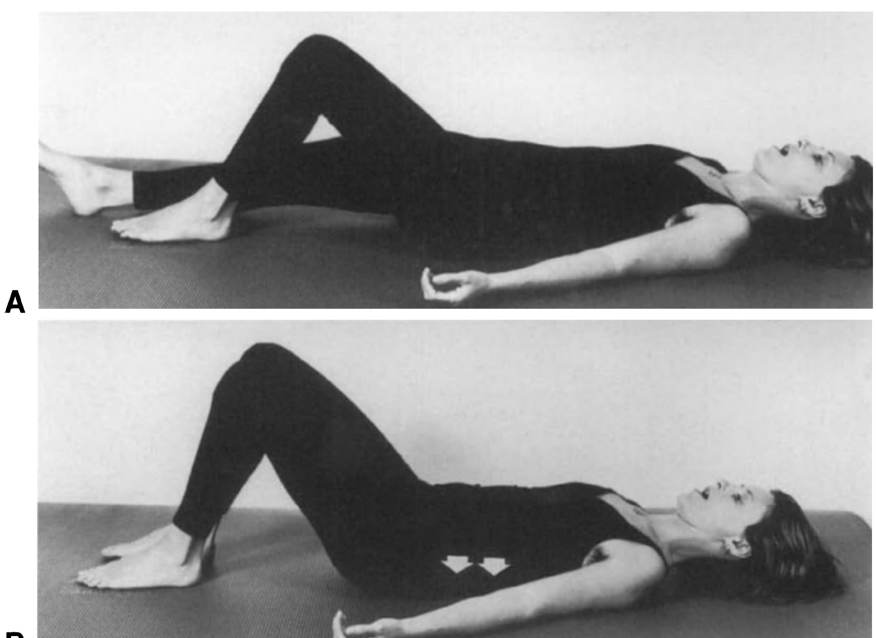


Fig. 14.13. *Flexion of a lower limb* (A) *and then of both limbs* (B) *during expiration.*

aim is to lengthen the posterior kinetic chain and strengthen the abdominal and quadriceps muscles; 4) the exercises are always performed in flexion of the spine to avoid the mechanical stress produced by extension.

Therapeutic efficacy

Acute pain. Few randomized controlled trials have analyzed the efficacy of low back school in patients with acute lumbar or lumboradicular pain. Of four studies, two reported positive results (10, 143) and two negative results (110, 177). In one trial (10), 70 patients took part in a Swedish low back school program, 72 were submitted to manual therapy and 72 to placebo treatment (shortwave diathermy at very low intensity): the patients in the first group had significantly better results compared with those in the placebo group, but not with those udergoing manual therapy. In another study (110), a group of 24 patients followed a low back

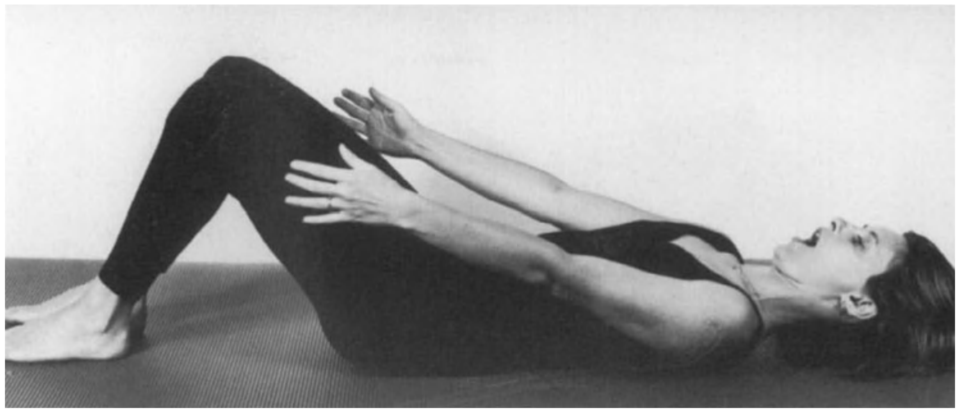
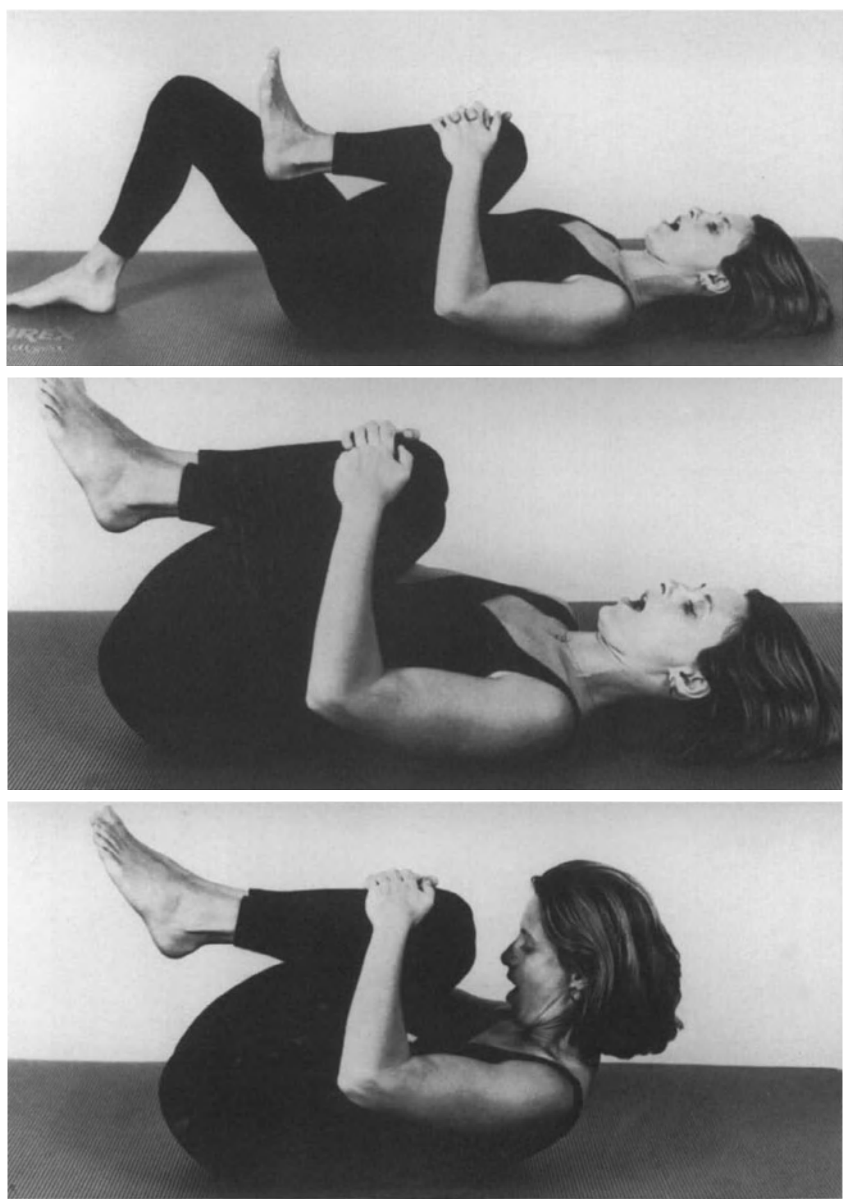


Fig. 14.14. *Isometric contraction of the abdominal muscles.*

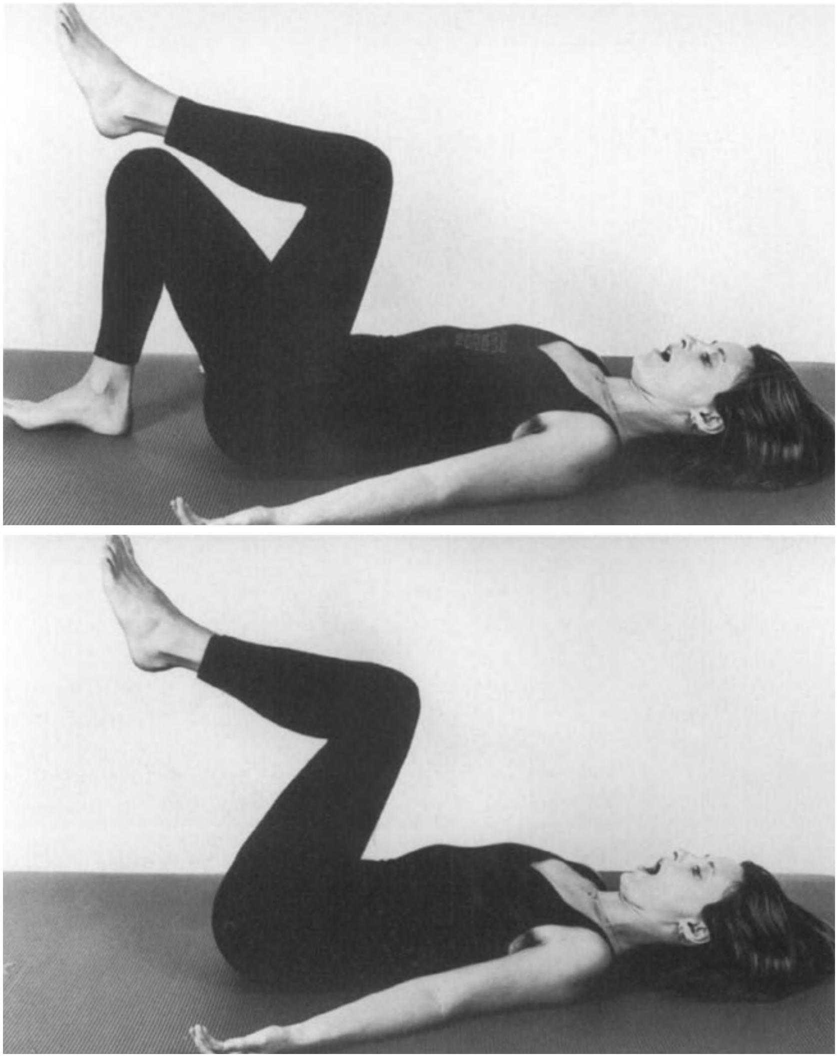


A

B

C

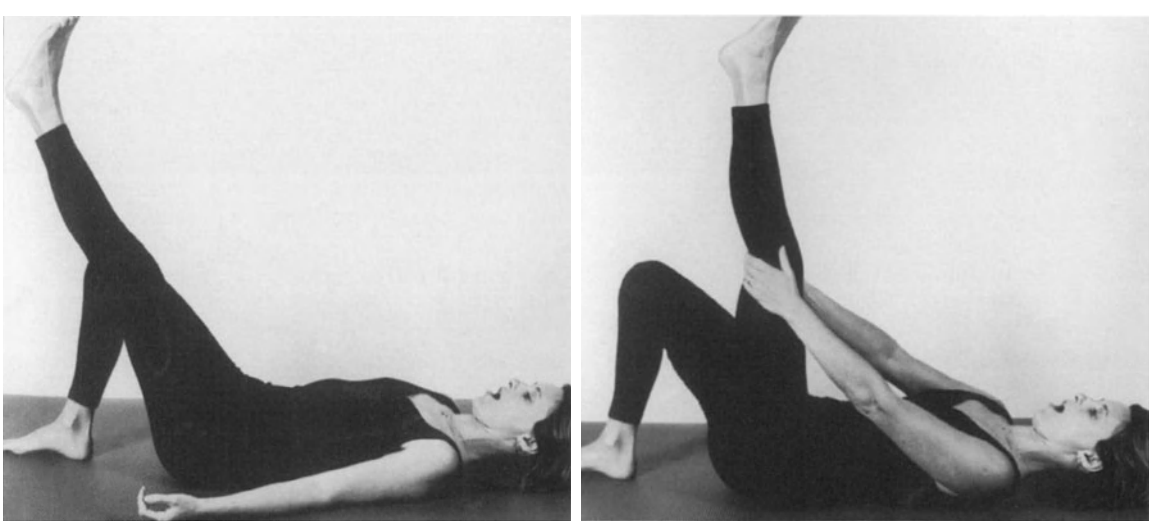
Fig. 14.15. *Passive flexion of a lower limb* (A), *of both limbs* (B) *and contraction of the abdominal muscles to assume an egg-like position* (C). *The single exercises should be performed during expiration.*



A

B

Fig. 14.16. *Active flexion of a lower limb* (A) *and then of both limbs* (B) *during expiration.*



A

B

Fig. 14.17. *Active* (A) *and passive* (B) *stretching of the hamstrings. These exercises should be performed when radicular pain is considerably decreased or disappeared. Usually they should be carried out in the advanced or final phase of the re-education program.*

school-like program of postural education, whilst another group of 32 patients were taught not to stress the lumbar spine and to use analgesics when needed; the percentages of pain-free patients after 1, 3 and 6 weeks, respectively, were 21%, 75% and 83% in the first group and 16%, 66% and 81% in the second.

Numerous randomized controlled studies have compared exercise therapy alone (not associated with a low back school program) with other forms of conservative management or a placebo treatment (36, 38, 50, 52 ,53, 55, 118, 152, 154, 177, 178, 192). Most of these studies (36, 50, 52, 53, 55, 118, 152, 192) failed to find exercise therapy significantly better than other treatments, including bed rest, manipulation, mini-back school, a placebo or no treatment at all.

It should not be forgotten, however, that in the vast majority of these trials, no clear-cut distinction was made between patients with low back pain alone and those with lumboradicular pain or, as far as concerns the latter, between those with disc herniation diagnosed by imaging studies and patients with radicular pain of unproven etiology.

Subacute or chronic pain. A large number of randomized controlled studies have attempted to analyze the therapeutic efficacy of the various types of low back school (44, 83, 84, 89, 90, 92–94, 102, 113, 132, 133, 162, 170). Most of them, including those employing the most rigorous methodologies (83, 84, 89, 90, 113, 132, 133), indicate that low back school is more effective than placebo and probably also than other forms of conservative treatment, such as physiotherapy, NSAIDs, manipulation, exercise therapy alone or a placebo treatment (ultrasounds or detuned short-wave diathermy).

Exercises alone appear to have a significant therapeutic efficacy in patients with chronic low back pain, as shown by several randomized controlled trials of good methodological quality (41, 48, 82, 107, 111, 112, 121–123). The latter as well as other investigations, however, seem to indicate that no significant differences exist, as far as concerns the therapeutic efficacy, between the various types of exercises.

However, also for the subacute or chronic syndromes, as well as for the acute forms, there are no precise data on the therapeutic efficacy of either low back school or exercise therapy alone in patients with low back or lumboradicular pain caused by proven disc herniation, compared to patients with pain due to other pathologic conditions or idiopathic pain.

Role in lumbar disc herniation

Lack of reliable data on the efficacy of exercises and low back school in patients with lumbar disc herniation does not allow us to determine the role of these two forms of treatment in this pathologic condition. However, the information available indicates, on the one hand, that physical inactivity has negative deconditioning effects on the musculoskeletal system and, on the other, that in patients with chronic lumbar or lumboradicular pain of undefined etiology both forms of treatment are effective.

In our experience, exercises are often poorly tolerated by patients with an acute lumboradicular syndrome and may even exacerbate pain, at least in the first few weeks after the onset of symptoms; in this phase, therefore, exercises should usually be avoided. Later, it may be useful to encourage the patient to perform simple exercises of postural gymnastics. If the latter exacerbates pain, the exercise program should be stopped or limited to non-painful exercises.

In the subacute, and even more in the chronic, phase, postural gymnastics is generally well tolerated by the patient and symptoms often improve, particularly back pain. In this instance, it should represent one of the key points of the treatment, since exercise therapy, once learned under the supervision of a physiotherapist, may be done at home by the patient, and it is, thus, a low-cost treatment, as well as a treatment with no adverse effects.

Low back school, independently of exercises, is indicated in patients with chronic pain and may be useful in those with a subacute syndrome, if this is recurrent. So-called mini-schools, and those attended by a large number of patients, are less effective than those of longer duration and with a limited number of patients (12, 163, 177).

Orthoses

The orthoses currently used in patients with lumbar disc herniation may be classified, according to their rigidity, as elastic, semirigid and rigid.

The elastic corsets have no stays of rigid or semirigid material and are usually short, i.e., limited to the lumbosacral region (Fig. 14.18). The most typical example of a semirigid corset is the canvas lumbosacral corset, made of cloth with lateral and posterior metal stays (Fig. 14.19). This corset, which extends from the lumbosacral region to the lower part of the chest, follows the lordotic curve of the lumbar spine without modifying it. The rigid orthoses consist of plastic non- or scarcely flexible material; these may be short or long (thoracolumbar brace) (Fig. 14.20).

The semirigid, and particularly the rigid, orthoses, have three points of fixation: two applied at the upper and lower ends of the brace, and the third midway between the two. The proximal support is generally located at the level of the lower end of the sternum and below the scapulae, and the distal one at the level of the sacrum. The intermediate counterforce is situated at the level of the suprapubic region or in the middle of the lumbar spine. An anterior support tends to flex the lumbar spine, whereas a posterior counterforce may maintain normal lordosis or increase it.

A rigid orthosis may incorporate the thigh in order to immobilize the hip joint. This type of brace considerably decreases the movements of the pelvis and the lower lumbar spine.

Biomechanical effects

Lumbosacral corsets and braces may produce three effects: a decrease in the spinal range of motion, a decrease in load on the lumbar spine and change of posture.

Decrease in spinal range of motion

The effects on vertebral motion may be of two types: decrease in intervertebral movements in the individual motion segments, and restriction of trunk movements.

The effects of orthoses on lumbar intervertebral mobility have been analyzed with various methods. In a study (57), in which flexion-extension lateral radiographs were used, the canvas lumbosacral corset was found to reduce the mean angular motion at each level by about one third. The Raney flexion jacket decreased the mean angular movements in the middle of the lumbar spine by about two thirds, and in the lower lumbar spine by 40%–55%. A baycast spica decreased the movements of the lower lumbar vertebrae by about 70%–90%.

The results of this study, however, are not in keepng with those of other investigations. Two studies have examined vertebral motion by evaluating, upon flexion-extension and axial rotation, the movements of Steiman pins inserted into bone structures. In these investigations, it was found that the intervertebral motion on flexion-extension not only was not affected by corsets and braces, but was occasionally increased (150), and that axial rotation at lumbosacral level did not decrease during normal walking (117). Roentgen stereophotogrammetric analysis (in operated patients in whom metallic markers had been left at surgery) has confirmed that a canvas lumbosacral corset or a rigid lumbosacral brace do not restrict sagittal and vertical intervertebral motion of the lower lumbar spine (4) and that no significant reduction in mobility is obtained even with a spica cast (5).

Restriction of trunk movements may decrease the loads on the lumbar spine and trunk muscles. In physical activities involving no efforts, the loads are generated by the need to equilibrate the movements produced by displacement (forwards, backwards or lateral) of the center of gravity of the upper part of the body (172).

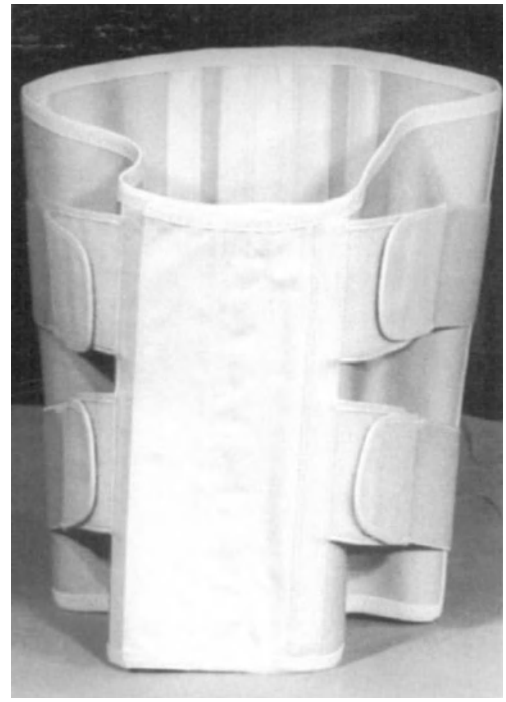


Fig. 14.18. *Elastic lumbosacral corset.*

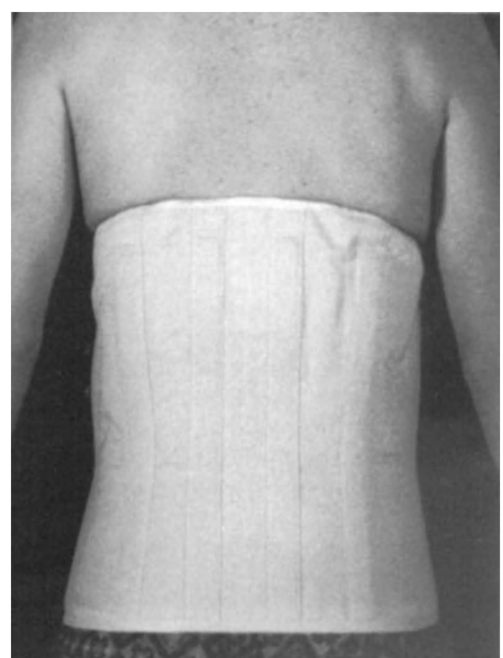


Fig. 14.19. *Semirigid lumbosacral canvas corset.*

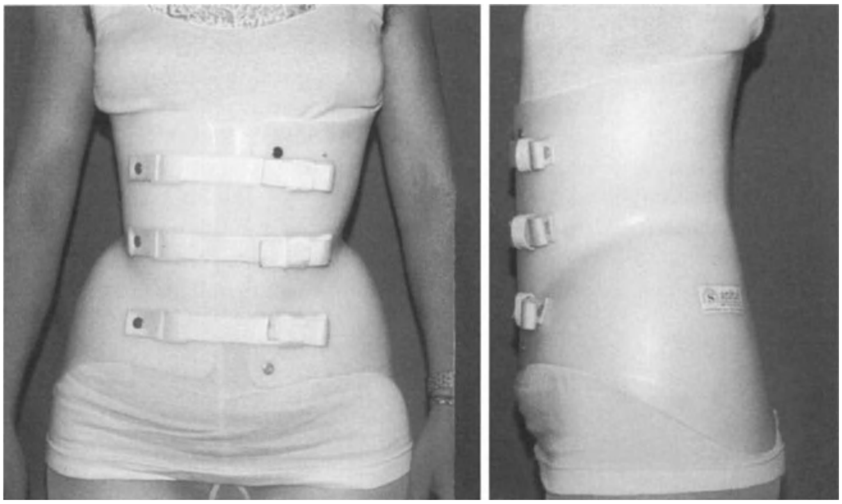


Fig. 14.20. *Thoracolumbar brace made of plastic material.*

Restriction of trunk movements decreases the amount of displacement of the center of gravity; this leads to a decrease in both the movements and the concomitant vertebral compression and tension of the erectores spinae muscles which is necessary to maintain trunk equilibrium (103). The decrease in mobility may reach 20% for flexion and 48% for extension, lateral bending and axial rotation. With the canvas corset, mobility is less limited than with the thoracolumbosacral orthosis (TLSO). The decrease in load on the lumbar spine (regardless of the possible effects of the intra-abdominal pressure) is probably proportional to the degree of reduction of trunk mobility.

Decrease in load

The decrease in load on the lumbar spine may be the result of the reduction in trunk movements (analyzed above) or the increase in intra-abdominal pressure, or may be directly produced by the orthosis.

The intra-abdominal pressure does not appear to be affected in a single way and to a significant extent by corsets and braces (142, 147, 148). If these increased the intra-abdominal pressure and, thus, reduced the load on the lumbar spine, the myoelectric activity of the trunk muscles would decrease. Electromyographic studies performed in normal subjects, during numerous movements carried out under isometric effort (104), have shown that the mean myoelectric signals of the abdominal or erectores spinae muscles ranged from −9% to +44% when the physical tasks were performed with the corset or brace, compared with the values recorded without orthosis.

The orthosis may reduce the load if it is rigid and well fitting to the body proximally and distally; in this instance, the load is partly transmitted, through the brace, from the upper portion of the trunk to the pelvis. This mechanism could explain the lower myoelectric activity of the erectores spinae muscles recorded during movements performed under effort while wearing a rigid orthosis, compared with those carried out with a canvas lumbosacral corset (104).

Decrease in load on the lumbar spine may produce a decrease in the intradiscal pressure. The available data, however, are conflicting also in this respect. In one study (147), analyzing the changes in the intradiscal pressure produced by an inflatable corset, it was found that a non-inflated corset produced no changes of the intradiscal pressure, which decreased by about 25% when the corset was inflated. In another study (148), the intradiscal pressure was measured during various movements performed under effort in subjects wearing or not an orthosis: the latter often decreased, but occasionally increased (only on flexion), the intradiscal pressure.

Change of posture

Vertebral orthoses may modify the posture by decreasing or increasing lumbar lordosis, or correcting trunk list.

The kyphosing braces have a suprapubic support which exerts pressure on the low abdomen. A brace with these characteristics would have various effects: to reduce a posterior annular bulging; to produce an increase in size of the spinal canal; and to increase the intra-abdominal pressure and reduce the load on the facet joints (99). The latter effect, however, would involve an increased load on the vertebral bodies and the intervertebral discs. Furthermore, it remains to be elucidated whether the braces which produce abdominal compression really increase the intra-abdominal pressure or have little effect on it, like those braces which do not exert a marked abdominal counterforce (104).

The braces preserving lumbar lordosis, particularly those which increase it, tend to displace the load from the anterior vertebral pillar (vertebral bodies and intervertebral discs) to the posterior joints. These braces may also have an anterior support exerting abdominal compression, which might increase the intra-abdominal pressure.

Orthoses may decrease sciatic scoliosis. The decrease is probably due to reduction of muscle tension resulting both from restriction of trunk motion and the tendency of the orthosis, when rigid, to straighten the spine in the coronal plane.

Conclusions

Studies on the effects of corsets and braces on vertebral mobility have led to conflicting results; most of the experimental data indicate that orthoses do not decrease intervertebral mobility in the lower lumbar spine. Orthoses decrease trunk movements to a varying extent depending on the rigidity and height of the corset or brace. Reduction of trunk motion probably involves a decrease in the load on the lumbar spine and in the tension of lumbar paraspinal muscles. Rigid braces may partly transfer the load from the upper part of the trunk to the pelvis: this might, to some extent, decrease the load on the lumbar spine.

Intra-abdominal pressure does not seem to be influenced in a single way and to a significant extent by orthoses. The available data, although conflicting, suggest that the orthoses currently used have little effect on intradiscal pressure. The kyphosing braces tend to displace the load on the anterior pillar of the spine (vertebral bodies and intervertebral discs), whereas those with lordosing effects tend to shift it over the posterior joints. However, there is no experimental evidence or quantitative data, in this respect.

Therapeutic efficacy and indications

In many patients with acute or subacute low back pain, corsets or braces are effective in relieving pain. This holds also for patients with lumboradicular pain, in whom, however, the radicular symptoms are less frequently improved, and often to a lesser extent, than low back pain. Many patients, on the other hand, do not report significant improvement with the use of orthoses and a few may even have exacerbation of pain, particularly of radicular pain.

The reasons for the different clinical response to the use of corsets or braces are still unclear. On the other hand, there are conflicting opinions on the possible differences, in terms of therapeutic efficacy, between the various types of orthoses – semirigid or rigid, short or long, kyphosing or lordosing. The orthosis most commonly used in patients with pathologic conditions of lumbar discs is the canvas lumbosacral corset, but many clinicians prefer more rigid orthoses. Furthermore, a few believe that the kyphosing braces are more effective; others have had little success with these braces (140), whilst they have obtained pain relief in a significant proportion of patients by restoring lumbar lordosis (130).

In patients with symptomatic disc herniation, the use of an orthosis is indicated when the clinical features require prolonged conservative treatment. Since restriction of trunk movements appears to be the main, or only, biomechanical effect of corsets and braces, rigid orthoses would be the most indicated. Often, however, the latter are poorly tolerated by patients. We thus prefer, in most cases, a lumbosacral corset. The patient should be informed that the orthosis may not relieve the pain, in which case use of the corset or brace should be withdrawn. When effective in relieving pain, the orthosis should be worn for 3–6 weeks, initially full time and then for a few hours each day.

Confusion is increased by the little and, at times, conflicting information on the biomechanical effects of orthoses, which would appear to inconsistently decrease the load on the lumbar spine and only to a mild extent (104). However, the clinical response to corsets and braces should not be evaluated only in biomechanical terms, since their therapeutic efficacy may also be related to other factors. The orthosis may represent a stimulus for the patient not to perform trunk movements or physical efforts, or it may have a thermic effect, if fitting close to the skin (74). In addition, the orthosis may have a placebo effect, the role of which is not negligible in pathologic conditions characterized by pain.

In patients with chronic lumboradicular pain, there is usually little indication for the use of orthoses. The latter may be worn during periods of exacerbation of pain or in specific circumstances or physical activities. Prolonged use of orthoses full time should be avoided, since they may lead to wasting and fibrosis of the trunk muscles, and psychologic dependence (145, 173).

The use of orthoses is not indicated to prevent recurrences of low back or radicular pain in patients involved in manual work, since experimental evidence indicates that corsets and braces produce a slight and inconstant decrease in the load on the lumbar spine, even in activities requiring physical efforts.

Orthoses, particularly those exerting compression on the abdomen, may be contraindicated in patients with gastrointestinal disorders, diaphragmatic herniation or inguinal herniation. Obesity and respiratory disorders may also make the use of orthoses poorly indicated.

Results of conservative treatments

Much clinical evidence exists indicating that in a large proportion of patients conservative treatments relieve pain after a period of time ranging from a few days to several months. Resolution of symptoms may occur in the presence of herniations of any type or size (Fig. 14.21).

In a retrospective study (168), 58 patients with disc herniation treated conservatively (analgesics, anti-inflammatory medications, epidural injections of steroids, low back school, exercises) were followed-up for a mean period of 31 months. Due to inadequate resolution of the symptoms, surgery was necessary in 10% of cases. Of the remaining 52 patients, 50 had an excellent or good clinical result and 48 resumed work after a mean period of 3.8 months. Of the patients with extruded herniation (26%), 87% obtained satisfactory results and all returned to work (mean, 2.9 months). The patients with a neurologic deficit presented similar results to those with no deficit. In a series of 114 cases (23), 14% of patients underwent surgery in the course of conservative treatment; in the remaining cases, non-surgical therapy (epidural or paraforaminal injections of anesthetics and steroids) led to satisfactory results. Similar outcomes – 90% satisfactory results with a combination of several treatments (bed rest, NSAIDs, epidural injections of steroids, corset) – have been reported by Maigne et al. (119).

Conservative versus surgical management

Over the last few decades, with the increased use of surgical therapy, we are faced with the question of whether or not conservative therapy provides comparable results to surgery in terms not only of the proportions of satisfactory results, but also of the quality of the latter and rapidity with which resolution of symptoms is reached.

Hakelius (77) retrospectively analyzed 417 patients treated conservatively (bed rest, corset, physical therapy) and 166 submitted to surgery. The patients were evaluated monthly for the first 6 months after the beginning of treatment or surgery, and the majority were followed-up for a mean period of 7.4 years. In the first month, 76% of patients treated conservatively had "benefitted" from treatment, compared with 97% of the operated patients; at 6 months, the percentages were similar (93% and 99%, respectively). In the first month, the proportion of asymptomatic patients in the conservatively treated group was considerably lower than that in the surgical group, but at 6 months there were no significant differences between the two groups.

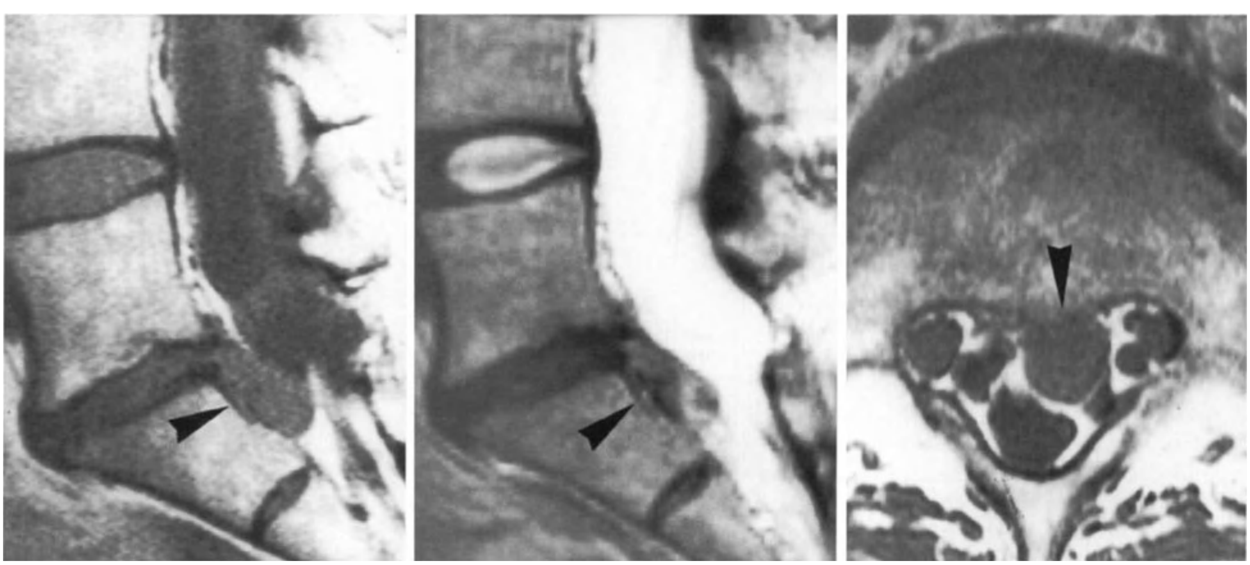


Fig. 14.21. *Sagittal and axial MR images of a 37-year female with large midline disc herniation migrated caudally (arrowheads). Symptoms gradually disappeared over a 40-day period with medical anti-inflammatory therapy (steroids for 10 days and then NSAIDs for 2 weeks) and physiotherapy (massage, TENS and magnetic field therapy for 3 weeks).*

The mean time off work was only slightly longer in the conservatively treated cases than in those submitted to surgery. However, at 6 months, the percentage of patients still off work was 37% in the conservatively treated group with disc herniation demonstrated by myelography and 7% in the surgical group. At long term, the results were only slightly better in the patients in the surgical group. Regression of motor and sensory deficits was found in similar proportions in the two groups. The incidence of recurrences of radicular pain in the years following conservative treatment was twofold (20%) that observed in the operated patients (10%). The limitation of this important study is that the choice of treatment was not randomized, thus the two groups of patients are not comparable.

In a prospective study by Weber (194), 280 patients with disc herniation demonstrated by myelography were assigned to three groups. Group I included 87 patients with mild symptoms who were treated conservatively. The 67 cases in Group II, in which there were absolute indications for surgery, underwent operative treatment. Group III included 126 patients with an uncertain surgical indication: these patients were randomly assigned to conservative (81) or surgical (73) management. Conservative treatment consisted in bed rest, administration of analgesics, isometric exercises and low back school. All patients in Group III were followed-up for 1, 4 and 10 years after treatment. At 1-year follow-up, the proportion of satisfactory results was significantly lower in the conservative (61%), than in the surgical (80%), group. At 4-year evaluation, the percentage of satisfactory results was still lower in the conservative group, but the difference was no longer statistically significant. Comparable results were observed at 10-year follow-up. Of the 66 patients in the conservative group, 25% had undergone surgery during the first year of follow-up due to persistence or worsening of symptoms. Neurologic deficits improved or disappeared in comparable proportions of cases in the two treatment groups. The main defect of this study is that only the patients with an uncertain surgical indication were randomized to treatment.

A recent investigation (175) retrospectively evaluated 55 truck drivers, 30 of whom were submitted to prolonged conservative management (over 3 months) and 25 underwent surgery. The results of treatment were analyzed, as well as the cost of health care (medical expenses + salary in the period off work) in the 5 years following the beginning of treatment. In both groups, 80% of patients presented a satisfactory outcome; no significant differences in the costs of treatment emerged between the two groups. Also in this study, only patients with uncertain indication for conservative or surgical management were included.

Conclusions

1. Conservative management ensures satisfactory results in a large proportion of patients with lumbar disc herniation. There appear to be no significant differences between the various conservative treatments. In most cases, it is advisable to associate more than one form of treatment.

2. In 10%–20% of cases, improvement in the clinical syndrome is not sufficient. These percentages increase if we include those patients in whom the severity of pain and neurologic deficit makes surgical treatment indicated without waiting to see the results of conservative therapy. The percentage of patients in whom this occurs is not yet known, however, in our experience, it does not exceed 20%. Thus, some one third of patients need surgery, whereas in the remaining two thirds symptoms are resolved with conservative therapy.

3. In most cases, with conservative therapy, a longer time period is required to obtain satisfactory results compared with surgery. This is particularly true for complete resolution of pain, which is usually obtained after a significantly longer time interval in patients treated conservatively than in those operated upon. It is unclear whether, in patients with a satisfactory outcome, the quality of the result regarding both low back and radicular pain is, on average, better or worse after conservative therapy than after surgical treatment.

4. At medium and long term, there are no statistically significant differences in the quality of the result between conservative and surgical treatment. The chances of recurrence of radicular pain are slightly higher in patients treated conservatively.

5. The presence of motor or sensory deficits of mild or moderate severity is not a contraindication for conservative therapy, since the chances that these will be resolved are comparable to those following surgical treatment.

6. The time off work is slightly longer in patients treated conservatively than those operated upon. For employees, there are no significant differences between the costs (medical expenses + salary during sick leave) of the two types of treatment in the first few years after onset of the disease, even if conservative therapy is prolonged over time.

Treatment regimens

Treatment of a lumboradicular syndrome due to disc herniation varies in the different clinical phases – acute, subacute or chronic. The first 5 weeks may be considered as the acute phase, subacute that comprised between 6 and 12 weeks and chronic that after 12 weeks (62).

As far as concerns most of the treatments currently performed in syndromes due to disc herniation, there is no definite proof that any of these are actually effective (39). This may have one of two meanings. First, these treatments are really ineffective and the improvement obtained is only due to the natural evolution of the disease. Second, the treatments do have a therapeutic efficacy, but this has not yet been demonstrated due to methodological defects in the studies in which their clinical effects have been evaluated. Although the former hypothesis appears to be the most plausible, it should be taken into account that a) it is extremely difficult to determine the therapeutic efficacy of conservative treatments in a pathologic condition, such as disc herniation, which may undergo spontaneous resolution, and b) a conservative therapy may have multiple effects, including a placebo effect, which may not have been fully ascertained or difficult to quantify. These considerations should not lead us to resort to treatments of highly uncertain therapeutic efficacy; however, they justify the use of therapies, of which the efficacy is not definitely proven, but which the clinical experience indicates to be effective in a large number of patients.

Acute lumboradicular syndrome

The therapeutic approach varies depending upon the severity of the lumboradicular pain. Whatever the treatment performed, it is important to inform the patient that: pain will last for at least a few weeks; there are good chances that it will resolve with conservative treatment; if this does not occur within a few weeks, there can be an indication for surgery.

Severe pain

The patients with severe pain should be confined to bed for a few days. Usually, bed rest needs not be absolute: if the pain allows it, the patient should get up 3–6 times a day, for 15–30 minutes each time. In the supine position, the use of two pillows below the legs is useful to ensure relaxation of the hamstrings and paraspinal muscles. Bed rest should not exceed 4–7 days, unless the pain is so severe as to prevent prolonged standing.

If low back pain prevails over radicular pain, it is preferable to administer NSAIDs via the parenteral route, at high doses for 2–4 days and then at medium doses for about 1 week; thereafter, the oral or rectal route is preferable. During the first week of treatment, it may be useful to associate muscle relaxants, particularly in the presence of sciatic scoliosis. Muscle relaxants may be administered by the parenteral route, mixed with NSAIDs, if the two medications do not interact; otherwise, they should be given by the oral or rectal route. If pain is not sufficiently decreased with NSAIDs, it may be useful to administer analgesics, twice or more a day for a few days. The use of sedatives is indicated only in patients who are clearly anxious or agitated.

When radicular pain is as severe as low back pain or prevails over the latter, it is preferable to administer a steroid, provided there are no contraindications. Steroid therapy should be given at high doses for 2 days, medium doses for 4–6 days and then low doses for further 2 days. The steroid may then be replaced by oral administration of a NSAID. In the presence of radicular pain alone, there is no indication for the use of muscle relaxants.

If adequate pain relief is not obtained by systemic pharmacologic therapy, protracted for at least 7–10 days, it may be indicated to carry out epidural injections of a slowly absorbable steroid combined with a local anesthetic. Epidural injections may be the treatment of choice when systemic pharmacologic therapy at high doses cannot be performed on account of comorbidity. There is, instead, no indication for performing paraspinal injections, as these will likely not be effective. It may also be useful to perform mesotherapy, both in the lumbosacral region and the areas where the pain radiates.

Physical therapy is usually indicated at least a week after the onset of pain. This is useful especially in patients with prevalently low back pain, whilst it is of little usefulness in those complaining only of radicular pain. In the first few days, the only forms of physical therapy indicated are analgesic electrotherapy and massage of the lumbosacral area. TENS appears to be the form of electrotherapy with the greatest therapeutic efficacy, and should be performed for at least 30 minutes, one or more times a day. Massage is aimed at reducing muscle spasm and, thus, the lumbar component of pain. If massage exacerbates pain or the patient has difficulty in maintaining the prone position, the treatment should be discontinued.

If, 3 weeks after the onset of symptoms, lumboradicular pain is considerably decreased, it may be useful to begin light exercise therapy. This, however, should be stopped if it exacerbates low back and/or radicular pain. In a few cases, it may be useful to have the patient fitted with an orthosis, which he/she should wear all, or most of, the day. The most suitable orthosis is the lumbosacral canvas corset. If the patient refuses this type of corset, a semielastic corset may be used, the biomechanical efficacy of which, however, is very uncertain. The corset should be worn 2–4 weeks and gradually left off.

The treatment guidelines are given in Table 14.1.

Moderate pain

Bed rest is not necessary. Usually it is sufficient to limit physical activity and stay off work, if physically demanding, for at least 2 weeks.

Anti-inflammatory medications play the key role in the treatment. Usually, it is sufficient to give NSAIDs, initially by the parenteral route at medium doses and then by the oral or rectal route for an overall period of 2–3 weeks. When radicular pain is the only or prevailing symptom, it may at times be advisable to start with a steroid at a medium dose for 5–7 days and then continue with a NSAID by the oral route. Muscle relaxants are useful only in the presence of low back pain, particularly when there is paraspinal muscle spasm. Sedatives are usually not indicated.

It may be useful, 1–2 weeks after the onset of pain, to carry out physical therapy. Initially this should consist in analgesic electrotherapy and massage of the lumbosacral and gluteal regions. Microwave diathermy or phototherapy may be useful in prepearing for the massage. Autotraction may also be indicated. Manipulation according to the principles of manual medicine may be indicated in patients with bulging annulus fibrosus or small contained disc herniation, when no neurologic deficit is present.

The patient is instructed, 2–3 weeks after the onset of symptoms, to do exercises for 5–10 minutes, several times a day. In the presence of motor deficits in the lower limb, the program should include isotonic and isometric exercises for the weak muscles. Exercise therapy should be stopped if lumboradicular pain increases.

When symptoms are not significantly relieved 3–4 weeks after onset, two other therapeutic measures may be considered: wearing a corset and epidural injections of steroids. The corset should be worn for a large part of the day for the first 2 weeks and during physical activities which may be more demanding than usual for 2–3 weeks. If the first injection has only partially relieved pain, a second injection may be indicated after 2 weeks.

Table 14.2 summarizes the recommeded treatments in these syndromes.

Table 14.1. *Treatment guidelines in acute lumboradicular syndromes.*

Severe pain	
Prevalently lumbar	*Prevalently radicular*
Bed rest 2–4 days	Bed rest 2-7 days
NSAIDs, muscle relaxants, analgesics	Steroids, then NSAIDs
TENS, massage (1–2 weeks after onset of symptoms)	TENS
Light exercises (3 or more weeks after onset of symptoms)	Epidural injections (if failure with systemic therapy)
Orthosis (if severe pain persists)	

Table 14.2. *Treatment guidelines in acute lumboradicular syndromes.*

Moderate pain	
Prevalently lumbar	*Prevalently radicular*
Work leave	Work leave
NSAIDs, muscle relaxants	NSAIDs, or steroids and then NSAIDs
TENS, phototherapy, massage, autotraction	TENS, autotraction
Light exercises (2 or more weeks after onset of symptoms)	Epidural injections (if failure with systemic therapy)
Mobilization and manipulation	Light exercises (2 or more weeks after onset of symptoms)
Orthosis (rarely)	

Subacute lumboradicular syndrome

Anti-inflammatory medications may be indicated for short periods, particularly during temporary exacerbation of radicular pain. Those most comonly employed are NSAIDs; it is usually sufficient to administer these by the oral route for periods of 1–2 weeks. Generally, there is no need for the use of steroids. Muscle relaxants may be useful only in the presence of muscle spasm resulting from recurrence of acute low back pain.

In patients with still fairly severe radicular pain, 1 or 2 epidural injections of steroids may be required. There is usually no indication for paraforaminal or paraspinal injections, due to the unlikelihood of obtaining pain relief. The only exception is represented by lateral herniations, in which paraforaminal injection may be helpful in relieving leg pain.

In subacute syndromes, physical therapy represents an important therapeutic tool, the most indicated being analgesic electrotherapy, shortwave diathermy or ultrasounds and massage in patients with prevailing or exclusive low back pain, and analgesic electrotherapy in those with prevalently radicular pain. Manipulation may be performed, according to the above-mentioned indications, when therapy with physical agents is ineffective.

Exercise therapy may be useful, particularly in patients with prevalently low back pain. Low back school is indicated in patients with recurrent symptoms.

A corset may be employed during periods of exacerbation of pain, particularly in the low back.

The treatment of these syndromes is summarized in Table 14.3.

Chronic lumboradicular syndrome

In the chronic phase, medical therapy is not indicated, except for short treatment periods with NSAIDs in the event of flare up of the pain, and with antidepressants. In patients with chronic pain, antidepressants may contribute to relieve pain, particularly when there is clinical evidence of depression. However, we do not usually prescribe these drugs, at least in the absence of an overt depressive syndrome. Epidual injections of steroids are rarely indicated, since in the absence of an acute inflammatory process this therapeutic practice is scarcely effective.

Management of chronic syndromes is based upon exercise therapy and low back school and, to a lower extent, upon physiotherapy and manipulation.

The choice of the various forms of physical therapy depends, as in the subacute syndromes, on the characteristics of the pain. Manipulation may be indicated in patients with small or medium-sized herniation, mild radicular symptoms and absence of motor deficits or presence of chronic deficits of mild severity.

Table 14.3. *Treatment guidelines in subacute lumboradicular syndromes.*

NSAIDs
TENS, ultrasounds, massage
Epidural injections (if prevalent radicular pain)
Exercises Low back school, if recurrent symptoms
Mobilization and manipulation

Table 14.4. *Treatment guidelines in chronic lumboradicular syndromes.*

NSAIDs (if recurrence of acute pain), antidepressants
Exercises, low back school
TENS, ultrasounds, shortwave diathermy
Mobilization and manipulation
Acupuncture

Acupunture may be attempted, particularly when other conservative measures have been ineffective.

Patients resuming work should follow, at least for a few months, all the ergonomic measures available in the attempt to avoid excessive mechanical stresses, which may induce exacerbation or recurrence of lumboradicular symptoms.

The recommended treatments are reported in Table 14.4.

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·CHAPTER 15·

PERCUTANEOUS TREATMENTS

F. Postacchini, H. M. Mayer

Chemonucleolysis

History

The history of chemonucleolysis begins with the observation of Lyman Smith (160) that intradiscal injection of chymopapain in rabbit dissolves the nucleus pulposus, but leaves the annulus fibrosus essentially intact. This experiment had been suggested by a previous study of Thomas (172), who found that the intravenous injection of papain in the rabbit caused drop of the ear, which resumed the erect position 48 hours later, due to a reversible action of the enzyme on the intercellular matrix of the auricular cartilage. The term "chemonucleolysis" was also coined by Smith (158), who used it to indicate the treatment of pathologic disc conditions with chymopapain injection, even if presumably he meant, with this term, the dissolution of the nucleus pulposus by a chemical substance, as the etymology of the word indicates. The first patient was treated by Smith in 1963. A few years later, he sold the patent for chymopapain, for the symbolic sum of 1 dollar, to Baxter-Travenol Laboratories, which marked the product under the trade name Discase, a combination of chymopapain, cysteine sodium sulfite and EDTA. In the United States, this product was injected in many thousands of patients until 1975, when the FDA induced Baxter-Travenol to withdraw the request of approval of the substance, based on a randomized double-blind study (154), indicating that chymopapain was not significantly more effective than placebo in lumbar disc herniation. Chemonucleolysis, however, continued to be widely carried out in Canada and a few European countries.

In 1979, Smith Laboratories developed Chymodiactin, a new form of chymopapain, containing only two of the three protein fractions of Discase, and cysteine. In 1981, a multicenter randomized double-blind study on 108 patients showed that the proportion of satisfactory results obtained with chemonucleolysis was significantly higher than that following placebo (86). Similar results were obtained in an open study including 1498 patients treated by a large number of doctors (123). Based on these investigations, FDA authorized the clinical use of Chymodiactin in 1982 and of Discase in 1984.

Over the next few years, chemonucleolysis – or nucleolysis – with chymopapain became a method of treatment widely used in many countries, often by inexperienced doctors and in private practice. This was probably the main reason for the dramatic increase in complications, particularly the more severe, of the procedure. News of these complications and the advent of new methods of percutaneous treatment, such as automated percutaneous nucleotomy, led to a progressive decrease in the popularity of chemonucleolysis. In the 90's, chemonucleolysis continued to be carried out in a limited number of centers by experienced physicians, and this has led again to the frequency of serious complications, essentially allergic in nature, falling to the very low percentages of the 70's.

During the period of maximum popularity of chemonucleolysis, Sussman and Bromley (18, 167) began to use collagenase, based on experimental studies showing that the enzyme was active on collagen of the intervertebral disc and that intravenous and epidural injection had no toxic effect (19, 168). However, collagenase, which has the advantage of only occasionally causing mild allergic reactions, has always been carried out in very few centers.

Chymopapain

Biochemistry and toxicity

Chymopapain is one of the proteolytic enzymes contained in the latex of the fruit Carica Papaya. Compared with crude papain, chymopapain has a higher tissue specificity, a lower activity, a greater electrophoretic mobility and a higher solubility at neutral pH (164). The form currently used remains stable, even with no refrigeration, for more than 3 years.

The main enzymatic action of chymopapain is hydrolysis of the peptide bonds of the proteoglycan protein core. The bond between the enzyme, which has a positive charge, and mucopolysaccharides, which are charged negatively, is of the ionic type. Proteolytic action leads to the release of glycosaminoglycans (GAGs), which are much smaller molecules than proteoglycans. The GAGs of the disc tissue can thus diffuse out of the disc together with the water molecules bound to them. The GAGs enter the blood circulation and are excreted with urine, in which a moderate and temporary increase in acid mucopolysaccharides occurs after enzymatic dissolution of the nucleus pulposus. Chymopapain, incubated in vitro with fragments of normal human nucleus pulposus or herniated nucleus pulposus at pH 7.4, results in dissolution of the tissue (165). The faster degradation of the normal, compared with the herniated, nucleus pulposus has been attributed to the higher collagen content in the herniated tissue. The process of dissolution is limited by the concentration of substrate or enzyme. The collagen component is essentially unaffected by chymopapain after incubation for 12 hours.

Chymopapain acts very fast on the substrate and would be inactivated by the α-2-macroglobulin and cathepsins present in tissues and serum (92, 164). In the dog, however, proteolytic activity of the enzyme on disc tissue has been shown to persist 2 weeks after injection (16). The enzyme, or its residues which pass into the circulation, possibly bound to GAGs (165), stimulate the synthesis of specific antibodies, which, in animals injected with multiple doses, decrease in concentration after a few weeks (59).

Numerous experimental studies have analyzed the systemic and local toxicity of chymopapain. The studies by Garvin et al. (59) on small and medium-size animals indicate that intradiscal and epidural injection of doses of the enzyme up to 100 times higher than those effective are well tolerated. The lethal doses injected into the disc or the epidural space caused death due to systemic hemorrhage and at times produced slight intrathecal and epidural hemorrhage. Subsequent studies (132) on small animals, who had receiv-ed the injection of the enzyme in the cheek, have shown, by vital microscopy, that chymopapain stops the circulation in the site of injection and causes microhemorrhages in the adjacent areas.

There is general agreement concerning the high toxicity of the enzyme following intrathecal injection. Toxicity would be due to dissolution of the basal membranes of the capillaries in the pia mater and arachnoid, which results in intrathecal hemorrhage, causing paralysis or death. Furthermore, it has been clearly shown that dura mater is not affected by the enzyme.

Results of several experimental studies indicate that the contact of chymopapain with the spinal nerve roots does not produce axon damage, due to the presence of the dural sleeve (51, 62, 184). On the other hand, other investigations (151, 188) have revealed that chymopapain produces degenerative neuropathy both in the peripheral nerves and the spinal nerve roots, and that neuropathy is more severe if the nerve root has previously been traumatized (188).

Gross and microscopic effects on disc tissue

Studies on lumbar discs of dogs treated with varying doses (0.1–20 mg) of chymopapain have shown that the enzyme causes, within a few days, a decrease in disc height to an extent proportional to the dose of enzyme injected. At autopsy, it was found that small doses of enzyme produce small defects in the nucleus pulposus, whilst high doses (10 and 20 mg) completely dissolve the nucleus pulposus and cause changes in color and focal hemorrhages in the inner portion of the annulus fibrosus, but do not affect the outer annulus. With these doses, the cartilage end-plate appears largely eroded. At histologic level, in dogs examined 1 month after injection, the lower doses cause no significant changes in the cells and intercellular matrix neither in the nucleus pulposus, nor in the surrounding structures. The high doses, on the other hand, produce large defects in the nucleus pulposus and the cartilage end-plate, but not in the annulus fibrosus.

When a fragment of herniated nucleus pulposus is incubated with a water solution containing 4000 U of chymopapain, the solution becomes opalescent within a few minutes, due to enzymatic digestion of the tissue (Fig. 15.1). The small amount of tissue which remains after 30-minute incubation is soft, but fibrous, in consistency.

Postacchini et al. (144), in ultrastructural investigations, studied the effects of chymopapain on fragments of herniated nucleus pulposus, and human and rabbit annulus fibrosus, incubated in vitro with the enzyme

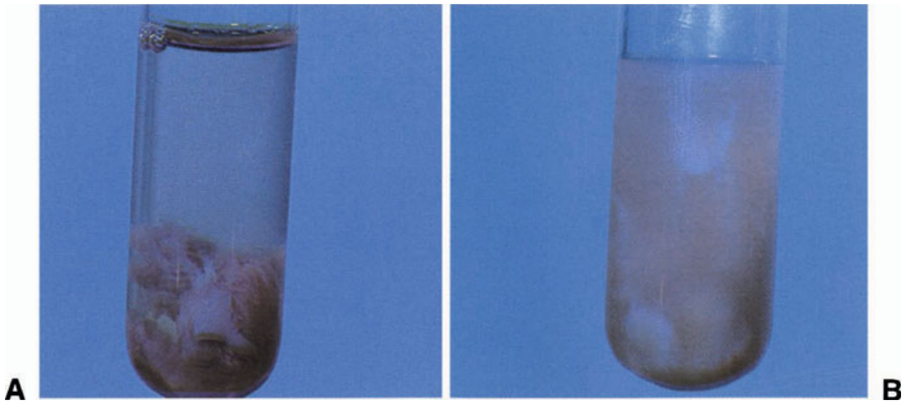


Fig. 15.1. *Herniated nucleus pulposus incubated, after surgical excision, with saline* (A) *or chymopapain* (B). *The nucleus pulposus appears partially digested after incubation for 10 min with chymopapain.*

soon after excision. The effects on the herniated nucleus pulposus consisted in rapid digestion of the proteoglycan granules and the masses of electron-dense granular material in the tissue (Fig. 15.2). Proteoglycan granules are no longer visible and the electron-dense material is partially digested 3 hours after incubation (Fig. 15.2 B). After 6 hours, the electron-dense material has also disappeared. The tissue appears to consist only of collagen fibers, isolated or grouped in bundles, which show a normal morphologic structure (Fig. 15.2 C). The cells in the tissue show marked degenerative changes after 3 hours and are completely disintegrated after 12–24 hours; similar regressive changes, although less marked, are visible in the control tissue maintained in distilled water for 3–24 hours before being fixed. These tissue changes can be seen throughout the entire tissue fragments incubated with enzyme, when they are of small dimensions. In fragments 5–8 mm in diameter, digestion is complete in the peripheral portion, but only partial in the central portion. Likewise, in the outermost portion of fragments of annulus fibrosus, the enzyme digests the proteoglycans and the electron-dense granular material, whereas in the rest of the tissue, enzymatic digestion may be partial or completely absent. These findings indicate that the clinical effects of chymopapain are related to the digestion of proteoglycans and the electron-dense granular material and depend on the amount of collagen fibers in the tissue and the volume of tissue to be digested.

Subsequent histologic and ultrastructural studies (145, 150) on fragments of herniated tissue obtained from patients submitted to unsuccessful chemonucleolysis less than 3 weeks previously, confirmed that the in vivo effects of chymopapain are similar to those observed in vitro.

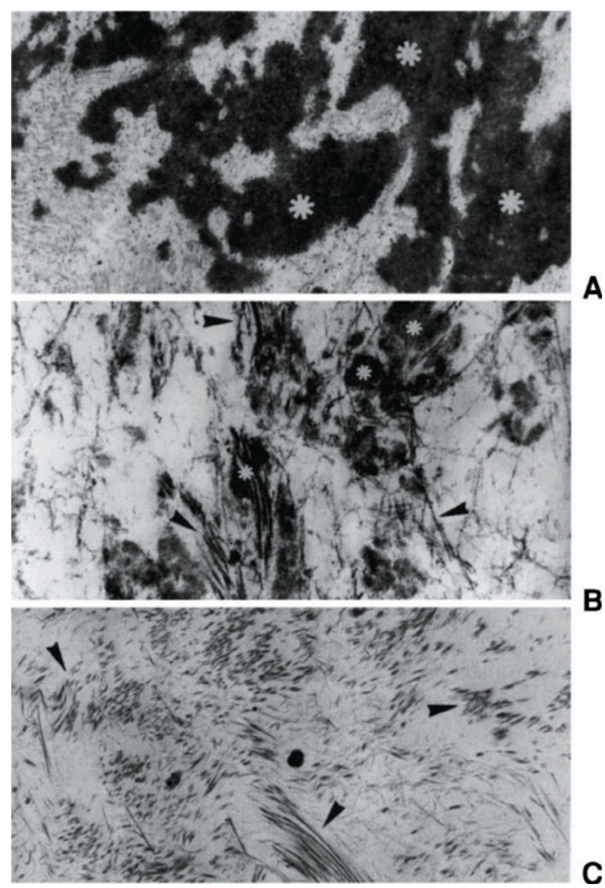


Fig. 15.2. *Electron micrographs showing the effects of chymopapain on the nucleus pulposus incubated with the enzyme.* (A) *Control nucleus pulposus: large masses of electron-dense material (asterisks), thin collagen fibers and proteoglycan granules are visible.* (B) *After incubation for 3 hours, the electron-dense material (asterisks) is partially digested and proteoglycan granules are no longer visible between the collagen fibers (arrowheads).* (C) *After incubation for 6 hours, the tissue appears to consist only of collagen fibers (arrowheads) showing normal morphologic features.*

Effects on herniated tissue

After injection of the enzyme, the herniated disc decreases in height within the first 2–3 weeks. This phenomenon, caused by digestion of the nucleus pulposus, is likely to be one of the main causes of postprocedural

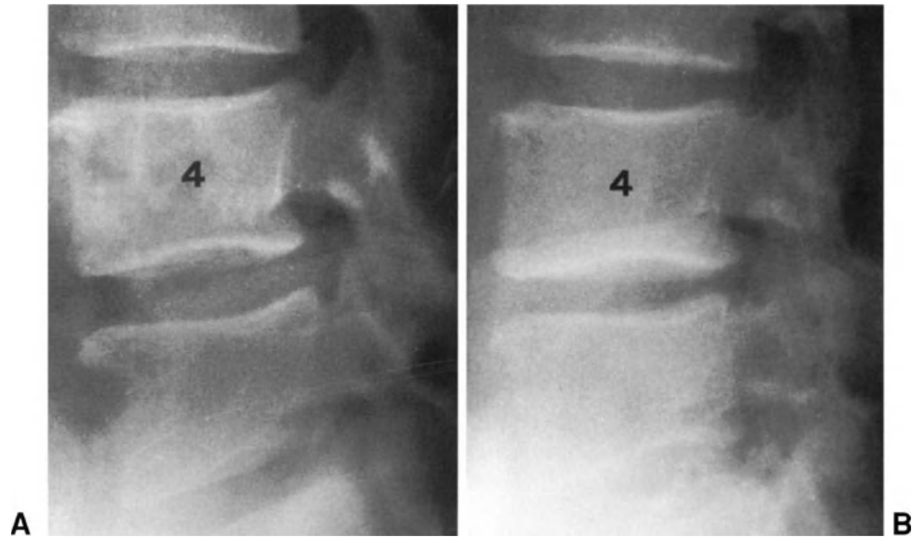


Fig. 15.3. *Plain radiographs carried out before chemonucleolysis* (A) *and 1 month after the procedure* (B). *Disc height has decreased by about 40% after chemonucleolysis.*

low back pain. The extent of the decrease in height of the disc space is related to the dose of chymopapain injected and the extent of the digestive action, which, in turn, is affected by the characteristics of the disc tissue and the possible leakage of enzyme from the disc. High doses of enzyme tend to produce a marked decrease in disc height. Similarly, a disc with a high proteoglycan content tends to lose more height than a disc with marked fibrotic changes. Therefore, in young or middle-aged subjects, disc height tends to decrease to a greater extent than in elderly subjects. The doses of enzyme currently employed (3000–4000 U) usually lead to a reduction of disc height by 20%–50% (Fig. 15.3). The decrease in height, on the other hand, also confirms the digestive action of the enzyme. In our experience, the vast majority of patients who, after chemonucleolysis, show a decrease in height of at least one third have a satisfactory clinical result, unlike the patients presenting no change in disc height. On the other hand, in patients assessed more than 6 months after treatment, we found no correlation between the extent of decrease in height of the disc and severity of the postprocedural low back pain.

Before the advent of CT and MRI, it was difficult to determine the in vivo effects of chymopapain on disc herniation. In fact, only occasionally did the patient, submitted to myelography preoperatively, underwent repeat myelography after chemonucleolysis. In our series, this occurred in two patients, who, a few months after a successful nucleolysis, presented with recurrent radicular symptoms, which required new myelographic studies. In both cases, repeat myelography showed disappearance of herniation and no evidence of compression of the neural structures at the level of the injected disc (Fig. 15.4).

Numerous studies have evaluated the modifications in the herniation by comparing preprocedural CT with CT performed at varying time intervals after treatment (15, 61, 97, 98, 108, 175). Konings et al. (97) have compared preoperative CT with the study performed 3 months after chemonucleolysis in 30 cases; of the 28 patients whose preoperative CT revealed disc herniation, 20 showed a decrease in size or disappearance of herniation, a diffuse annular bulging being present in 23. These authors found a close correlation between the clinical outcome and CT changes. By contrast, other investigators (175) found no relationship between the clinical outcome and the results of CT carried out 2–3 months after nucleolysis. However, of the 91 patients examined (including 11 cases subsequently operated on due to failure of the procedure), 32 showed a clear-cut decrease, and 12 a moderate decrease, in size of the herniation; in the remaining 47, herniation was slightly decreased in size or showed no changes. After 1 year, 27 patients underwent a third CT: 77% showed a considerable or moderate decrease in size of the herniation.

An MRI study (63) on patients who had undergone chemonucleolysis showed that chymopapain produces, on T2-weighted images, a progressive decrease in signal intensity of the nucleus pulposus until complete loss of signal, which occurs at least 6 weeks after nucleolysis. Subsequent studies (93, 95) on patients with a satisfactory clinical outcome revealed that the signal intensity of the disc begins to decrease 2 weeks after chemonucleolysis and continues to decrease in the next weeks, until it completely disappears in the majority of cases. The reduction in size of the herniation begins after 4 weeks and continues progressively over the next 12 months. At this time, the signal of the treated discs is still decreased. In one fifth of patients, the

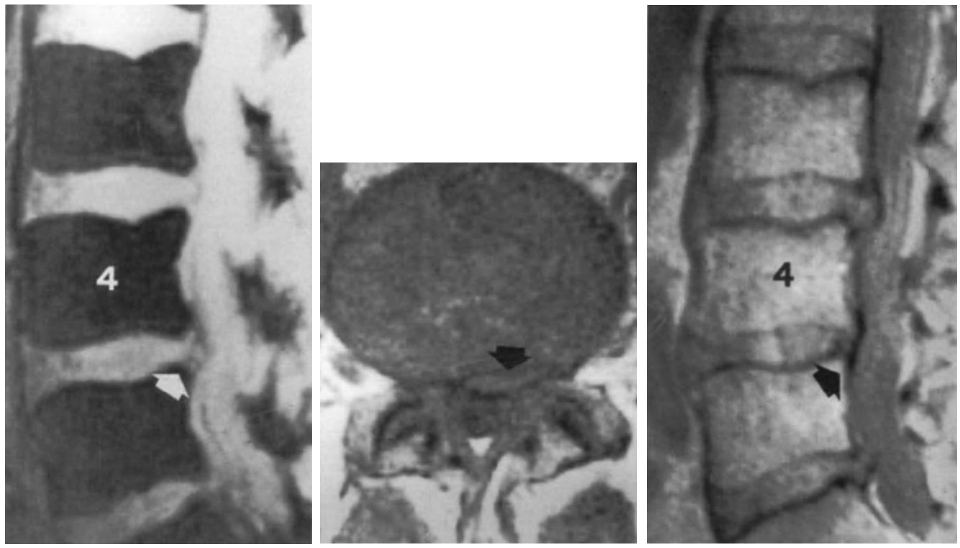
Fig. 15.4. *This patient underwent chemonucleolysis due to a medium-sized L5-S1 disc herniation* (A)–(C) *on the left side (arrows). Radicular symptoms were completely relieved 1 month after the procedure. One year later, the patient began to complain again of lumboradicular pain on the left side. Repeat myelograms* (D)–(F) *showed normal filling of the left S1 nerve-root sleeve due to disappearance of herniation at L5-S1 level (arrows), and a slight filling defect of the left L5 root due to a new herniation, of small size, at L4-L5 level. Note the decrease in height of the L5-S1 disc after nucleolysis.*

vertebral end-plates show changes in signal intensity, consisting in a transient increase in intensity on T-2 weighted images; the changes appear 3 months after treatment and disappear after 2 years. In another one fifth of the patients, the vertebral end-plates present a progressive increase in signal intensity on T1-weighted images and an isointense or hypointense signal on T2-weighted images; these changes appear after 2 years and are associated with sclerotic changes of the subchondral bone in the vertebral bodies on plain radiographs. These changes are an expression of spondylotic alterations of the motion segment.

Radiologic investigations or MRI, therefore, indicate that the vast majority of patients with a satisfactory outcome present a decrease in size or disappearance of the herniation after nucleolysis. Changes on CT or MRI tend to occur slowly, over a few months. When performed too early, therefore, these investigations may not display clear-cut changes in the size of herniation, even if the patient has already obtained a good clinical result. After 6 months or more, patients with a satisfactory outcome almost always present a considerable decrease in size or disappearance of the herniation (Fig. 15.5); a diffuse disc bulge with no significant compression of the neural structures often remains, particularly in the first few months (Fig. 15.6). Annular bulging is likely to be due, at least to a large extent, to the decrease in disc height.

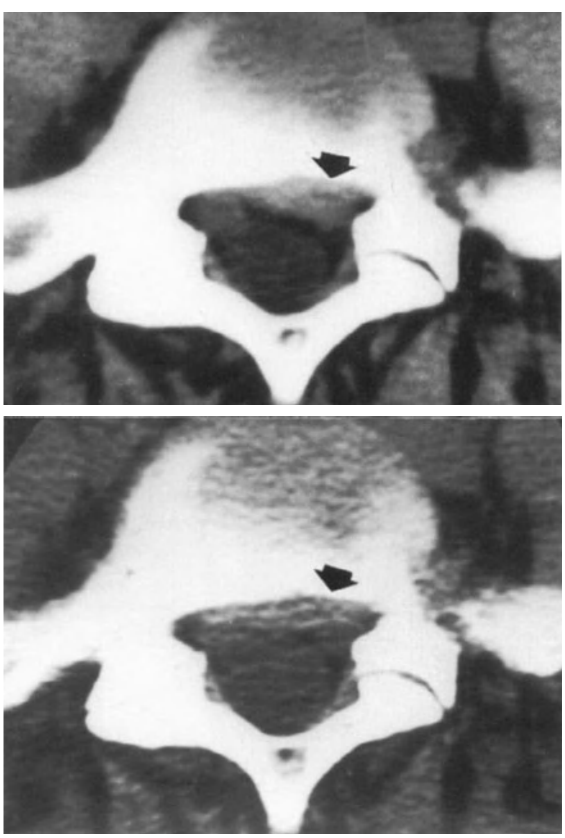
Regeneration of nucleus pulposus

In studies on dogs aged about 9 months, Garvin and Jennings (58) found that, 2 years after chymopapain injection, all discs injected with low doses of enzyme (0.1–1 mg) had reached a normal height, and gross and microscopic features similar to those of the normal discs. Those injected with 10 mg of the enzyme – a dose considerably higher than that effective – had increased in height, but were still not as high as the controls; furthermore, the nucleus pulposus was decreased in volume and few viable cells were visible.



A B C

Fig. 15.5. (A) and (B) *Sagittal and axial MR images of a patient with contained L4-L5 disc herniation on the left (arrows), treated successfully with chemonucleolysis.* (C) *Sagittal MR image obtained 9 months after nucleolysis due to recurrence of lumboradicular symptoms caused by a new herniation at L3-L4 level. At L4-L5 level, the herniation has disappeared (arrow).*



A

B

Fig. 15.6. *Axial CT scans at L5-S1 level, obtained before chemonucleolysis* (A) *and 4 months after the procedure* (B). *The extruded disc herniation present on the left side before nucleolysis is no longer visible after the procedure, however the disc shows diffuse annular bulging, probably resulting from decrease in height. Lumboradicular symptoms had completely disappeared.*

In another study on dogs (16), in whom 1 mg of chymopapain (a comparable dose to that employed in man) had been injected into lumbar discs, the disc height, after an initial decrease, progressively increased over the next 6 months. After 3 months, the nucleus pulposus appeared slightly more fibrotic than in controls, but Safranin O staining was again intensely positive. At 6 months, cell arrangement in the nucleus pulposus appeared to be normal. The cartilage end-plates and annulus fibrosus also displayed normal features. At this stage, the chemical and physical properties of proteoglycans isolated from nucleus pulposus were similar to those of the controls. The results of this study thus suggest that recovery of disc height is related to the reformation of intercellular matrix and synthesis of proteoglycans with essentially normal characteristics, rather than substitution of nuclear tissue with fibrocartilage.

The ability of the human disc to increase in height after the initial decrease, and the frequency with which this occurs, are still unknown. Unlike in animals, disc re-expansion undoubtedly occurs in a minority of subjects. In our experience, disc height increases over the course of at least 1 year and in less than 20% of subjects. Disc re-expansion can be partial or, occasionally, total or almost total. The latter occurrence is usually observed in subjects in whom disc height had decreased moderately after the procedure (Fig. 15.7). The different behavior with respect to animals might be related not only to the standing posture of human beings, which makes it more difficult disc re-expansion, but also to the presence, in human herniated nucleus pulposus, of degenerative changes, which are absent or of mild entity in non-herniated discs of young animals.

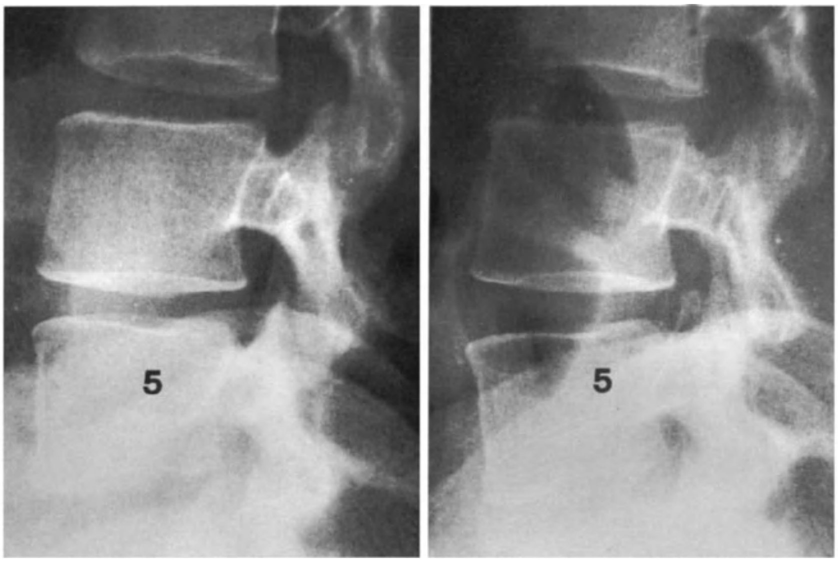
A  B

Fig. 15.7. *Plain radiographs of a patient submitted to chemonucleolysis at L4- L5 level.* (A) *1 month after the precedure.* (B) *1 year after the procedure; the height of the L4-L5 disc is comparable to that before nucleolysis and that of the disc above.*

Little is known also about the structural changes occurring, with time, in human discs submitted to chemonucleolysis. The histologic and histochemical examination of fragments of disc tissue excised at surgery in patients undergoing surgical discectomy due to unsuccessful nucleolysis, may show, during the months immediately after the procedure, a tendency of the cells to proliferate and synthesize proteoglycans, with a return to similar histologic and histochemical features to those of the normal disc (Fig. 15.8). However, this is likely to occur only in those discs which were not markedly degenerated prior to nucleolysis (68, 140).

Mechanism of action

The exact mechanism of action of chymopapain on the herniated nucleus pulposus and the mechanism responsible for the relief of radicular pain remains to be completely elucidated.

The most likely hypothesis is that diffusion outside the disc of glycosaminoglycans and the molecules of water bound to these, as well as the digestion of non-collagenous proteins of the disc, such as those forming the electron-dense material visible under the electron microscope, reduces the mass of the nucleus pulposus. This leads to a decrease in intradiscal pressure and, thus, the pressure exerted by herniation on the nerve root (99). Furthermore, dissolution of the digestible components of the herniated nucleus pulposus possibly contributes to determine an early decrease in size of disc protrusion, which, even if slight, may be sufficient to reduce the inflammatory reaction of the nerve root and, thus, the radiated pain. With time, cicatricial retraction of the residual collagenous portion of the disc might lead to a progressive decrease in size, until possible disappearance, of the herniation (95).

A few authors have also hypothesized a direct anti-inflammatory effect (124), or a chemical effect (151), on the nerve root. However, none of these mechanisms, have been proved.

Chymopapain, being dissolved in water, can reach any part of the disc where the injected solution can spread and digest any reachable portion of the nuclear tissue, including extruded fragments. However, since the enzyme does not affect the collagen fibers, the herniated tissue made up entirely, or to a large extent, of annulus fibrosus is not digested or is insufficiently digested by the chymopapain, and this results in treatment failure.

Indications and contraindications

At the beginning of the 80's, McCulloch and McNab (121) identified five parameters – two symptoms, two clinical signs and a diagnostic investigation – on which the indication for nucleolysis should be based. The parameters were: 1) radicular pain more severe than low back pain; 2) neurologic symptoms, such as paresthesias or muscle weakness (if present as a symptom) with a metameric distribution; 3) straight leg raising limited to 50% of normal; 4) presence of at least two neurologic signs of the following: depression of a reflex, motor loss, muscle wasting and hypoesthesia; 5) positivity of an imaging study, such as myelography or CT. According to this "rule of five", the best candidates for nucleolysis are those in whom all criteria are satisfied, whilst patients in whom four criteria are satisfied have

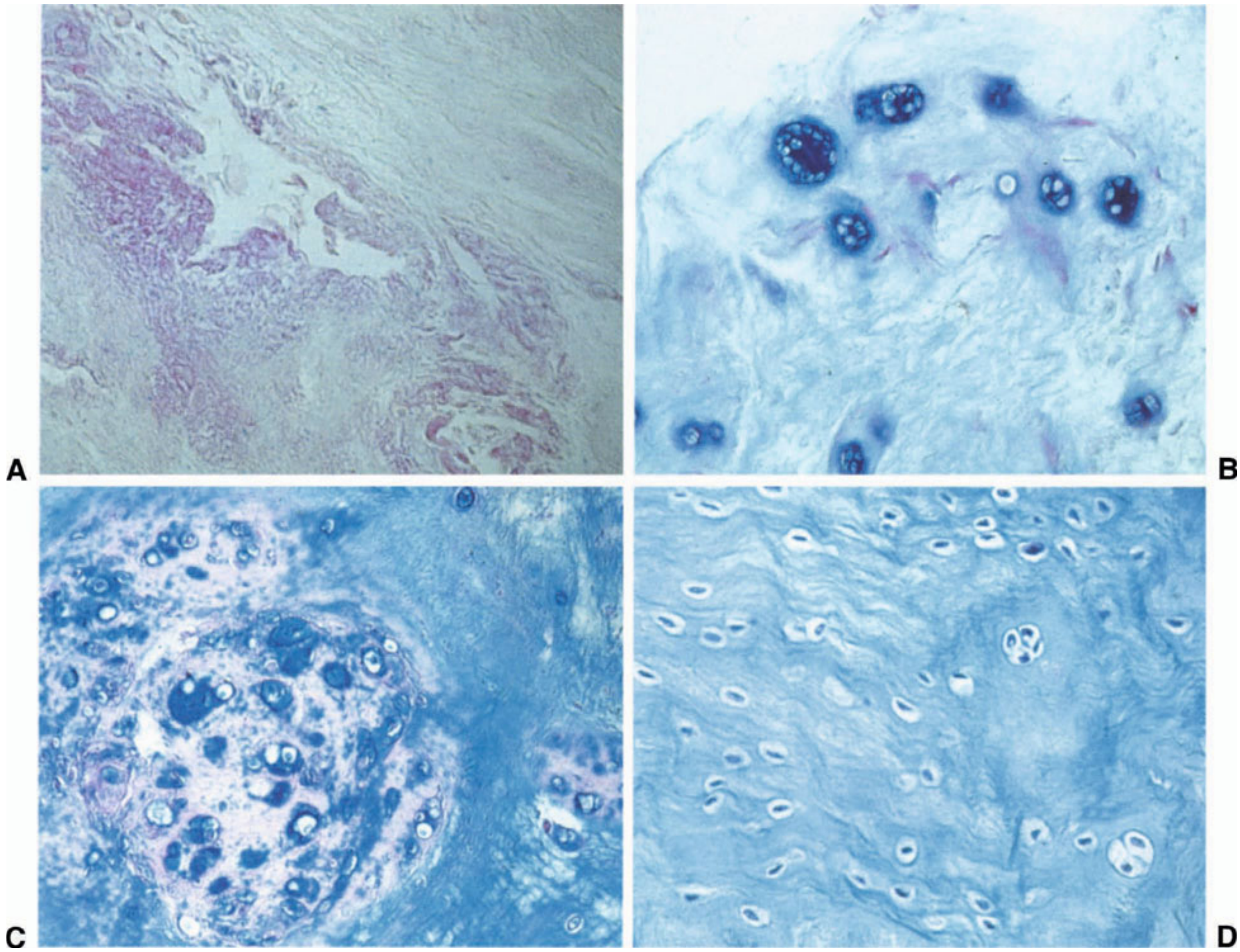


Fig. 15.8. *Fragments of disc tissue excised at surgery in four patients at varying time intervals after chemonucleolysis.* (A) *5 days after nucleolysis; Mowry staining. Marked decrease in proteoglycan content. No viable cells are visible.* (B) *34 days after nucleolysis; Mowry staining. The interterritorial matrix is poorly stained, whilst the cells are in active proteoglycan synthesis, as revealed by the intense staining of the territorial matrix.* (C) *51 days after nucleolysis; Mowry staining. The cells are actively proliferating. Intense staining of the interterritorial matrix, which again shows a high proteoglycan content.* (D) *53 days after nucleolysis; alcian blue staining. The disc tissue contains numerous cells and the intercellular matrix presents a normal proteoglycan content (from Ref. 68).*

good chances of a successful outcome. However, the five parameters indicate the presence of a herniated disc, rather than determining the indication for nucleolysis, since they do not take into account either the type of herniation or the severity of nerve-root compression.

The only points upon which all authors agree are that chemonucleolysis should be carried out only in the presence of a herniated disc responsible for radicular pain, after failure of conservative management prolonged for an adequate period. On all other points, opinions are very conflicting. The procedure has been carried out in patients with contained or extruded herniations of all sizes, in the absence or presence of neurologic deficits, even severe, and in patients of all ages, results being in the same type of pathologic condition – for instance a large disc herniation – satisfactory in some studies and unsatisfactory in others.

Postacchini (143, 146) has defined the indications for the procedure based on the size of herniation, severity of neurologic deficits and type of herniation. The concept that must orientate us in the choice of the patient to treat is that nucleolysis should not be considered an extreme semiconservative therapeutic attempt, before resorting to surgery, but a mode of treatment which should have high chances of success, within a time interval not very dissimilar to that of surgery. Based on this concept and the results of the procedure, we believe that nucleolysis is indicated when the following criteria are satisfied: 1) contained herniation of small or medium size (i.e., encroaching on the spinal canal, respectively, for less than 25% or for 25% to 50%) or subligamentous extruded herniation of small size, when the extruded fragment is in front of the disc or an adjacent vertebral end-plate; 2) absence of neurologic deficits or presence of slight or moderate deficits (for example, muscle strength 4/5 or 3/5); 3) non-excruciating radicular pain. When the herniation is large, in fact, the enzyme may not be able to digest the entire herniated tissue, or herniation is likely to be extruded behind the posterior longitudinal ligament and, thus, cannot be reached by the enzyme, or may consist, to a large extent, of annulus fibrosus, which is not digested by chymopapain. The presence of a severe neurologic deficit indicates that the nerve root is markedly compressed and this occurs more easily in the presence of a migrated or transligamentous extruded herniation than in other types of herniation; on the other hand, the severity of the neurologic deficit makes a fast and complete nerve-root decompression necessary, which may be better achieved by surgery than nucleolysis. Likewise, excruciating radicular pain, which should be rapidly relieved, is not a good indication for nucleolysis, since this often improves pain gradually, over a few weeks. Patient's age does not affect the indications; however, it should be borne in mind that, in the elderly, concomitant stenosis is often present or herniation consists of annulus fibrosus, rather than nucleus pulposus.

Chemonucleolysis is contraindicated in patients with known papaya allergy, cauda equina syndrome, migrated herniation, stenosis of the spinal canal or non-discal pathologic conditions. Pregnancy is generally considered a contraindication, although no studies have been carried out on the use of the procedure in pregnancy. Stenosis of the spinal canal is usually a contraindication, at least when the condition appears to play a significant role in nerve-root compression. A previous chymopapain injection has long been considered a contraindication for repeat treatment due to the higher risks of allergic complications. Sutton (169) observed an anaphylactic reaction in 14% of the 21 patients submitted to a second injection; however, in the 12 cases preoperatively treated with H1 and H2 antagonists (respectively, hydroxizine and cimetidine), no anaphylactic reactions occurred. Similar findings are reported by others (11). A recurrent herniation following surgical treatment is generally a contraindication for chemonucleolysis, since the disc tissue has a low proteoglycan content and a high collagen fiber content, which reduce the digestive efficacy of the enzyme.

Technique

The procedure should preferably be carried out in the operating room. It can also be performed in the radiology department, however it may be difficult to obtain not only adequate assistance of an anesthetist, in the event of allergic reactions, but also conditions of absolute sterility. To reduce the risk of infection, the operator should wear a sterile gown as in an open surgical procedure and this can be done more easily in an operating room.

Anesthesia

Anesthesia can be general or local. The advantages of general anesthesia are that the procedure is not painful and, in the case of anaphylaxis and laryngospasm, the latter can be more easily controlled in the intubated patient. The three main advantages of local anesthesia are: 1) there is no risk of the needle perforating the nerve root emerging from the intervertebral foramen, since with the patient awake, he/she feels a sharp radiated pain as soon as the needle tip approaches the root; 2) if an anaphylactic reaction occurs, the conscious patient can describe the prodromal symptoms (warmth, tingling, nausea and a feeling of impending doom) of the reaction, thus allowing treatment to be immediately commenced (71). Laryngospasm, on the other hand, can be more easily controlled when treatment is commenced without delay. Furthermore, anaphylaxis can be treated more effectively when no anesthetic agents have been administered, particularly halothane, which sensitizes the heart to epinephrine (the drug of choice for hypotension) and increases the probability of arrythmia (3, 81); 3) the risks related to general anesthesia are avoided. For these reasons, the procedure is generally performed under local anesthesia, with the assistance of an anesthetist.

Our protocol includes: application of an intravenous needle for administration of fluids; intravenous Fentanest; cutaneous and subcutaneous local anesthesia with a standard needle and, then, deep anesthesia along the needle path using a 22 G spinal needle, administering a total volume of 15–20 ml anesthetic. A further dose of sedative may be given upon enzyme injection.

Patient positioning

The patient may be placed in the lateral or prone position. The choice is largely one of personal preference. We prefer the lateral decubitus on the left side (Fig. 15.9). In this position, the disc is approached on the right side. However, there seem to be no great differences between the right or left approach (121). In order to widen the disc space, a support (a pillow, a rolled surgical sheet or a radiotransparent rigid support) is placed under the patient's left flank. The patient is positioned with the hips and knees flexed, and a pillow is

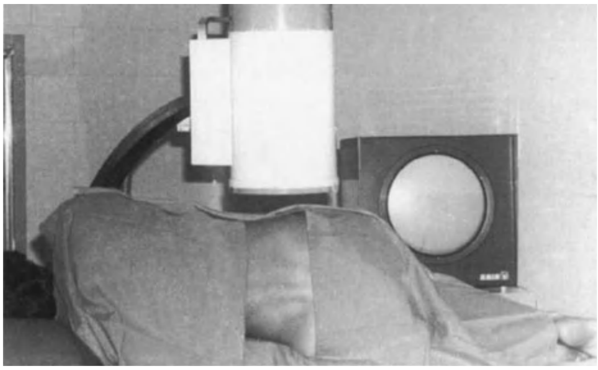


Fig. 15.9. *Patient in left lateral decubitus before chemonucleolysis. A small pillow has been placed under the left flank. The entry point of the needle has been marked on the skin, at 10 cm from the line of the spinous processes.*

placed between the legs to make the position more comfortable.

The disc to be injected is identified with the fluoroscope in the lateral view. For a correct visualization of the disc, the patient should be in a perfectly lateral position. Otherwise, the operator should roll the patient's trunk ventrally or dorsally until optimal visualization of the disc is obtained. For the L5-S1 disc, which has an oblique position with respect to the longitudinal axis of the body, it may be necessary to place the fluoroscope obliquely. If in doubt concerning level identification – for instance, in the presence of sacralization of the L5 vertebra – the spine should be visualized also in the anteroposterior view. This is useful particularly for the L5-S1 level, in order to preoperatively determine the degree of inclination of the x-ray beam which allows perpendicular visualization of the intervertebral space with no overlap of the adjacent vertebral end-plates.

The operator, before sterile dressing, should leave the fluoroscope placed in the lateral view, centered on the intended disc and in the position allowing the best visualization of the intervertebral space.

Needle placement

Chemonucleolysis is carried out using a lateral approach to the disc, with a similar technique to that of discography (104, 122).

L4-L5 disc (and more cranial discs). The needle is inserted at some 10 cm from the midline at the level of the disc to be treated (Fig. 15.9). To calculate the distance from midline, the operator can use his own hand: placing his thumb on the spinous processes, the entry point is 1–2 cm above the little finger. The entry point in the cranio-caudal direction, which is usually in close

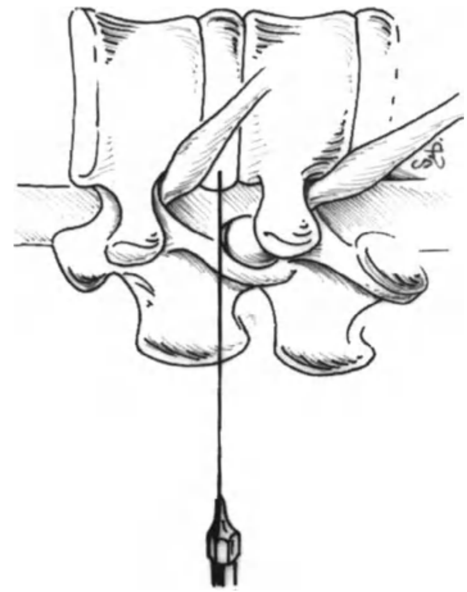


Fig. 15.10. *Schematic drawing showing the discography needle path (L4-L5 disc) and entry point into the disc. If the needle is too ventral, it encounters the nerve root. If too dorsal, it is impeded by the articular processes (subject in the left lateral decubitus position).*

proximity to the iliac crest, can be identified in two ways: 1) a Kirschner wire is placed on the skin at the level of the intended disc under fluoroscopic vision and the position of the wire is then marked; 2) local anesthesia of the skin is started at a level presumably corresponding to the involved disc; the position of the needle is checked with the fluoroscope and, if incorrect, is changed until the correct site is identified.

The discography needle is advanced in a perpendicular direction to the disc, with an inclination of some 60° with respect to the patient's coronal plane. The needle should reach the annulus fibrosus dorsally to the nerve root emerging from the intervertebral foramen (Fig. 15.10). The operator, once the annulus fibrosus is reached, feels a kind of elastic resistance. At this point, the technique changes depending on whether one or two needles are used (Fig. 15.11). In the former case, the needle (15 cm long) is introduced until the central area of the disc; an 18 G needle should preferably be used, which can be better controlled than a thinner needle. When two needles are used, the procedure is started with an 18 G, 8.5 cm long needle, with which one reaches the annulus fibrosus as close as possible; a straight 22 G needle is inserted in this needle and advanced to the center of the disc. The second method would have the advantage of decreasing the risks of discitis, since the needle which enters the disc has no contact with the skin (54).

The difficulties that may be encountered are essentially due to the wrong choice of the site of skin

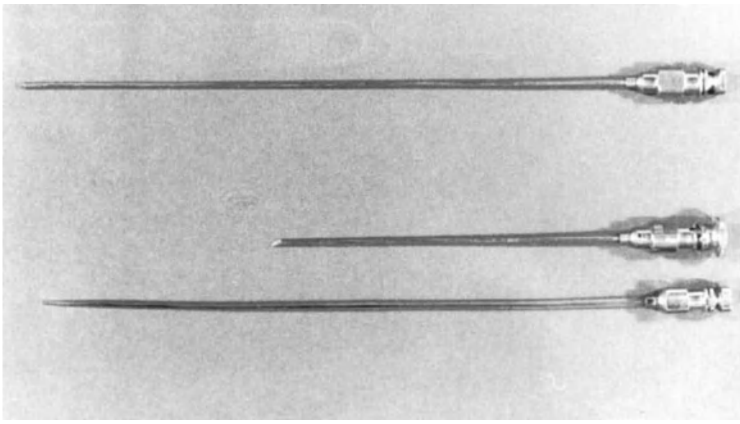


Fig. 15.11. *Discography needles for L4-L5 and more cranial discs. Above: an 18 G, 15 cm long needle. Below: an 18 G guiding needle and a straight 22 G needle to enter the disc.*

insertion of the needle, wrong needle inclination with respect to the coronal plane or a distorted fluoroscopic vision of the spine. If the entry point is too medial, the needle hits against the articular processes and cannot reach the disc space; the needle should be extracted and introduced at a greater distance from the midline. When the inclination is too horizontal (less than 60°), the needle may meet the nerve root emerging from the intervertebral foramen, thus causing radiated pain, or may pass anterolaterally to the disc. Conversely, if the inclination is too vertical, the needle may be stopped by the spinous process or even penetrate into the spinal canal through the neuroforamen. Technical errors more easily occur due to a distorted visualization of the disc,

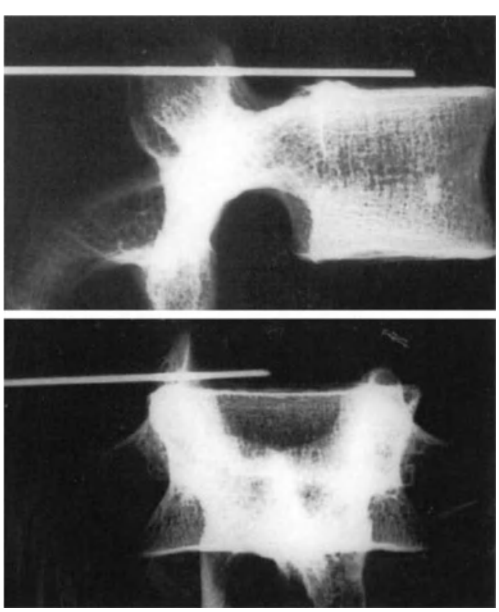


Fig. 15.12. *Simulated lateral and anteroposterior radiographic views of discography needle when the tip reaches the center of the disc.*

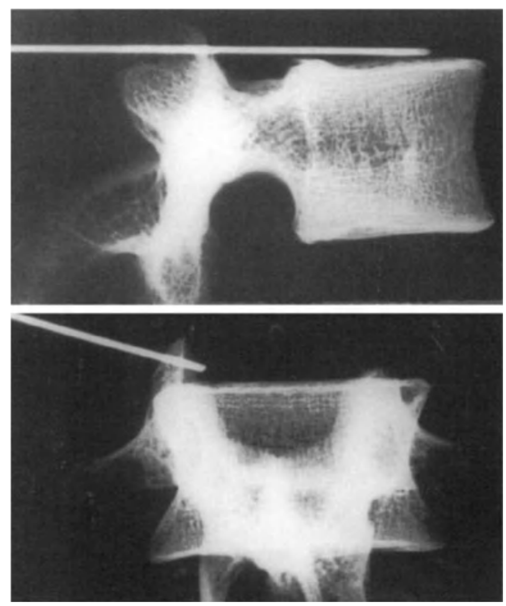
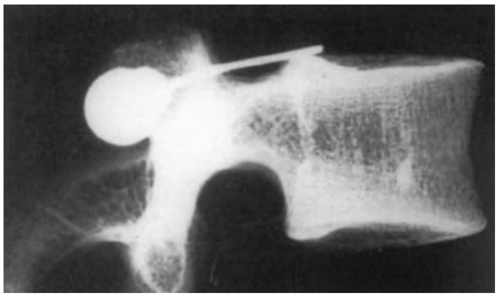


Fig. 15.13. *Simulated lateral and anteroposterior radiographic views of a needle directed too ventrally. In the lateral view the tip reaches the anterior portion of the disc, whilst in the anteroposterior view the tip is situated in the lateral portion of the disc space.*

generally due to an oblique position of the patient with respect to the fluoroscope tube; patient position may easily change when the procedure is carried out under local anesthesia and should be corrected by rolling the patient's trunk ventrally or dorsally.

The needle tip should reach the center of the disc, i.e., the point corresponding to the center of the adjacent vertebral bodies in the lateral view, and the line of the spinous processes in the anteroposterior view (Fig. 15.12). If introduced too medially, the needle goes beyond the center of the adjacent vertebral bodies in the lateral view, but does not reach the line of the spinous processes in the anteroposterior view (Fig. 15.13). The



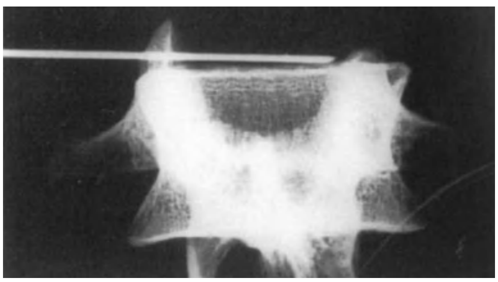


Fig. 15.14. *Simulated radiographic views of a needle inserted too dorsally into the disc. The tip is located in the posterior portion of the disc in the lateral view, whereas it goes beyond the midline in the anteroposterior view.*

opposite occurs when the needle is in a too dorsal position (Fig. 15.14). If too ventral or dorsal, the needle tip is located in the annulus fibrosus and this usually hinders the injection of any liquid due to the resistance of the dense fibrous tissue of the annulus. In effect, one does not often reach exactly the center of the disc; what is important, however, is that the needle reaches the area of the nucleus pulposus, and that the contrast medium, or any other liquid, can be injected without excessive resistance.

L5-S1 disc. It is usually necessary to use an 18G, 8.5 cm long guiding needle and a 22 G, 15 cm long needle, the extremity of which is bent manually (Fig. 15.15). Straight needles can be used only in those rare cases in which the disc is only slightly caudal to the iliac crest.

The guiding needle is inserted at about 10 cm from the midline, in close proximity to the iliac crest. The needle is inserted with an inclination of 30° caudally and an angle of 50°–60° to the patient's coronal plane. Advancement of the needle should be checked on the lateral view until the tip reaches the level of the posterior aspect of the L5-S1 disc. The 22 G needle is then passed through the guiding needle with the concavity

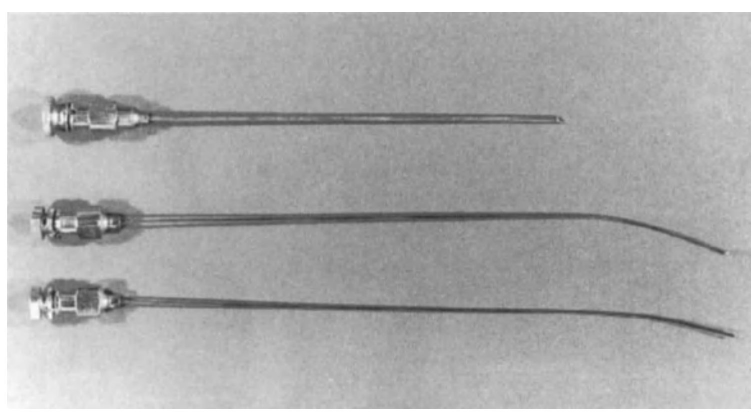


Fig. 15.15. *Discography needles for the L5-S1 disc. From top to bottom: an 18 G, 8.5 cm long guiding needle and two 22 G, 15 cm long needles, the ends of which have a different degree of bending.*

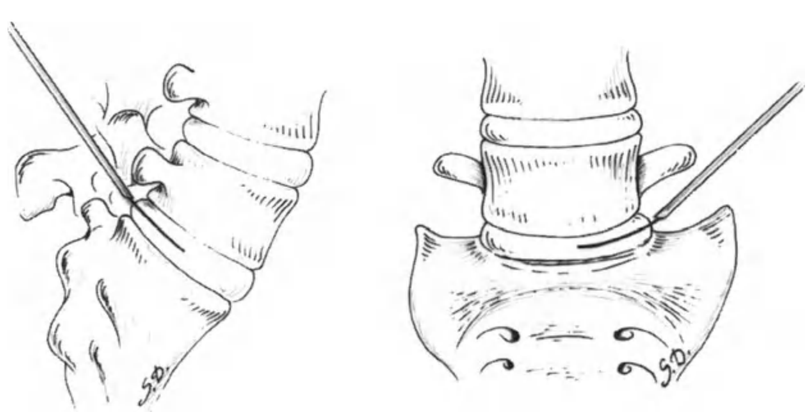


Fig. 15.16. *Schematic drawings showing the direction of the guiding needle and the optimal position of the intradiscal needle for chemonucleolysis at L5-S1 level.*

of the curve orientated towards the spine. The position of the needle tip is checked as soon as it emerges from the guiding needle. When the tip is at the level of the midpoint of the posterior aspect of the disc space, the needle is advanced in the central area of the disc (Fig. 15.16). At times, the needle appears to be within the disc in the lateral view, but caudally to the disc space in the anteroposterior view; this is due to the fact that the direction of the x-ray beam is not parallel to that of the disc. To see the needle in the disc space, the fluoroscope should be tilted in a caudo-cranial direction.

When the tip of the guiding needle is not well positioned, the thin needle hits against the vertebral endplate of the L5 or S1 vertebra, or it advances laterally or dorsally to the disc. In these cases, the guiding needle should be extracted for at least half of its length and repositioned. If the position of the guiding needle is satisfactory, but the thin needle does not penetrate into the disc, the latter should be extracted and re-introduced into the guiding needle, checking that the concavity of the curve is maintained turned towards the spine; this is obtained by strongly gripping the needle head, so that it does not rotate within the guiding needle. Occasionally, needles with different curvatures should be tried until a proper bend is found. In patients with the L5-S1 disc at a very deep level with respect to the iliac crest, in whom the guiding needle of standard length does not reach close to the disc, a guiding needle 15 cm long and a thin needle 20 cm long should be used.

If the two lower lumbar discs have to be injected, the needle should generally be placed first in the L4-L5, and then in the L5-S1, disc. The guiding needle for the lowermost disc should be introduced proximally to that for the disc above.

Discography

Despite numerous experimental and clinical studies, conflicting opinions still exist regarding the usefulness of discography.

The advocates of discography attribute various prerogatives to this investigation: 1) discography may allow us to determine whether herniation is contained or extruded; the latter condition is more likely when contrast medium leaks out of the disc; 2) a massive leakage of contrast medium into the epidural space suggests that chymopapain may also flow into the spinal canal. The result could be an insufficient action of the enzyme on disc tissue and an increased risk of allergic reactions and neurologic complications; 3) discography allows detection of an abnormal communication between the disc and the intrathecal space or the vessels of the vertebral body; in the latter case, a typical opacification of the vertebral body is observed; 4) provoking the patient's typical lumboradicular pain during injection of the contrast medium confirms the clinical diagnosis and makes a successful outcome of nucleolysis more likely; 5) the contrast media do not significantly inhibit, or even increase, the digestive action of the enzyme (127).

Those not in favor of discography do not employ this procedure for several other reasons: 1) leakage of contrast medium into the spinal canal does not appear to increase the likelihood of complications or to imply a lower rate of satisfactory outcomes (119, 184); 2) provocation of radicular pain with discography is not constant, even in the presence of a large disc herniation and cannot, thus, represent a criterion for selection of possible candidates for the procedure (121); 3) it is not unequivocally proven that the contrast media have no effect upon the action of the enzyme; 4) the rate of serious allergic or neurologic complications was found to be higher in patients submitted, compared with those not submitted, to discography (14).

As a rule, we do not perform a full discography, but only a mini-discography, i.e., we inject a small amount of contrast medium (0.5–1 ml) to check the position of the needle within the disc (and we record it for medicolegal reasons), particularly in the area of the nucleus pulposus. If considerable resistance to injection of the contrast agent is encountered, in fact, the needle tip is likely to be placed in the annulus fibrosus and should, therefore, be re-positioned.

On the other hand, following the advent of CT and, particularly, MRI, discography is not very useful in demonstrating whether herniation is contained, extruded or migrated. Disco-CT may be more useful than discography, since it can demonstrate whether the herniated tissue takes up the contrast medium and is in continuity with the central area of the disc; in this case, the enzyme will reach even a subligamentous extruded disc herniation. However, disco-TC cannot provide any information on the nature of the herniated tissue – nucleus pulposus or annulus fibrosus – and thus on the digestive effects of the enzyme. Furthermore, this investigation must be performed as a procedure independently of nucleolysis, if the latter is carried out in the operating room.

Discomanometry. This consists in measuring, by means of a special manometer, the resistance encountered during discography and, thus, the intradiscal pressure (24). In a healthy disc, a marked resistance is encountered during injection of the contrast agent and the resistance does not change while continuing the injection. In the presence of an annular cleft, the resistance, initially high, decreases gradually or brusquely (depending on the degree of leakage of the contrast medium into the epidural space), until it ceases completely. This technique, after the initial enthusiasm, has been found to be of little usefulness in patients undergoing nucleolysis and has been abandoned as a clinical diagnostic test.

Injection of enzyme

A luer lock syringe should be used, since a standard syringe may become disconnected from the needle, if considerable resistance is encountered during injection. In this case, not only is the residual portion of the enzymatic solution lost, but the operator may not know exactly what volume of solution has already been injected.

The enzymatic solution should be injected very slowly – usually in 5–10 minutes – for several reasons: with a fast injection, under pressure, the solution could more easily overspill from the disc; due to the rapid action of chymopapain, the initial portion of the enzyme may begin to digest the nuclear tissue and this can make the injection of the remaining portion easier, if a considerable resistance is encountered upon inoculation; chymopapain injection often causes low back and/or radicular pain, which is less severe if the solution is injected slowly; slow inoculation allows the anesthetist to monitor the patient by frequent measuring of blood pressure, as the enzyme is injected, and to detect the prodromal signs of anaphylaxis before the entire dose of enzyme is injected.

Milky fluid occasionally flows back from the disc into the syringe during injection of the enzyme. This occurs in the presence both of a high intradiscal pressure and of nuclear tissue which is easily digested by the enzyme. The reflux is a positive prognostic sign, since the patients in whom this phenomenon occurs have better chances of a satisfactory clinical outcome.

Postoperative monotoring

At the end of chymopapain injection, the patient is placed supine on the operating table and checked by the anesthetist. If there is no evidence of an allergic reaction, he is taken to the recovery room and again repeatedly checked by the anesthetist for a further 30 minutes after the end of the procedure, since anaphylaxis usually occurs within this time interval. In the presence of severe low back pain, administration of analgesics and muscle relaxants is started in the recovery room.

Postprocedural management

Most of the patients complain of moderate to severe low back pain in the first 12 hours after chemonucleolysis. Pain, however, is rarely very severe. It progressively decreases over the next few days, but will usually persist for a few weeks at least. The behavior of radicular pain varies considerably. In a few patients, it is completely relieved a few hours after the procedure; this occurs in less than 15% of cases. In the majority of patients, radicular pain decreases progressively over the first 3–6 weeks; often, in the first few days pain is mild or absent in the recumbent position, but appears or becomes more severe in the standing position or on walking. Very occasionally, radicular pain may increase in severity after nucleolysis, but usually only for a few days.

Postprocedural treatment varies depending on the type and severity of symptoms. Usually, NSAIDs or analgesics and muscle relaxants are administered at high doses for 1–3 days and then at medium or low doses for 1–2 weeks after nucleolysis. The vast majority of patients can be discharged on the same day as, or 1–2 days after, nucleolysis. Longer hospitalization is rarely needed. In the presence of severe radicular pain, it is advisable to administer high doses of cortisone and to keep the patient in bed for a few days.

In the first 2 or 3 weeks after nucleolysis, the patient should observe bed rest for a considerable length of time. We generally recommend bed rest for about 20 hours a day in the first week and 16 hours a day in the second week. Then, if low back and/or radicular pain is moderate, the patient may leave the house for short walks and resume sedentary work. If, in the third week, pain is still severe, the patient should remain in bed for 12–14 hours a day. We do not generally advise a corset, unless low back pain is severe. The corset is definitely left off if, as occasionally occurs, it exacerbates radicular pain. The patient should drive the car when he/she feels fit enough to do so, however usually not before the second week after nucleolysis.

Complications

Chemonucleolysis with chymopapain may give rise to three main types of complications, namely allergic, neurologic and infective (Table 15.1). In addition, very occasionally cardiac, visceral or thromboembolic complications have been reported (Table 15.1).

Allergy

Minor allergic reactions include itching, skin rash, urticaria, slight hypotension, Quincke's edema, prevalence ranging from 1.8% to 5% (13, 14, 96). Treatment of these complications, which may occur from a few hours to several days after the procedure, is based on the

Table 15.1. *Complications in 43,662 patients undergoing nucleolysis with chymopapain (from Ref. 14).*

Complications	No. of patients
Allergic reactions	
skin rash	366
angioneurotic edema	40
hypotension	120
anaphylaxis	61
others	245
Total	832 (1.9%)
General complications	
deep venous thrombosis	37
pulmonary embolism	15
fever	114
meningitis	2
ileus	4
pancreatitis	1
others	34
Total	207 (0.4%)
Disc complications	
spondylodiscitis	105 (0.25%)
Neurologic complications	
sphincter problems	270
new radicular deficits	170
cauda equina syndrome	15
intrathecal hemorrhage	1
epilepsy	1
paraplegia	2
arachnoiditis	2
others	1
Total	462 (1.58%)
Grand total	1606 (3.7%)

administration of antihistamines, corticosteroids and / or epinephrine.

Major allergic complications are represented by anaphylactic reactions. In a series of 4282 patients treated by McCulloch under local anesthesia, 15 (0.35%) sustained an anaphylactic reaction (71). No bronchospasm was seen in any of the patients, whilst profound and sustained hypotension occurred in all of them. In most cases, hypotension was preceded by warning signs, such as a burning or tingling sensation all over the body, pruritic skin rash, nausea, a cool feeling or a general sensation of malaise. In 14 cases, the initial symptoms appeared within 10 minutes of the enzyme injection, whist in one patient anaphylaxis occurred 30 minutes after the procedure. All patients survived with no sequelae. In a series of 29,075 patients treated in the United States, the prevalence of anaphylaxis was 0.67% (1). The frequency was considerably higher in females than in males. The prevalence of the complication in the patients treated under local anesthesia was half (0.4%) that observed under general anesthesia (0.8%). In almost all cases, the complication occurred within 20 minutes of the enzyme injection. The death rate due to anaphylaxis was 1:14,537, a similar prevalence to that found in a series of 135,000 American patients (130), in which the rate was 1:19,286. The prevalence of anaphylactic reactions in Europe is lower than in North America. In a series of 43,000 European patients, the frequency of anaphylactic reactions was 0.14% (14). In this series, local anesthesia was not associated with a lower frequency of the complication and no death or permanent sequela occurred; furthermore, prophylactic treatments, when carried out, did not decrease the frequency of the complication.

Prevention and treatment. The first form of prevention is to carefully record the patient case history in order to exclude allergy to papain, severe reactions to drugs, foods or other substances as well as atopy, which may aggravate an anaphylactic reaction. Beta-blockers should be suspended prior to the procedure, since they inhibit the effect of adrenaline in the treatment of anaphylaxis.

The second stage of prevention is the use of skin tests and serum assays, such as RAST (Radioallergo Sorbent Test) and FAST (Fluorescent Allergo Sorbent Test), aimed at determining the concentration of IgE. In the latter test, the presence of more than 0.06 U/ml of IgE antibodies implies a 42% probability of an anaphylactic reaction, whilst in the absence of antibodies the risk of anaphylaxis is less than 0.002% (96). Whilst a negative test does not exclude a possible anaphylactic reaction, it does, however, allow patients at risk to be identified, in whom nucleolysis should be avoided.

The third form of prevention is administration of H1 and H2 antagonists (diphenhydramine and cimetidine) for 24 hours prior to the procedure. These substances, however, whilst decreasing the severity, do not prevent, an anaphylactic reaction.

Treatment of anaphylaxis is based on intravenous administration of adrenaline 1:10,000, antihistamines and cortisone. Corticosteroids would appear to decrease the release of chemical mediators of anaphylaxis by stabilizing cell membranes, but their efficacy remains to be proven. Dopamine may also be used to increase cardiac output and improve renal perfusion. Furthermore, oxygen should be administered (by intubation, if necessary), as well as large doses of colloids and cristalloids.

Neurologic complications

In a series of 2136 European patients (13), four cases presented a marked increase in the preoperative nerve-root deficit or onset of new deficits after nucleolysis. This complication may be due to nerve-root needling outside the intervertebral foramen in patients treated under general anesthesia, increase in disc protrusion as a result of enzyme injection or a possible toxic effect of chymopapain on the nerve root.

Paraplegia occurred in 11 out of 29,075 American cases studied by Agre et al. (1). In 10 cases, the complication was certainly, or very probably, related to errors in needle placement and intrathecal injection of chymopapain, whereas in one case the complication was due to extrusion of herniation in the days following nucleolysis. In the series of 135,000 American cases analyzed by Nordby et al. (130), the author identified nine patients with paraplegia (probably all included in the above-mentioned series), three of whom recovered partially or completely, and 17 patients with paraparesis, 15 of whom had a partial or complete neurologic recovery, whereas no information on recovery was obtained in two cases. In many of these patients, the complication appeared days or weeks after chemonucleolysis. In a few cases, the neurologic disorders could not be attributed to the procedure; in others, they were due to technical errors and, in yet others, to extrusion of fragments of disc tissue. The series of 43,662 European cases reported by Bouillet (14) includes two cases of paraplegia, one of which was probably due to technical errors. In addition, there are 15 cases of cauda equina syndrome due to extrusion of the herniation into the spinal canal, with complete recovery after surgical treatment in 13 cases.

Of the American patients with paraplegia or paraparesis, six were initially considered as having acute transverse myelitis, a syndrome of as yet uncertain etiology. For one of these patients, a viral etiology and an autoimmune pathogenetic mechanism was hypothesized (45). No new cases of this syndrome have been reported since 1984 (130).

The series of Nordby (130) includes 32 cases of hemorrhage in the central nervous system, mostly occurring within a few hours of nucleolysis. Just over 50% of these patients sustained subarachnoid hemorrhage and the others, brain hemorrhage. In 13 cases, intrathecal injection of chymopapain or contrast medium was demonstrated or strongly suspected. Five cases were found to have a cerebral aneurysm or cerebrovascular malformation. In 10 patients, hemorrhage led to death. Only one case of a hemorrhagic complication, with no permanent sequelae, was reported in the European series of Bouillet (14).

Infections

In two large series, the frequency of spondylodiscitis after chemonucleolysis was, respectively, 0.013% (130) and 0.25% (14). In smaller series, however, the prevalence of discitis after discography, without or with chemonucleolysis, was 1%–3% (54). Fraser et al. (54, 138) found that the prevalence of discitis after discography considerably decreased when the double needle technique was used also for the L4-L5 disc and those more cranial, and when antibiotics were given prior to the procedure.

Cases of so-called chemical discitis following chemonucleolysis have often been described, particularly in the past. These cases are generally characterized by a decrease in disc height associated or not with moderate erosions of the vertebral end-plates, a similar clinical picture to that typical of infectious discitis, except for the absence of fever, negative bacterial culture, histopathologic evidence of chronic inflammatory process and tendency to spontaneous resolution (53). Since in postoperative discitis the clinical presentation may vary considerably and bacterial cultures are often negative, chemical discitis could also be caused by infectious agents.

Six cases of systemic infection, often associated with bacterial endocarditis, have been reported. Two of these patients died as a result of the infection (130).

Chemonucleolysis versus surgery

Bouillet (14) have compared 43,662 cases submitted to chemonucleolysis with 2051 cases of conventional surgical discectomy operated by 18 surgeons. The rate of complications in the chymopapain series was 3.7% and 0.45% of patients had a serious complication (Table 15.1). In the surgical series, the total rate of complications (intraoperative, postoperative or late) was 26%, serious complications accounting for 4.2%. The most frequent were allergic complications in the chymopapain group and postoperative complications (neurologic, infective, meningocele) in the surgical group.

Results

Negative studies. The first randomized double blind study performed on chemonucleolysis (154) analyzed 31 patients treated with chymopapain and 35 controls in whom only CEI (cysteine-edetate-iothalamate) was injected (Table 15.2). In the chymopapain group, the proportion of satisfactory results was 58%, compared with 49% in the control group. In this study, however, the dose of chymopapain was only 4 mg, whilst the dose usually administered in the following years was 8 mg. In a double blind study (67), 20 patients injected with chymopapain and 20 with intradiscal cortisone were evaluated 2 years after treatment: 40% of patients in both groups obtained no improvement. A retrospective study (157) on 150 patients submitted to chemonu-

Table 15.2. *Prospective randomized double blind studies on chymopapain.*

	Schwetsenau et al. (154)	Fraser (52)	Javid et al. (86)	Dabezies et al. (33)
Year	1976	1982	1983	1988
No. of patients	66 (31[a], 35[b])	60 (30[a], 30[b])	108 (55[a], 53[b])	159 (78[a], 81[b])
Mean age	38.1[a], 34.9[b]	37.1[a], 37.2[b]	37.9[a], 39.9[b]	37.2[a], 38.7[b]
Dose	4 mg	8 mg	8 mg	8 mg
Placebo	CEI	Saline	Saline	CEI
Follow-ups	2–11 mesi	1.5–6 m.	1.5–6 m.	1.5–6 m.
Successes chymopapain	58%	80%	73%	71%
Successes placebo	49%	57%	42%	45%

[a] Chymopapain; [b] placebo; CEI: cysteine-edetate-iothalamate

cleolysis, assessed by questionnaire on average 2 years after treatment, revealed that the results were excellent or good in 40% of cases, fair in 18% and poor in 42%. Loew et al. (105), based on a series of 19 cases, concluded that chymopapain was ineffective, since only 42% had satisfactory results, however in two of the failures, nucleolysis had been performed at a wrong level.

An interesting observation is that most of the negative studies have been carried out by neurosurgeons.

Positive studies. In a randomized double blind study (52), 30 patients were treated with chymopapain, whereas in 30 only saline was injected into the herniated disc; at 6-month follow-up, the results were satisfactory in 80% of patients treated with chymopapain and 57% of controls. In a similar study (86) carried out in seven centers, 55 patients received chymopapain and 53 only saline; the rate of successes, 6 months after treatment, was 73% in the chymopapain group and 42% in the control group. Dabezies et al. (33) evaluated 78 patients treated with chymopapain and 81 with CEI, based on a randomized double-blind protocol, by 30 surgeons; at 6-month follow-up, the success rate was 71% in the former group and 45% in the controls (Table 15.2).

In numerous other prospective or retrospective studies, the rate of satisfactory results has been 70% or more (8, 38, 50, 57, 60, 70, 120, 124, 143, 159). McCulloch (119) followed 480 patients treated at one or more levels for a mean period of 18 months; of the patients with typical disc herniation not previously operated on, 70% had satisfactory results, whereas most of the patients with stenosis, a psychogenic component in pain or a history of previous surgery in the lumbar spine reported a failure. Hill and Ellis (79) treated 225 patients at one or multiple levels under general anesthesia after discography and 110 patients at a single level under local

Table 15.3. *Long-term and very long-term results of chemonucleolysis with chymopapain.*

Author	No. of cases	Follow-up (years)	Success rate
Postacchini (1991)	68	5–10	82%
Dubuc (1986)	842	5–12	81%
Wilson (1994)	200	5–13	71%
Sutton (1986)	208	6–11	79%
Jabaay (1986)	130	8–10	71.5%
Dabezies (1986)	94	8–12	80.6%
Nordby (1986,2)	739	8–13	76%
Thomas (1986)	42	9–13	81%
Maciunas (1986)	268	10	80.1%
Gogan (1992)	30	10	80%
Mansfield (1986)	146	10–14	66%
Flanagan (1986)	357	10–20	74%

anesthesia without discography; a 73% success rate was obtained in the former group, and 83% in the latter. In two multicenter studies (4123), each analyzing more than 1000 patients, the success rate were 70% and 87%, respectively.

Long-term and very long-term results. Numerous studies have analyzed the results of chemonucleolysis after more than 5 years (Table 15.3). In a series of 189 patients assessed by questionnaire after 6–11 years (169), 79% were found to be satisfied with the treatment. In numerous other studies which assessed the results 5–13 years after nucleolysis, the proportions of satisfactory outcomes ranged from 71% to 82% (32, 41, 82, 107, 109, 129, 171, 183). Postacchini and Perugia (147) evaluated 68 patients after 5–10 years; six patients had been operated on; of the remaining 62, 91% had obtained an excellent or good result. Gogan and Fraser (66) assessed, after 10 years, the patients of a previous randomized double-blind study (52); of the patients treated with chymopapain, 20% had undergone surgery; of the remainder, 80% maintained that the treatment had been successful, whilst the outcome was rated as satisfactory by only 34% of patients treated with saline, who meanwhile had not undergone surgery. Nordby (128) analyzed the results obtained by 13 authors in 3130 patients assessed 7 to 20 years after treatment; satisfactory results ranged from 71% to 93%, mean 77%. An analysis of 357 patients 10–20 years after treatment (49) revealed that 44% had no pain, 30% complained of slight discomfort and only 6% reported a failure.

An important finding emerging from these studies is that the results of chemonucleolysis do not tend to change with time. An excellent or good outcome at short term rarely becomes poor at long term; likewise, patients with a fair or poor outcome generally remain in these categories (183).

Comparison with surgery. In a study (2), 100 military servicemen submitted to chemonucleolysis (51 cases) or treated surgically (49 cases) were assessed about 1 year after treatment. All patients had been considered good candidates to either treatment and the choice depended on the patient's preference. Satisfactory results were obtained in 78% of patients in the chymopapain group and 80% of those in the surgical group; the rate of complications was 4% in the former group and 10% in the latter. Comparable results were found in a retrospective study (179), in which 85 patients submitted to chemonucleolysis and 71 treated surgically were assessed at short (1 year) and long term (10 year). At long term, the results were comparable in the two groups; both at short and long term, the percentage of repeat procedures was slightly higher in the surgical, compared with the chymopapain, group. Javid (85), in the follow-up of 104 patients submitted to chemonucleolysis and 68 treated surgically 1–4 years after treatment, found that results were satisfactory in 86% of cases in the former, and in 83% of those in the latter, group. In a comparative analysis (173) of patients injected with chymopapain or treated surgically, after a mean time of 10 years, satisfactory results (excellent, good or fair) were 72% in the chymopapain group and 83% in the surgical series.

In several other studies, however, the percentage of satisfactory outcomes was found to be higher after conventional surgery (31, 46, 174, 178) or microdiscectomy (111, 177, 187) than after chemonucleolysis. In the prospective randomized study by Crawshaw et al. (31), satisfactory results were obtained in 48% of the 25 patients submitted to chemonucleolysis and in 89% of the 27 undergoing conventional surgical treatment. In the series of Zeiger (187), the outcome was satisfactory in 60% of the 45 patients treated with chymopapain injection and in 98% of the 81 submitted to microsurgical discectomy. Similar success rates were found in the retrospective study by Maroon and Abla (111), comparing chemonucleolysis with microdiscectomy (58% and 90% of successes, respectively). The main criticisms that can be directed to some of these studies are that: the chymopapain groups included patients with herniations of any size, as pointed out by Wilson and Mulholland (183) for the series studied by Crawshaw; no distinction was made between contained, extruded or migrated herniations (46); the presence of severe neurologic deficits, which is usually in contrast with the diagnosis of contained herniation, or the presence of concomitant stenosis were not considered possible criteria for exclusion from chemonucleolysis (111, 178).

Postacchini et al. (146) studied prospectively 72 patients treated with chymopapain injection and 84 submitted to conventional surgery. Herniations were classified as small, medium-sized or large and three types of clinical presentation were identified, corresponding to mild, moderate or severe nerve-root compression. The final follow-up was carried out a mean period of 2.8 years after treatment. In the patients with small herniation who had undergone chymopapain injection, the proportion of satisfactory results (84%) was comparable with that in the surgical series (82%). In medium-sized herniations, the percentage of satisfactory results was slightly higher in the surgical (86%), than the chymopapain (76%), group. In the latter group, most of the patients with excellent or good results showed evidence of mild or moderate nerve-root compression, both in small and medium-sized herniations. In large herniations, surgery led to a significantly higher percentage of satisfactory results (89%) compared with nucleolysis (50%). This study indicates that, in patients with presumably contained herniation, the degree of preoperative nerve-root compression and size of herniation are of considerable prognostic value regarding the results of chemonucleolysis.

Adolescents and elderly patients

In patients younger than 20 years, chemonucleolysis provides satisfactory results in a comparable, or even higher, proportion than in adults. Lorenz and McCulloch (106) followed 55 patients aged 13–19 years for a mean time of 4.5 years. The percentage of success was 80%. Similar rates of success were obtained in other series (40, 170, 183). Our experience also indicates that most adolescents are good candidates for nucleolysis, although they frequently reach a satisfactory outcome more slowly than adults. In most adolescents, in fact, herniation is contained, however the annulus fibrosus often bulges considerably into the spinal canal, thus contributing significantly to compression of the neural structures. Digestion of the nucleus pulposus reduces disc bulging, but does not affect the annulus fibrosus, which tends to retract slowly, over a few months, and only when this process has occurred, does the clinical result become satisfactory. On the other hand, in adolescents, once a satisfactory result is reached, it almost always remains stable, even at long term (129).

Only two studies have analyzed the efficacy of chemonucleolysis in patients over 60 years of age. In one series of 19 patients, satisfactory results were obtained in 63% of cases (110). Benoist et al. (5) assessed the results of the procedure in 42 patients with a mean age of 67 years, on average 4.5 years after treatment. All patients, except for three, had a medium-size herniation. The results were excellent in 43% of cases and good in 35%. Of the nine patients with an unsatisfactory outcome, two underwent surgery and four continued to complain of lumboradicular symptoms, despite the disappearance of herniation on postoperative CT, which showed persistent herniation in the remaining three. In most of the elderly patients in whom clinical success was obtained, the signs and symptoms were of less than 6 months' duration.

Low doses

Low doses of enzyme are as effective as the standard dose, but do not lead to a significant decrease in postoperative low back pain. Benoist et al. (6) injected a standard dose (4000 U in 2 ml) in 60 patients and a lower dose (2000 in 2 ml) in 58 randomly selected patients. Both the percentages of satisfactory results and the severity of postoperative low back pain were comparable in the two groups. Similar results were obtained in other studies, in which the enzyme was injected at a dose of 500 to 1500 U (35, 87, 180).

Recurrence of herniation

The rate of recurrences of herniation after chemonucleolysis seems comparable to that observed after surgery. In a series of 30 patients studied prospectively by Gogan and Fraser (66) for 10 years, the percent recurrence was 3%. On the other hand, of 124 patients followed by Javid (84) for 9–12 years, 16% showed a recurrent herniation. Table 15.4 reports the percent recurrence of herniation in 10 clinical series, the mean percentage being 7%. In most of these series, however, only those cases operated on at variable time intervals after nucleolysis are considered as recurrences; it is, thus, not known how many patients had a recurrent herniation and did not undergo surgery, in how many cases the herniation was at the same level as the primary herniation or at other levels, and in how many patients surgery was performed due to a stenotic condition rather than a true recurrent herniation. Postacchini and Perugia (147) analyzed 68 patients after a mean time of 7.2 years; those patients who had undergone surgery a short time after nucleolysis were excluded from the study. Of the patients with a satisfactory outcome at short term, six (7%) underwent surgery due to recurrent herniation at the same level and on the same side as the primary herniation 1.5 to 4 years after nucleolysis, and one patient was operated due to bulging of the annulus fibrosus in a stenotic nerve-root canal. Of the remaining patients, 12% reported one or more episodes of radicular pain of more than 1 week's duration.

Table 15.4. *Recurrence of disc herniation following chemonucleolysis.*

Author	No. of cases	Follow-up (years)	Surgical discectomy
Gogan (1992)	30	10	3%
Wilson (1992)	364	5–13	4%
Lavignolle (1992)	190	10	4.5%
Mansfield (1986)	146	10–14	5%
Maciunas (1986)	268	10	5%
Postacchini (1991)	68	5–10	7%
Dabezies (1986)	100	8–12	7.5%
Sutton (1986)	189	6–11	9.5%
Tregonning (1991)	145	10	9%
Javid (1985)	105	9–12	16%

Surgery after failure of chemonucleolysis

The pathologic conditions usually found in those patients operated on in the first few months after failed chemonucleolysis are: a migrated, extruded or contained herniation; bulging of annulus fibrosus associated or not with nerve-root canal stenosis; or only isolated stenosis of the radicular canal.

With the advent of CT and MRI, a migrated disc fragment can generally be diagnosed or suspected preoperatively, with the exception of intraforaminal herniations, in which even these imaging studies may not demonstrate the type of herniation. On the other hand, since most intraforaminal herniations are extruded or migrated, there is little indication for nucleolysis in these types of herniated disc. Extruded herniation, instead, is frequently encountered after failure of chemonucleolysis. In most cases, the herniation is small inasmuch as it was small even before nucleolysis or on account of partial digestion of the herniated tissue by the enzyme; often the herniated tissue consists of an annular fragment not digested by chymopapain. A true contained herniation is a fairly rare finding and, when found, it is usually large.

Stenosis of the spinal canal is rarely a cause of failure, since this condition is usually easily diagnosed preoperatively. Isolated stenosis of the nerve-root canal, instead, is a frequent cause of failure either because this condition is more difficult to diagnose preoperatively or because narrowing of the nerve-root canal may increase as a result of a decrease in height of the disc space. When disc height is markedly reduced, in fact, it may be responsible for annular bulging and / or an increased bulge of the ligamentum flavum into the spinal canal.

Previous nucleolysis does not affect the results of surgery, which are comparable to those obtained after a first operation for disc herniation as far as concerns both pain and restoration of working ability (17, 39, 107, 109, 119, 184).

A small proportion of patients with chronic low back pain after nucleolysis undergo spinal fusion, with a similar percentage of satisfactory results to that observed in patients with chronic low back pain presumably of discogenic nature. According to some authors (155), arthrodesis would be indicated in many cases of persistent low back pain following nucleolysis, since the latter might cause or increase vertebral instability (155). However, several studies indicate that, a few months after nucleolysis, the normal biomechanical properties of the disc are restored (page 89). Persistent postprocedural low back pain, therefore, is probably not due to vertebral instability, unless this is present prior to treatment.

Cost

In one study (148), the cost of chemonucleolysis was compared with that of conventional surgical discectomy, both procedures having been performed at a single level. Mean hospital stay was 1.4 days in the nucleolysis group and 6.4 days in the surgical series. Of the patients in the former group, 7.5% had a failure and underwent surgery, whilst repeat surgery was carried out in 10% of the patients in the surgical group. The mean cost of treatment, taking into account the cost of the repeat procedure, was some 15% lower in the nucleolysis group than in surgical group. The higher cost of surgical treatment was essentially due to the longer hospitalization. It should not be forgotten, however, that, at present, the mean hospital stay is considerably less than in the past decade, even for conventional discectomy. Furthermore, if microdiscectomy is carried out, the mean hospital stay is comparable to that of chemonucleolysis. At present, therefore, the cost of nucleolysis is comparable to that of surgery, or even higher, if one takes into account the costs of postprocedural treatments in the patients with unsuccessful nucleolysis who do not undergo surgery, and the costs related to the longer time off work that nucleolysis implies (177).

Collagenase

Collagenase, injected in lumbar discs of monkey, dissolves the nucleus pulposus and the adjacent portion of annulus fibrosus and, on average, leads to a 40% decrease in disc height; the enzyme, when brought in contact with the L4 root in the intervertebral foramen, causes a slight perineural inflammatory reaction, but no significant changes in the nerve tissue (188).

In patients with lumbar disc herniation, the success rate with collagenase chemonucleolysis ranges from 69% to 85% (20, 21, 30, 101). Hedtmann et al. (74) assessed 61 patients treated with a high dose of collagenase (600 ABC units) and 43 with a low dose of the enzyme (400 ABC units); the success rate was 63% with a high dose and 71% with a low dose at the 3-month follow-up, and 72%, using a high dose, at 6-month follow-up; in comparable groups of patients treated with chymopapain, the results were similar to those of the cases treated with low dose collagenase. With this dose, postoperative low back pain is less severe and of similar entity to that produced by chymopapain, compared to which collagenase is slower in improving radicular pain (22). As for chymopapain, short-term results do not tend to change with time. Wittenberg et al. (185) assessed, after 5 years, 42 of the first 50 patients treated. Of these, 28% had undergone surgery, mostly within the first few months after treatment. Of the remaining patients, 93% presented satisfactory results.

Collagenase very occasionally causes allergic reactions of mild severity. In the series of Chu (30), including 252 patients submitted to epidural, rather than intradiscal, injection of the enzyme, no neurologic complications occurred. Other investigators (74, 185), however, have reported a high rate (18%) of neurologic complications, consisting of monoradicular motor or sensory deficits, but also three cases of cauda equina syndrome.

Other enzymes

Chondroitinase ABC (CABC) is a disaccharidase with a specificity for chondroitin sulphate types A, B and C. The enzyme, which is a product of metabolism of Proteus vulgaris, does not induce microhemorrhages after subcutaneous injection and has no effect on intathecal nerve tissue or peripheral nerves at doses (200 U/ml) 4–8 times higher than the effective dose (94, 132). In rabbits and dogs, intradiscal injection of 10, 50 or 100 U/ml of CABC causes a decrease in disc height and in proteoglycan content in the ventral portion of the annulus fibrosus adjacent to the nucleus pulposus (48, 56). In rabbits, injection of even 1 unit of the enzyme produces cell death and a decrease in the proteoglycan content in the nucleus pulposus in a few days (76). Despite these promising findings and the very slight chance that pre-sensitization to this exogenous protein exists in human beings, CABC has not as yet been used for clinical purposes.

Cathepsins B and G, obtained from liver and human leucocytes, respectively, and chymotripsin, extracted from pancreatic juice, are endogenous proteases, which should have a lower antigenicity compared with chymopapain, an exogenous protein. In rabbits, all three enzymes lead to a reduction in disc height following intradiscal injection. Cathepsin G and chymotripsin are able to remove 80% of disc proteoglycans, whilst cathepsin B removes only 45% (34).

Calpain I, like chymopapain, is a cysteinic protease, which leads to degradation of proteoglycans in vitro. This enzyme is present in human erithrocytes and is thus devoid of antigenic properties, when obtained from the same subject in whom it is injected. In the rabbit, intradiscal injection of calpain I leads to a decrease in disc height and in the content of proteoglycans, which, over 2 months, tend to return to the initial levels (176). Proteolytic action, however, is lower than that of chymopapain. Prior to its possible use for clinical purposes, various problems should be solved regarding dose and sterilization of the enzyme as well as the inhibitory effects of endogenous calpastatin.

Conclusions

Chemonucleolysis with chymopapain is a technically simple procedure not only for L4-L5 disc, but also for L5-S1 disc, in which it may be difficult, or at times impossible, to enter with instruments used for other percutaneous methods. Of all the percutaneous procedures, nucleolysis is that which provides the highest rate of satisfactory results. In the three most recent randomized double-blind studies (Table 15.2), the mean rate of success at short term was 74% with chymopapain and 48% with placebo, and in 12 retrospective studies in which the long-term or very long-term results were evaluated (Table 15.3), the mean percentage of successful outcomes was 77%. The high therapeutic efficacy of nucleolysis is probably related to the fact that the enzyme, carried in a liquid agent, is able to reach any portion of the disc into which the injected solution can penetrate.

Compared with the other percutaneous procedures, chemonucleolysis implies a higher risk of complications, particularly of a serious type. The prevalence of the latter, namely neurologic complications, has become an issue of concerns, particularly when the procedure has been used indisciminately, often by the inexperienced. Experienced physicians have never reported serious neurologic complications or anaphylactic reactions leaving permanent sequelae. On the other hand, it should not be forgotten that, in recent years, the use of antiallergic prophylaxis has further reduced the chances of uncontrollable anaphylactic shock. However, nucleolysis with chymopapain should not be considered, for these reasons, a minor therapeutic modality, representing the last stage of conservative management, but rather a procedure with clear-cut indications, which is performed on account of its intrinsic advantages.

Chemonucleolysis requires very careful patient selection, which greatly affects the chances of a successful outcome. In our experience, good candidates for chemonucleolysis are those patients presenting with small or medium-size herniation, mild or moderate neurologic deficits, no marked disc narrowing, radicular symptoms of less than 8 months' duration, and no evidence of nerve-root canal stenosis. This does not imply that patients with other pathologic conditions (large contained herniation, subligamentous extruded herniation or severe radicular deficits) may not have also satisfactory results. In these cases, however, the chances of success are considerably less and the procedure, to a certain extent, becomes a therapeutic attempt aimed at avoiding surgical treatment. This approach, instead, should be avoided, since nucleolysis is not a form of treatment to be taken lightly and should be carried out not as a makeshift or as an attempt, but rather because it is technically simple, has high chances of successful outcome and the results obtained, when satisfactory, are comparable to, or even better than, those of surgery. Compared with patients submitted to surgery, those undergoing chemonucleolysis have similar chances of recurrence of the herniation.

Collagenase does not offer any significant advantages with respect to chymopapain. The absence of major allergic reactions is, in fact, balanced by a lower therapeutic efficacy and a comparable or higher rate of neurologic complications with respect to chymopapain. The enzymes still under experimentation do not appear to be able to compete with chymopapain.

Percutaneous automated nucleotomy (PAN)

Percutaneous automated nucleotomy (PAN) was introduced by Onik, who, in the early part of the 80's, developed a smaller sized instrumentation than those used by other surgeons for manual percutaneous nucleotomy (55, 78, 90), which had a novel mechanism of automatic cutting and aspiration. After experiments in animals and cadavers (133), a straight instrumentation was put on the market, allowing discs located at the level of, or proximally to, the iliac crest to be approached. The technique quickly became very popular due to its technical simplicity and innocuity, and the high rate of satisfactory results initially reported. A curved cannula was later developed to approach the L5-S1 disc (134). After an initial period of great acclame, the popularity of this technique started to wain, as results of clinical studies only partly confirmed the therapeutic efficacy of PAN. This technique is, however, still used by many doctors, although much less frequently than at the beginning.

Instrumentation

The instrumentation developed by Onik consists of a disposable kit and pneumatic suction equipment.

The kit includes the instruments to approach the disc and a drain tube which can be connected to a bottle, where the material aspirated is collected. The approach instruments include: 1) a guiding needle 1 mm in diameter with a removable hub; 2) two coaxial cannulae. The outer cannula (guiding cannula), 2.6 mm in diameter, contains a tapered dilator (inner cannula), 2 mm in diameter, the end of which is cutting and just out from the outer cannula by 2 mm. A straight cannula is available for the L4-L5 and more cranial discs, and a slightly curved cannula for the L5-S1 disc (Fig. 15.17); 3) A 2 mm wide trephine with a cutting end to perforate the annulus fibrosus (Fig. 15.17). 4) A nucleotome probe, which has a needle 2 mm in diameter attached to it (Fig. 15.17). The needle has a rounded end with a port near to the distal end. A cannula with the end sharpened to a surgical blade is fitted through the center of the needle. Suction is applied to the center of the cannula aspirating the disc material into the port of the needle. The end of the cannula is pneumatically driven across the port, thus cutting off the disc tissue, which is then aspirated through the cannula to a collecting bottle. The cutting instrument operates at up to 300 cycles/min. The nucleotome, as well as the dilator and trephine, are moderately flexible in order to adapt to the curved guiding cannula, which is rigid.

In recent years, a flexible nucleotome has been developed, which can be angled from 0° to 90°. One can reach, with this nucleotome, those areas which cannot be reached with the standard nucleotome, particularly the posterior portion of the disc.

Technique

The procedure is performed in the operating room, under local anesthesia with a similar technique to that for chemonucleolysis. General anesthesia is not advised due to the risk of injuring the nerve root emerging from the intervertebral foramen.

The patient is placed in the lateral decubitus or prone position. Unlike in chemonucleolysis, the prone position is preferable, since the procedure lasts longer, which may make the lateral decubitus position uncomfortable for the patient. The operating table may be bent to allow the hips to be flexed at 45° or a radiotransparent support, kyphosing the lumbar spine and making use of the fluoroscope easier (10), may be employed. The disc is approached on the side of the herniation or, in the case of a midline herniated disc, on that corresponding to the more symptomatic lower limb.

A few doctors use a paramount CT of the abdomen, performed with the patient in the prone position at the level of the affected disc (and also at the level above

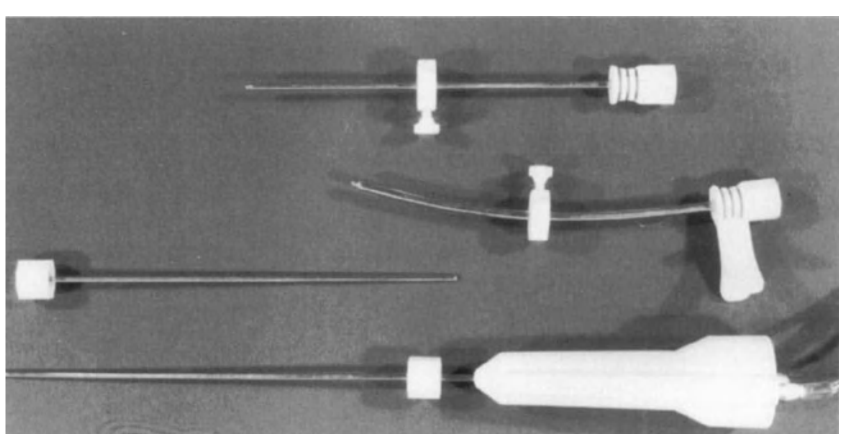


Fig. 15.17. *Onik's instrumentation for percutaneous automated nucleotomy.*

when the L5-S1 disc is involved), to exclude a retropsoic position of the colon and vascular, ureteral or renal anomalies, and to calculate the distance of the cutaneous entry point from the midline and the path of the instruments.

The disc is approached with a technique similar to that described for chemonucleolysis. As for the latter, a few operators perform a preprocedural discography. In this case, the needle should be placed as precisely as possible in the center of the disc, so that it can be used for inserting the guiding needle of Onik's instrumentation. There are two options in this respect: if the guiding needle of the instrumentation is used, it is inserted in close proximity and parallel to the discography needle; alternatively, a thinner guiding needle is used, which is passed through the discography needle, that is then removed, leaving in place the guiding needle.

When the guiding needle has been confirmed fluoroscopically to be in the center of the disc, the hub of the needle is removed. After a small skin incision, the coaxial cannulae (guiding cannula and dilator) are passed over the guiding needle and advanced to the outer aspect of the annulus fibrosus. The dilator is removed, leaving the guiding cannula and needle in place. The trephine is then inserted and a 8-mm deep hole is created by rotating the instrument. The trephine and guiding needle are removed and replaced by the nucleotome, which has a maximum excursion of 3 mm beyond the end of the guiding cannula.

A curved guiding cannula is used for the L5-S1 disc, since it cannot usually be entered with a straight instrument. The cannula is placed over the guiding needle of the instrumentation or a thinner curved needle passed through an 18 G needle, using the technique described for chemonucleolysis. When the needle of the instrumentation is used, the tip of the needle is positioned in contact with the outer surface of the annulus fibrosus. The curved guiding cannula containing the dilator is placed over the guiding needle and advanced until it reaches the annulus fibrosus; if the trephine, and then the nucleotome, hit against one of the vertebral end-plates, the guiding cannula is orientated cranially or caudally until the instruments can enter the disc as parallel as possible to the vertebral end-plates. This is made easier with the use of the 18 G needle and the curved needle previously inserted into the disc parallel to the vertebral end-plates (Fig. 15.18).

The nucleotome is advanced to the center of the disc and then switched on, using first a high cutting frequency and then a lower frequency so that small fragments of disc tissue are more easily attracted into the port of the instrument. The port should be advanced in all those areas that can be reached within the nuclear space and slowly deepened and retracted, with uninterrupted movements, so that it can encounter and suck out new disc material. Furthermore, the instrument should be rotated so that the port is orientated in the direction in which nucleotomy is needed. The saline flowing in the drain tube, in which the fragment of disc tissue passes, should always be transparent. Sometimes, usually at the beginning of nucleotomy, the saline may be pinkish in color due to the presence of blood. The nucleotome should then be switched off, and its position checked and possibly changed. During the procedure, the guiding cannula should be maintained in contact with the outer aspect of the annulus fibrosus; this avoids not only injuries to the peridiscal tissues if the nucleotome is inadvertently extracted from the disc, but also excessive penetration of the instrument into the disc space.

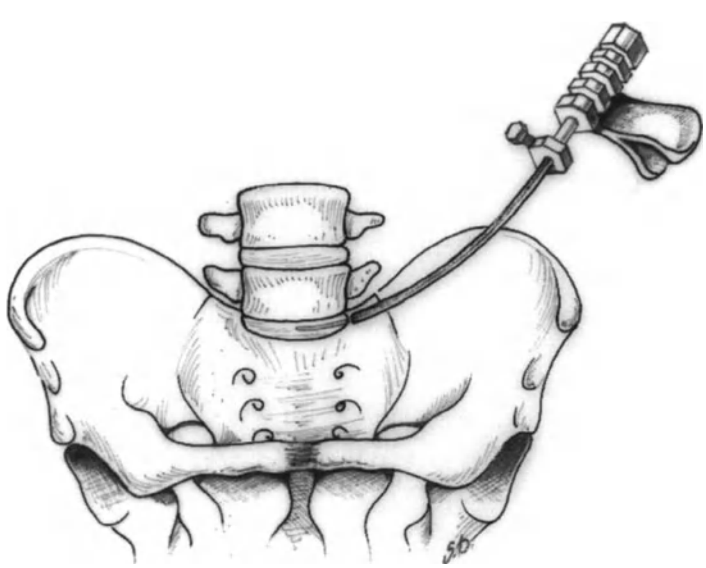


Fig. 15.18. *Curved guiding cannula for percutaneous automated nucleotomy at L5-S1 level. The cannula is inserted with the concavity orientated cranially over a curved 22 G needle, previously placed in the disc through an 18 G guiding needle.*

The nucleotome should be activated for 15–20 minutes. The amount of tissue removed varies considerably (Figs. 15.19 and 15.20). Usually 2 to 5 g of tissue are excised.

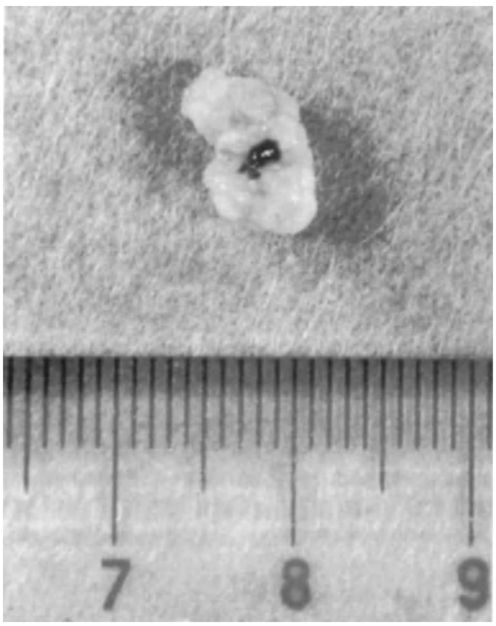


Fig. 15.19. *Small amount of nucleus pulposus removed by percutaneous automated nucleotomy at L4-L5 level.*

Technical difficulties

It is uncommon to encounter any difficulty in introducing the nucleotome into the L4-L5 or more cranial discs. This may occur, however, in the presence of nerve-root anomalies, particularly when two roots emerge from the spine through one intervertebral foramen. In this instance, the space behind the nerve root may be so narrow that the patient feels radiated pain as soon as any instrument thicker than a needle reaches the disc.

It may often be difficult or impossible, on the other hand, to enter the L5-S1 disc. Difficulties are usually encountered in the presence of hypertrophy of the transverse process of L5 and, particularly, if the disc is in a deep position with respect to the iliac crest. When, on the anteroposterior view, the angle between the tangent line to the disc and the theoretical path of the guiding needle is 35° or more, it is very difficult or sometimes impossible to insert the nucleotome into the disc, even if a curved guiding cannula is used (10) (Fig. 15.21). Occasionally, even the expert has difficulty in entering the disc, despite the absence of anatomic anomalies. This may be due to marked radicular edema or an intraforaminal herniation, either of which will modify the course of the nerve root. If the patient, after several attempts to enter the disc, by modifying the cutaneous entry point or the path of the instruments, still feels a sharp radicular pain as soon as the guiding cannula reaches the annulus fibrosus, the procedure should be suspended. The increasing intolerance on behalf of the patient, in fact, upsets the operator, thus reducing his level of technical precision and care of sterility rules, leading, in turn, to a progressive decrease in the chances of correct penetration into the disc and

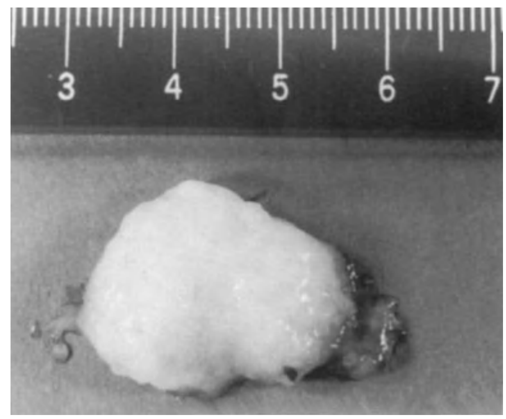


Fig. 15.20. *Nucleus pulposus excised by percutaneous automated nucleotomy at L4-L5 level.*

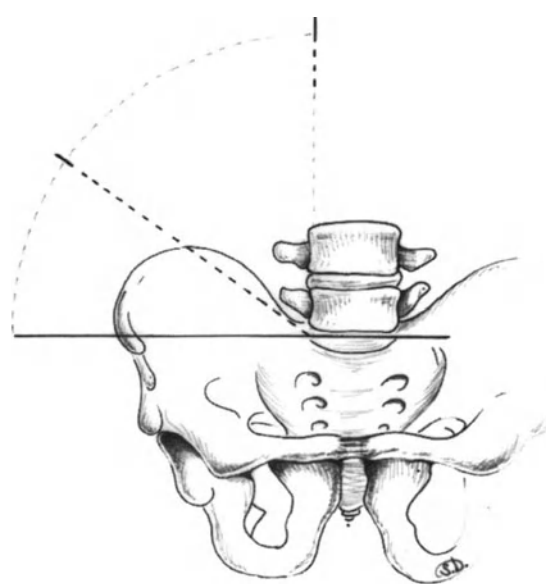


Fig. 15.21. *Schematic drawing indicating how to determine whether it will be difficult or impossible to perform percutaneous nucleotomy at L5-S1 level. This occurs when the angle between the horizontal line through the disc and the path of the guiding needle is 35° or more. In this case, it may be difficult to enter the disc even if a curved guiding cannula is used.*

increasing the risk of infectious complications. Injection of local anesthetic around the neuroforamen should be avoided, since nerve-root anesthesia exposes to the risk of injuring the root.

The pain felt by the patient may be of annular, rather than, radicular origin. In this case, it is felt in the low back rather than in the leg and is rarely severe. This pain ceases when the trephine has perforated the annulus fibrosus.

The nucleotome, when placed in the disc in an oblique direction, easily hits against the vertebral endplate. This drawback, which occurs particularly for the L5-S1 disc, may prevent a wide movement of the instrument within the disc space and, thus, adequate nucleotomy; the instrumentation should be removed and re-positioned correctly.

Postoperative regimen

The patient is usually discharged on the same day as the procedure or the day after.

During the first few weeks, postoperative treatment is similar to that carried out after chemonucleolysis. The main difference, compared with the latter, is that low back pain is generally milder after PAN and, thus, postprocedural bed rest is less prolonged, unless severe radicular pain is present. Return to sedentary work, however, is not usually permitted earlier than 3 weeks after the procedure.

Mechanism of action

In a study (44), preoperative CT scans of 69 discs submitted to PAN have been compared with those obtained a mean period of 6 months after the procedure; furthermore, 43 discs were re-examined 11 months, on average, after the initial CT examination. At the first follow-up CT examination, 73% of herniations were unchanged or occasionally increased in size, 25% showed a slight, and 2% a moderate to marked, decrease in size. At last examination, the proportions were, respectively, 65%, 28% and 7%. The medium-size and large herniations more often showed a decrease in size than the small herniations. Similar results were obtained with MRI (83).

In no clinical investigations was a significant correlation found between the amount of nuclear tissue excised with the nucleotome and the quality of the clinical outcome at short term or long term.

A biomechanical study on cadaver motion segments analyzed the effects of PAN protracted for 45 minutes (25). The mean amount of nuclear material excised was 4.6 g, and disc height and intradiscal pressure decreased by 1.42 mm and 5.7 bar, respectively. The radial bulge of annulus fibrosus increased by 0.45 mm.

Based on these data, the mechanisms by which PAN leads to a decrease in lumboradicular pain in patients with disc herniation still appear unclear. One possible mechanism could be the decrease in intradiscal pressure due to fenestration of the annulus fibrosus – rather than (or in addition to) nucleotomy (141) – resulting in retraction of the herniation. However, this interpretation is in contrast with the observation that, in most patients, the size of the herniation does not change after PAN and with the biomechanical findings indicating an increase, rather than a reduction, of radial bulge of the annulus fibrosus after the procedure. Castro et al. (25) have suggested that the radicular pain relief could be related to the decrease in disc height. This phenomenon, in fact, leads to a decrease in the pressure of herniation on the nerve root (163) and, thus, in nerve-root tension, which plays an important role in the genesis of pain. The reduction in nerve-root tension obtained by this mechanism might exceed the increased tension caused by the increase in radial bulge of the disc, thus leading to relief of radicular pain.

Indications

According to Onik and collaborators (75, 137), patients with lumboradicular pain unresponsive to conservative management for at least 6 weeks and not previously operated on, may be candidates for PAN if at least two out of four clinical criteria are satisfied. These are: 1) monolateral radicular pain more severe than back pain; 2) paresthesias with a specific dermatomal distribution; 3) positivity of nerve-root tension tests; 4) presence of at least two of the following neurologic findings: muscle wasting, motor loss, sensory alteration, decreased reflex activity. Furthermore, at least two other criteria should be satisfied: 5) evidence, on CT or MRI scans, of contained disc herniation in a site consistent with the specific clinical findings; 6) no evidence, on CT or MRI scans, of severe degenerative changes of the facet joints, central or lateral spinal stenosis, or migrated herniation.

In this protocol, therefore, the actual size of the herniation is not taken into account. Many physicians, however, have carried out the procedure only when the herniation did not encroach upon the spinal canal for more than one third of the sagittal dimensions of the canal. Others have considered as not eligible only those patients in whom the herniation exceeded 50% of the dimensions of the spinal canal. Again others have considered the procedure as unsuitable in lateral or calcified herniations (139). A few physicians have performed PAN only when preprocedural discography showed no dye leakage into the spinal canal, which might be an indicator of extrusion of the herniation (139, 161).

In our opinion, five additional criteria should be added to those of Onik: 1) muscle weakness of only mild or moderate severity (strength 3/5 or more); 2) size of herniation not exceeding one third of the midsagittal diameter of the spinal canal; 3) absence, on CT or MRI scans, of disc material extending for 5 mm or more beyond the vertebral end-plate; 4) decrease in disc height of less than 50%; 5) absence of spondylolisthesis, as well as tumors and severe congenital or acquired vertebral malformations.

We believe that preprocedural discography is not necessary, at least routinely. Disco-CT may occasionally be useful to perform, since it can demonstrate better than CT whether herniation is contained or extruded.

Complications

A few authors (10, 137, 162) consider severe postoperative low back pain as a complication; if so, this is the most frequent complication, the prevalence being 0.6% to 13%. Apart from low back pain, the most frequent complications are spondylodiscitis, temporary dysesthesia in the lower limbs and muscle hematoma. In the largest series, the frequency of spondylodiscitis was 0.4% (10, 137). One study (65) reported a CSF fistula, which resolved spontaneously. Furthermore, two cases of cauda equina syndrome, due to penetration of the nucleotome in the thecal sac, have been reported (47, 136); in both cases, nucleotomy had been performed for L5-S1 herniation. Gill (64) reported three cases in which a small portion of the instrumentation broke and was left in situ with no sequelae.

Results (Table 15.5)

High rates of success. In 1989, Davis and Onik (36) reported the results of PAN in 200 patients followed for at least 6 months. The outcome was rated as satisfactory when pain was moderately to completely relieved and the patient required no narcotic medication, had returned to pre-injury functional status and was satisfied with the result. Based on these criteria, the percentage of successful outcomes was 77% in the entire series and 80% in the patients who received no workers' compensation. Of the patients with unsuccessful outcome (22%), about one third (8%) underwent surgery. In this series, 40% of patients had PAN at multiple levels and in 50% of cases three-level discography was performed, which indicates a high degree of uncertainty in patient selection (115). A prospective multicenter study (137) analyzed, at least 1 year after treatment, 495 patients, in 327 of whom the authors' selection criteria were satisfied, whereas in 168 these criteria were not satisfied. The percentage of satisfactory outcomes was 75% in the former group and 49% in the latter. Only some 20% of patients were treated at L5-S1 level, probably because only towards the end of the study had the instrumentation for approaching this disc become available. However, the percentages of successes, as related to the level of the herniation, are not reported. Numerous other publications in which the inventor of the technique was involved reported high percentages of successful outcomes (75, 112, 113, 134, 135).

Table 15.5. *Results of percutaneous automated nucleotomy in 10 clinical series.*

Author	No. of cases	Follow-up (months)	Success rate
High success rate			
Davis (1989)	200	6	77.5%
Onik (1990)	495	12 (minimum)	66.4%
Bocchi (1991)	500	6–29	71%
Bonaldi (1991)	237	11–40	75%
Gill (1993)	109	15–60	79%
Low success rate			
Kahanovitz (1990)	38	16	55%
Revel (1993)	69	12	37%
Dullerud (1995)	142	21	56%
Grevitt (1995)	115	55	45%
Shapiro (1995)	57	27	58%

In several other investigations in which the inventor of the technique was not involved, the success rates were 70% to 80% (12, 65, 102, 142), at least when Onik's criteria of patient selection were satisfied. In a multicenter study of over 650 cases, the proportion of satisfactory results was 72% (9). The largest monocenter study assessed the outcomes in 500 patients, 6 to 29 months after the procedure (10). Almost half of the patients were treated at L4-L5 level and about one third at L5-S1 level. Using Cabot's assessment method (23), the percentage of excellent or good results was 71%. The success rate reached 85% in patients with small or medium-size, single-level contained herniation, but only 60% when herniation was associated with stenosis. Both in the latter and other studies (12, 162), no significant differences were found in the results, as far as concerns L4-L5 and L5-S1 discs.

Low rates of success. In several studies the results of PAN were not gratifying. In a multicenter investigation (88) on a small group of patients, it was found that only 55% had resumed work a mean time of 16 months after treatment. In a prospective analysis (42) of 63 patients followed for at least 4 months, the percentage of successful outcomes was 62%; results were not found to be related to patient, age or sex, duration of symptoms, level of herniation or amount of nuclear material excised. Shapiro (156) followed 57 patients for a mean period of 27 months: relief of radicular pain was reported by 88% of patients at 2 weeks, but by only 70% at 2 months; at the latest follow-up, 58% reported pain relief and only 5% were asymptomatic. Similar results emerged from another study (43) carried out on 142 patients: the rate of satisfactory outcomes was 67% at 3-month follow-up and 56% after a mean time of 21 months.

Wilson and Kerslake (182), analyzing the results of PAN in 50 patients 1 year after treatment, found satisfactory results in 72%. Another later investigation (69) assessed 115 cases, including also the 50 patients in the previous study (182), a mean time of 55 months after the procedure. Prior to treatment, the patients complained primarily of radicular pain rather than low back pain, had positive nerve-root tension tests, and presented no stenosis, no decrease in disc height greater than 50% or herniation encroaching on the spinal canal for more than 50% of the midsagittal diameter of the canal. The percentage of excellent or good results was 45%; of the patients in the former study who had an excellent or good outcome (36 out of the 50), two thirds had remained in the same category, whereas in one third the result deteriorated to fair or poor.

Comparison with other percutaneous methods. A prospective randomized multicenter study (149) analyzed 69 patients submitted to PAN and 72 injected with chymopapain. At 1-year follow-up, the percentage of satisfactory results was 37% in the former group and 66% in the chymopapain group. However, it should be taken into account that in the patients in this study the indication for percutaneous treatment, on the basis of the findings of imaging studies, may be partially questionable. In fact, in some 60% of patients, the herniation occupied one fourth to half of the sagittal dimensions of the spinal canal and in some 75%, the herniation had migrated as far as 5 mm cranially or caudally to the vertebral end-plate.

No clinical investigation has been carried out to compare PAN with manual percutaneous nucleotomy, with or without discoscopy. In a study on cadavers, it was found that neither PAN nor manual nucleotomy with discoscopy allow removal of the entire nucleus pulposus (141). With the latter technique, however, less amount of nuclear material can be excised and the technique is less effective in severely degenerated discs. Pre-treatment with chymopapain did not lead to an increase in the amount of tissue removed by PAN.

Conclusions

PAN is a simple technique, at least for the L4-L5 and more cranial levels. The L5-S1 disc, instead, may be difficult to approach and, occasionally, the nucleotome cannot be inserted in the disc space or this is possible only after numerous attempts, which make the procedure poorly tolerated by the patient and also increase the risk of infectious complications. These are the only real complications, even if exceptional cases of neurologic injuries, resulting from errors in the surgical technique, have been reported. These prerogatives – easy technique and low frequency of complications – made the procedure very attractive, until serious doubts arosed concerning its therapeutic efficacy. In several studies, in fact, the proportion of satisfactory results, at short term or medium term, did not exceed, or only slightly exceeded, the success rates obtained with a placebo in the double-blind studies carried out to assess the therapeutic effects of chymopapain (Tables 15.1 and 15.5). This suggests that PAN might not be truely efficacious, the successful outcomes being essentially due to spontaneous resolution of the symptoms. This hypothesis is in keeping with studies using serial CTs, which showed that, after a mean period of 6 months, the size of the herniation was not modified or had increased in some 75% of patients submitted to PAN (44). On the other hand, the indications for this form of treatment are so limited that only a small proportion of patients with disc herniation are good candidates for PAN and, moreover, in these patients conservative management has a good chance of relieving the symptoms. Furthermore, it should be borne in mind that little is known concerning the mechanism of action of this technique and the few available studies suggest that PAN may increase, rather than reduce, the disc bulge in the spinal canal.

Manual percutaneous discectomy and laser discectomy

Historical aspects

The first description of manual percutaneous discectomy dates back to 1975, when Hijkata (78) reported on a series of patients with lumbar disc herniation in whom removal of nucleus pulposus was performed by a percutaneous posterolateral approach to the disc space. However, Kambin (90) and Hoppenfeld (80) claimed, in papers published in the 80's, that they first used this method in 1973 and 1974, respectively. In 1983, a group of orthopaedic surgeons (166) reported on the endoscopic control of nucleus pulposus removal. During this period, however, the methods of percutaneous nucleotomy did not gain popularity. Indeed, they were used in few centers and in a limited number of patients; moreover, there was no commercial interest from the biomedical industry, no specific surgical instruments being produced at that time. It was also the "flowering time" of chemonucleolysis, which switched from the USA to Europe and the rest of the world. Thus, percutaneous nuleotomy appeared to be simply an unnecessary method, with no demand for its routine clinical use.

With the increase in reports on technical and anaphylactic complications of chemonucleolysis, the popularity of chymopapain injection began to decrease, parallel to the introduction in clinical practice of percutaneous automated nucleotomy. The advent of this technique, and in particular its limitations, led to increased interest both in manual percutaneous surgery and microdiscectomy, which, from the second half of the 80's, reached a rapid and widespread popularity amongst spine doctors as well as spine patients.

The pioneer of laserdiscectomy was Choy, who realized that ablation of the nucleus pulposus by laser might lead to a decrease in intradiscal pressure and nerve-root compression caused by a contained herniation (26, 27). The first laser discectomy in man was carried out in 1986 by Ascher and Choy (28). In 1987, Choy et al. (29) reported on the results of percutaneous laser discectomy in 12 patients treated with Nd: YAG 1064 nm laser. Over the next 3 years, Ascher and Choy treated 377 patients with the same type of laser, using primarily a wavelength of 1320 nm (28). In those same years, Mayer et al. (118) carried out experimental studies on the effects of Er: YAG 2940 nm laser on disc tissue, whereas other authors began to use different laser systems, such as XeCl-Excimer 308 nm (186), Ho: YAG 2100 nm (7) and KTP 532 nm (37, 126).

Manual percutaneous discectomy

Types and terminology

Percutaneous excision of nucleus pulposus can be carried out without or with the use of an endoscope. The former procedure, which is scarcely used nowadays, has been referred to as manual percutaneous discectomy, percutaneous discectomy or percutaneous nucleotomy. The latter, in turn, has been termed percutaneous nucleotomy with discoscopy, endoscopic microdiscectomy, endoscopic nucleotomy or endoscopic percutaneous discectomy.

We prefer the term percutaneous discectomy (PD) for the former technique and percutaneous endoscopic discectomy (PED) for the latter.

Instrumentation

The instrumentation for PD includes instruments to approach the disc and instruments for discectomy. Several types of instrumentation have been developed, but they are very similar. The instrumentation described below (Fig. 15.22) is that used by us.

The approach instruments include: 1) an 18 G needle, 155 mm long; 2) a guiding wire 0.8 mm in diameter and 350 mm in length, with both tips rounded off; 3) a blunt obturator 4.5 mm in diameter and 180 mm in length, which has a central drilling 0.9 mm in diameter; the instrument has a removable luer lock cone; 4) a working sleeve 155 mm long, with an inside diameter of 4.6 mm; the sleeve has a large luer lock cone for suction and a small luer lock stop cock for irrigation; 5) a trephine with a small diameter tip (3.5 mm) and another with a larger tip (4.5 mm).

The instruments for discectomy consist of rigid or flexible, straight or angled forceps, 205 mm long with cup sizes of 3, 3.5 or 4.5 mm. The flexible forceps are passed through a sleeve, which allows the end of the forceps to bend in order to reach the lateral and posterolateral portion of the disc. A special reverse opening forceps can be used for removal of the nucleus from the posterior part of the disc. The instrumentation includes automated resectors connected to a high-power suction device, which cut the disc tissue, sucking up the tissue fragments and, thus, allowing a more rapid discectomy (72, 73).

Endoscopic instrumentation for PED includes rigid optical systems (0°, 30°, 70° and 90°), which allow inspection of a large portion of the cavity created within the disc (Fig. 15.23). The light source and the TV monitor are identical to those used for arthroscopy. The optical systems, 2.7 mm in diameter, are introduced into the working sleeve, which allows both irrigation and suction.

Technique

The procedure is carried out in the operating room, under sterile conditions. The patient can be placed in the prone or lateral decubitus position. The latter position can be used for discectomy without discoscopy or endoscopic discectomy with intermittent discoscopy, when the disc is approached on only one side. For a bilateral approach, (if bilateral PD, or PED with continous endoscopy, are performed) the patient should be placed in the prone position. We use this position also for a unilateral approach, since it is more comfortable for the patient, who can better tolerate a long procedure. The patient is positioned with the hips and knees flexed at 30°, by means of pillows placed ventrally and/or by bending the operating table in order to reduce lumbar lordosis. Antibiotic prophylaxis is carried out, generally with third generation cephalosporins. The procedure is performed under local anesthesia.

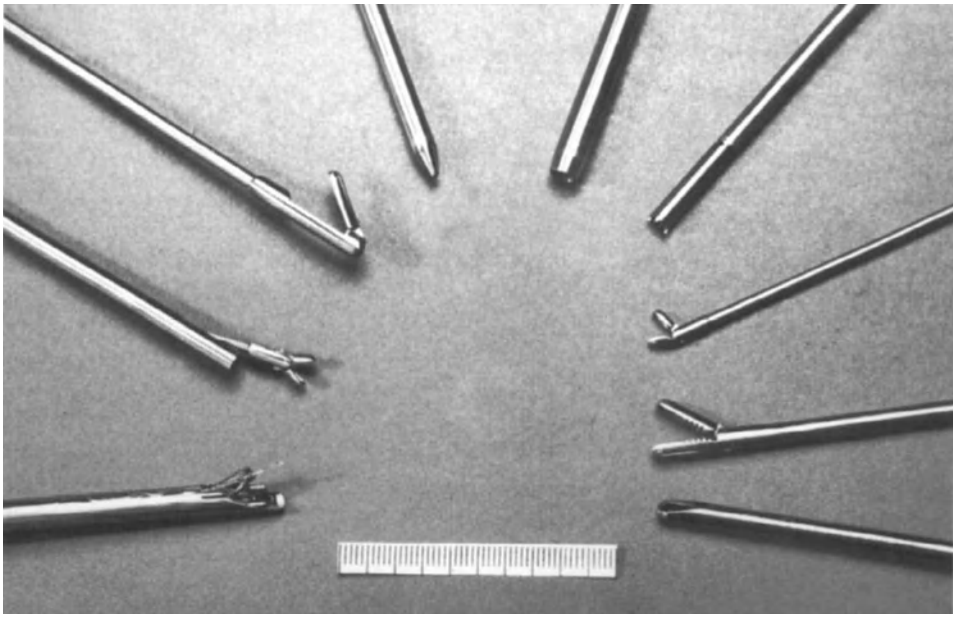


Fig. 15.22. *Instrumentation for manual percutaneous discectomy.*

Approach to the disc

Usually a unilateral approach is preferred, both for PD and PED, on the side of radicular symptoms.

The surgeon traces a longitudinal line along the spinous processes and a transverse line at the level of the disc to be treated, after fluoroscopic identification of the latter. After local anesthesia, an 18 G needle is inserted at 9–11 cm from the midline with an angulation of 45°–60°. The needle should be inserted in the midpoint between the vertebral bodies, as seen in the anteroposterior view with the fluoroscope. Furthermore, the needle should if possible be introduced in the dorsal one third of the intervertebral space in order to remove the posterior portion of the disc.

Before proceeding with the operation, it may be useful to perform discography to confirm that herniation is contained and, thus, the indication for percutaneous discectomy (Fig. 15.24). If the contrast medium leaks abundantly into the epidural space or reveals a subligamentous extruded herniation occupying a large portion (more than one third) of the sagittal diameter of the spinal canal, discectomy should not generally be carried out.

The guiding wire is passed through the needle and advanced to the center of the disc. The guiding wire is left in place, whilst the needle is removed and replaced, after making a short skin incision, with the blunt obturator, which is advanced until the outer aspect of the annulus fibrosus. The wire is removed and the working sleeve is passed over the obturator. The latter is replaced with the trephine, which is used to create a circular window in the annulus fibrosus. In the presence of a midline disc herniation or bilateral radicular symptoms, it may be advisable to approach the disc on both sides. The same holds if discectomy is performed under continuous endoscopic control.

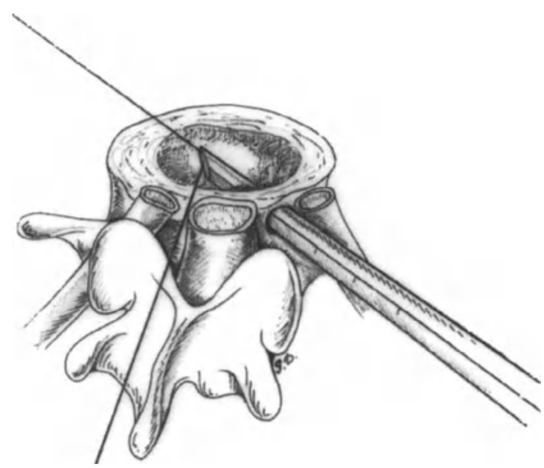


Fig. 15.23. *Discoscope placed in the disc. Using endoscopes with a different angulation of the visual field and/or moving the guiding cannula ventrally and dorsally, it is possible to inspect a large portion of the disc space.*

Discectomy

The central portion of the nucleus pulposus is removed with a set of rigid forceps (Fig. 15.25). This phase of discectomy can be accelerated by using automatic cutters. The flexible forceps is then used to reach the lateral and

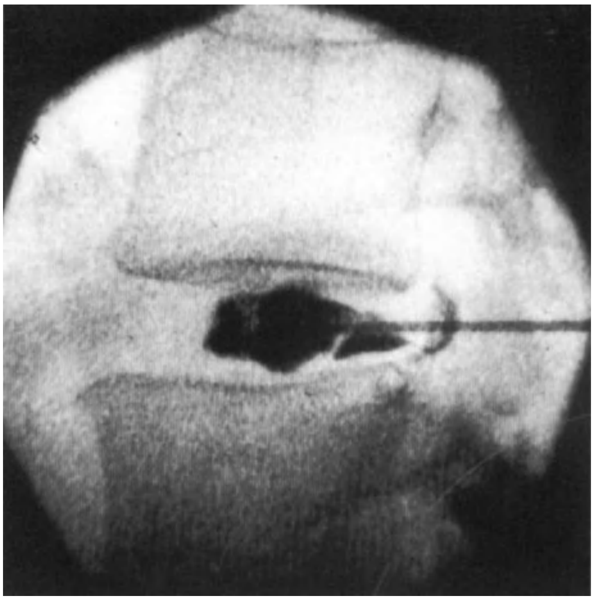


Fig. 15.24. *Discography at L4-L5 level. The contrast medium outlines the posterior border of the disc, indicating that herniation is probably contained.*

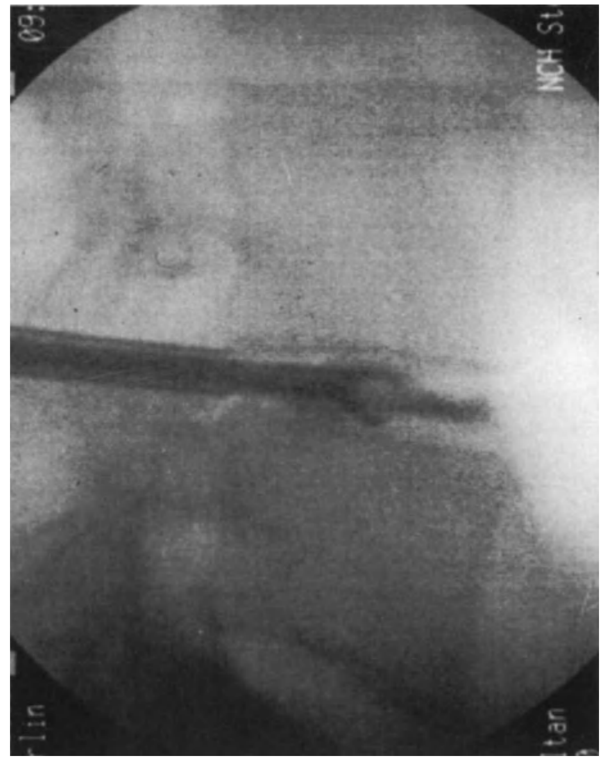


Fig. 15.25. *Fluoroscopic vision of a forceps during percutaneous automated nucleotomy. The radio-opaque stria located ventrally to the forceps is due to residual contrast medium. The forceps can exceed from the guiding cannula for no more than 2 cm. This avoids perforation of the annulus fibrosus, if the guiding cannula is correctly positioned.*

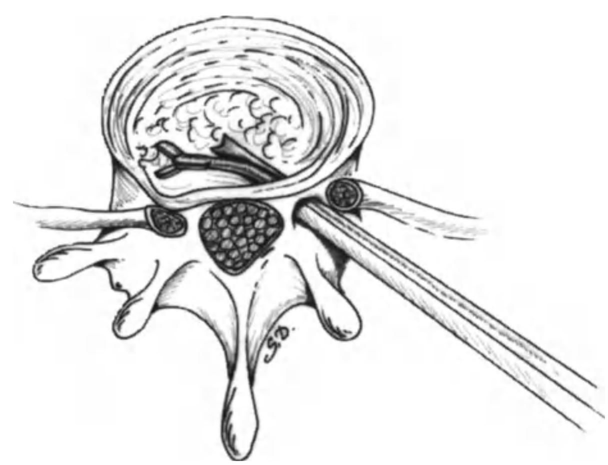


Fig. 15.26. *Flexible forceps used for removal of the lateral and posterolateral portion of the nucleus pulposus.*

posterolateral portion of the nucleus pulposus (Fig. 15.26). The drawback of this kind of forceps is that it may, at times, be difficult to push it through the end of the deflector sleeve so that the bite can grasp disc tissue. If this occurs, the forceps should not be forced, but it should be partially extracted and re-inserted until it goes through the end of the sleeve. Pushing the working sleeve ventrally, the intradiscal end of the latter, and thus the tip of the forceps (rigid or flexible), can be advanced dorsally to remove the posterior portion of the disc. In the presence of a paramedian or midline herniation, the reverse opening forceps can be used to remove the most posterior portion of the nucleus pulposus (Fig. 15.27). If the endoscope is not used, the position of the tip of the forceps is checked with the fluoroscope to avoid going beyond the borders of the adjacent vertebral bodies both in the anteroposterior and lateral projection. Discectomy ends when disc tissue can no longer be removed. In the presence of midline disc herniation, a bilateral approach may allow removal of a larger portion of nucleus pulposus. However, the bilateral approach rarely allows excision of a significantly larger amount of tissue with respect to that removed with unilateral approach. With either approach, it is difficult or even impossible to excise the most posterior portion of the disc, since this site cannot be reached with the forceps.

Endoscopic control of discectomy may be intermittent or continuous. For intermittent discoscopy, a unilateral approach to the disc is made and the endoscope is passed through the approach cannula after removal of the central portion of the nucleus pulposus by rigid forceps. The extent of discectomy is checked, and possible residual disc fragments are visualized, between one phase and the other of removal of disc contents. For

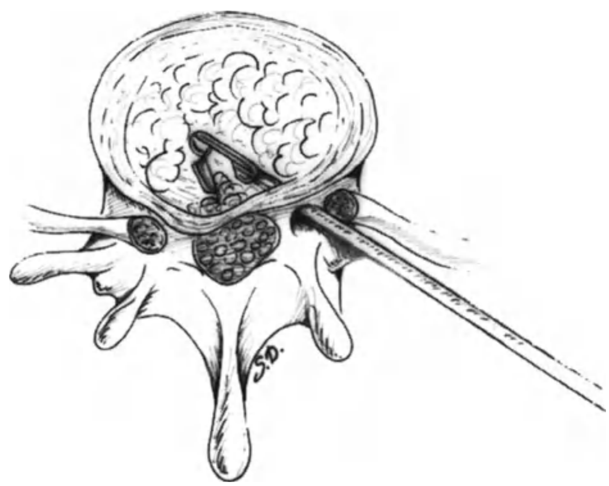


Fig. 15.27. *Reverse opening forceps removing the most posterior portion of the nucleus pulposus.*

Results

Little information is still available on the results of percutaneous discectomy, with or without endoscopy. Only few studies have, in fact, reported on the outcomes in a reasonably large number of patients, followed for at least 2 years, and most of these studies were retrospective and did not include a control group.

Kambin and Schaffer (91) analyzed 100 patients submitted to PD, of whom 51 were followed for more than 2 years. Of these patients, 93 were assessed 15 months or more after treatment: the results were rated as satisfactory in 87% of cases (absence of pain and return to preoperative work). The outcome was significantly better in the patients with herniation at L3-L4 or L4-L5 level, in whom the rate of successes was 90%, than in the patients with L5-S1 herniation, in only 50% of whom were satisfactory results obtained. In 13% of cases with failure of PD, surgical discectomy was carried out within 1 year of percutaneous treatment. In another study (80), 50 patients with L4-L5 disc herniation were followed for 10 years. In 86% of cases, pain and sensory disturbances disappeared, but only one of the eight patients with motor deficit had complete resolution of the deficit. No patients were subsequently submitted to surgery and all returned to previous levels of physical activities. Hijikata (77) reported on the results of PD in 136 patients treated over a 12-year period. Outcomes were excellent or good in 72% of cases and fair or poor in 28% of patients, 19% of

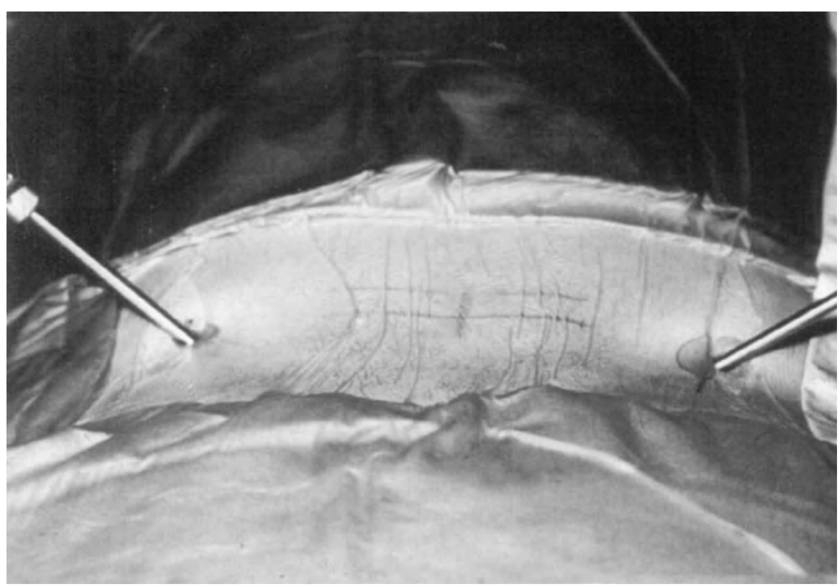


Fig. 15.28. *Intraoperative photograph of a bilateral approach to the disc. One guiding cannula is used for discoscopy and the other for discectomy.*

continuous discoscopy, the disc is approached bilaterally, using one working cannula for discectomy and the other for endoscopy (Figs. 15.28 and 15.29). Usually, it is sufficient to perform a discontinuous discoscopy, associated with fluoroscopy to check the location of the end of the forceps within the disc space.

Early postoperative treatment

This is similar to that performed after automated percutaneous nucleotomy.

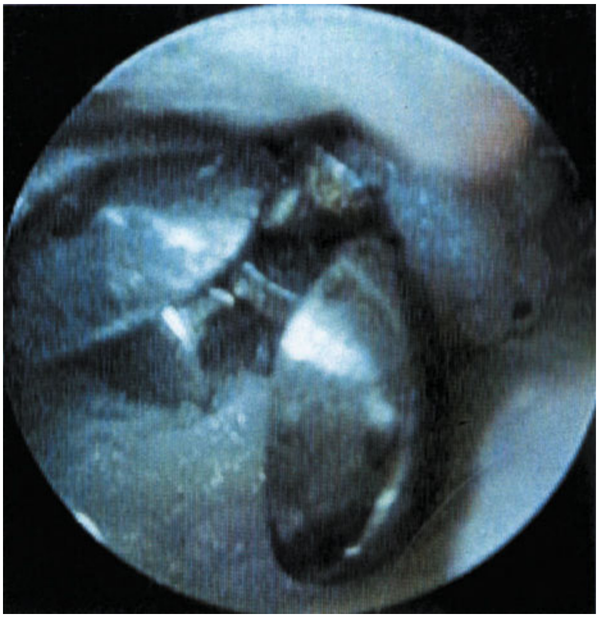


Fig. 15.29. *Endoscopic view of a forceps for manual discectomy.*

whom had undergone surgery. The best results were obtained in patients under 30 years of age presenting a contained herniation. In another retrospective study of 70 patients (125), satisfactory outcomes were observed in 72.9 % of cases; of the remaining patients, 17% underwent surgical discectomy. The best results were obtained in patients under 40 years of age, in whom CT revealed the posterior longitudinal ligament to be intact. Furthermore, predominance of radicular pain over low back pain and continuity, in the preoperative discogram, of the image of the contrast medium in the center of the disc with that of the herniated tissue were identified as positive prognostic factors.

In 1989, a group of Swiss authors (153) reported on the results of PED in 109 patients followed for a mean period of 2.7 years. The results were rated as excellent, good or fair in 72.5 % of cases. In 26.6% of patients, open surgery was subsequently carried out, usually due to persistence or recurrence of herniation. In eight cases, spondylodiscitis occurred and two other patients showed evidence of transient injury to the lumbosacral plexus following unsuccessful attempts at entering the L5-S1 disc. In one patient, injury to the sigmoid artery occurred, which required surgical repair. In a detailed retrospective analysis of 100 patients submitted to PED, who were followed for at least 2 years after the procedure, Kambin (89) found satisfactory results in 88% of cases. This high success rate was attributed to a very rigorous selection of patients eligible for percutaneous discectomy. The presence of nerve-root canal stenosis or migrated disc fragments not diagnosed preoperatively were the main causes of failure.

A prospective study (116) compared the results of PED and microdiscectomy in 40 patients randomly assigned to one or other of the procedures. A minimum of 2 years after treatment, radicular pain had resolved in 80% of cases in the PED group and in 65% of those submitted to microdiscectomy. Neurologic deficits had disappeared in over 90% of patients undergoing PED and in almost 70% of those in the microdiscectomy group; of the former patients, 95% had resumed preoperative work, whereas only 72% of those in the latter group had returned to their work. Hospitalization time was shorter and functional recovery faster in the PED group.

Laser discectomy

Lasers

The term laser is an acronym for Light Amplification by Stimulated Emission of Radiation. This type of electromagnetic radiation is produced by the external stimulation of a laser medium. Laser light has three characteristics; it is monochromatic, coherent and collimated. The laser-biological tissue interaction is determined by the physical properties of the laser, such as wavelength, pulselength, applied energy or energy density, and the physiologic characteristics of the tissue, such as absorption, scattering, reflection, tissue structure and density, heat conduction (Fig. 15.30). A variety of effects – drying, coagulation, carbonization, vaporization and ablation – can thus be produced with one single laser system. They result from processes ranging from simple photochemical effects to so-called non-linear effects, which start at a power-density of 10^7 watt/cm^2 and exposure times in the order of nanoseconds.

Effects on nucleus pulposus

The absorption spectrum of the nucleus pulposus is comparable with other non-vascularized biological tissues. It shows non-specific absorption peaks in the ultraviolet range (e.g., at 262 nm and 272 nm) as well as in the near and far infrared range of wavelengths (2900, 3200 and 6100 nm). The absorption peaks represent the absorption of these wavelengths by the water contained in the tissue. The absorption bands in the ultraviolet are due to peptide bonds of amino acids, such as phenylalanin (250 nm), histidine and cysteine (260 nm), tyrosine (274 nm), or tryptophan (280 nm). The most marked ablative effects on disc tissue are obtained with laser wavelengths lying within these absorption peaks.

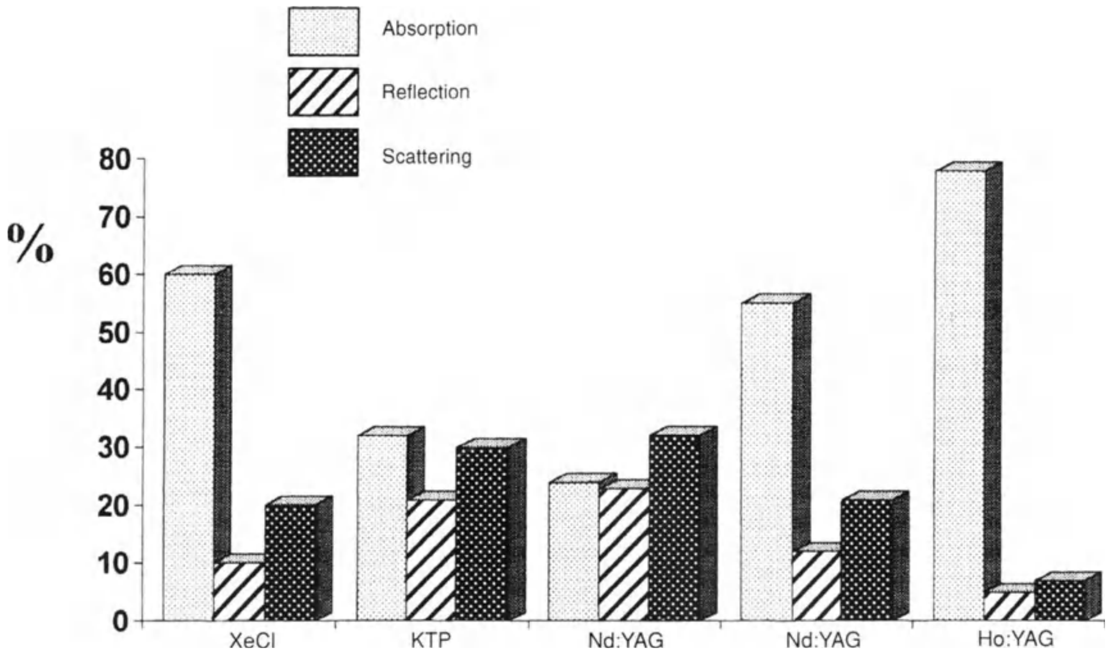


Fig. 15.30. *Absorption, reflection and scattering of various lasers by degenerated disc tissue.*

Lasers for percutaneous nucleotomy

Ultraviolet wavelengths

XeCl-Excimer 308 nm. The Excimer (EXCIted diMERs) laser is a gas-pulsed laser, which emits light at wavelengths between 157 and 351 nm. The laser medium is a mixture of halogen with an inert gas (e.g. xenon/chloride, argon/fluoride). The most commonly used wavelength is 308 nm, emitted by the XeCl-Excimer laser. Due to the high energy density which is achieved on the tissue surface, this laser light initiates the non-linear process of photoionization; this means that the molecular bonds of the tissue are disrupted and the irradiated tissue is ablated in a microexplosion. Since the ablation process proceeds very rapidly, there are virtually no thermal side-effects. This is the main advantage of this type of laser. The disadvantages are the low radiation power (which makes the ablation process time-consuming), the mutagenic and carcinogenic potential, and the high cost. For these reasons, few clinical applications have been reported.

Visible wavelengths

KPT 532 nm. The device uses a potassium titanyl phosphate crystal to produce laser light which is visible (green), with a wavelength of 532 nm. Since the nucleus pulposus has no absorption peak at 532 nm, the action of this laser is thermic. Disc tissue exposed to 0.5 sec pulses of 15 watts shows areas of thermal damage of less than 0.9 mm in width. In clinical practice, 0.2 sec pulses of 12 watts, emitted at intervals of 0.5 sec, are currently employed, using 400–600 micrometer optic fibers.

Infrared wavelengths

Neodymium: YAG 1064/1318 nm. This is the most widely used medical laser system. The laser wavelengths of 1064 or 1328 nm are emitted by neodymium embedded in an yttrium-aluminum-garnet crystal. The absorption of these wavelengths by biological tissues is low. The scattering effect is thus pronounced and leads to a distribution of the applied energy throughout the tissue. Penetration in the cartilaginous tissue can reach 6 mm in depth. However, with controlled application of powers between 20 and 40 watts and pulses of 0.05–0.1 sec, the coagulation zone can be reduced to 0.6 mm, using a contact probe. Experimental and clinical studies have shown that this laser is effective in coagulating and removing lumbar disc tissue. Its advantages are: fiberoptic delivery, possibility of using in dry and acqueous media, and ability of coagulation and hemostasis. The disadvantges consist in heat generation and energy transmission through the tissue, risk of tip breakage and high costs, which, however, have decreased in recent years.

Holmium: YAG 2100 nm. This is a pulse near-infrared laser, which produces light with a wavelength of 2100 nm. It is absorbed mainly by tissue water. This laser delivers 400 microsec, 0–2 J pulses, at a repetition rate of 1–20 Hz. The application on cartilaginous tissue leads to its instant vaporization. The thermal effects are less marked as compared with those of the Nd:YAG lasers. The reported clinical applications in arthroscopic surgery and percutaneous discectomy are as yet limited, but promising. The main advantages are: fiberoptic delivery, use in dry and aqueous media, limited zone (0.4–0.6 nm) of thermal lesion in cartilaginous tissues, possibility of hemostasis, coagulation and vaporization. The disadvantages are still the high cost and the low power range, which may prolong surgery.

Erbium: YAG 2940 nm. This is a solid laser, which contains ions of the element erbium, embedded in an yttrium-aluminum-garnet crystal. It delivers micropulses of laser light with a wavelength of 2940 nm, a duration of 1–340 microsec and an energy density which can reach 500 mJ / mm^2. The ablation threshold for nucleus pulposus is 7 mJ / mm^2; 5 grams of tissue can be ablated in 30 minutes, with a peripheral zone of thermal lesions of less than 0.5 mm. Despite these prerogatives, this laser is not used at present in endoscopic techniques, since no safe and adequate flexible means of light transmission is as yet available.

Surgical technique

The laser may be used at the end of manual percutaneous discectomy to remove the posterior portion of

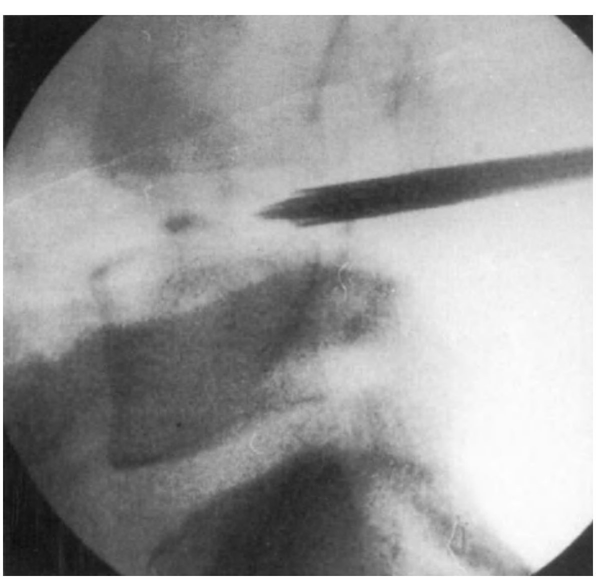


Fig. 15.31. *Rigid laser applicator placed in the L4-L5 disc.*

the disc or it may be used on its own. The laser applicator is passed through the guiding sleeve and advanced until it reaches the center of the disc and / or the posterior portion of the disc space, checking its position by fluoroscopy. The applicator can be rigid or flexible (Figs. 15.31 and 15. 32). With the flexible instrument, the posterior portion of the disc is more easily reached. Discectomy may be performed without or with endoscopy. The latter allows the position of the applicator, and particularly the completeness of discectomy, to be checked (Fig. 15.33). The optimal instrument is a laser applicator which includes a deflectable arm for the quarz fiber, two suction and irrigation openings and a 70° angled optical system (Fig. 15.34). The use of laser does not expose to greater risks than the flexible forceps for manual discectomy, since the tissue is coagulated or ablated for a very limited extent.

Results

In a series of 333 patients with contained disc herniation submitted to percutaneous laser discectomy using Nd: Yag 1060 nm or 1320 nm, who were assessed after a mean of 26 months (28), satisfactory results were observed in 78% of cases; in 63% of these, pain was relieved or resolved during the procedure. Some one third of the MRI studies performed 4–6 months after the procedure reveled a slight to moderate decrease in size of the herniation. Mayer et al. (117) assessed their first 40 patients treated with laser at least 2 years after treatment. The patients had a L4-L5 or L3 L4 disc herniation responsible for lumboradicular pain, and some of them reported sensory deficit (25) or mild motor loss (3). In 77% of cases, radicular pain had disappeared and no patient had motor deficits. In four cases, microdiscectomy was subsequently carried out due to persistence or recurrence of radicular symptoms. However, Matthews et al. (114) found that, whilst at 3-month follow-up 81% of patients treated with KPT 532 nm had a satisfactory outcome, at 2-year follow-up the success rate had dropped to 55%, and 35% of patients had undergone surgery.

In a multicenter study (131), 164 patients were evaluated 1 year after treatment by means of a questionnaire. In this retrospective analysis, it was found that only in 41 cases were all the criteria for the indication to laser discectomy satisfied (radicular pain, neurologic deficits, contained herniation at discography, absence of stenosis or spondylolisthesis); of this group of patients, 70% had a satisfactory outcome. In the group in which the selection criteria were not satisfied, the percentage of successes was 28%, whilst of the patients who could not be assigned to one or other of the groups, 55% had a satisfactory outcome.

Fig. 15.32. *Fluoroscopic view of a flexible laser applicator placed in the disc.*

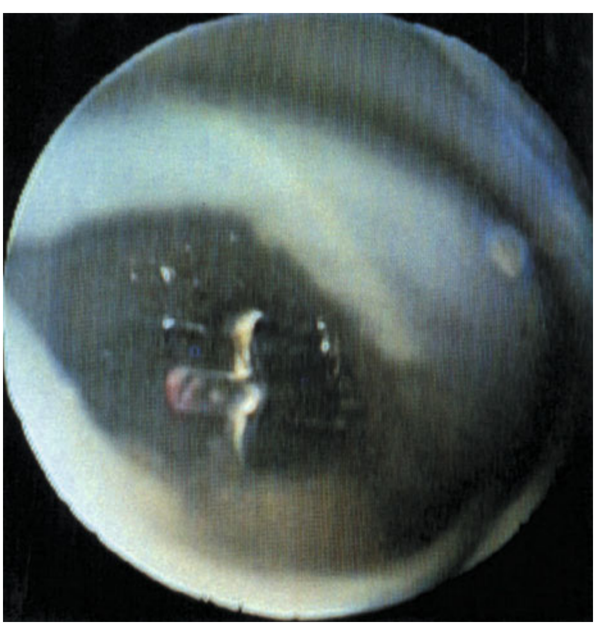


Fig. 15.33. *Endoscopic view of a laser applicator in the disc during laser discectomy.*

The type of laser system does not appear to affect the clinical results. One study (103) compared 36 patients treated with Nd: YAG 1318 nm laser and 46 patients in

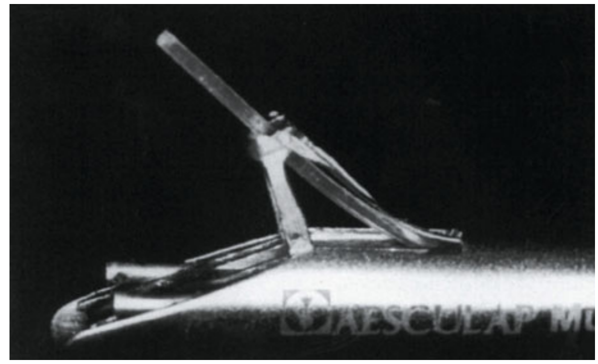


Fig. 15.34. *5.4 mm wide laser applicator with suction and irrigation tubes and endoscope with 70° vision angle.*

whom KTP 532 nm laser had been used, all followed for 1 year after treatment. The percentage of successes was 70% in the former group and 75% in the latter. In this group, the satisfactory outcomes had decreased to 72% at 2-year follow-up.

Complications

Classification

The possible complications of PD, PED or laser discectomy may be classified as intraoperative and postoperative, both including complications related to the surgical procedure and general complications (118).

The intraoperative complications depending upon the procedure are either related to the disc approach or to discectomy, and they may be correlated to the surgical technique or the instrumentation. The general complications are usually due to patient positioning or anesthesia, or may be represented by allergic reactions to the contrast medium.

The postoperative surgically-related complications may be specific, when associated with the technique of discectomy (hematoma of psoas muscle or retroperitoneal hemorrhage) or aspecific, such as spondylodiscitis. General complications refer to those associated with the entire surgical procedure (e.g., cardiovascular problems).

Analysis of complications

Although the use of percutaneous discectomy has become fairly widespread, few data are available on the complications occurring during discectomies performed with or without endoscopy or use of the laser.

Intraoperative complications. In a group of patients submitted to PD (152), there were two hematomas of the psoas muscle and one transient radicular deficit. In a series of 164 laserdiscectomies (131), the tip of the instrument bent in one case, 12 patients complained of postoperative dermatomal dysesthesia, which resolved in five cases, and two patients presented a reflex sympathetic dystrophy.

Mayer, in a retrospective analysis of 658 cases treated in nine centers, observed seven cases (1.1%) of intraoperative complications and 10 cases (1.5%) with postoperative complications.

In four patients (0.5%), radicular deficits appeared postoperatively. In three cases, the L5 nerve root was injured while approaching the L5-S1 disc; in one case the involved root was not specified. One of the four procedures had been performed under general anesthesia. Nerve-root impairment resolved in two cases, and was permanent in one. In the remaining patient the outcome is unknown.

In two cases (0.3%), significant vascular injuries were reported. One patient sustained an injury to the sigmoid artery and another patient, to an anomalous iliolumbar artery; in both cases during access to the L5-S1 disc. In these two patients the injury was detected intraoperatively due to a drop in blood pressure and in both the lesion was successfully repaired by a vascular surgeon under emergency conditions. Both lesions were produced by the needle used for preprocedural discography. In one patient, a transverse process was injuried, with no sequelae.

No complications related to the discectomy, or to instrument failure during the procedure, were reported. Likewise, no general intraoperative complications occurred, nor have such reports appeared in the literature.

In conclusion, all the intraoperative complications occurred while approaching the disc and all during discectomies at L5-S1 level.

Postoperative complications. Aspecific postoperative complications, all represented by spondylodiscitis, occurred in 10 cases (1.5%). In none of these patients had preoperative antibiotic prophylaxis been carried out. Two patients underwent spinal fusion and the other two were treated conservatively.

No complications specifically related to the use of lasers have been reported.

Conclusions

PD and PED

PD usually allows removal of nucleus pulposus to a similar extent as PED and, thus, the results obtained are comparable to those with endoscopic discectomy. The endoscope, however, enables the operator to check the completeness of discectomy, particularly in the posterior portion of the disc. Of the two methods, percutaneous discectomy with endoscopic control should therefore be preferred.

If strict scientific criteria are applied in the evaluation of the results of manual percutaneous discectomy, with or without endoscopy, the therapeutic efficacy of this method remains to be proven. The number of studies, as well as the number of patients assessed under prospective, randomized and controlled conditions is too small to draw definite conclusions. However, a few clinical trials support the impression that, in skilled hands of experienced surgeons, the selective removal of nucleus pulposus under endoscopic control leads to a clinical success rate of 70% to 80%. This is indeed the case for a carefully selected group of patients with mild neurologic deficits due to a contained or small extruded herniation, in whom the clinical outcome would be similar to that obtained with conventional discectomy or microdiscectomy. The advantages of PED compared with open surgical techniques, particularly conventional discectomy, are shorter hospitalization, lower morbidity and faster postoperative functional recovery, as well as a lower rate of complications. However, if one considers that patients with contained or small extruded herniation often undergo spontaneous resolution of clinical symptoms, percutaneous endoscopic disc surgery seems to be an adequate procedure in less than 15% of all patients amenable to surgery. This method, however, should not be considered part of conservative therapy either because it implies potential risks of nervous, vascular or infectious complications, or because its failure almost always makes the patient a candidate for open surgery.

Laser discectomy

Numerous experimental studies indicate that various laser systems are able to coagulate, shrink, carbonize, vaporize or ablate nucleus pulposus, but only a few lasers have been used for clinical purposes.

In endoscopic disc surgery, the laser, if correctly used, with adequate parameters, appears to be as safe as manual instruments. So far, no complications related to its use have been reported. Furthermore, MRI studies performed by one of us (M.H.M.) after laser discectomy showed no thermal lesions in the cartilage end-plates or soft tissues adjacent to the disc. The laser has been used in particular for ablation of the most posterior portion of the nucleus pulposus. In our experience, however, flexible forceps for manual discectomy are as effective as laser to this end. Moreover, the use of laser does not reduce the surgical time and is technically simpler than techniques with manual instruments, however the cost is considerably higher. The clinical results appear comparable to those with manual or automated percutaneous discectomy. At present, therefore, the laser appears to be a tool that is neither necessary, nor particularly useful for endoscopic surgery. It should be considered as an additional tool to manual instruments, which may be used to remove the posterior third of the nucleus pulposus. So far, however, its use has been limited and this may be one of the reasons why no prospective, randomized, controlled studies, which might provide a conclusive answer on the advantages and limitations of this method of percutaneous discectomy, have been performed.

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·CHAPTER 16·

SURGICAL TREATMENT

F. Postacchini, G. Cinotti

Indications and contraindications

Many operations for lumbar disc herniation could probably be avoided if energetic conservative management were continued for longer periods before considering surgery. However, it is clearly a mistake and potentially dangerous to obstinately carry out conservative treatment in all patients with a herniated disc. Several studies (31, 67, 81) have indicated that the results of conservative care can be as effective as those of surgery, at least a few months after the completion of treatment. However, this is more likely to occur in patients with a disc protrusion, a small extruded herniation or a small migrated fragment of disc, in the absence of spinal stenosis.

Many herniations decrease in size or disappear with time, but many months or a few years may elapse before this occurs and indeed the process may not even occur. Conversely, many reports indicate that patients with long-standing preoperative symptoms have fewer chances of obtaining satisfactory results from surgery than those in whom symptoms are of short duration (12, 32, 34, 76). Two requisites should therefore be borne in mind: to avoid too prolonged conservative treatment that may increase time off work and reduce the chances of successful surgical treatment; and to avoid surgery in patients with a herniated disc which may become asymptomatic, or even disappear, a few months after onset. Unfortunately, too little information is available on the influence of the pathologic characteristics (i.e., size, site and type of herniation, and size of the spinal canal), on the speed and completion of spontaneous resolution of symptoms, and on the resolution of a hernia itself. The aim of treatment in a benign condition, such as a disc herniation, is to resolve the symptoms rapidly, as well as completely, to allow early and full return to daily activities.

Absolute and relative indications

The indication for surgery is absolute in those rare patients with a cauda equina syndrome, in the presence of severe motor deficits resulting from a large extruded or migrated disc fragment, and in patients with intractable pain. In patients with a cauda equina syndrome, surgical management should always be performed, and rapidly, to increase the chances of satisfactory neurologic recovery (28, 37, 73). The same holds in the presence of severe sensory and motor deficits, especially if they are ingravescent or the type and size of herniation make spontaneous regression of symptoms unlikely. In patients with untractable radicular pain, conservative management should be attempted, but rapidly abandoned if it appears to be inefficacious. In all other cases, the indication is relative. It depends on four factors: 1) Duration of radicular symptoms. The chances of resolving symptoms with conservative care decrease progressively with increasing time. If 2 weeks after the onset of symptoms the chances are very high, after 3 months of continuous or almost continuous lumboradicular pain the chances are slight and decrease further after 6 months. 2) Type and size of herniation. It is more likely that the symptoms decrease in severity or disappear when the herniation is contained and small, rather than in the presence of a large migrated disc fragment. In the first instance, in fact, the compressed nerve root can more easily adapt to the new situation and, when the acute radicular inflammation has subsided, the radiated symptoms may gradually disappear, even if moderate compression of the nerve root persists. 3) Presence of nerve-root canal, or central spinal canal, stenosis. The chances of spontaneous resolution of symptoms are significantly higher if the size of the spinal canal is normal. The nervous structures, in fact, may more easily escape compression by a herniated disc in the presence of a large reserve space in the spinal canal. 4) Quality and severity of symptoms. Surgery is more indicated in patients with severe, exclusively radicular, pain than in those with moderate low back and leg pain, since in the former, symptoms are less likely to resolve spontaneously and the results of surgery tend to be better.

The presence of a mild or moderate motor deficit does not necessarily affect the indication for surgery or conservative management, since the chances of resolution of the deficit are similar with the two types of treatment.

Surgery should be performed in all patients with a relative indication when no significant improvement has been obtained with conservative care. The duration of the latter has not been well defined; however, in most cases, it should not be less than 2–3 months, since it is in this interval that an improvement in symptoms usually occurs. Patients who do not improve considerably after this period have fewer chances of achieving an adequate resolution of symptoms with increasing time. The risk of waiting too long is to find a patient who still has so severe pain as to make him dissatisfied and unable to work, but not so severe as to make surgical management strictly necessary.

Contraindications

The only absolute contraindication is represented by disc herniations discovered incidentally in asymptomatic subjects. The other contraindications are relative.

Discectomy is generally contraindicated in five situations: 1) When the only clinical abnormality is a mild or moderate motor loss. However, even when weakness is severe, surgery is rarely indicated. The same holds for sensory deficits, which usually disappear spontaneously with time. 2) In patients with psychologic disorders or legal controversy, unless a clear-cut and severe organic pathologic condition is present. Even in this instance, however, the result may not be satisfactory. 3) When disc pathology is bulging of the annulus fibrosus. This rarely requires discectomy, unless the spinal canal is narrow or stenotic, since in this event, particularly in the presence of nerve-root canal stenosis, annular bulging may cause significant nerve-root compression. 4) In the presence of vague radicular symptoms, or symptoms in a different dermatome than expected, based on the level of herniation (for example, anterior thigh pain in the presence of herniation of the fifth lumbar disc). In these conditions, further investigations should be performed, but, anyway, the indication for discectomy should be considered with caution. 5) In patients whose radiated pain is confined to the buttock, who very often are not good candidates to discectomy. The latter is rarely indicated in patients complaining of only low back pain, in whom fusion of the motion segment should be considered in case there was an indication for surgery.

Planning of surgery

Disc herniation at two levels

With the advent of CT, and even more of MRI, patients are frequently observed presenting a herniated disc at two, usually adjacent, levels, on the same side or opposite sides. The problem of planning of surgery generally arises when both herniations are on the same side.

In the majority of patients, one of the herniations is contained and small in size, and clearly asymptomatic; as such, it should not generally be excised (Fig. 16.1). In a minority of cases, there may be some doubt that both herniations are symptomatic on account of their site, type and/or dimensions (Figs. 16.2 and 16.3). In general, an acute or subacute lumboradicular syndrome is caused by a single herniated disc and only this should be removed, particularly when one of the herniations is of large dimensions and/or extruded or migrated, whilst the other is small and contained, and there is no clinical evidence that the smaller herniation is responsible for nerve-root compression (Fig. 16.4). The choice to carry out operative treatment only at one level may lead to the risk of leaving a symptomatic condition untreated. When such a risk appears to be high, discectomy should be performed at both levels. When this is not the case, surgical treatment should possibly be limited to only one disc for several reasons: operative time is shorter and postoperative recovery faster; postoperative low back pain tends to be milder; the spinal canal is not invaded by scar tissue, which may lead to radicular symptoms not present preoperatively; and the risk is avoided of recurrent herniation at the asymptomatic level. Furthermore, it should not be forgotten that the asymptomatic disc herniation may undergo spontaneous regression over the months or years following surgery (Fig. 16.2); and that it is very unlikely for a small contained or extruded herniation, asymptomatic at the time of the first operation, to become subsequently symptomatic.

Fig. 16.1. *MR images of two patients with lumbar disc herniation at two levels.* (A) *Spin-echo T1-weighted sagittal scan of a patient with an extruded L4-L5 disc herniation (arrowhead) and a small contained herniation at L5-S1 level (arrow) which does not impinge on the thecal sac.* (B) *Turbo spin-echo T2-weighted image of a patient with a disc fragment migrated cranially to the L4-L5 disc (arrowheads); at L3-L4 level, a concomitant intraforaminal disc herniation is visible (arrow), which, however, does not compress the L3 nerve root.*

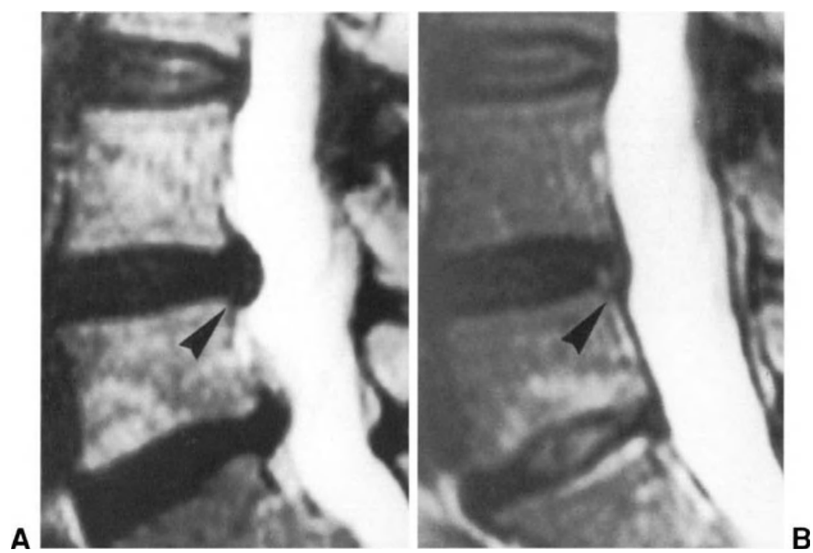


Fig. 16.2. *MR images of a patient with disc herniation at two levels.* (A) *Turbo spin-echo T2-weighted sagittal scan showing disc herniation at L4-L5 and L5-S1 levels. The herniation at L5-S1 level was extruded and the patient had clinical evidence of severe compression of left S1 nerve root; surgery was performed at this level with complete resolution of symptoms, whereas the L4-L5 disc herniation (arrowhead) was not excised.* (B) *Turbo spin-echo T2-weighted sagittal scan obtained 13 months after surgery. The L4-L5 disc herniation has disappeared (arrowhead).*

Occasionally, both disc herniations are clearly symptomatic; this occurs, for instance, when they are located on opposite sides and the patient complains of bilateral symptoms which correspond to the site of the herniations. In these cases, there is generally no doubt concerning the need to excise both herniations.

Migrated herniation

In the presence of a migrated disc herniation, laminotomy should be performed at the intervertebral level from which the disc fragment originates. There are two reasons for this choice: the disc fragment usually originates from the closest interspace and may, thus, be more easily removed by exposing the latter; the disc of origin often presents a moderate protrusion, which needs to be excised (Fig. 16.5).

A disc fragment migrated into the intervertebral foramen originates almost consistently from the disc below and laminotomy should, therefore, be performed at this level and extended proximally. In those rare cases in which the fragment rises as far as the cranial part of the foramen or medially to the caudal end of the pedicle of the vertebra above, there may be some doubt as to whether laminotomy should be carried out at the intervertebral level above the involved neuroforamen and extended downwards. Such an approach,

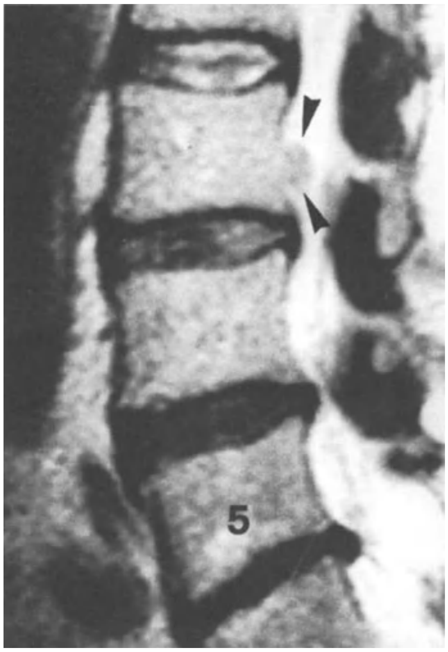


Fig. 16.3. *MR image of a patient with two-level disc herniation. The sagittal scan reveals a disc fragment migrated proximally to the L3-L4 disc (arrowheads) and an L5-S1 extruded herniation, which was asymptomatic. Constriction of the spinal canal at L4-L5 level is also visible. Only the migrated herniation at L3-L4 level was removed, with complete resolution of symptoms.*

however, is more demolitive, since it almost always requires complete unilateral laminectomy and there is more risk of inadvertently performing complete foraminotomy.

Bilateral syndrome

A bilateral radicular syndrome may be due to a midline disc herniation, particularly in the presence of a narrow spinal canal, a bilateral contained or extruded herniation at the same level, a transligamentous or retroligamentous extruded disc herniation, or a disc fragment migrated in the midline or centrolaterally. Signs and symptoms usually prevail on one side, and may be of moderate severity, or almost absent, on the opposite side. Occasionally, there are no symptoms on the opposite side, but only motor loss or a depressed tendon reflex, and this may even be the side on which the disc herniation is located either entirely or to a large extent. In these cases, the decision should be taken as to whether operative management should be performed on both sides or only on one, and, in this case, which one.

In the presence of a midline disc herniation, surgery can generally be limited to the side where radicular signs and symptoms are more severe, since the middle portion of the disc can usually be adequately excised by operating on one side only. However, if the spinal canal is narrow or stenotic, it may be advisable or necessary to perform laminotomy also on the opposite side. The decision depends on the severity of the constriction of the spinal canal, and may be taken intraoperatively if a

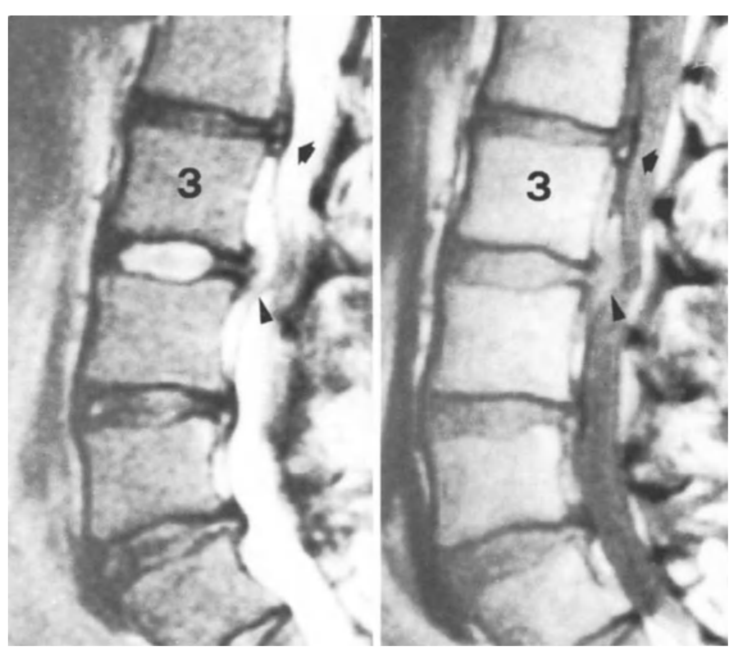


Fig. 16.4. *MR images of a patient with disc herniation at multiple levels. Sagittal scans show a large retroligamentous extruded herniation at L3-L4 level (arrowheads), which was responsible for the radicular symptoms. An extruded herniation at L2-L3 level (arrows) and contained herniations at L4-L5 and L5-S1 levels are also visible. The patient underwent discectomy only at L3-L4 level with complete disappearance of radicular symptoms.*

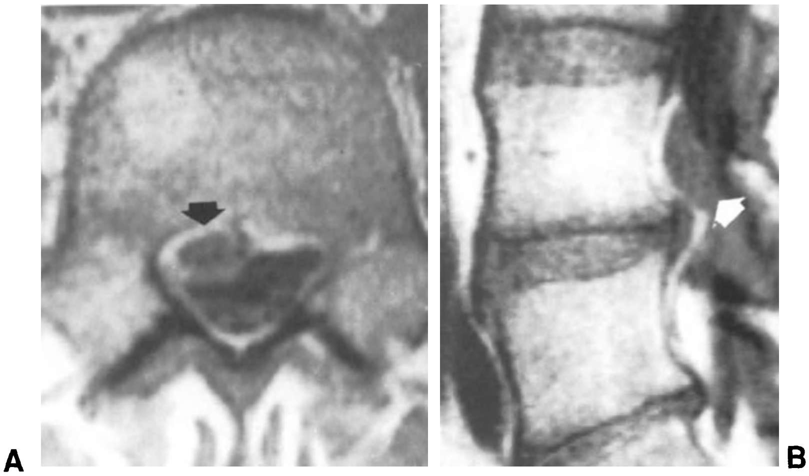


Fig. 16.5. *MR images of a migrated herniation.* (A) *Axial scan showing a disc fragment migrated cranially to the L4-L5 disc (arrow).* (B) *Sagittal scan showing the proximity of the large migrated disc fragment (arrow) to the fourth lumbar disc, from which it originated. This disc appears to be protruded and was evacuated.*

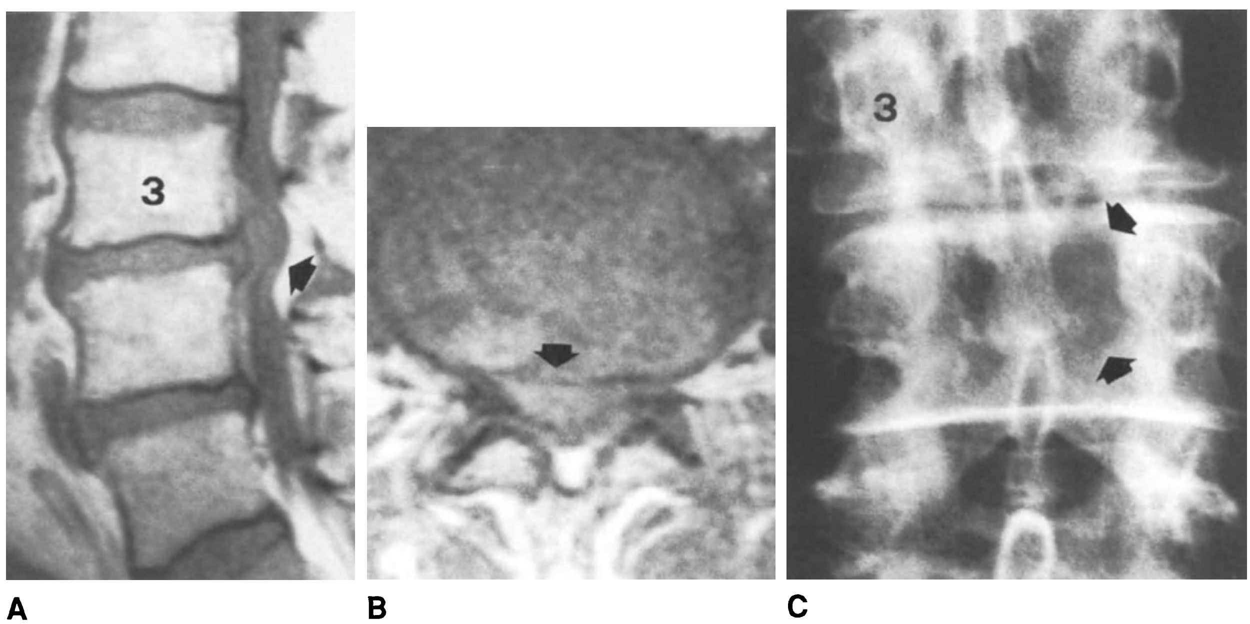


Fig. 16.6. *MR images and radiograph of a patient who had undergone surgical removal of right midline-paramedian disc herniation responsible for radicular pain prevalently on the left.* (A) *Spin-echo T1-weighted sagittal image showing a large extruded disc fragment at L3-L4 level (arrow).* (B) *Spin-echo T1-weighted axial scan showing a midline and right paramedian herniation and a narrow spinal canal (arrow).* (C) *Postoperative radiograph showing the laminotomy (arrows) through which the herniation was excised with complete resolution of symptoms.*

small amount of disc tissue is removed by discectomy on one side.

In the rare cases of bilateral disc herniation, discectomy should generally be performed on both sides. This holds particularly when on the side with milder symptoms, these are moderate or severe, or in the presence of a narrow spinal canal.

In patients with a retroligamentous or transligamentous disc herniation, or a disc fragment migrated in the midline or centrolaterally, a unilateral approach is usually adequate, since the disc fragment can almost always be removed by operating on one side only.

There is no doubt concerning the choice of the side when disc herniation is located on the side where the radicular syndrome is more severe. When the signs and symptoms prevail on the opposite side to that on which the herniation is located, or located to a larger extent, laminotomy should generally be performed on that side (Fig. 16.6). In fact, the greater severity of the clinical syndrome usually indicates that the nervous structures are more severely compressed, and that the disc fragment is located, at least to a large extent, on that side. When, operating on this side, the herniation cannot be completely excised, or doubts exist on the complete removal of the extruded or migrated disc tissue, contralateral laminotomy should be carried out.

Central laminectomy

Central laminectomy may be indicated when disc herniation is associated with stenosis of the spinal canal (page 541). Other conditions in which central laminectomy may be planned are: a cauda equina syndrome, and intradural herniation. In the former, central laminectomy should be performed to be certain that complete decompression of the neural structures is obtained; in the latter, disc herniation has very often to be removed through an intradural approach and this may be done only by a central laminectomy.

Preparation for surgery

Anesthesia

Anesthesia may be general, peridural or local.

The main advantage of general anesthesia is that controlled hypotension may be induced in the presence of profuse epidural bleeding, which obstructs visualization of the anatomic structures, thus making the operation difficult and increasing the risk of damage to the neural structures. The advantages of hypotensive anesthesia become apparent when blood pressure is decreased by at least 50 mmHg compared with the patient's basal values. With these pressure values, blood loss may be reduced by as much as one third. Hypotensive anesthesia, however, exposes the patient to various complications, such as reactive hemorrhage, persistent hypotension, oliguria or anuria, thromboembolism, and cardiovascular or neurologic disorders (44). Deliberate hypotension should, therefore, be avoided in patients with acute hepatic disease, renal conditions, cerebrovascular disease, or any other condition causing a significant reduction in pulmonary ventilation, cardiac output, hemoglobin concentration or oxygen saturation of arterial blood.

Peridural anesthesia may be preferable in patients with respiratory disorders. This type of anesthesia may be particularly indicated in patients undergoing microdiscectomy, who can walk a few hours after surgery. With this type of anesthesia, the patient may be placed in any operative position.

Local anesthesia, employed in the early days of spinal surgery, has recently been employed again (40, 41). The patient is sedated and placed in the operative position. The skin, subcutaneous tissue and superficial portion of paravertebral muscles are injected with 2% carbocain or 1% xylocain. Prior to sectioning the thoracolumbar fascia, the entire thickness of the paravertebral muscles are infiltrated. When a Taylor retractor is used, both the muscles lateral to the facet joints and the joint capsule are injected, after muscle detachment. Once the spinal canal is opened, local anesthetic is instilled on the posterior epidural tissue, the emerging nerve root and, after retracting the latter, the anterior portion of the spinal canal. If the patient complains of pain on retraction of the nerve root, 0.5 ml of anesthetic are injected into the subdural space, at the level of the proximal portion of the root, using a 30 G needle. Excision of disc herniation does not usually cause any pain. If this occurs, a small amount of anesthetic is instilled into the disc. The total amount of anesthetic should not exceed 25 ml in a patient of medium body weight.

Patient positioning

The patient may be placed in the lateral, prone, knee-chest or kneeling position.

The lateral position has been almost completely abandoned. It has the advantage of reducing bleeding from the epidural vessels, but makes use of the operating microscope difficult and bilateral posterolateral arthrodesis impossible. Decubitus on the side, however, may be indicated in certain circumstances, for example in extremely obese patients or in the presence of severe respiratory disorders (13).

For the prone position, the patient is placed on a support, which, leaving the abdomen free, avoids compression of the large abdominal vessels, which hinders blood flow from the lumbar veins and the venous vertebral network, thus favoring intraoperative epidural bleeding (8). The support may be represented by: three pillows placed under the anterosuperior iliac spines and the chest; two long cylindrical pieces of rubber sponge placed under the lateral regions of the pelvis and trunk; or a Wilson frame, which has two iliac supports that may be regulated in height and width. Generally, since it is easier to operate on the spine placed in the horizontal position, the caudal portion of the operating table is placed in the horizontal position and the rest of the table in the anti-Trendelemburg, position. To avoid the patient moving during the operation, two strips of adhesive tape may be used to anchor the thighs to the Wilson frame. The main drawback of the iliac supports is possible compression of the lateral femoral cutaneous nerve, resulting in hypoesthesia of the anterolateral aspect of the thigh for a few days or weeks after surgery. This drawback, occurring especially in operations of long duration, can be

Fig. 16.7. *Positioning of the patient on the Wilson frame. Patient's movements may be avoided by using an adhesive tape to anchor thighs to the Wilson frame. The main disadvantage of this frame is the limited length of the iliac supports which may often be responsible, following operations of long duration, for hypoesthesia in the anterolateral aspect of the thighs. This may be avoided by abundant padding of the iliac supports.*

avoided by placing cottonwool or rubber sponge pads on the iliac supports (Fig. 16.7).

For the knee-chest position, the patient is placed prone on the operating table. Then, while the pelvis is raised, the hips and knees are flexed and the thighs are pushed beneath the abdomen. One or two pillows are placed under the chest, between the thighs and the legs, and under the feet. It is helpful to use a frame to support the patient's buttocks. In this case, the operating table may be raised in the anti-Trendelemburg position in order for the spine to be horizontal. The latter, however, may then be at a too high level for the surgeons, who should thus use a platform. The main disadvantage of this position is the difficulty in positioning patients with hip osteoarthrosis or a stiff knee. Furthermore, excessive flexion of the knee may cause venous obstruction at the level of the popliteal region.

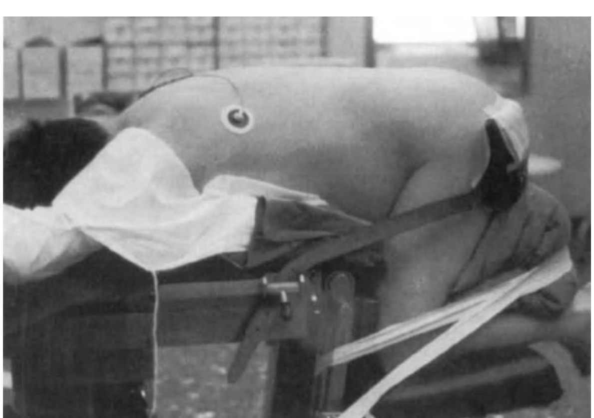


Fig. 16.8. *Kneeling operative position.*

The kneeling position has become widely used over the last decade. The patient is placed in a kneeling position at one extremity of the operating table, which is angled in a Z shape, so that the patient's chest rests on the proximal part of the table and the abdomen is completely free (Fig. 16.8). This position is maintained by a gluteal support.

Preparation of operative field

After painting the skin with antiseptic solution, the surgical field is delimited with four sheets, which are placed, for standard discectomy, so as to leave free a rectangle. When spine fusion using bone from the iliac crest is planned, one of the drapes is placed obliquely so as to leave uncovered the posterior one third of one iliac crest. Care is taken not to touch the skin with the sterile gloves. An adhesive sterile sheet is then placed over the skin and the adjacent parts of the drapes. A large fenestrated sheet is added, and towel clips are applied at each corner of the previously delimited rectangle and turned out of the fenestrated sheet, so that the latter cannot invade the surgical field.

Position of the surgeons

As a rule, the surgeon stands on the side of the herniation. A few surgeons prefer to stand on the opposite side. This may be advantageous in a few circumstances, such as in disc herniations migrated into the intervertebral foramen, which may be well visualized while standing on the opposite side (1), but not in other types of herniation; another maneuver that may be achieved as easily, or even more easily, is an oblique osteotomy of the articular processes, aimed at decompressing the nervous structures in the lateral portion of a stenotic spinal canal (25).

The assistant stands on the side opposite to that of the surgeon. A second assistant is not necessary for excision of a herniated disc through an interlaminar approach, whereas he/she is helpful when an extravertebral approach is performed for a lateral herniation or an intertransverse fusion is carried out. The second assistant stands on the right or the left of the surgeon, depending on the need.

Checking the side of disc herniation

Before proceeding to skin incision, one should always check, with exaggerated scrupulness, that the operation will be performed on the correct side. To this purpose, several steps may be useful: 1) Immediately before the induction of anesthesia the patient may be asked which is the symptomatic side. 2) The anesthetist is instructed to insert the intravenous needle always on the side of the herniation. 3) The assistant must know, independently of the surgeon, the side of the herniation so that he/she can alert the surgeon of the error if the latter, due to distraction, stands on the wrong side at the beginning of the operation. 4) Before the operation, the films with the most diagnostic CT and/or MR images should be hung on the viewbox of the operating theatre. The images are also useful to compare surgical findings with the condition diagnosed preoperatively.

Antibiotic prophylaxis

Experimental and clinical findings indicate that it is much more difficult to cure a disc infection when it has occurred, than to prevent infection by means of prophylactic administration of antibiotics (22, 23, 30, 56). Fraser et al. found that percutaneous injection of a bacterial suspension containing few Staphylococci epidermidis into the intervertebral disc in the sheep causes spondylodiscitis (22, 23) and that the administration of cephazolin 1, 2 or 3 weeks after injection does not affect the course of the infection (24). The latter, instead, did not develop when cephazolin was administered intravenously 30 minutes before injection of bacteria (24, 56). These findings indicate that in patients undergoing surgery for lumbar disc herniation, or any intradiscal diagnostic or therapeutic procedure, intravenous antibiotic prophylaxis should always be carried out before the beginning of the procedure. In the case of open operative procedures, it is advisable to continue the antibiotic treatment for 1–2 days after the operation.

Antibiotics have a different ability to penetrate into the disc and reach the highest blood and intradiscal concentration at different time intervals after administration. Two types of antibacterial agents may be identified: those penetrating into the nucleus pulposus, such as aminoglycosides, glycopeptides (vancomycin and teicoplanin); and those which do not penetrate into the nucleus at all, or only insufficiently. The ability to penetrate is related to several factors, such as molecular weight, electric charge, and chemical and structural characteristics of the antibiotic. The electric charge plays an important role: for example, penicillin (negatively charged) and gentamycin (positively charged) penetrate into the annulus fibrosus which has a neutral charge, but penicillin, unlike gentamycin, penetrates only slightly into the nucleus pulposus, which presents a negative charge (65).

Clindamycin and tobramycin easily penetrate into the disc, where concentrations are over 50% higher than in the serum 1 hour after administration (19). Also the glycopeptides teicoplanin and vancomycin, both active on gram positive bacteria, are well able to penetrate into the nucleus pulposus. Teicoplanin reaches the highest intradiscal concentration 1–2 hours after administration (69). Vancomycin would reach the highest concentration after 8 hours (69); in one study, however, the antibiotic was found to be efficacious only when administered within 1 hour of infection (30). Gentamycin, which is active on gram negative bacteria, penetrates into the disc in adequate doses; the highest concentration is reached after 2 hours and remains constant for at least 4 hours (14). Cephazolin reaches the highest intradiscal concentration within 1 hour; however, it easily penetrates into the annulus fibrosus, but with difficulty into the nucleus pulposus (24). Other antibiotics, such as cephadrin and cephazolin (cephalosporins), and flucloxacillin and oxacillin (derivatives of penicillin), do not seem to penetrate into the intervertebral disc (19, 26).

At present, therefore, clindamycin, tebromycin, vancomycin, teicoplanin and, for gram negatives, gentamycin appear the most efficacious antibiotics for therapy and prophylaxis of disc infection. The choice of antibiotic for prophylactic purposes is particularly important in percutaneous procedures. In the case of surgery, even other antibiotics, with a broad-spectrum antibacterial effect, may be used, since they enter the disc together with the extravasated blood. The antibiotic selected should be administered at such a time interval as to reach the highest intradiscal concentration when the procedure is carried out. In the case

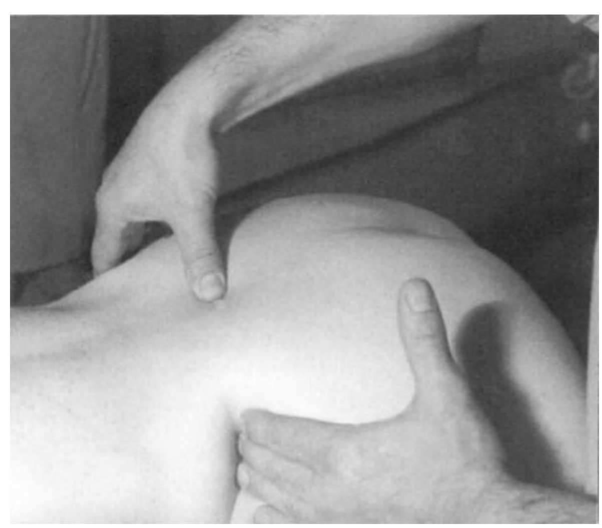


Fig. 16.9. *Preoperative manual identification of the involved interspinous space. The surgeon, standing on the patient's left side, grasps the iliac crest with the left hand, while palpating the middle sacral crest and lumbar interspinous spaces with the right hand.*

of a long surgical operation, the antibiotic should be administered again if its halflife in the blood is shorter than the operation itself.

Antibacterial prophylaxis is of paramount importance in diabetic patients, in whom the most adequate prophylaxis is represented by the association teicoplanin-gentamicyn, administered before anesthesia is induced.

Identification of pathologic level

Preoperative manual identification

Palpation of the interspinous spaces allows, in many cases, identification of the intervertebral level where the herniation is located, particularly when this is the fourth or fifth lumbar interspace. The surgeon, before draping the surgical field, stands on the patient's left side and, while grasping the iliac crest with the left hand (when right-handed), palpates first the middle sacral crest and then the lumbar interspinous spaces with the right hand (Fig. 16.9). The middle sacral crest is usually felt as a continuous bony prominence, at the cranial end of which, the depression of the lumbosacral interspinous space is found. The latter is, at times, narrower than the upper spaces. The bony prominence of the L5 spinous process, and then the successive depression, are palpated proximally to the lowest interspinous space.

For identification of the interspinous processes, it is useful to examine an anteroposterior radiograph of the lumbar spine including the entire iliac crests in order to detemine the vertebral level to which they correspond. In most subjects, the iliac crests correspond to the L4-L5 interspinous space. In many subjects, however, the crests are slightly above or below the fourth lumbar disc, and this should be known while checking the position, with respect to the iliac crests, of the interspinous space detected by palpation.

In nonobese patients, particularly if young and with no lumbosacral transitional anomalies, it is generally easy to identify the intervertebral levels by palpation. This may be difficult in obese subjects, since the level of the iliac crests may appear to be more cranial, on account of the fat layer that the palpating hand encounters above the crests. Errors in the identification of the vertebral levels may easily occur in the presence of lumbosacral bony anomalies and in patients with narrow interspinous spaces due to hyperlordosis, ossification of the interspinous ligaments or marked loss of disc height. Furthermore, the more proximal the pathologic vertebral level, the greater the chances of mistakes.

Once the pathologic level has been identified, and following disinfection of the surgical field, a transverse line is traced on the skin, at the level of the interspinous space, using a dermographic pen. The alternative is to use the small saw employed to cut the neck of medicinal vials.

Preoperative fluoroscopic identification

After skin disinfection, the surgeon manually identifies the intervertebral level involved and inserts a 20 G spinal needle vertically, in close proximity to the distal spinous process. Use of sterile gloves allows the interspinous space and the proximal margin of the distal spinous process to be palpated with the left hand, while introducing the needle with the right hand. The fluoroscope is positioned so as to obtain a lateral view of the lumbar spine, and the position of the needle is checked. The latter should be pointed towards the proximal end-plate of the vertebra below the disc involved (51) (Fig. 16.10). In this case, it is difficult, at the time of surgical exposure, to slide into the interlaminar space above or below. Conversely, when the needle is inserted into the proximal portion of the interspinous space and its tip is directed towards the lower end-plate of the proximal vertebra, it is easy, during surgical exposure, to slide inadvertently into the interlaminar space cranial to the required interspace. If the needle appears to be located too proximally, it should be inserted more distally and its position checked again.

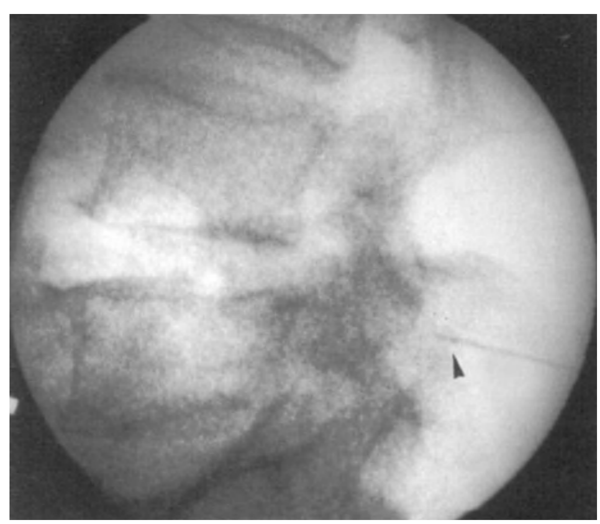


Fig. 16.10. *Preoperative fluoroscopic identification of the involved interspace. To decrease the risks of slipping into the interspace above or below, the needle tip (arrowhead) should be directed towards the proximal end-plate of the vertebra below the disc to be explored.*

Intraoperative manual identification

L5-S1 level

This level can be easily identified, since it is sufficient to verify that an interlaminar space, i.e., a space occupied by a ligamentum flavum, has been exposed and that it is the lowest lumbar interspace. One may have doubts in identifying the ligamentum flavum when the interlaminar space is narrow, either constitutionally or as a result of degenerative changes. To identify the ligamentum flavum, a blunt dissector may be used to test the consistency and depressibility of the exposed structure. A fibrous consistency indicates that the structure is a ligamentum flavum. In the absence of vertebral transitional anomalies, the only doubt that may arise is that a posterior sacral foramen has been exposed. The latter, besides being smaller than an interlaminar space, is located along the line of the facet joints rather than that of the laminae, and it is not occupied by a fibroelastic membrane. To verify that the exposed interlaminar space is the lowest lumbar interspace, one's index finger or a dissector should be run along the caudal lamina: the sacral lamina (or groove) presents no discontinuity due to the absence of interlaminar spaces and often has a characteristic backwards oblique orientation.

Identification of the L5-S1 interspace may be difficult in the presence of lumbarization of the first sacral vertebra, the only exception being the rare cases of complete lumbarization of S1 vertebra, in which the L5-S1 level becomes the last but one. In cases of incomplete lumbarization, an anteroposterior radiograph of the lumbosacral spine should be examined to evaluate whether an S1-S2 interlaminar space of normal or decreased width is present. However, the best choice, in these instances, is to check the disc level intraoperatively by fluoroscopy.

L4-L5 level

In the absence of transitional anomalies, the L4-L5 interlaminar space may be easily identified when a conventional discectomy is carried out. The latter, in fact, implies a sufficiently long skin incision as to permit partial exposure and identification of the lowermost lumbar interspace. The risk, in these cases, is to expose the L3-L4 interlaminar space mistaking it for the fourth lumbar, especially having identified, below this, an interlaminar space, without, however, having identified the sacral lamina. The most frequent error in identifying the vertebral level is to mistake L3-L4 for L4-L5 level. The most common causes are: 1) To be mistaken in level identification at preoperative palpation of the interspinous spaces. This occurs particularly in obese patients or in those with narrow interspinous spaces. 2) To slide into the interlaminar space above, after correct identification of the L4-L5 interspinous space. This may easily occur in the presence of an abnormally narrow L4-L5 interlaminar space, a more transverse (vertical in the surgical field) orientation than normal of the L4 lamina, or when the L4-L5 space has an elongated shape in the vertical direction. In the first case, the interlaminar space may not be identified, because the two laminae are mistaken for a single lamina. In the second case, the craniocaudal dimensions of L4 lamina are shorter than normal, and this makes it easy to slide into the interlaminar space above. In the third case, it is possible that the interspinous space is abnormally caudad with respect to the interlaminar space and is, thus, mistaken for the L5-S1 interspinous space.

The precautions to avoid these mistakes are: 1) To examine the anteroposterior radiograph of the lumbosacral spine prior to surgery to detect the position of the iliac crests with respect to the L4-L5 disc space and to evaluate the shape and orientation of the lowermost lumbar laminae. 2) To check, by palpation, that the level of the iliac crests corresponds to the exposed interspinous space, using, as a reference, the radiographic image and the line traced on the skin prior to surgical incision; it should not be forgotten, however, that the interspinous space is more caudad than the disc space. 3) Once the interspinous space has been identified, to follow the lateral aspect of the spinous processes to identify the corresponding laminae. 4) When the Taylor retractor is used, to note whether the weight usually used for the two lower lumbar levels exerts an excessive traction on the retractor; as far as concers the weight required for an adequate retraction, in fact, the more proximal the lumbar level exposed the less retraction needed. 5) In case of doubt, to expose and identify the lamina of the S1 vertebra rather than only the L5-S1 interlaminar space.

These precautions, except for the latter, are valid also for microdiscectomy. When the microscope is used, in fact, the limited extent of the surgical field does not usually allow exposure of the L5-S1 interlaminar space or, anyway, the S1 lamina. A further precaution, when performing microdiscectomy, is to place the skin incision just above the interspinous space.

When the L5 vertebra is sacralized, the L4-L5 intervertebral space corresponds to the L5-S1 interspace in a normal spine. However, this holds only in the presence of complete fusion also of the L5 and S1 posterior arches. If an interlaminar space is present, it is usually abnormally narrow and should be recognized, as such, at surgical exposure. In these cases, the L5 lamina often displays a more transverse orientation than normal, thus appearing abnormally short in the craniocaudal direction.

In patients with lumbarization of the S1 vertebra, the L4-L5 interlaminar space corresponds to that which, in normal conditions, is the L3-L4 or L4-L5 space, depending upon whether or not an S1-S2 interlaminar space exists.

L3-L4 level

When conventional discectomy is carried out, the skin incision may be prolonged downwards as far as the S1 lamina to identify the two lower interlaminar spaces. This, however, should be avoided if possible, since it implies extensive vertebral exposure.

Usually, the L3-L4 interspinous process is the first to be encountered proximally to the iliac crests. Palpation of the latter, and simultaneous evaluation of the position of the third interspinous space compared with the iliac crest on the anteroposterior radiograph of the spine, may allow us to check whether the exposed interspinous space is the third lumbar; having done this, the lateral aspect of the spinous processes is followed to identify the corresponding laminae. This method, however, is open to error, especially in obese patients or in those with narrow interspinous spaces.

The L3-L4 interlaminar space is generally more elongated in the vertical direction than the space below, and this should be recognized on the anteroposterior radiograph. If the surgical findings do not correspond to the radiographic picture, one should suspect the wrong level having been exposed. Similarly, when the Taylor retractor is used, one should cast some doubt that the exposed level is the third lumbar, if retraction of the paraspinal muscles requires a similar weight to that usually necessary for the subjacent levels or a much lower weight, as occurs for the L2-L3 level.

Intraoperative fluoroscopic identification

Occasionally, once the interlaminar space has been exposed, some doubts may arise concerning the correct identification of the pathologic level. This may easily occur in one or more of the following circumstances: obese patients; herniation of the second or third lumbar disc; interlaminar spaces abnormally narrow or orientated more vertically than normal; laminae with very transverse (vertical in the surgical field) orientation. In these cases, before proceeding with laminotomy, it may be useful to check, by means of fluoroscopy, that the exposed intervertebral space is the intended interspace. As for the preoperative control, a spinal needle is inserted into the interspinous space and its position is checked with the fluoroscope. Alternatively, (or in addition), a dissector is placed on the ligamentum flavum and maintained by means of cotton swabs.

In general, it is preferable to make the intraoperative check, rather than to begin laminotomy with the risk of a mistaken identification of the interlaminar space. In fact, the waste of time that the check involves is repaid by the ease of mind with which the surgeon operates, the time that is saved in the event the surgeon has mistaken the level and realizes the error during the operation, as well as the advantages for the patient by avoiding a useless laminotomy.

In a few cases, it may be more useful to decide not to carry out the preoperative control and to perform only the intraoperative. This choice may be made when there is the certainty, or likelihood, of doubts in the identification of the pathologic level. This occurs particularly in patients with severe spondylotic changes and considerable narrowing of the interspinous and interlaminar spaces. In these cases, the intervertebral level presumably involved is identified before skin incision and, once the interlaminar space is exposed, fluoroscopic control is carried out. By thus doing, it is possible to avoid preoperative fluoroscopic control, but one runs the risk of having to prolong the skin incision in case of error in the manual preoperative identification of the intended interspace.

Definition of terms

Numerous terms are used to indicate the various stages of excision of a lumbar herniated disc or decompression of the nervous structures in a stenotic spinal canal. A same term is often used to indicate different procedures or several terms are used for a same procedure.

Conventional or standard discectomy is the operation for removal of disc herniation accomplished with the naked eye. Microdiscectomy is the operation carried out using the operating microscope, regardless of the width of the interlaminar access to the vertebral canal and radicality of discectomy.

The term laminotomy means removal of part of a lamina. The term is generally used to indicate the approach to the spinal canal through a very limited excision (not more than one third) of the two adjacent laminae; usually, the procedure implies removal also of the most medial portion of the articular processes. The same procedure is referred to as interlaminar fenestration (4).

The term hemilaminectomy is used to indicate, at times, the removal of the whole lamina on one side and, at others, of the cranial or caudal one half of the lamina on one side. Since one vertebra has two laminae, excision of the entire lamina on one side should be referred to as laminectomy. The term hemilaminectomy should be used, as is generally the case, to indicate removal of one half, or a large part, of two adjacent laminae, even if this use is incorrect, because the term refers to a single lamina. The expression partial hemilaminectomy, rarely used, should indicate a similar procedure to laminotomy.

Excision of the laminae of a vertebra may be called bilaminectomy (2) or bilateral laminectomy. The procedure is also indicated as central or complete laminectomy.

The term foraminotomy indicates removal of a part of the posterior wall of the intervertebral foramen, whilst the term foraminectomy refers to complete excision of the wall of the foramen.

Facetectomy consists in the resection of the articular facets of the zygoapophyseal joints. The term, however, is generally used to indicate removal of the articular processes, at the end of which the facets are located (2). It is synonymous of the term arthrectomy, which is anatomically more correct.

Conventional discectomy

Indications

The conventional procedure is indicated in any patient with a herniated disc. It is also the only possible procedure when an arthrodesis of the motion segment is performed in association with discectomy or when, in the presence of lumbar stenosis, bilateral laminectomy has to be carried out prior to discectomy. Furthermore, the conventional modality may be the procedure of choice in patients with disc herniation at multiple levels or a recurrent herniation. In the latter case, it may, at times, be indicated to start the operation with the naked eye and use the operating microscope only when the neural structures are visualized. The advantage of performing surgery with the naked eye is to have a paramount vision of the surgical field and the anatomic structures, and this, at times, may make the surgical maneuvers considerably easier. The conventional operation, on the other hand, does not necessarily imply a large exposure of the spine and a large laminoarthrectomy, even if discectomy performed with the naked eye through a limited approach may be more difficult than microdiscectomy.

Surgical instruments

1. Bipolar cautery, which may be used from the beginning of the operation for dermal and subcutaneous vessels.
2. Superficial self-retaining retractor (such as Weitlaner) and deep hand-held retractor (such as Mathieu).
3. A periosteal elevator 2 cm in width. A too narrow elevator exposes to the risk of inadvertently perforating the ligamentum flavum.
4. Straight curettes with a long shaft and large (1.3 cm), medium-size or small (3 mm) cup.
5. 0.5–1.5 cm large osteotomes.
6. Bayonet forceps.
7. Bone rongeurs with straight or angled, medium-size, cutting cups.
8. Kerrison rongeurs with small (2 mm) medium-size (3 or 4 mm) or large (5 mm), 90° or 45° angled, forwards or backwards angled, bite.
9. Deep self-retaining retractor. We use Taylor retractors of three widths (1.3 cm, 2 cm and 3 cm), to which a weight of 1.8 or 2.3 kg is hung (Fig. 16.11).
10. Basket cutter for arthroscopic meniscectomy with 90° angled bite, used to cut the ligamentum flavum (Fig. 16.12).
11. Medium-size and small suckers.
12. Pituitary rongeurs with varying size, straight, 30° or 45° forwards angled, and 30° backwards angled, bite.
13. Blunt dissector, such as Freer dissector (Fig. 16.13). If used to retract the neural structures, the retractor should not be too narrow (less than 4 mm) in order not to traumatize the nerve root, or too wide (more than 6 mm) not to hinder the surgical maneuvers. The working end of the dissector should be only slightly curved forwards.

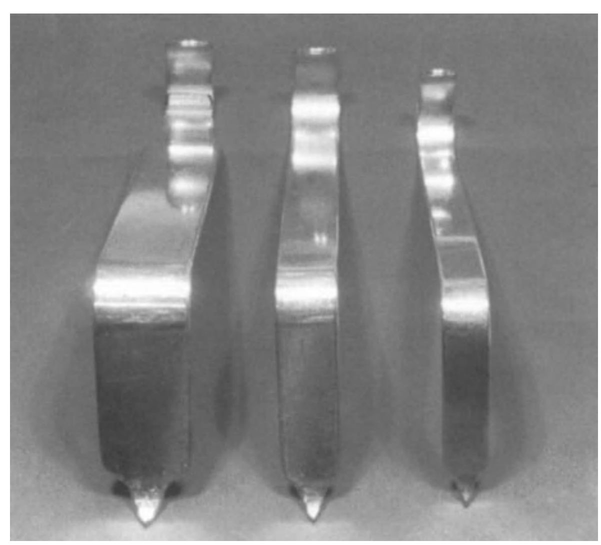


Fig. 16.11. *Taylor self-retaining retractors. Depending on the length of the surgical wound, 1.3 cm, 2 cm or 3 cm wide retractors are used, to which a weight of 1.8–2.3 kg is hung.*

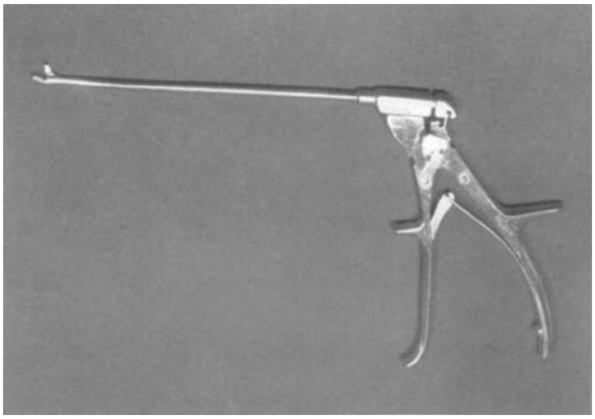


Fig. 16.12. *Basket cutter used for arthroscopic meniscectomy. It may be used instead of the Kerrison rongeur to resect the medial portion of the ligamentum flavum.*

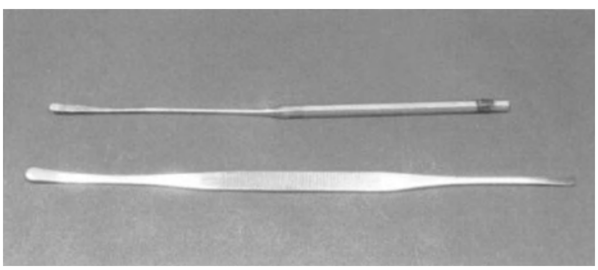


Fig. 16.13. *Blunt dissectors. These may be used to retract medially the emerging nerve root or the thecal sac. The width of the dissectors should be 4 to 6 mm not to angle excessively the nerve root and hinder surgical maneuvers.*

14. An instrument to incise the annulus fibrosus. This may be a fixed-blade tenotome with a straight or angled handle, or a scalpel.
15. Frazier probes with 5 mm or 9 mm long foot (Fig. 16.14).
16. Nerve root retractor with shallow hook and angled handle.
17. Squared and rectangular cottonoids and narrow, long hemostatic gauzes.

Surgical technique

Exposure of interlaminar space

The skin incision is placed in the midline and, for discectomy at a single level, is 6–8 cm long. The middle portion of the incision usually corresponds to the intervertebral space involved. However, when the herniation is located at L4-L5 level, it may be advisable to make the incision slightly more caudad to expose, even partially, the L5-S1 ligamentum flavum and identify the sacral lamina. This may enable fluoroscopic checks to be avoided.

The subdermal vessels are coagulated, preferably using a bipolar cautery. The alternative is to grasp the vessels with curved Klemmer clamps, which are successively turned outside the surgical wound, connected with an elastic band and left in situ; for a discectomy at a single level, 3–4 clamps are necessary for each cutaneous flap. This method enables bleeding of subdermal vessels to be arrested very quickly, it does not alter the subsequent blood supply to the skin and it enlarges the surgical wound, thus improving illumination of the deep surgical field.

After sectioning the subcutaneous tissue, the lumbosacral fascia is exposed and cut using the diathermy blade in close proximity to the spinous processes, on the side of the herniation. In some patients, it is difficult to recognize the tip of the spinous processes upon palpation. In these cases, the surgeon's assistant should depress the paraspinal muscles and lumbosacral aponeurosis using a periosteal elevator pressed against the tip of the spinous processes, while the surgeon makes a similar maneuver with the index finger of the left hand and cuts the fascia with the right.

The paraspinal muscles are detached by running the periosteal elevator along the lateral aspect of the spinous process and the lamina of the uppermost of the exposed vertebrae. The instrument should be maintained in close contact with the bony surface to reduce bleeding of muscle vessels. The osteomuscular space thus created is filled with cotton swabs, packed into the

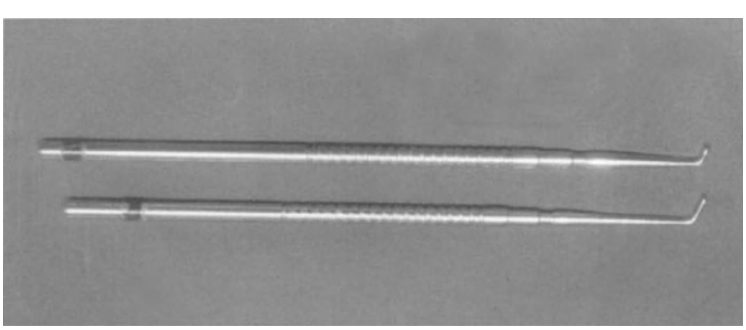


Fig. 16.14. *Frazier probes. These may be used to interrupt the most medial portion of the annulus fibrosus, to mobilize fragments of disc ventrally to the neural structures and to test the dimensions of the nerve-root canal. The foot of the probes is 3 mm wide, and 5 mm and 9 mm long, respectively.*

depths of the wound with the periosteal elevator. The same maneuvers are made at the level of the lowermost vertebra. The swabs are then taken out, and the attachments of the transversospinalis muscle to the spinous processes are cut with scissors or diathermy blade. Detachment of the muscle is completed with the periosteal elevator and prolonged laterally until at least the medial half of the articular processes is exposed.

When muscle detachment is correctly performed, bleeding is rarely profuse. Bleeding may be due to muscle vessels of medium size, which should be identified and coagulated, or small muscle vessels responsible for diffuse bleeding, which occurs mainly at the ends of the detached muscle flap. Often, it is better to pack a cotton swab at one or both ends of the detached muscle flap than try to identify and cauterize the small blood vessels. Bleeding usually stops if the swab is left for a few minutes.

At the end of this stage, the self-retaining retractor is applied. When the Taylor retractor is used, the pointed end of the instrument is introduced externally to the articular processes and directed against them. A weight is hung at the opposite end of the retractor, which is usually of a large or medium size.

Laminotomy

Excision of proximal lamina

The cranial attachment of the ligamentum flavum is scraped off using a small curette, inserted beneath the caudal end of the proximal lamina (Fig. 16.15). The curette is pressed against the deep surface of the lamina and, starting from the medial end, allowed to slide laterally. After the ligament has been detached for a few millimeters along the outer two thirds of the lamina, about 1 cm of the corresponding bony portion is resected using a Kerrison or bone rongeur (Fig. 16.16). The most common mistake, in this stage, is to start detachment of the ligament too far laterally, resulting in the need to repeat the maneuver for the medial portion of the lamina after removal of the lateral portion. This makes the detachment of the ligament less easy due to the difficulty in sliding the curette in the transverse direction along a very short bony surface.

This sequence of surgical maneuvers may be difficult or impossible in the presence of marked narrowing of the interlaminar space due to spondylotic changes. In these cases, an osteotome 5–8 mm wide may be used to

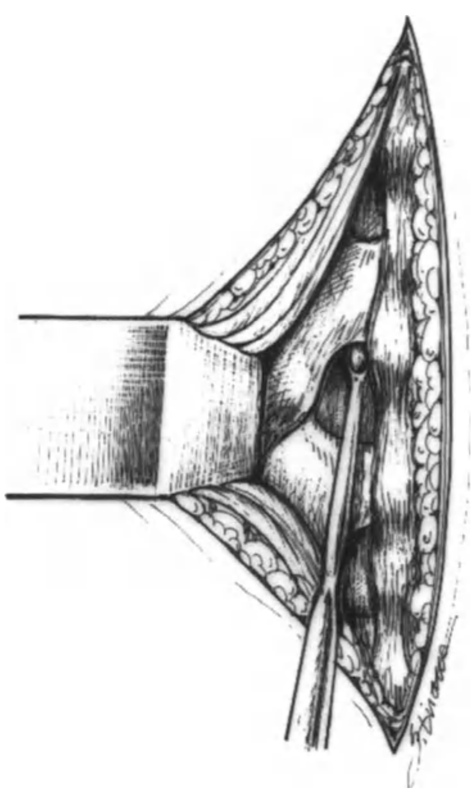


Fig. 16.15. *Detachment of the ligamentum flavum using a small curette inserted beneath the caudal end of the proximal lamina.*

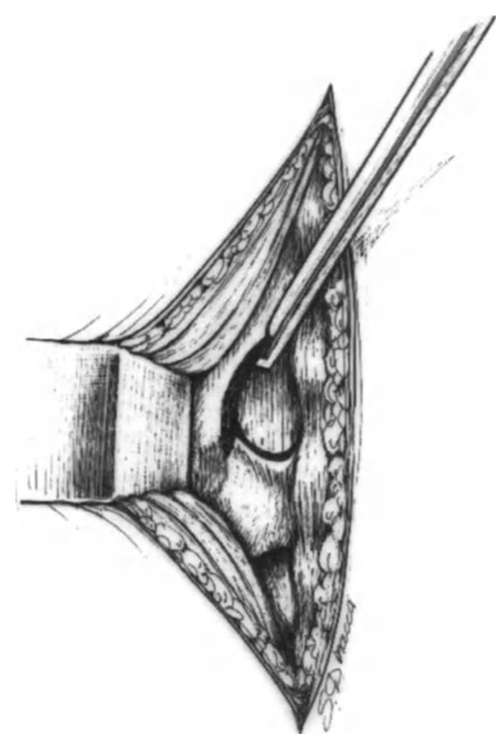


Fig. 16.16. *Removal of the caudal end of the proximal lamina using a Kerrison rongeur.*

resect the medial one third or one half of the inferior articular process of the vertebra above. The ligament is then detached and laminotomy carried out, if this is easy, or, still with the use of the osteotome, the distal one third of the proximal lamina is removed (Fig. 16.17). The use of the osteotome in resecting the inferior articular process does not usually imply any risks, due to the protection provided by the superior articular process of the distal vertebra. Similarly, excision of the distal portion of the lamina implies little risk of damage to the neural structures due to the presence of the underlying ligamentum flavum.

Excision of distal lamina and ligamentum flavum

With the small curette previously used, the ligamentum flavum is detached by scraping in a mediolateral direction on the proximal portion and the edge of the distal lamina. Often, before the ligament is entirely detached from the laminal edge, the most dorsal portion of the ligament, attached to the posterior aspect of the proximal end of the lamina, is scraped off. The resulting detached flap is grasped with a Kocher clamp and tractioned proximally to separate the superficial layer of the ligament from the deep layer with a medium-size curette; once the proximal lamina is reached, the ligamentous flap is cut using a scalpel. By scraping a small curette against the laminal edge and then introducing the curette beneath the latter, the ligament is completely detached at least far enough for the foot of the Kerrison rongeur to be inserted beneath the lamina and then bone removal can be started. With the rongeur, one proceeds medially and laterally, as well as distally, detaching the part of the ligamentum flavum not disinserted with the curette. Generally, it is sufficient to remove about 5 mm of distal lamina in this stage. Lateral to the latter, is the medial border of the superior articular process, which is resected by directing the Kerrison rongeur laterally and upwards.

The medial portion of the ligamentum flavum may be excised using a medium- or large-bite Kerrison rongeur (Fig. 16.18). More efficient than the latter, is the angled basket cutter used for arthroscopic meniscectomy. The lateral portion of the ligament is then removed, together with the part of the articular process to which it is attached, by inserting the rongeur below the ligament. Alternatively, a Frazier probe is introduced beneath the medial portion of the ligament, which is elevated and sectioned with a scalpel blade along the foot of the probe (Fig. 16.19). After longitudinal section, the lateral portion of the ligament is grasped with a fine toothed forceps and cut with the scalpel, or is removed with the Kerrison rongeur.

The alternative is to remove the ligament first and the

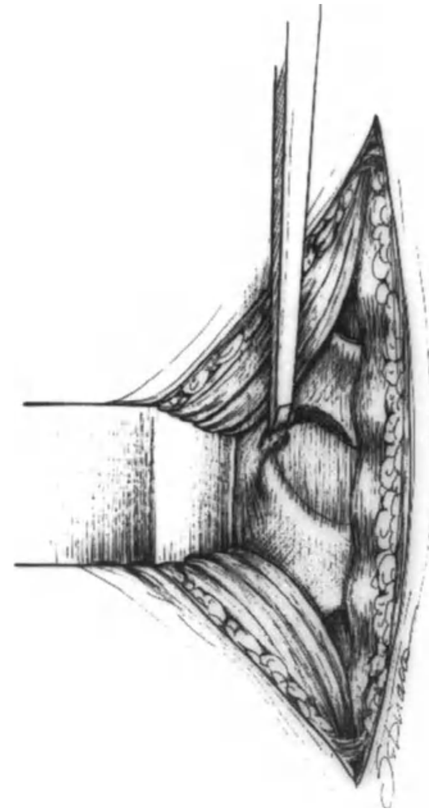


Fig. 16.17. *Enlargement of proximal laminotomy using an osteotome.*

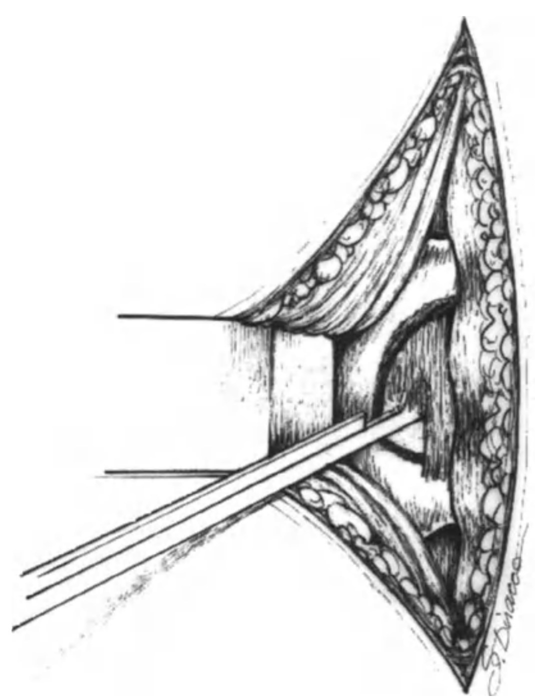


Fig. 16.18. *Removal of the lateral portion of the ligamentum flavum using a medium-size Kerrison rongeur.*

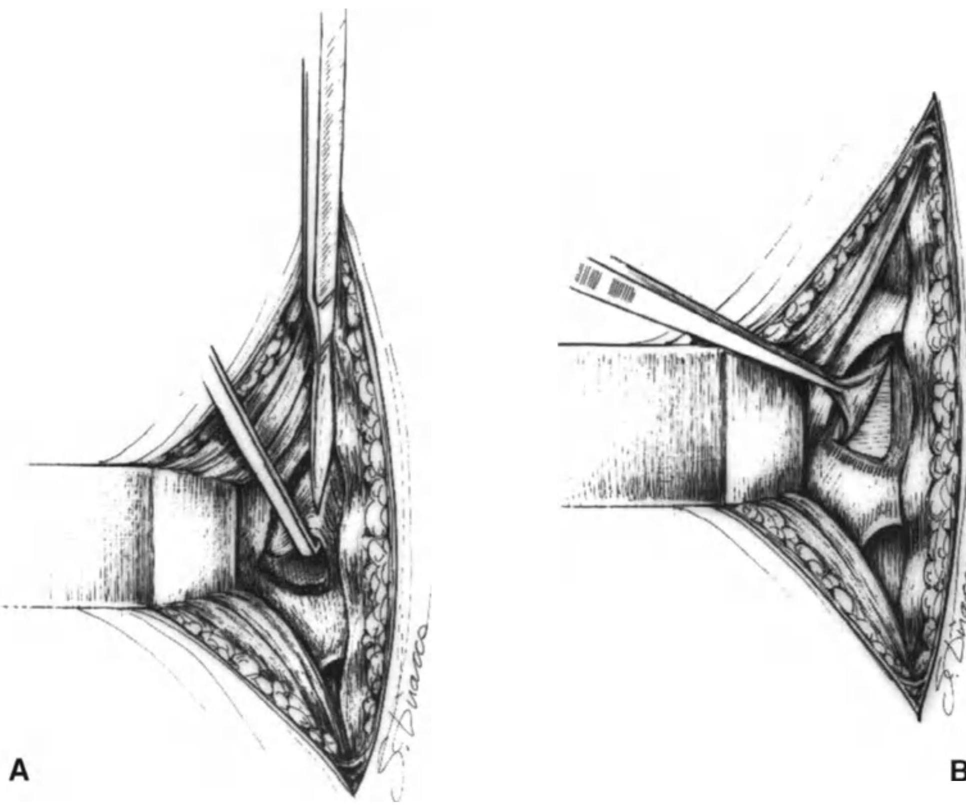


Fig. 16.19. *Removal of the lateral portion of the ligamentum flavum following its longitudinal section.* (A) *The ligament is raised with a Frazier probe and sectioned with a scalpel.* (B) *The ligament is grasped by a flap; this allows exposure of the epidural fat and fast completion of flavectomy.*

distal lamina afterwards. In this instance, the ligament is cut longitudinally in proximity to its medial end, until the distal lamina is reached. Sectioning is then continued transversely along the laminal edge, to form a L. A No. 11 scalpel blade should be used, since its end can be better controlled visually. Caution should be used in deepening the cut, until the epidural fat is reached. As soon as a flap of ligament can be grasped with a toothed forceps, a small patty is inserted between the ligament and the epidural tissue, and the section is continued while elevating the flap (Fig. 16.19). Rather than in the medial portion, the longitudinal section may be made laterally, in proximity to the facet joint. The section in this site, however, is more difficult and risky. If the cut is deepened excessively, the nerve root emerging from the thecal sac may be damaged, whilst with the medial section a fissure in the sac may, at the most, be created. Once sectioned in an L shape, the ligament can be removed by completing the section with the use of the scalpel or Kerrison rongeur.

Distal laminotomy may be accomplished after the ligament has been excised or cut in an L.

Arthrectomy

We generally prefer the use of the Kerrison rongeur. Bone resection should be started in the proximal portion of the articular complex (Fig. 16.20). In this zone, in fact, there is no root emerging from the thecal sac; furthermore, the disc is located at the level of the cranial or, at the most, middle portion of the interlaminar space and may be adequately explored only after resection of the upper portion of the articular complex.

In performing facetectomy, the Kerrison rongeur should be inserted medially to the ligamentum flavum and the foot-plate of the instrument introduced into the subarticular space. The two most common mistakes are: not to precisely identify the ligamentum flavum and, thus, to resect the articular processes posterolaterally to the ligament; or not to penetrate adequately below the articular processes. In these cases, arthrectomy is difficult to perform or bone resection is limited to the inferior articular process, situated dorsally to the superior process, which is excised only subsequently, with necessarily a longer operative time. It is easier to

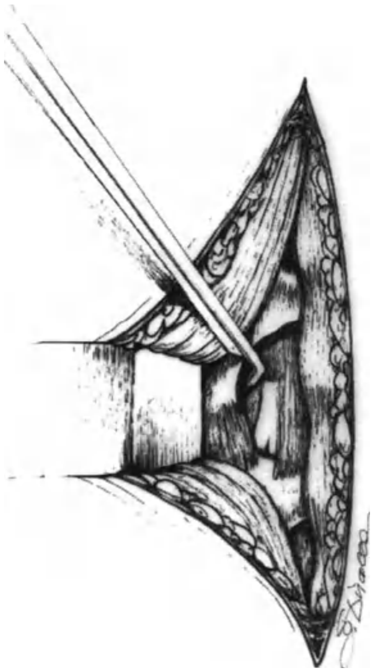


Fig. 16.20. *Arthrectomy is preferably started at the level of the proximal portion of the articular complex.*

make this mistake when using Kerrison rongeurs with small jaws, which do not allow the articular processes to be grasped in their entire thickness or easily slip between the two articular facets.

Facetectomy should be extensive enough to allow adequate visualization of the neural structures and the disc, as well as easy insertion of the pituitary rongeur into the disc space with no risk of damage to the emerging nerve root. Following resection of the medial one third of the articular processes, the nerve root should be retracted and the disc visualized to confirm the presence of the herniation and evaluate whether there is enough space to carry out discectomy with no undue traction of the neural structures. At the first exploration, one often realizes that laminoarthrectomy is not extensive enough to perform discectomy. This requires further resection of the laminae and articular processes.

Facetectomy, however, should not be extended excessively, particularly in the uppermost portion, on account of the risk of interrupting the pars interarticularis, thus making the residual part of the inferior articular process mobile. If this occurs, the articular process may be either removed or left in place. When possible, it is better to leave it in place, since with time bony continuity between the inferior articular process and the pars interarticularis may be restored. On the other hand, the scar tissue which develops, makes the remainder of the inferior articular process rapidly immobile.

When arthrectomy is initiated with the osteotome, this may also be used for resection of the articular processes, which is done either by remaining on the side of the herniation or moving to the opposite side. In the former case, the osteotome is used with a vertical direction to remove first the tip and then the base of the superior articular process. Subsequently, the upper portion of the distal lamina may also be resected. Use of the osteotome in this way, however, requires experience and great caution, since the emerging nerve root runs anteriorly or anteromedially to the articular process. From the opposite side, an oblique osteotomy can be carried out. This is done by directing the osteotome laterally with a slant of 45°, in order to resect the inferomedial portion of the articular processes. With this method, there is less risk of damage to the nerve root, since the blade of the osteotome is not directed towards the root; furthermore, vertebral stability is better preserved, because the dorsolateral portion of the articular processes is left intact. Oblique osteotomy, however, is better indicated in stenosis, in which the nerve root should only be decompressed dorsally, than in disc herniation, where an adequate space should be created to expose and excise the herniated disc. This type of arthrectomy, furthermore, is easier to carry out when the spinous process has been removed and central laminectomy performed.

Disc exposure

The thecal sac and emerging nerve root are retracted medially, using two blunt dissectors to expose the disc. When the herniation is very large, this maneuver should be accomplished with great care in order not to excessively stretch the emerging root. If the disc is covered by epidural fibroadipose tissue, as often occurs, one or two dissectors are used to separate this tissue in order to expose the maximum disc surface possible. The purposes of this maneuver are: to avoid bleeding of the epidural vessels which may be sectioned when the disc is incised; and to make sure that the disc is exposed. If in any doubt in this respect, the consistency of the exposed structure should be tested with a dissector. The vertebral body is hard like a bone, whereas the disc is a depressible structure of fibrous consistency. If doubts persist, the dissector is forced into the disc, if this has been exposed.

Disc incision

When disc herniation is extruded beneath the posterior longitudinal ligament, it is often sufficient to apply pressure with a dissector to interrupt the continuity of the ligament and see the herniated disc tissue emerge like a cauliflower. In the other cases, the ligament and annulus fibrosus should be incised so as to create a large opening in the disc.

Before doing this, it is important to verify that the disc has been exposed rather than other structures, particularly the emerging nerve root. This doubt may arise when the spinal canal is narrow or excision of the articular processes has been excessively limited, and particularly when epidural bleeding obstructs vision of the anatomic structures. If doubts persist, before incising the disc, the nerve root should be clearly visualized by enlarging the arthrectomy and/or retracting or removing, with forceps, the fat covering the root.

While retracting the thecal sac and the emerging nerve root medially, the disc is incised in a cruciate fashion using a tenotome or a No. 11 scalpel blade (Fig. 16.21). The transverse incision should be started as medially as possible and prolonged as far as the outer edge of the emerging root; longitudinally, the incision should extend for the entire height of the disc. A large incision makes it easy to remove either a possible extruded disc fragment or the contents of the disc. When a large opening cannot be created (due to narrowing of the spinal canal, a marked decrease in disc height or inadequate exposure of the disc) such a hole should be created to allow at least the introduction of the thinnest pituitary rongeurs. The alternative to disc incision is to force a thin dissector into the disc space and then replace it with a larger dissector, which is rotated within the disc to enlarge the opening and thus allow the introduction of the pituitary rongeur. This method permits penetration into the disc space when, for any reason, incision of the disc with a blade was either not possible or not desired.

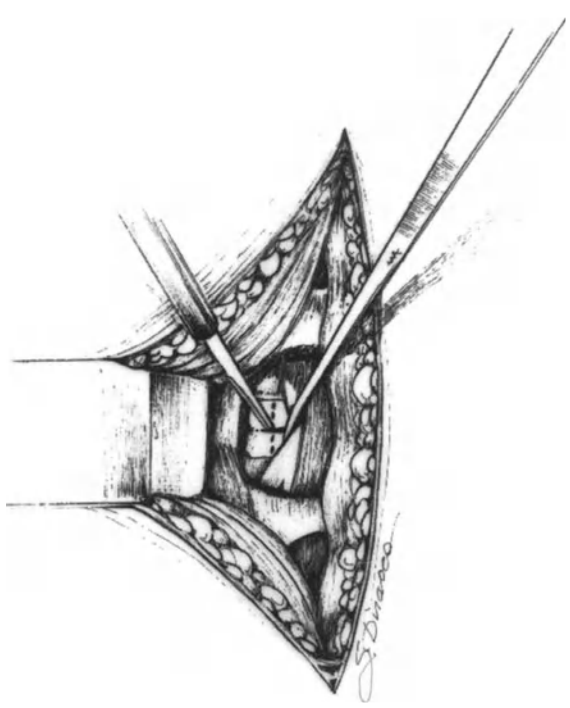


Fig. 16.21. *Retraction of the thecal sac and emerging nerve root, and incision in a cruciate fashion of the disc using a tenotome.*

Discectomy

Discectomy is started with a straight pituitary rongeur, generally of small cup size, which is inserted into the disc space, while displacing the thecal sac and the emerging nerve root medially. Retraction may be performed with a nerve-root retractor or a dissector. When the latter is used, as we often prefer, the sac should be retracted proximally to the emerging root or, at the most, where the root emerges, to avoid undue pressure on the latter. In fact, whilst the rootlets contained in the thecal sac are protected from direct pressure by the CSF, pressure on the nerve root in the extrathecal course is transmitted directly to the neural tissue.

Subsequently, a straight medium- or large-sized pituitary rongeur is inserted into the interspace and the disc contents are excised. The rongeur should be introduced closed into the interspace with the jaws closed and these are opened once inside the disc. Care should be taken not to insert the rongeur too deeply into the disc or exert any pressure on the anterior annulus fibrosus to avoid perforation of the disc.

The forwards curved pituitary rongeurs are then used: initially the less curved, and then the more angulated, rongeur. After excision of the central portion of the disc, the tissue located in the middle posterior portion of the disc space is removed, when necessary. This is not usually required in a typical posterolateral disc herniation. In the presence of a paramedian or midline herniation, on the other hand, this surgical step should be performed with extreme caution. To this end, the forwards curved rongeur is inserted as dorsally as possible, beneath the posterior longitudinal ligament. To verify that the herniated tissue has been completely removed, a Frazier probe is introduced between the thecal sac and the disc wall. Generally, the annulus fibrosus displays a mild or moderate posterior bulging and is very hard in consistency. In the presence of an extruded disc fragment or central disc herniation, the surgeon has the feeling of a marked bulging of the disc, which is also of lesser consistency than normal. In these instances, two maneuvers can be made: the probe is moved both in the transverse and craniocaudal direction, and it is thus usually possible, after one or more attempts, to mobilize and grasp the extruded fragment;

or the foot of the probe is pushed down to break the residual portion of the posterior annulus fibrosus and displace the herniated tissue towards the center of the disc, from where it can subsequently be removed (Fig. 16.22).

The backwards curved pituitary rongeur, which allows excision of the lateral portion of the disc, should be used only when preoperative investigations or surgical findings indicate, or lead to suspect, the presence of a contained or extruded intra- or extraforaminal herniation.

Once the disc has been emptied, to satisfy any possible doubts on the presence of migrated disc fragments, the probe is used to explore beneath the thecal sac and the emerging nerve root (Fig. 16.23). Similarly, if the radicular canal appears to be stenotic, the probe is inserted between the nerve root and the posterior wall of the canal to evaluate whether there is sufficient space available for the root (Fig. 16.24). If not, the posterior wall of the radicular canal is resected using the Kerrison rongeur until the root is adequately decompressed. In effect, it is often difficult to be certain that the nerve-root canal is, or not, significantly constricted. In the case of doubt, it is better to exceed in opening the canal than to leave the stenosis behind. However, unless strictly

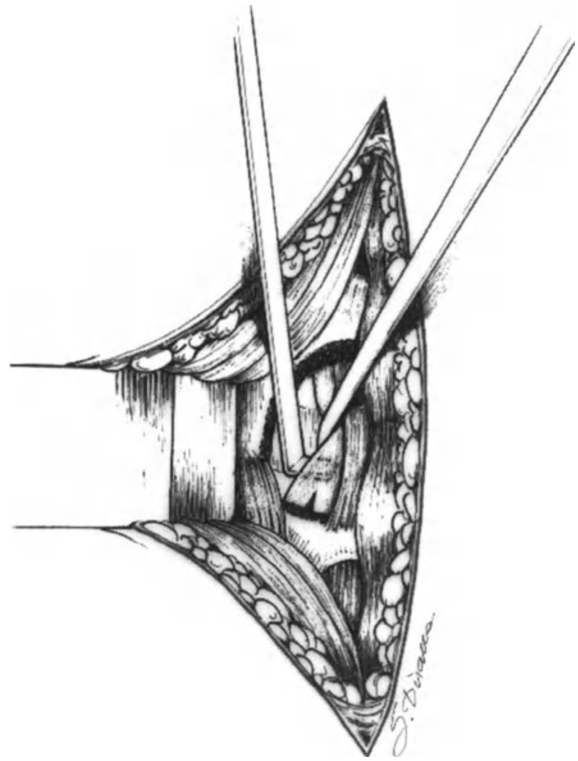


Fig. 16.23. *Frazer probe used to detect whether migrated disc fragments are present beneath the thecal sac and emerging nerve root.*

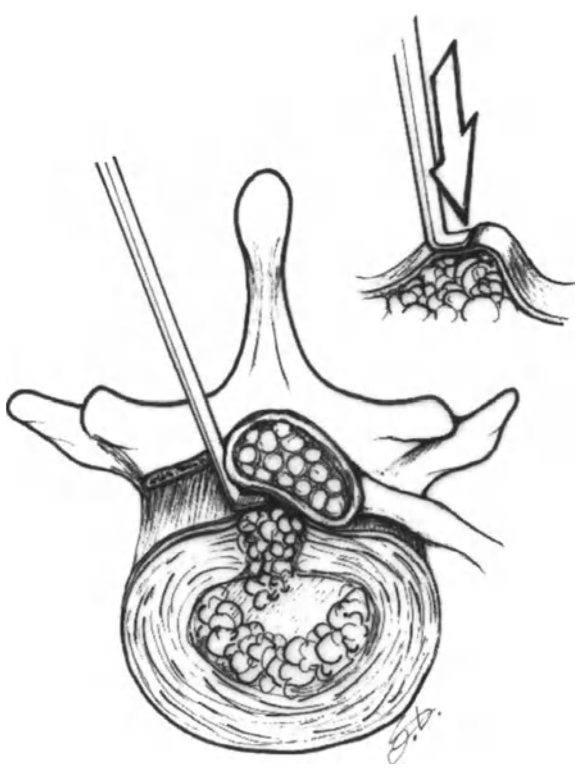


Fig. 16.22. *Frazier probe may be used to break the most medial portion of the annulus fibrosus. This allows the herniated tissue to be mobilized, pushed into the disc and then removed with the pituitary rongeur.*

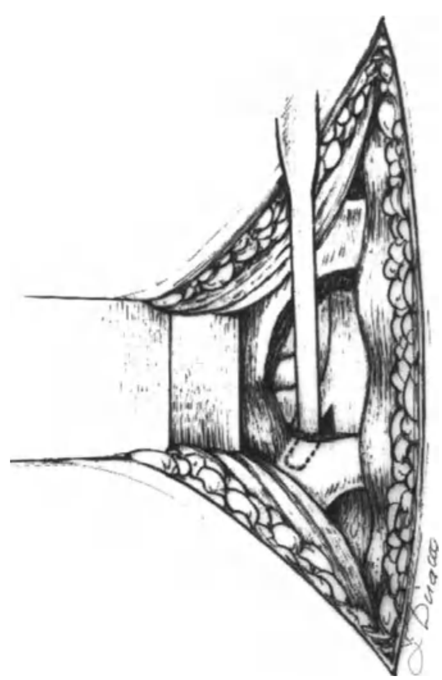


Fig. 16.24. *The Frazier probe, introduced into a narrow or stenotic radicular canal, may help to determine whether there is enough space for the nerve root or whether the radicular canal should be opened.*

necessary, opening of the canal until a complete foraminectomy is performed should be avoided, since this decreases vertebral stability.

Radical or partial discectomy ?

Radical discectomy consists in the removal of all the contents of the disc, i.e., the nucleus pulposus and the inner portion of the annulus fibrosus, that can be reached with the pituitary rongeur, as well as the median posterior portion of the annulus fibrosus, which may be cut with a scalpel or ruptured by means of the Frazier probe. In addition, curettage of the cartilage end-plate may be carried out (21).

The aim of partial discectomy is to remove only that portion of the disc impinging on the emerging nerve root (35, 74). The procedure may be accomplished in one of two ways: only the extruded disc fragment, or the portion of the disc protruding beneath the annulus fibrosus, may be excised; or also a limited amount of the nucleus pulposus located in the central area of the disc space may be removed.

Radical discectomy has several drawbacks: it lengthens the operative time, it may compromize the stabilizing function of the disc and favor a decrease in disc height, and it appears to increase the severity of postoperative low back pain (6). Furthermore, radical disc excision increases the risks of infectious complications due to lengthening of the operative time and removal of the cartilage end-plates, which allows possible penetration of bacteria into the bone tissue. This may occur even when no curettage of the cartilage is carried out, since radical excision of disc contents easily produces interruptions in the cartilage layer. Radical discectomy, on the other hand, ensures a better guarantee of not leaving residual portions of disc tissue, which may be responsible for persistent compression of the neural structures. On the other hand, it is unknown whether there are fewer risks of recurrence of the herniation at medium or long term.

With partial discectomy, portions of the nucleus pulposus possibly impinging on the nerve structures may not be removed, particularly in the median or paramedian posterior zone of the disc. We have experience of many cases where only a tenacious search for possible extruded disc fragments allowed detection and removal of large pieces of disc tissue, generally situated in the midline. It is not yet clear, however, whether partial discectomy involves (66) or not (6) a higher risk of recurrence of herniation compared with radical disc excision.

A third type of discectomy, which may be referred to as complete, consists in excision of all tissue contained in the central and posterolateral portion of the disc, and removal of the middle posterior portion only when the latter bulges excessively or extruded disc fragments are found. Care should be taken, however, not to damage the cartilage end-plates. This procedure, which is intermediate between radical and partial discectomy, enables the drawbacks of the latter types of discectomy to be avoided and adequate disc excision to be accomplished.

In our opinion, radical discectomy should be avoided, since the potential drawbacks are more numerous than the advantages. Partial discectomy may be indicated in patients with a large extruded or migrated disc fragment and a small amount of nuclear tissue within the disc. In the other cases, complete discectomy should be preferred. This holds particularly for patients with midline disc protrusion and those with only slightly degenerated nucleus pulposus, who often show marked annular bulging. In these patients, only adequate excision of disc contents gives the surgeon the certainty of complete removal of the tissue which may impinge on the neural structures.

Migrated herniation

The disc of origin of the migrated fragment is usually the closest to the fragment itself, and this disc should be exposed before searching for the migrated tissue.

In the presence of a migrated disc fragment of large size, the disc of origin may be evacuated, or only the migrated fragment may be removed, with the advantage, in the latter instance, of decreasing the operative time and preserving, to a larger extent, vertebral stability. In our opinion, discectomy should always be carried out, for several reasons. The disc often presents slight or moderate posterior bulging or protrusion, which may be responsible for persistent compression of the neural structures (Fig. 16.25). Evacuation of the disc often helps to identify and remove the migrated fragment, if this is located in proximity to the disc. Occasionally, in addition to the migrated fragment, extruded disc fragments are present, which may be excised only by discectomy. One often suspects the presence of a migrated fragment, but has no certainty preoperatively; discectomy may eliminate the suspicion, or provide the certainty, that a migrated fragment is present when the disc contents are negligible. In these cases, however, discectomy may even be partial.

The search for migrated fragments which do not appear evident at first inspection, and of which the exact site is unknown preoperatively, should be made sistematically. The first sites to be explored are those where a migrated fragment is more often located, i.e., the spinal canal beneath the emerging nerve root and the central portion of the canal distally to the disc. Subsequently, the nerve root axilla and the area behind

Fig. 16.25. (A) *and* (B) *Spin-echo T1-weighted axial and sagittal MR images showing a large disc fragment migrated proximally to the L4-L5 disc (arrowheads).* (C) *Postoperative radiograph showing the proximal enlargement of laminotomy (arrows), which was necessary to remove the large migrated fragment.*

the cranial vertebral body are explored. To do this, laminotomy should be extended proximally and distally until we are sure, based on the preoperative investigations, that the spinal canal has been explored for an adequate extension (Fig. 16.25). The exploration is carried out with the help of the dissector and the Frazier probe.

The most difficult site to explore is the nerve-root axilla. To explore this area, first the nerve root and then the tissue separating it from the thecal sac are identified. In normal conditions, this tissue consists of epidural fat. In the presence of a migrated disc fragment, it is usually impossible to clearly identify the anatomic limits of the root and the thecal sac, and the nerve-root axilla appears to be occupied by a tissue of fibrous consistency and white in color. To verify the presence of a migrated fragment, attempts are made to dissect the thin fibrous sheath which usually envelops the migrated tissue, until it is ruptured. At this point, disc tissue is seen to emerge, which may be freed from the surrounding adhesions and excised. Occasionally, the migrated fragment is in continuity with the disc of origin and cannot be removed by grasping and pulling the portion situated in the nerve-root axilla. In these cases, attempts are made to dissect the tissue connecting the fragment to the disc with the use of the probe. If this is not possible, the annulus fibrosus is sectioned in close proximity to the vertebral end-plate and pushed down with the probe until it breaks.

The second most difficult site to explore is that behind the median posterior portion of the cranial vertebral body. For exploration of this area, after removal of at least one half of the proximal lamina, the sac is retracted as proximally as possible, while the probe is moved beneath the sac to palpate and attract any disc fragments possibly present. If necessary, prior to this maneuver, the fibrous wall of any possible bulges that may appear as migrated disc tissue are ruptured, using the tip of the dissector. At the level of the vertebral body, the posterior longitudinal ligament may give the false sensation of disc material. However, a tissue fragment migrated in this site, is almost consistently of large size and it is rarely mistaken with the fibrous bundles of the posterior longitudinal ligament.

Migrated fragments in other sites are generally easily excised. This holds particularly for fragments located ventrally or laterally to the nerve root.

Whatever the location, before grasping and removing the fragment, it is wise to expose it as extensively as possible and grasp a large portion of tissue. In this instance, the fragment may often be excised intact or almost; if not, it should often be removed piecemeal, with the risk of leaving some portions behind.

Intraforaminal and extraforaminal herniations

These herniations may be excised through the usual interlaminar approach or through approaches leading to the outer aspect of the intervertebral foramen without passing through the vertebral canal. Para-articular, paraspinal and lateral extravertebral approaches have been described.

Interlaminar approach

The spinal canal is generally entered at the level of the disc of origin of the migrated fragment. When the disc tissue has migrated very cranially, there may be some doubt concerning the disc of origin. Almost always, however, the fragment originates from the disc below, when it is located, entirely or to a large extent, caudally to the pedicle of the proximal vertebra. The fragment should, thus, be removed through a laminotomy exposing the underlying disc. Alternatively, one may start from the intervertebral level above and resect the whole distal lamina until the nerve root running in the foramen is visualized. This procedure should generally be avoided, for several reasons: to visualize the area of the foramen caudally to the nerve root contained therein, subtotal or total arthrectomy should be carried out; if the disc of origin is that below the disc initially exposed, opening of the spinal canal should be prolonged downwards to evacuate the latter disc; an extensive access to the spinal canal causes profuse epidural bleeding, which may make detection of a small migrated fragment exceedingly difficult. To identify the disc of origin of the migrated fragment, it may be useful to analyze, particularly on MRI scans, the characteristics of the suspected discs and the distance between the fragment and the adjacent interspaces: a disc which is the site of herniation is usually degenerated and shows posterior bulging of the annulus fibrosus on the midline and/or posterolaterally; a migrated fragment originates almost always from the closest disc.

Laminoarthrectomy is performed in the usual manner. After exposure of the involved disc, discectomy is carried out. Disc excision may be avoided in those rare cases in which the disc shows no posterior prominence and is hard in consistency. However, not to excise the disc when it protrudes, even slightly, may expose to the risk of recurrence of herniation posterolaterally or of persistence of radicular symptoms. Once the disc has been evacuated in the central and posterior area, the nuclear tissue still present in the lateral portion is removed using a backwards angled pituitary rongeur or a forwards angled rongeur handled in the opposite direction to the usual.

Contained or extruded disc herniation. If disc herniation is contained or extruded, a discrete or abundant amount of disc tissue can usually be excised piecemeal or a large fragment of disc may be grasped and removed from the most lateral portion of the interspace. This may provide the certainty that herniation is contained or extruded. If this was coincident with the preoperative diagnosis, there is no need to search for free disc fragments in the upper part of the neuroforamen, but the lateral portion of the disc is completely evacuated. To do this, it may be necessary to enlarge arthrectomy laterally, in front of the disc, until little more than one half of the articular processes is resected. Furthermore, a Frazier probe may be introduced ventrally to the articular processes to push down the lateral non-visible portion of the disc, and then the pituitary rongeur be used to remove the disc tissue displaced towards the center of the disc space. This maneuver is repeated several times, using first the short-foot, and then, the long-foot, probe. The risk, in using the long-foot instrument, is to damage the nerve root running in the foramen; this, however, does not occur if care is taken to mantain the foot of the probe in close contact with the disc surface.

Not only intraforaminal, but also extraforaminal disc herniations may be removed through the interlaminar access, since a forwards angled pituitary rongeur, used in the opposite direction to the usual, may reach the outermost part of the disc (Fig. 16.26). Removal of an extraforaminal herniated disc, which is generally contained or extruded, does not require total arthrectomy.

Migrated herniation. If preoperative investigations demonstrate, or lead to suspect the presence of, a

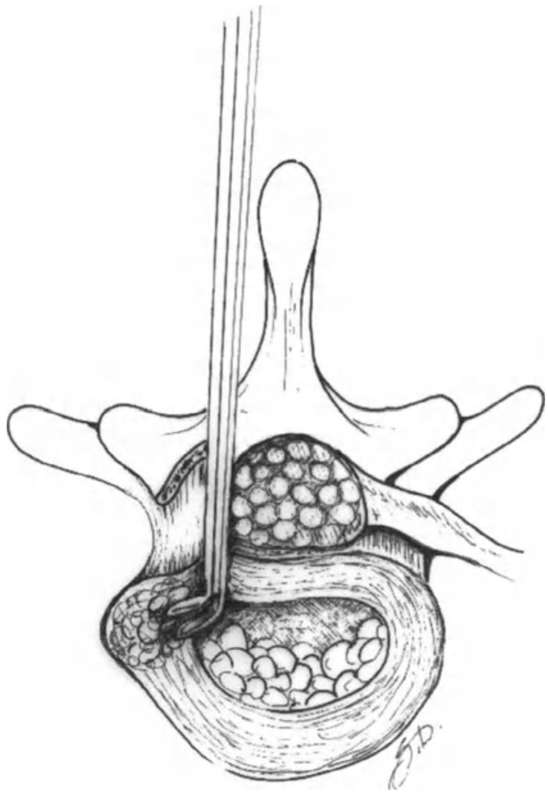


Fig. 16.26. *Using a backwards angled pituitary rongeur, it is possible to excise also an extraforaminal herniation through an interlaminar approach.*

migrated disc fragment, laminoarthrectomy should be extended proximally, since the fragment is consistently located in the cranial part of the neuroforamen. Some two thirds of the proximal lamina and the medial two thirds of the inferior articular process usually need to be resected. Care is taken not to interrupt the pars interarticularis, since this may jeopardize the stability of the motion segment. However, the pars interarticularis is often interrupted in the attempt to expose the inferolateral portion of the vertebral body, where the migrated disc fragment is usually located, or to visualize the nerve root running in the neuroforamen. This occurs due to the difficulty in detecting a small disc fragment, or the root itself, with the naked eye in a narrow and poorly illuminated space. Detection of a large fragment, extending in part into the spinal canal, is easier, since it can be seen proximally to the disc after excision of the uppermost portion of the ligamentum flavum.

Once identified, the migrated disc fragment is grasped with a pituitary rongeur and removed. A single fragment is usually found, but occasionally multiple fragments close to each other are present. If the first fragment removed is large in size, a quick search for other possible fragments in the area is sufficient. If the first excised fragment is smaller than expected, other fragments should be sought laterally and / or proximally to the first.

The nerve root running in the upper part of the neuroforamen does not consistently need to be exposed, particularly when the excised disc fragment or fragments are very large. When, contrary to expectations, the fragment is very small and no other fragments are found in the foramen, the nerve root should be exposed, at least in the portion situated inferomedially to the pedicle, to ascertain that there are no additional fragments or that the root is not compressed by an extruded fragment located at the level of the lower endplate of the cranial vertebra and not removed at initial discectomy. It is often difficult, with the naked eye, to identify the nerve root surrounded by the epidural fat and covered by the ligamentum flavum, particularly when a limited arthrectomy is performed. The nerve root appears as a roundish, scarcely mobile structure, which can be differentiated from the surrounding tissues due to its mother of pearl color.

Excision of a disc fragment migrated in the neuroforamen may be a very demanding procedure with the naked eye, especially if the fragment is small or if one is not certain preoperatively whether herniation is extruded or migrated. This holds, in particular, when attempts are made to extensively preserve the articular processes. When a migrated fragment is strongly suspected, which however is not found, total arthrectomy and extensive exposure of the nerve root may be indicated, rather than run the risk of leaving behind the herniated fragment. When total arthrectomy is performed, spinal fusion may be indicated if the motion segment is, or risks becoming, unstable.

Extravertebral approaches

All three extravertebral approaches may be carried out with the naked eye, provided the approach is extensive enough to allow adequate illumination of the deep surgical field. Even with an extensive approach, however, it may be difficult to identify the anatomic structures in the intervertebral foramen and handle the nerve root without trauma in order to visualize and excise the herniated disc. Thus, in performing an extravertebral approach, it is preferable to use the operating microscope or at least a frontal source of light. These approaches are analyzed in detail in the description of the microsurgical technique.

Control of bleeding

Before starting laminotomy, all subcutaneous, fascial and muscular vessels should be cauterized, preferably with bipolar cautery. To dry the surgical field, the surgeon's assistant should use, alternately, the sucker and middle-size swabs until the vertebral canal is opened and, subsequently, a small caliber sucker and cottonoids of varying size.

The amount of bleeding from the epidural vessels is related to the vertebral level explored. At the upper vertebral levels, bleeding is generally more abundant than at the two lower levels. When the profuse bleeding hinders surgical maneuvers, blood pressure should possibly be lowered. The intravenous use of coagulants does not reduce bleeding, when the patient has no coagulation defects.

In the presence of profuse epidural bleeding, the surgeon should establish whether it is due to individual vessels that should be identified and coagulated. If not, fragments of hemostatic sponge may be packed into the bleeding area. This should mostly be carried out for the vessels located beneath the articular processes or behind the proximal vertebral body. When bleeding is diffuse, use of the sucker should be limited and cottonoids should be employed, particularly when incising the disc, which should be clearly visible in this surgical step.

At the end of the operation, epidural bleeding should be negligible or absent. If this is not the case, attempts may be made to cauterize the larger vessels; usually, it is easier to identify and coagulate the epidural vessels when herniation has been excised and the spinal canal adequately opened than in the previous stages. The alternative is to leave one or more cottonoids pressed against the anterior wall of the spinal canal for a few minutes, until bleeding decreases or stops.

The pieces of hemostatic sponge previously used may be left in situ when located at a distance from the neural structures. Large pieces which impinge on the nerve structures, or may compress these if they displace postoperatively, should instead be removed.

If bleeding is still fairly profuse at the time of starting the suture, a medium-size drain should be applied. If in doubt, it is better to apply the drain, since a postoperative epidural hematoma may cause neurologic complications.

Morphine and epidural steroids

The central nervous system is known to have receptors for opiates and epidural instillation of morphine to have powerful analgesic effects (88). Morphine may be instilled, at the end of the operation, on the epidural tissue in the area of laminectomy, or 2–3 cm proximally to the latter through an epidural catheter. The dose of morphine is 3–5 mg (62, 68). Greater doses may produce respiratory depression and itching. In a series of 500 patients treated with 2–4 mg of morphine, none showed evidence of respiratory depression (59). In the event this should occur, administration of naloxone easily resolves the symptoms. The association of epinephrine does not significantly increase the analgesic effects of the opiate, whilst tends to increase the frequency of urinary retention (62). The effect of morphine lasts 12–20 hours, during which there is usually no need for systemic administration of analgesics. However, once the effect of the opiate has worn off, the dose of consumed analgesics is greater than normal. This observation, and the higher frequency of urinary retention after epidural morphine, do not justify the routine epidural instillation of the opiate after surgery for a simple disc herniation.

Methylprednisolone acetate may be instilled on the exposed root or roots at doses of 40–80 mg. The aim is to decrease the radicular inflammation present prior to the operation or induced by the latter, thereby avoiding, or decreasing the need of, systemic administration of steroids or analgesics in the immediate postoperative period (15, 34). Local use of slowly resorbing steroids may be indicated in patients with pathologic conditions (hypertension, digestive ulcer) which make the systemic use of steroids or analgesics contraindicated.

Fat graft

The problem of decreasing or avoiding peridural fibrosis resulting from opening of the spinal canal – so-called laminectomy membrane – remains to be resolved, in spite of the numerous experimental and clinical studies carried out in the last two decades. Non-biological and biological materials have been used.

Of the non-biological materials (27, 39, 43, 45, 46), only Gelfoam (gelatin sponge) has been employed in man. However, after the early experimental studies, which appeared to prove the efficacy of this material (43), it has been demonstrated that Gelfoam is unable to isolate the dura mater from the surrounding scar tissue (27, 33, 89).

Of the biological materials (27, 39, 42, 45, 48, 89, 90), only fat has been widely employed in clinical practice. Free or pedicle fat graft may be used. The free graft is obtained from the subcutaneous tissue of the surgical wound and placed on the exposed dura mater of the thecal sac and nerve root. The pedicle fat graft, which would have better chances of survival, has been used in animals (27), but it is not currently employed in man due to the technical difficulties implied. On the other hand, it has been shown that a free fat graft usually survives over the time, provided it is not less than 5 mm thick (80).

Peridural scar tissue originates from the deep surface of the paraspinal muscles and, to a lesser extent, from the hematoma invading the spinal canal (43); following discectomy, also the annulus fibrosus contributes to the formation of scar tissue (36). Postoperative CT scans in patients with a free fat graft (80) have shown that the graft forms a barrier between the deep surface of the paraspinal muscles and the thecal sac, thus preventing contact between the scar tissue originating from the muscles and the dural wall. However, the graft does not hinder the formation of scar tissue from the deep hematoma and development of a fibrous membrane anterolaterally to the emerging nerve root.

Fat graft, therefore, undoubtedly makes repeat surgery easier, but there is no evidence that it improves the results of surgery as far as concerns the radicular symptoms. No prospective study, in fact, has compared the results of surgery in patients with or without a fat graft. It should be borne in mind, on the other hand, that in a thin person the withdrawl of fat may create an empty space subcutaneously, which favors the formation of serosity in the immediate postoperative period and may hinder healing of the skin wound; this holds, in particular, when access to the spinal canal has been extensive. We believe, therefore, that the indication for the use of a fat graft is still uncertain and that grafting should be avoided in the thin patients undergoing extensive opening of the vertebral canal.

Drain

It is not usually necessary to apply a drain. This is useful when there has been profuse bleeding in the deep surgical field, which continues, even moderately, at the time of wound closure. A drain should always be applied when bilateral laminectomy has been performed. It may be removed after 18–24 hours.

Closure

The thoracolumbar fascia is closed with slowly dissolvable thread. A continuous suture should be preferred, since it is more resistant and closes the fascial layer more tightly, thus hindering diffusion of a possible superficial infection to the subfascial region. When bilateral laminectomy has been performed, prior to fascial closure, the paraspinal muscles on the two sides should be sutured using a large-sized needle to grasp a thick layer of muscle.

The subcutaneous tissue may be anchored to the fascia with 2 or 3 stitches, to avoid an empty space between the two structures, which would favor the accumulation of serosity in the immediate postoperative period. The skin is closed with discontinuous stitches or 4–0 quickly dissolvable subcuticular suture.

Postoperative care

The patient remains in bed, free to assume any position, for 24–48 hours after surgery; if a drain has been applied, this is removed the day after the operation. The patient is then encouraged to get up and walk. This is advisable soon after surgery as muscle activation decreases postoperative pain and the risks of deep venous thrombosis in the lower limbs. On the first day, the patient is invited to get out of bed 2–4 times, for a few minutes each time, with or without the use of a walker. The day after, the number of times the patient gets up is increased to a maximum of 6–8. The patient is usually discharged on the third or fourth postoperative day. However, patients complaining of only a slight low back pain may even be discharged on the second postoperative day.

The use of steroids, at high doses (8 mg betamethasone) on the first day after surgery and at medium doses (3–4 mg) on the following 2 or 3 days, considerably decreases postoperative radicular pain. Subsequently, cortisone may be withdrawn, or continued at low doses for a few days in patients complaining of moderate or severe radicular pain following surgery.

At home, the patient walks 8–10 times a day for 10 to 30 minutes each time until the eight–tenth postoperative day and thereafter at his/her discretion. An excessive physical activity in this period is discouraged, since it may favor the formation of subcutaneous serosity and delay healing of the skin incision.

Once the skin wound has healed, the patient starts the exercise program.

Postoperative immobilization

In the past, it was routine practice to carry out some form of immobilization of the lumbar spine in the first few months after surgery. Until the early 70's, many surgeons applied a body jacket cast for 1 or 2 months, or a corset for one or more months. In the last decade, only a few have advocated postoperative immobilization, using a flexible, or less often, rigid, orthosis (38).

So far, the efficacy of the various forms of postoperative immobilization compared with no immobilization has not been investigated. Even rigid orthoses, however, are known not to decrease mobility of the lower lumbar spine. Furthermore, comparative analysis of patients carrying out an exercise program and patients undergoing no speficic treatment has shown that those in the former group more rapidly recover functional ability of the spine (58). These observations suggest that postoperative immobilization has no proven usefulness, whilst an exercise program favors recovery of normal spine mobility and decreases the severity of postoperative low back pain (49). In addition, early mobilization of the decompressed nerve root might contribute to limit the development of periradicular fibrous adhesions (9, 54).

Only patients with vertebral instability, in particular of L4 or upper vertebrae, may benefit from the use of a rigid corset. The latter or a flexible orthosis, however, are indicated or needed when spine fusion, with or without internal fixation, has been performed.

Microdiscectomy

Rationale of microscope

The main drawback of discectomy with the naked eye is the lack of an adequate illumination of the deep surgical field. The degree of lighting is certainly related to the extent of exposure of the spine; however, even an extensive exposure may not ensure adequate illumination of the spinal canal. This is due not only to the fact that the surgeons' head and hands obstruct penetration of the light beam into the depth of the surgical field, but also to widening of the light beam and the resulting dispersion of the latter when the source is far from the field to be illuminated. Thus, the surgeon is occasionally forced to operate without adequately seeing the anatomic structures. The risk may therefore be run of not clearly identifying the pathology or feeling the need to enlarge laminotomy and arthrectomy more than necessary.

The operative microscope, by providing a vertical light beam which is not obstructed by the head or hands of surgeons, ensures excellent lighting, regardless of the extent of surgical exposure and the depth of the anatomic structures. Furthermore, by slanting the objective, any part of the operative field can be perfectly illuminated. Another important advantage is to have a magnified view, allowing anatomic structures which are not visible, or poorly visible, with the naked eye, to be clearly seen. Thus, surgical maneuvers may be performed with greater precision, the causes of compression of the neural structures may be more easily identified and fewer risks are run of causing undue trauma to the emerging nerve root or thecal sac. Moreover, the use of the microscope allows both the surgical approach to skin, fascia and muscles, and the extent of laminoarthrectomy to be limited. Only occasionally, in fact, is an excessively large portion of the articular processes resected or a complete facetectomy inadvertently performed when using the microscope, as instead not infrequently occurs when operating with the naked eye.

No univocal data exist regarding better clinical results following microdiscectomy compared with those following conventional discectomy. However, there is no doubt that a more limited cutaneous, fascial and muscular access involves fewer risks of complications in the healing of the skin incision and less local pain in the early postoperative period (5, 11, 47, 51). Furthermore, limited arthrectomy, preserving better vertebral stability, tends to decrease the severity of low back pain, at least in the first few postoperative weeks. As a result, the patients undergoing microdiscectomy are able to more rapidly resume their everyday activities.

These advantages, although important, are not such as to make the use of the microscope indispensable. However, it does make the surgeon's work much easier and may, to a certain extent, improve the quality of the result. These considerations may explain why microdiscectomy has become a more and more popular technique (5, 7, 11, 17, 29, 50, 51, 57, 64, 70–72, 75, 77, 84, 85).

Misconcepts on microdiscectomy

Many surgeons still believe that microdiscectomy necessarily involves only excision of the ligamentum flavum or extremely limited laminoarthrectomy, and partial discectomy. In effect, either partial disc excision may be carried out, which in most cases is not advisable, or any other method of discectomy; that is, laminoarthrectomy of any extension and even radical discectomy may be carried out with the microscope.

Another misconcept refers to the possible difficulty in removing a very large herniation or disc fragments migrated at a distance from the interspace. In actual fact, disc herniation of any dimensions may be excised with the microscope. Removal of a migrated fragment is not only possible, whatever the distance of the fragment from the interspace, but is actually easier than with the naked eye. By moving the microscope or inclining the objective, migrated disc fragments, that are hardly identifiable with the naked eye, can easily be detected.

A third misconcept refers to the operative time, which is thought to be longer when using the microscope. This is true, but only until the surgeon has become sufficiently familiar with the use of the instrument. With experience, the average operative time initially equals, and then may be even less than, that of conventional discectomy.

However, the belief that less scar tissue develops in the spinal canal with microdiscectomy is also erroneous. This would occur on account of the better control of epidural bleeding and the less traumatic surgical maneuvers (75, 77, 85). In effect, the amount of scar tissue which forms after microdiscectomy is generally comparable to that following conventional discectomy. The advantage of microdiscectomy is that the limited surgical approach leaves the adjacent vertebral levels intact, thereby making their exposure easier, should the need for repeat surgery arise.

Learning curve

The operation performed with the microscope is basically similar to that carried out with the naked eye. Nevertheless, a period of learning is needed even for those surgeons with a long experience with conventional discectomy, for several reasons: 1) The short skin incision usually performed for microdiscectomy makes the surgical maneuvers more difficult for those surgeons who are accustomed to operating on larger spaces (Fig. 16.27). For these reasons, the surgeon who is not familiar with the use of the microscope may find it extremely difficult to carry out the operation and may require twice the time compared with that of conventional discectomy. 2) Vertebral structures, magnified and illuminated perpendicularly, assume a different appearance to that they are used to seeing with the naked eye (Figs. 16.28 and 16.29). 3) The visual field of the eye is wider than that of the objective lens and, on the other hand, the greater the magnification, the more the reduced visual field; with the microscope, therefore, some sectors of the surgical field remain outside the visual field and this may create difficulty in spatial orientation for the surgeon. 4) With the microscope, one of the three spatial dimensions, namely depth, is less than with the naked eye. The surgeon has, thus, to become accustomed to operating in a more bidimensional visual field. However, with the more modern microscopes, providing a stereoscopic vision, this drawback is, to a large extent, overcome. 5) Magnification necessarily implies more limited and delicate movements, and the need to get accustomed to getting, with the instruments, into a visual field of small dimensions.

Both the initial difficulties and the operative time rapidly decrease after about the tenth operation. Generally, 50 operations are needed to reach a satisfactory manuality and surgical rapidity. However, greater experience is needed to carry out difficult operations (obese patients, profuse bleeding, herniation migrated at a considerable distance from the interspace) smoothly or a standard operation in a time similar to, or less than, that of conventional discectomy. Excision of recurrent disc herniations or particular procedures, such as removal of a lateral disc herniation through an extravertebral approach, may be carried out with the microscope only once a long microsurgical exprerience has been acquired.

Fig. 16.27. *Microdiscectomy. The short skin incision which is usually performed for microdiscectomy may make surgical maneuvers difficult for a surgeon not experienced in the use of the operating microscope.*

A period of training, even short, is also necessary for the surgeon's assistant, who is usually able to adequately perform his task after 5–10 operations.

"Apprenticeship"

There are two ways to become familiar with the use of the microscope.

One possibility is that the trainee (already experienced in conventional discectomy) is taught by a surgeon experienced in microdiscectomy. Subsequently, he/she will operates, with the help of the experienced surgeon, who corrects any mistakes and, if necessary,

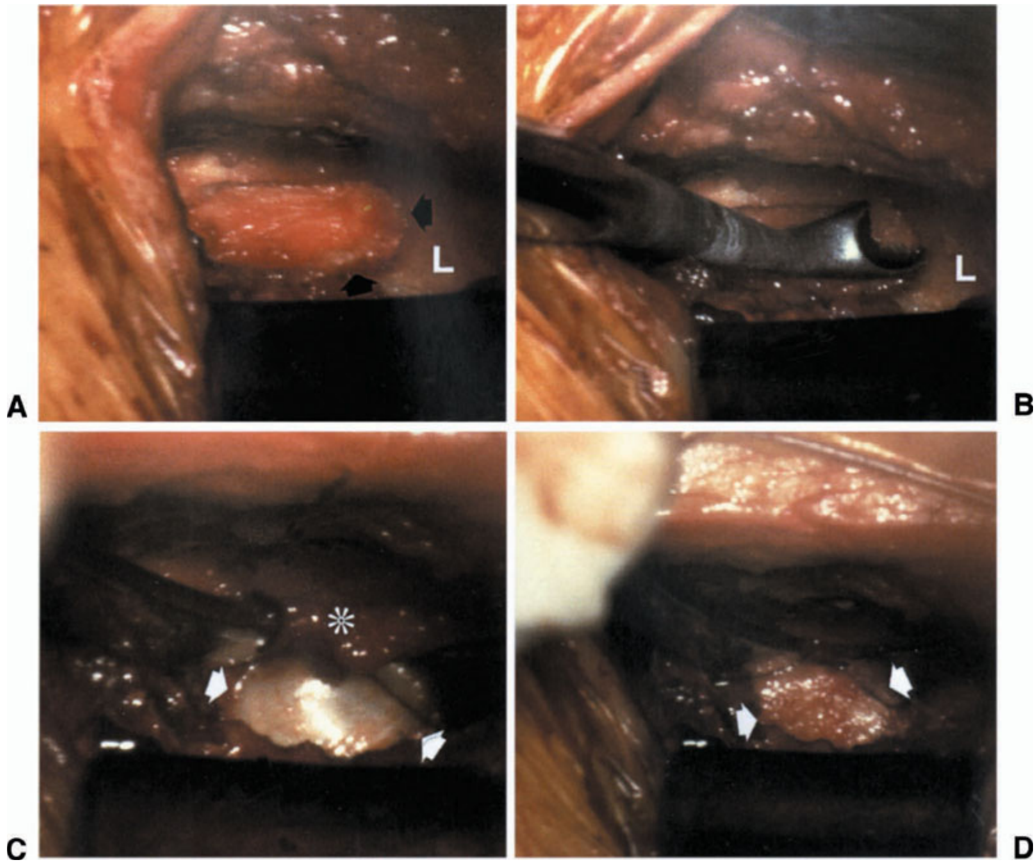


Fig. 16.28. *Microsurgical view of various stages of discectomy.* (A) *Exposure of the interlaminar space. The arrow indicates the ligamentum flavum.* (B) *Detachment of the ligamentum flavum from the proximal lamina* (L). (C) *Retraction of the emerging nerve root (asterisk) and exposure of the herniated disc (arrows).* (D) *Extrusion of disc tissue (arrows) following disc incision.*

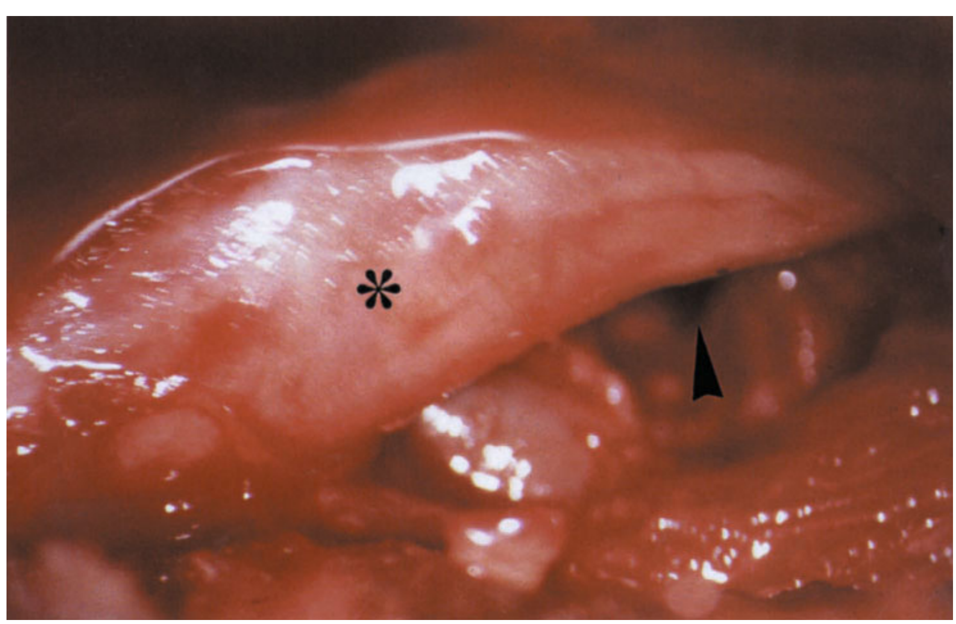


Fig. 16.29. *High magnification microsurgical view of the emerging nerve root (asterisk) following completion of discectomy. The arrowhead indicates the emptied disc space.*

replaces him/her in any stage of the operation. After some five operations, the trainee is generally able to operate on straight forwards cases.

Another possibility is that the trainee uses the microscope in a few stages of a conventional discectomy. For example, he/she may start laminotomy with the aid of the microscope and then continue with the naked eye. When an adequate manuality has been acquired, other surgical steps are carried out with the microscope, until the latter is used throughout the entire operation. This is usually possible after 10–15 operations. This gradual experience decreases the risk of complications and keeps the operative time within acceptable limits.

Mistakes to avoid. 1) Use of an inadequate microscope. In particular, objective lens with a focal distance of less than 300 mm should be avoided in order not to make the surgical maneuvers difficult or impossible, due to the narrowness of the space between the objective and the surgical field. 2) Using the microscope, even for a very short time, without adequate sterile protection. 3) To continue the operation with the microscope if, due to inexperience, great difficulties are encountered in carrying out the discectomy or the anatomic structures are not adequately recognized.

Indications

Microdiscectomy is indicated in all those patients with a single level herniated disc, regardless of the type of herniation. The use of the microscope is also indicated in recurrent disc herniations, provided the surgeon has adequate experience in microsurgery. If not, surgery should be performed with the naked eye or the microscope should be used only during disc excision. The presence of nerve-root canal stenosis in association with a herniated disc at the same level does not affect the indications for use of the microscope (57). In patients with only stenosis of the nerve-root canal, use of the microscope has less elective indications than in the presence of a herniated disc. In these patients, in fact, extensive laminoarthrectomy should be carried out, whilst exhaustive exploration of the disc or search for migrated disc fragments are not needed; the option thus depends, to a large extent, on the surgeon's habit. The same is true for two-level herniations, in which surgical exposure is necessarily extensive and, as such, allows good lighting of the surgical field. Also in these cases, however, the microscope enables the surgeon to operate with greater precision (57). It should also be borne in mind that as the surgeon becomes more familiar with the use of the microscope, so it becomes more and more difficult to do without the instrument.

Instrumentation

Operating microscope

The operating microcope consists of binocular lenses, a magnification chamber to allow for increasing or decreasing the size of the image, and an objective lens with a given focal distance. The latter is the distance between the lens and the object that is in focus. The focal distance affects the magnification of the image, the dimensions and depth of the visual field and the illumination of the object. As the focal distance increases, the magnification decreases, whilst the dimensions and depth of the visual field increase, and illumination decreases. The magnification obtained with the magnification chamber is generally 0.4 ×, 0.6 ×, 1.0 ×, 1.6 × and 2.5 ×. The actual magnification achieved, however, also depends on other parameters, such as the length of the binocular lenses and the focal distance.

For microdiscectomy, the focal distance of the objective lens should be 300 or 400 mm. Shorter distances do not leave adequate space between the objective and the anatomic structures, thereby making the operation difficult or impossible. We usually use a magnification factor of 0.6×. Higher magnifications may make the surgical maneuvers more difficult, since they excessively decrease the visual field and overmagnify the image.

It is mandatory that illumination and vision be coaxial. This provides excellent lighting also of a deep surgical field. The light is generated by halogen bulbs, resulting in little heating of the object.

The binocular lenses for the assistant may be placed obliquely to that of the surgeon or, in the modern microscopes, in front of the surgeon's binocular. With the latter microscopes, the assistant has a similar stereoscopic image to that of the surgeon.

Before use, the microscope should be covered with a sterile drap allowing manipulation of the instrument during surgery. The plastic drapes supplied by the manufacturer of the microscope are usually used.

Surgical instruments

These are basically the same as those used for conventional discectomy. For a single level herniation, we use a narrow Taylor self-retaining retractor (Fig. 16.30); alternatively, Williams, Mayerding or Caspar retractors may be employed. Most of the laminoarthrectomy may be performed using a high speed air drill, which avoids damage to the soft tissues. The Karrison rongeurs, like the osteotomes, should not have an excessively long shaft, since, otherwise, the hand in which the instrument is held hits against the

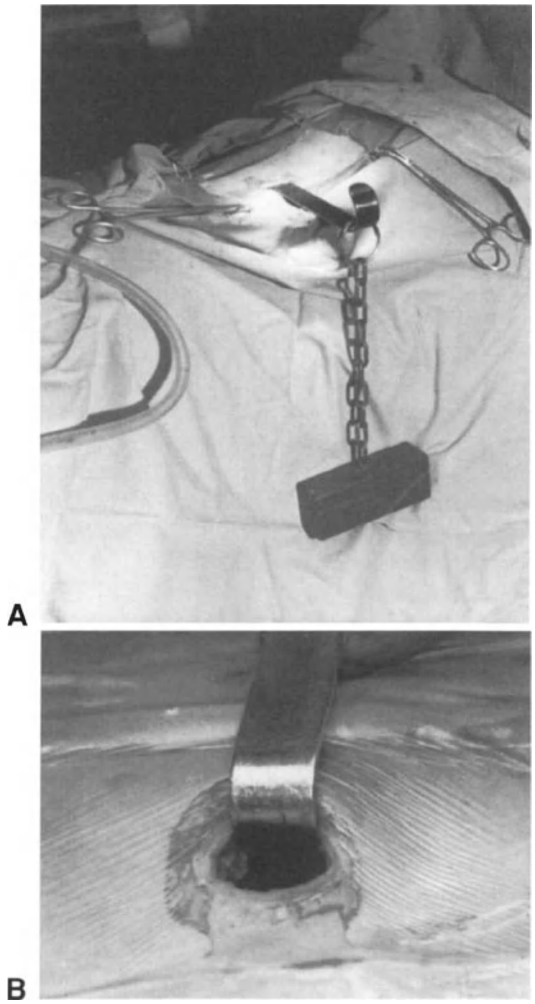


Fig. 16.30. *Microsurgical approach.* (A) *Use of a 1·3 cm wide Taylor retractor with a weight hung on the end.* (B) *Higher magnification view of the surgical incision and the retractor.*

objective of the microscope or obstructs the light beam; generally, rongeurs with a small or medium-sized bite are used. Preferably a bayonet, rather than straight, forceps is used. A dentist's mirror may be employed to see into sites that are not accessible to direct vision.

Surgical technique

Access to interlaminar space

The skin incision, 2–4 cm long, is placed at the level of the interspinous space. For a two-level disc exposure, the incision is 5–6 cm long. The dermal vessels are cauterized, preferably with the bipolar coagulator. The subcutaneous fat is sectioned using a scalpel or separated from the fascia with a periosteal elevator.

In the classic microsurgical technique (10, 11, 51, 83), the thoracolumbar fascia is sectioned in a semicircle, 1 cm from the midline (Fig. 16.31). The muscle fibers adhering to the resulting fascial flap are separated from the deep aspect of the latter and the flap is subsequently grasped with one or two sutures and turned outwards towards the side opposite to the surgeon. This technique would preserve the supraspinous and interspinous ligaments, thereby not affecting vertebral stability. In effect, there is no clinical or biomechanical evidence that sectioning the thoracolumbar fascia tangentially to the spinous processes damages the supraspinous ligament (absent at L5-S1, and often also L4-L5, levels) and the interspinous ligament, and decreases, even minimally, vertebral stability.

We prefer to section the thoracolumbar fascia with the cutting current diathermy in close proximity to the spinous processes (Fig. 16.32).

The paraspinal muscles are detached from the spinous processes and laminae with the periosteal elevator, cutting muscle insertions to the bone surface with the current diathermy or scissors. Muscle bleeding is arrested with swabs packed deep into the wound. Muscle detachment is continued laterally as far as the medial half of the facet joint is exposed.

The residual muscle tissue covering the ligamentum flavum and the adjacent portions of the laminae are removed with a medium-size curette, and the self-retaining retractor is placed in position.

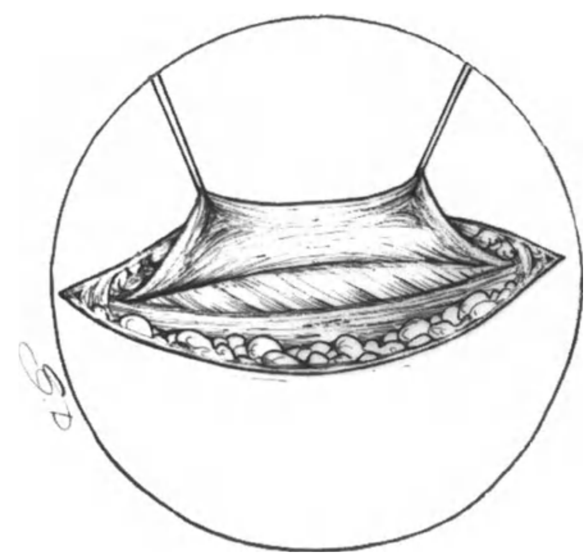


Fig. 16.31. *With the classic microsurgical technique, a half circle incision is made in the thoracolumbar fascia, approximately 1 cm off the midline, and the fascial flap is then turned back towards the opposite side.*

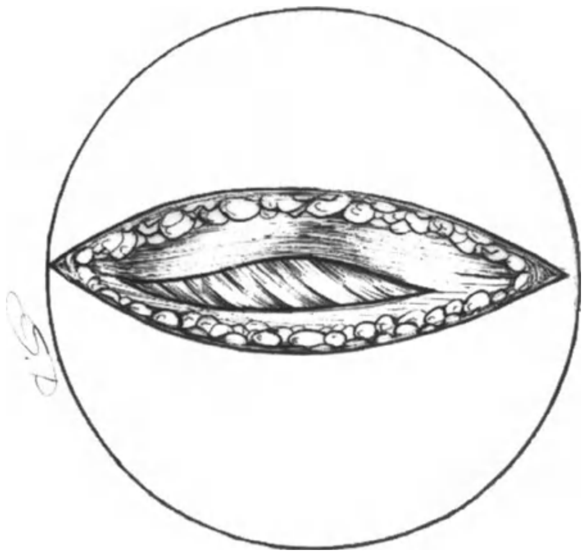


Fig. 16.32. *With the microsurgical technique preferred by the authors, the thoracolumbar fascia is sectioned in close proximity to the spinous processes.*

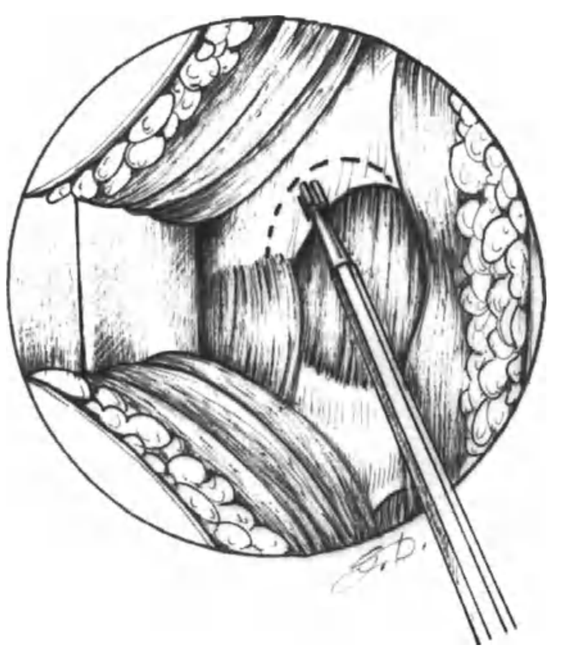


Fig. 16.33. *High speed air drill may be used to resect the distal end of the proximal lamina and the medial portion of the articular processes.*

Positioning of microscope

The operating microscope may be used from the beginning of the procedure (3) or, as we prefer, after placing the self-retaining retractor. The objective is positioned perpendicularly to the surgical wound or is inclined slightly lateromedially if, by doing so, the medial portion of the interlaminar space is better visible. The latter should be entirely contained within the visual field, which should also include one third of the two contiguous laminae. Otherwise, during surgery, the microscope must frequently be inclined, alternately in the cranial and caudal direction. This leads to a waste of time as well as difficulty in the surgical maneuvers, which are more hampered both for the surgeon and the assistant, when required to operate in an oblique position with respect to the anatomic structures.

The microscope should be handled as little as possible during surgery, since, although covered with a sterile drape, it is not sterile. The surgeons should wear two pairs of sterile gloves; the second pair should be put on after final positioning of the microscope.

Laminoarthrectomy

Some surgeons excise only the ligamentum flavum or perform a minimal laminoarthrectomy. In this case, the ligament is sectioned first longitudinally and then transversely (or viceversa) along the edge of the distal lamina. The sectioned flap is subsequently grasped and the ligament is excised using a scalpel or Kerrison rongeur. Such a limited access to the spinal canal represents a useless technical virtuosity. It exposes to three risks: excessive trauma to the neural structures when retracted medially to carry out discectomy; not to adequately excise the herniated disc or leave residual extruded or migrated disc fragments; not to sufficiently decompress the emerging nerve root in the presence of radicular canal stenosis. Laminoarthrectomy should be wide enough as to allow easy access to the disc as well as safe and complete decompression of the neural structures.

Most of the laminoarthrectomy may be performed with a high speed air drill (Fig. 16.33). This is generally used to remove the proximal lamina and the medial portion of the articular processes, particularly the inferior one.

The technique we prefer is similar to that described for conventional discectomy. The ligamentum flavum is detached from the proximal lamina using a small curette and 5–10 mm of the lamina are resected with Kerrison rongeurs. Very often, the innermost portion of the inferior articular process is also removed at this stage. When the interlaminar space is narrow and the inferior articular process is hypertrophic, the medial part of the process may be resected using an osteotome. Then, again using the curette, the ligamentum flavum is detached from the distal lamina, which is resected for 5–8 mm.

The ligamentum flavum is removed with the Kerrison rongeur or the basket cutter used for arthroscopic meniscectomy, or is sectioned longitudinally. In the latter case, in order to protect the nerve structures, the ligament is cut along the foot of the Frazier probe or a cottonoid is inserted deep into the ligament (55, 85). The choice of the method will depend, to a large extent, upon which is easier to perform in that particular case. For instance, when herniation is on the left, it is often easier to use the rongeur or the basket cutter than sectioning the ligament with the left hand, while the right hand raises it with the probe. The opposite occurs when herniation is on the right.

Arthrectomy is then performed by introducing the Kerrison rongeur between the residual lateral portion of the ligamentum flavum and the epidural tissue. Ligament excision using the rongeur is easy if the instrument has a well cutting bite. Conversely, the ligament should be torn to some extent, with the risk of causing dural tears.

Approximately the inner one fourth of the articular processes is initially resected. This usually allows visualization of the emerging nerve root and exposure of the disc. If the herniation can be easily excised, as often occurs at L5-S1 level, bone removal is stopped. Otherwise, laminoarthrectomy is extended as far as necessary. Very often, the initial laminoarthrectomy is wide enough to carry out discectomy with the straight pituitary rongeur, but not to use the forwards angled rongeur or to introduce the Frazier probe beneath the thecal sac. In these cases, the disc contents may first be partially evacuated with the pituitary rongeur and then arthrectomy enlarged until the forwards angled pituitary rongeur can be introduced into the interspace. Some one third of the articular processes should usually be resected. In the presence of a migrated disc fragment or nerve-root canal stenosis, laminoarthrectomy is enlarged until the migrated fragment is visualized or the emerging nerve root is adequately decompressed.

Undercutting, rather than vertical, arthrectomy may be carried out by removing only the deep portion of the articular processes using the angled Kerrison rongeurs. The advantage is to better preserve the facet joint and, thus, vertebral stability.

Discectomy

The interspace is exposed as in conventional discectomy. The disc is white-opaque and fibrous in consistency and is thus clearly distinguishable from the emerging nerve root (Fig. 16.34). If any doubts exist concerning the nature of the structure being exposed, the nerve root should be clearly visualized. An alternative method is to retract the neural structures at the level of the superoexternal corner of the laminoarthrectomy (Fig. 16.35). This site, which we term the "safe corner" of laminotomy, is usually proximal to the zone where the root emerges from the thecal sac; thus, the disc is unlikely to be mistaken for the root in this area (Fig. 16.35). The disc is often located more proximal than expected and, therefore, it is easier to find it in the upper than the lower portion of laminotomy. This occurs, in particular, when the portion of the proximal lamina excised is too small or the latter is more caudal than normal with respect to the vertebral body.

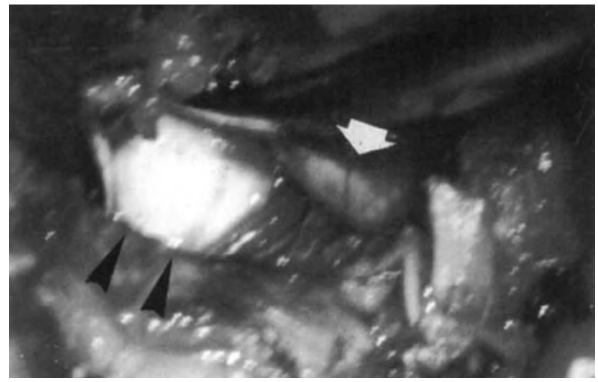


Fig. 16.34. *Microdiscectomy. Exposure of the herniated disc (arrowheads) and emerging nerve root (arrow).*

The surface of the disc is often covered by epidural fat or fibrous bands obstructing the vision of the interspace. It is useful, in this instance, to clean the disc surface with a cottonoid, pressed or slightly rubbed on the disc to remove the underlying tissue.

The disc is incised and evacuated as described for conventional discectomy.

Respect of anatomic structures

During excision of the herniated disc, great care should be taken to avoid traumas to the emerging nerve root, particularly in the presence of a severe preoperative neurologic deficit, which may increase following excessive manipulation of the root. The latter may be avoided as follows:

1) By exerting no excessive medial retraction of the nervous structures. One runs the risk of excessive retraction particularly when herniation is in the midline or one likes to visualize the middle portion of the disc. The risk is higher when using the microscope, as the visual field is narrower than with the naked eye. In order not to exceedingly retract the emerging nerve root, the objective may be inclined towards the midline and the Frazier probe used to palpate, rather than see, the middle portion of the disc. The probe may be employed as a rake to attract an extruded fragment or used to push down the middle part of the disc in order

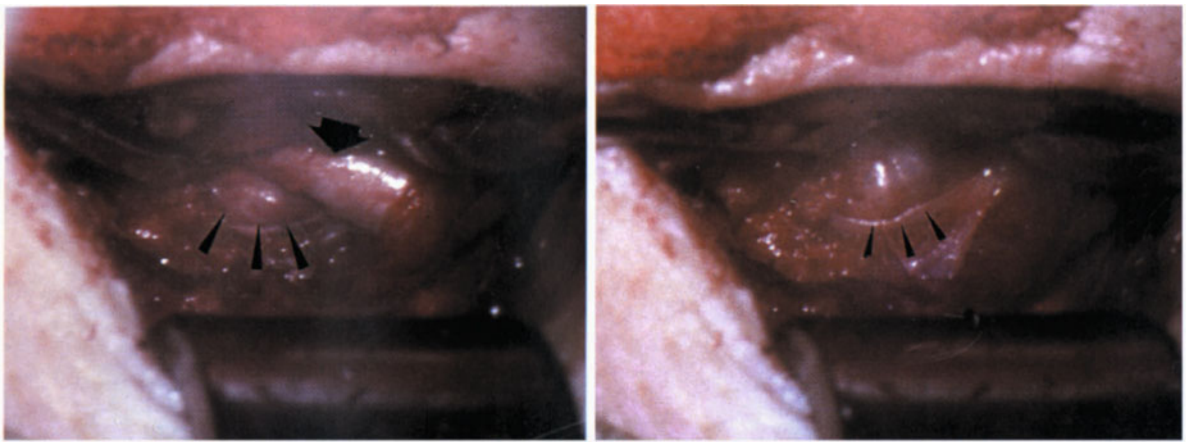
A  B

Fig. 16.35. *Microdiscectomy.* (A) *By retracting the nervous structures as proximally as possible, that is in the superoexternal corner of the laminotomy, it is more difficult to mistake the nerve root (arrow) for the disc (arrowheads).* (B) *Distal retraction of the emerging nerve root and exposure of the herniated disc (arrowheads).*

to displace the herniated tissue towards the center of the disc, where it can be easily grasped.

2) By retracting the thecal sac, rather than the emerging nerve root. This may be done by retracting the nerve structures at the level of the upper end of the laminotomy. This maneuver is easy, for a right-handed surgeon, when herniation is on the left. When the herniated disc is on the right, a very cranial retraction with the left hand may hinder disc excision with the right hand.

3) By retracting the emerging nerve root only when the pituitary rongeur is introduced into the interspace to grasp disc material. When the rongeur is extracted, pressure on the root should be reduced. A too prolonged root retraction with the dissector, produces a depression on the lateral aspect of the root and may cause intraradicular edema, possibly responsible for pain and/or dermatomal hypoesthesia in the first few days or weeks after surgery.

4) By using a root retractor rather than a dissector. The nerve-root retractor causes less trauma to the root. However, we usually prefer the dissector, since it is smaller and easier to handle.

Extent of discectomy

Partial discectomy proposed by Williams (82, 83) consists in the excision of only the extruded fragment of disc and the herniated portion of the nucleus pulposus. Using this method, however, Rogers (66) has observed 21% of recurrences of herniation in the first 6 months after surgery.

We prefer complete discectomy (page 438), which avoids the risk of leaving behind disc fragments responsible for persistent radicular symptoms or recurrence of herniation. This type of discectomy consists in the removal of all, or a large part of, the nucleus pulposus, particularly the part located ventrally to the posterior central zone of the annulus fibrosus.

Two maneuvers can be used to excise the posterior central portion of the disc. The former consists in applying pressure to the posterior annulus fibrosus using the foot of the Frazier probe and then removing the herniated tissue pushed into the central part of the disc. This maneuver can be done only when the annulus fibrosus, being degenerated, can be ruptured by means of mild

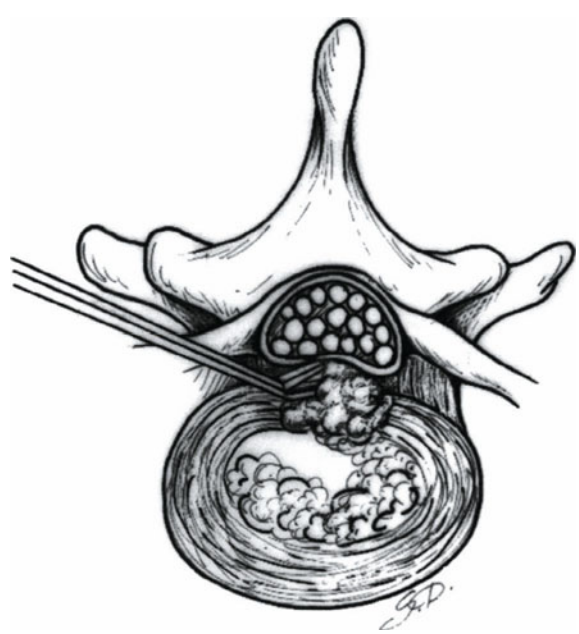


Fig. 16.36. *Microdiscectomy. The middle posterior portion of the disc may be excised by introducing a forwards angled pituitary rongeur into the most dorsal portion of the disc space.*

pressure. No attempts should be made to break a healthy, highly resistant annulus, not to decrease its ability to stabilize the disc. The second maneuver consists in introducing the 45° forwards angled pituitary rongeur in the most dorsal portion of the disc space, in contact with the posterior annulus (Fig. 16.36). This maneuver is usually easy and devoid of risks when using the microscope, since it enables the jaws of the rongeur to be seen when the instrument is inserted into the disc.

The microscope does not enable the posterior central portion of the annulus fibrosus to be seen. Visualization of this portion may, at times, be useful in the presence of a midline disc herniation. For this end, a dentist's mirror may be helpful (77).

Migrated herniation

The search for migrated fragments, which should mostly be carried out after excision of the disc contents, is usually quite easy with the microscope. The excellent lighting and visual magnification allow the surgeon to detect even small fragments, which are hardly visible with the naked eye and poor illumination. To adequately visualize a suspected anatomic structure, the microscope can be placed perpendicularly over the structure or the objective can be inclined. It is important, however, that the structure be in the center of the visual field; when the object is at the peripheral area, in fact, visualization is defective or distorted and difficulties may be encountered in manipulating the anatomic structures with the appropriate instruments.

The migrated fragment is often covered by a thin fibrous sheath. By pressing on the sheath or rubbing it with a dissector, the fibrous lamina is ruptured, thereby easily detecting the discal nature of the underlying tissue (Fig. 16.37).

The migrated fragment is usually in one single piece and should, if possible, be removed whole. It is easier, in fact, to excise a large fragment than small fragments disseminated in the spinal canal. If, when removing the fragment, the surgeon has the feeling that the latter may tear, it is better to first free the disc tissue from the surrounding structures as extensively as possible and then to grasp the fragment with a large-bite pituitary rongeur. When the excised fragment is large, no additional fragments are usually present. These should be carefully sought when the excised fragment is smaller than expected. As a general rule, all migrated fragments should be removed, but very small fragments, which, at the microscope, appear larger than they actually are, may even be left behind if excision is difficult or likely to cause trauma to the neural structures. This holds, however, only for fragments located in the middle portion of the spinal canal, beneath the thecal sac.

A fragment migrated ventrally to the emerging nerve root is usually detected as soon as the root is retracted to expose the disc. If the fragment is of medium or large size, the root appears to be tense and cannot easily be

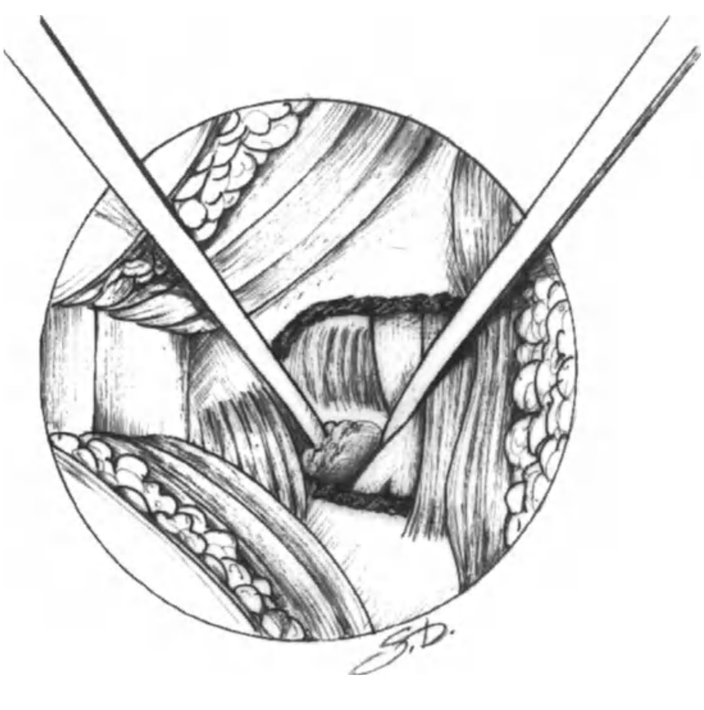


Fig. 16.37. *Migrated disc fragments are often covered by a thin fibrous sheath, that should be perforated to reveal the disc nature of the underlying tissue.*

retracted. This done, abnormal tissue is seen, which can usually be easily removed.

It may, at times, be difficult to detect a fragment migrated in the axilla of the nerve root even using the microscope. The fibrous sheath which usually covers the fragment, in fact, may not easily be distinguished from the dura mater and, on the other hand, it may not be detected if the root emerges more caudally than normal and/or too little lamina of the distal vertebra has been resected. A migrated fragment may be suspected in the presence of: 1) an abnormally opaque color of the anatomic structures in the region of the axilla; 2) no empty space between the root and the thecal sac; 3) too little mobility of the root when this is retracted, in the absence of other pathologic conditions; 4) lack of any pathologic condition in other sites, contrary to expectancy. When doubts persist after inspection of the posterior portion of the radicular axilla or the latter cannot be adequately exposed, the ventral portion of the axilla should be explored with the Frazier probe. In the presence of a migrated fragment, abnormal tissue is palpated or detected upon retracting the root.

To search for a migrated fragment proximal to the disc, the objective of the microscope should be inclined in a cranial direction. The fibroadipose tissue covering the posterior aspect of the vertebral body may, at times, be mistaken for a disc fragment. This can be recognized by the fibrous consistency, roundish shape and size, which is usually about that of a lente. The Frazier probe is extremely useful in searching for migrated fragments in this site.

Control of bleeding

In performing microdiscectomy through an interlaminar approach, only the sucker should be used in the deep operative field because of the small size of the surgical access. Medium caliber epidural vessels should be cauterized before severing them. Very small vessels may often be detected and cauterized. However, more often, those bleeding are small undetectable or inaccessible vessels. Bleeding, in this case, may be arrested by packing fragments of hemostatic sponge or a cottonoid in the area of the hemorrhage. In the presence of profuse bleeding of small epidural vessels at the time of discectomy, two cottonoid patties are placed proximally and distally to the disc, which is then rapidly incised (Fig. 16.38). Alternatively, the sucker is placed in a fixed site in proximity to the disc to suck blood for the time necessary for partial excision of the herniated disc. Removal of herniation, in fact, often leads to a drastic reduction in bleeding from the epidural vessels, that herniation has contributed to making congested.

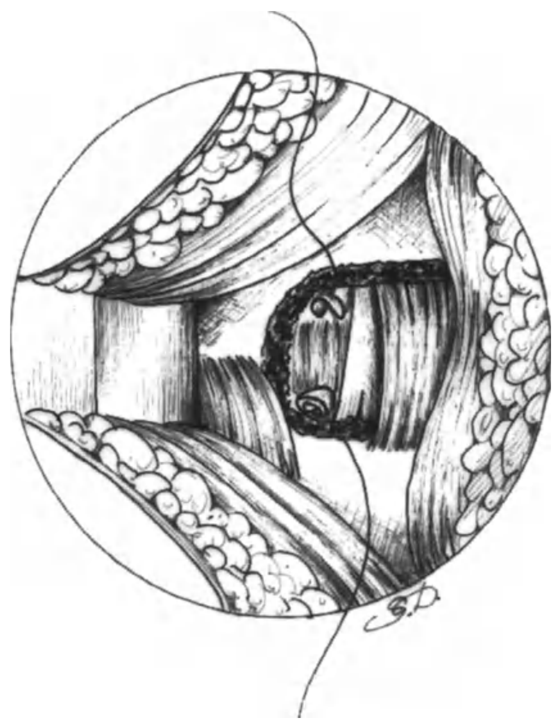


Fig. 16.38. *To stop profuse bleeding at the time of discectomy, two cottonoids, positioned above and below the disc, may be used.*

At the end of the operation, the subfascial surgical field should be as free of blood as possible, although a small accumulation of blood inevitably occurs and does not give rise to any inconvenience. On the other hand, there is no evidence indicating that perfect hemostasis decreases the amount of postoperative peridural scar tissue. A drainage tube should be applied, if moderate bleeding persists.

Preservation of epidural fat

Epidural fat should be preserved, if possible, since it forms a barrier between the neural structures and the scar tissue which develops after surgery (Fig. 16.39). The fat, however, may obstruct the vision of the thecal sac and emerging nerve root, particularly in young subjects who generally display abundant epidural fat. In these cases, if the nerve root has to be visualized to verify that it is decompressed or that no disc fragment is present in the radicular axilla, epidural fat is separated with two dissectors, until the mother of pearl-like surface of the root and thecal sac is seen; subsequently, or at the end of the operation, the fat should be layered over the root.

When difficulties are encountered in identifying the neural structures or removing extruded or migrated

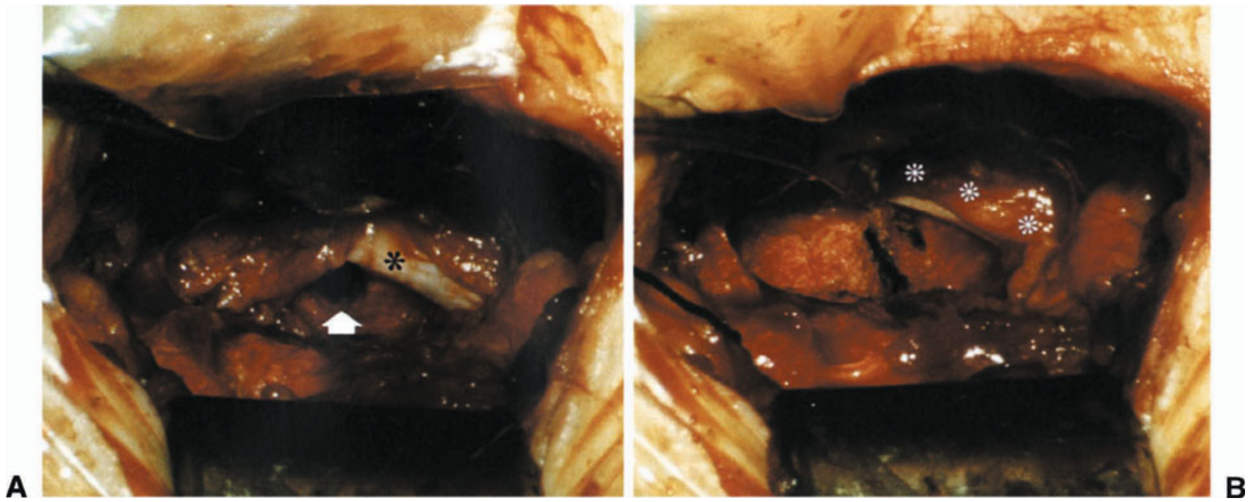


Fig. 16.39. *Microdiscectomy.* (A) *Operative field at the end of discectomy. The arrow indicates to the emptied disc and the asterisk the emerging nerve root.* (B) *The epidural fat around the emerging nerve root (asterisks) has been preserved.*

disc fragments, the epidural fat should be excised as far as is necessary to obtain a good view of the anatomic structures.

Intraforaminal and extraforaminal herniations

Interlaminar approach

Laminotomy should be performed at the level of the disc showing herniation or from which the migrated fragment originates. This is usually the disc below the fragment (page 440).

Contained or extruded herniation. After peforming laminotomy, the disc is evacuated first in the posterolateral and then in the lateral portion. The technique is that described for conventional discectomy, the main difference being that, with the microscope, arthrectomy is usually less extensive, although slightly wider in the transverse direction than in the other types of herniation. A too narrow arthrectomy, in fact, does not allow adequate space to maneuver either the pituitary rongeurs or the Frazier probe employed to depress the lateral portion of the disc, without excessively stretching the thecal sac and emerging nerve root. A few surgeons (1) occasionally resect the cranial end of the pedicle below the involved disc in order to enlarge the access to the neuroforamen; this has never been deemed necessary in our experience.

Migrated herniation. When preoperative investigations clearly show that the herniation has migrated into the upper part of the intervertebral foramen, the skin incision should be slightly longer (some 4 cm) and more cranial than normal. At least half of the proximal lamina is resected, together with the medial half of the inferior articular process of the cranial vertebra. In doing this, great care should be taken not to resect a too large part of the pars interarticularis to avoid it breaking (Fig. 16.40). This risk is relatively low when using the microscope, since the excellent vision makes extensive bone resection unnecessary in order to visualize the deep anatomic structures. The ligamentum flavum should gradually be excised as laminoarthrectomy is accomplished.

Discectomy should generally be carried out, since the disc very often shows a more or less marked bulging or a protrusion in the posterolateral or lateral portion. Discectomy, however, may be less radical than normal, particularly if the disc has little contents.

After discectomy, the objective of the microscope is inclined upwards and laterally to visualize the inferolateral area of the proximal vertebral body, just above the interspace, where the migrated fragment or fragments of disc are mostly located. It is extremely important to have excellent lighting of this area to easily identify the abnormal tissue. The control of bleeding, which tends to be profuse in the foraminal area, is equally important.

The herniated tissue is situated primarily just above the lower end-plate of the proximal vertebra, in the hollow of the posterior aspect of the vertebral body (Fig. 16.41). In this instance, the nerve root running in the neuroforamen usually needs not to be exposed if the excised fragment is large and / or has the size of that visible on CT or MRI scans. After excision of the fragment, which is usually removed whole, the Frazier probe is

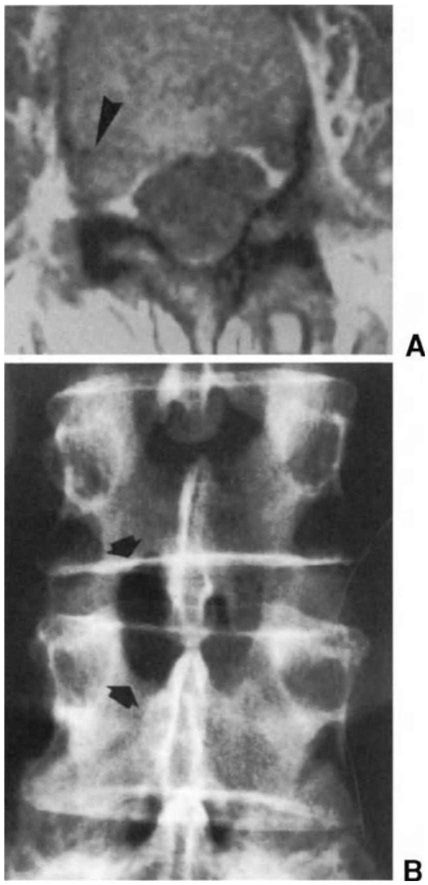


Fig. 16.40. *MR image and postoperative radiograph of a patient submitted to microdiscectomy for a migrated herniation at L3-L4 level.* (A) *MR axial image showing a disc fragment migrated into the proximal portion of the right L3-L4 intervertebral foramen (arrowhead).* (B) *Extension of laminotomy (arrows) and preservation of the pars interarticularis are visible on postoperative radiograph.*

used to search for further fragments, particularly proximally, beneath the nerve root. A very large fragment may migrate, at least in part, ventrally to the root. When this is the case, it may not be excised (or doubts may persist on its complete removal) without exposing the root. To this end, laminotomy should be prolonged proximally and laterally as far as the white-mother of pearl-like structure represented by the nerve root is seen.

Any migrated fragments, even those located for the most part extraforaminally, may be removed through the interlaminar approach (Fig. 16.42). What is most important is to see the fragment so as to grasp its end and excise it. This cannot usually be done without removing more than half of the articular processes; if arthrectomy risks becoming too extensive, the articular proceses may be undercut, rather than resected vertically (Fig. 16.43).

Fig. 16.41. *Migrated intraforaminal herniation. The disc fragment is usually located in the concavity of the posterior aspect of the vertebral body in close proximity to the intervertebral disc.*

Extravertebral approaches

Use of extravertebral approaches for removal of intraforaminal or extraforaminal herniations was first described by Ebeling and Reulen (para-articular approach) (18, 64) and by Recoules-Arches (paraspinal approach) (63). Subsequently, these approaches became increasingly popular, either alone or in association with the interlaminar approach (16, 20, 51, 61, 70).

Para-articular approach. The skin incision, 8 cm in length, may be placed on the midline or 2–3 cm off. The fascia is incised 1 cm off the midline, in order to reduce tension on retracting the muscles laterally, and the medial fascial flap is turned out towards the opposite side and retained with a few sutures. The paravertebral muscles are separated from the spinous processes and the laminae, proceeding as far as the outer aspect of the facet joint. Following detachment of the muscles from the outer aspect of the articular processes, the transverse processes of the two intended vertebrae are identified with the finger. Before proceeding with the operation, it may be necessary to check the level by fluoroscopy.

The posterior aspect of the transverse processes is then exposed, together with the outer aspect of the pedicles, the pars interarticularis and the articular processes. A self-retaining retractor is applied and the operating miscoscope is positioned.

Paraspinal approach. This approach was first used by Wiltse (86) for intertransverse fusion. It was then adopt-

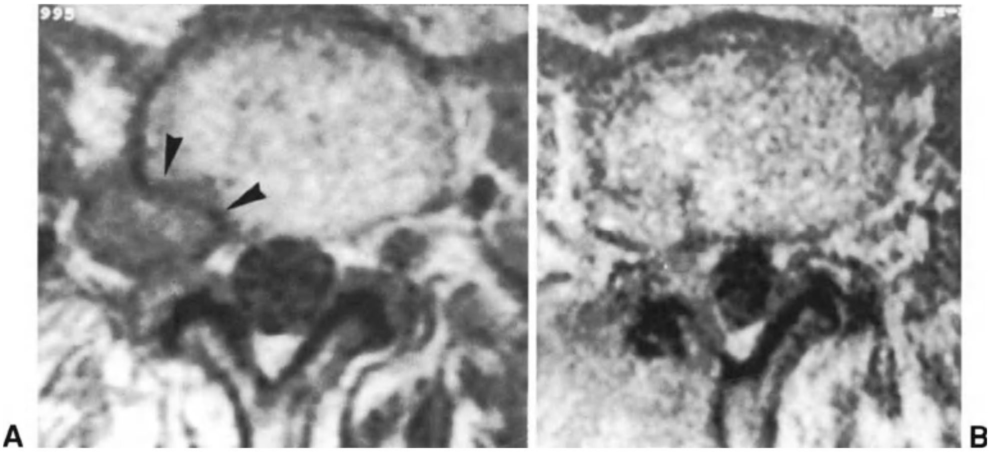


Fig. 16.42. *MR images of a patient with an extraforaminal disc herniation.* (A) *Preoperative spin-echo T1-weighted axial scan showing a large L4-L5 extraforaminal herniation on the right (arrowheads).* (B) *Spin-echo T1-weighted axial scan obtained 6 months after operation, performed through an interlaminar approach.*

ed by the author to perform discectomy or decompression of the neural structures through an interlaminar approach in association with fusion, to decompress the nerve root laterally to the pedicle or to excise intraforaminal or extraforaminal herniations (87).

The skin incision, 6–8 cm long, is made on the midline (87) or 3–5 cm off (51). When incision is on the midline, the skin is separated from the thoracolumbar fascia on the side of the herniation and the fascia is incised 2 cm laterally to the spinous processes. After retracting the lateral fascial flap, the intermuscular septum between the multifidus and longissimus dorsi is identified, the two muscles are separated with the finger, and dissection is made deeper with a slightly lateromedial oblique direction as far as the articular processes are palpated (Fig. 16.44). Dissection is further continued as far as the transverse processes of the two intended vertebrae. Fluoroscopy or radiographic images are used to check the level exposed, using a dissector placed between the two transverse processes. A self-retaining retractor is applied in order that the entire length of the transverse processes, the articular processes and the pars interarticularis remain exposed. The operating microscope is positioned after having detached all muscle insertions from the exposed bony surfaces.

Paralateral approach. This approach, described by Ray (60, 61), is very rarely used. The skin incision is made at the level of the lateral junction of the spinal muscles (multifidus, longissimus dorsi and iliocostalis) with the quadratus lomborum. The location of the junction, which is at 10–16 cm from the midline, is identified by palpation or by measuring the distance between the spinous processes and the lateral edge of the iliocostalis muscle on CT scans. The incision is 5–8 cm long and has a slightly curved, J-like, shape, particularly at L5-S1 level, for which the curved portion of the incision is placed along the iliac crest. After dissection of the subcutaneous tissue, the thoracolumbar fascia is incised and the lateral edge of the iliocostalis muscle is identified. Blunt dissection is deepened between the iliocostalis and quadratus lomborum muscles, in a lateromedial direction, until the tip of the transverse processes is palpated (Fig. 16.45). To expose the L5-S1 interspace, resection of a small portion of the iliac crest may be needed. The level exposed is checked by fluoroscopy and, after applying a self-retaining retractor maintaining the paravertebral muscles displaced medially, the transverse processes, articular processes and pars interarticularis are exposed.

Comparison of the extravertebral approaches. In our experience, the best approach is paraspinal, which is almost bloodless and allows the multifidus muscle not to be detached from the spinous processes and medial portion of the laminae and the intervertebral foramen to be easily reached. Furthermore, with this approach even an interlaminar access may be performed, after detaching the multifidus from the lateral portion of the laminae.

The disadvantages of the para-articular, compared with the paraspinal, approach are: the need to detach the multifidus from the spinous processes and laminae, the more profuse bleeding and the slightly greater difficulty in adequately retracting the paravertebral muscles to expose the transverse processes.

With the paralateral approach, the area of the intervertebral foramen is deeper with respect to the skin surface compared with other approaches, thus making surgical maneuvers more difficult. Furthermore, with this approach, a simultaneous interlaminar access, or a contralateral approach through the same skin incision, is not feasible.

Excision of herniation. The operating table should be inclined towards the opposite side to obtain a better

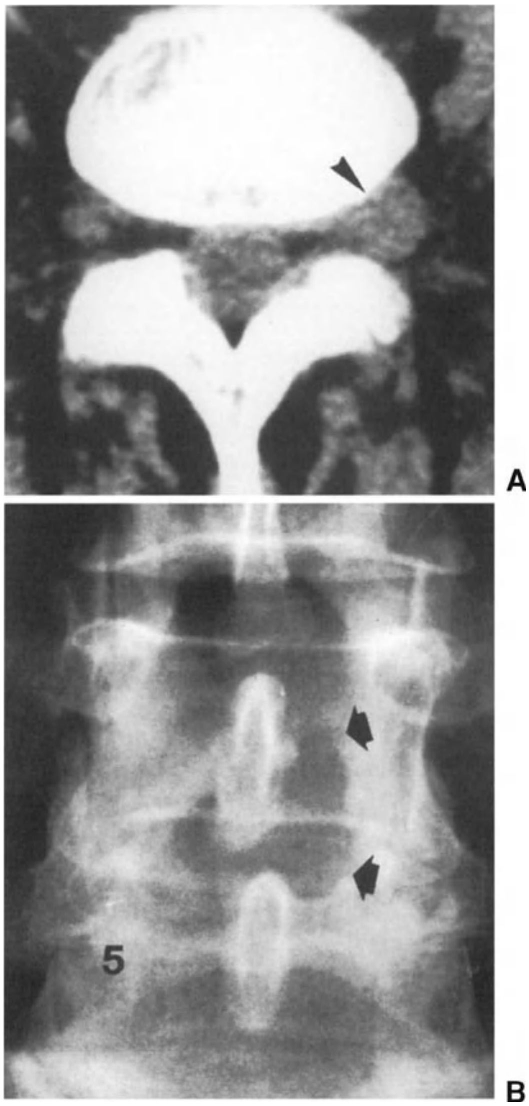


Fig. 16.43. *Preoperative CT scan and postoperative radiograph of a patient who underwent surgery for an extraforaminal herniation.* (A) *CT scan showing an L4-L5 extraforaminal herniation on the left (arrowhead).* (B) *Postoperative radiograph showing the laminotomy carried out to remove the herniation (arrows). The articular processes were undercut to allow removal of the herniation with no extensive arthrectomy.*

vision of the intervertebral disc. After exposure of the transverse processes and intertransverse muscles (Fig. 16.46), the outer one third of the pars interarticularis and the proximal portion of the articular processes with the attached ligamentum flavum are resected using Kerrison rongeurs or a high speed air drill, and then the intertransverse muscles and ligament are removed (Fig. 16.46). Alternatively, the muscles and ligament are first removed and then arthrectomy is carried out. The former procedure is preferable when the high speed air drill is used, since the soft tissues may better protect the underlying nerve root. The latter should be preferred when the pars interarticularis and the articular processes are resected by means of Kerrison rongeurs.

The dorsal branch of the lumbar artery, crossing the superomedial portion of the intertransverse space, is identified and cauterized. The nerve root and dorsal root ganglion are exposed by dissecting the periradicular fat. Upwards retraction of the nerve root allows exposure of the disc and the possibly migrated fragment (Fig. 16.46). If the latter is situated in the middle portion of the neuroforamen, the pars interarticularis and the articular processes are resected until the herniated tissue is sufficiently visible. The disc is then incised and discectomy carried out using, in particular, forwards angled Kerrison rongeurs. Finally, a Frazier probe is introduced into the foramen to make sure that no other disc fragments, migrated ventrally or caudally to the portion of the root contained in the spinal canal, are present.

Indications for interlaminar or extravertebral approach

Analysis of the surgical results appears to indicate that there are no significant differences between the interlaminar and extravertebral approaches. With the former, there is the risk of compromizing vertebral stability if too extensive or complete arthrectomy is carried out; however, this very rarely occurs when using the operating microscope, which, on the other hand, makes detection of a disc fragment migrated into the foramen easier than with the naked eye.

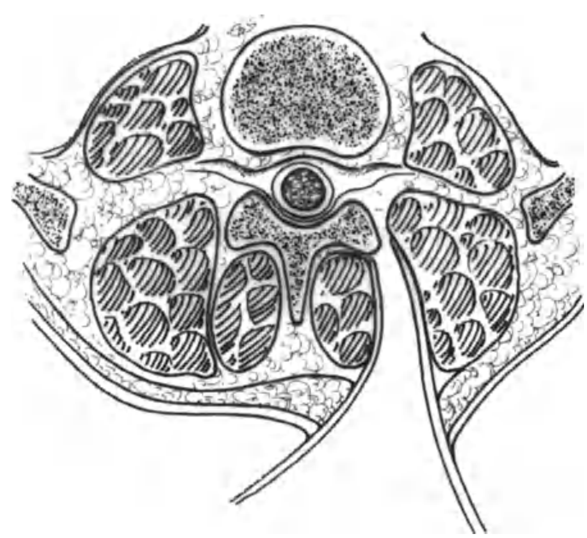


Fig. 16.44. *Paraspinal approach. The multifidus and longissimus dorsi muscles are split with the finger. Dissection is carried deep down until the articular processes are palpated.*

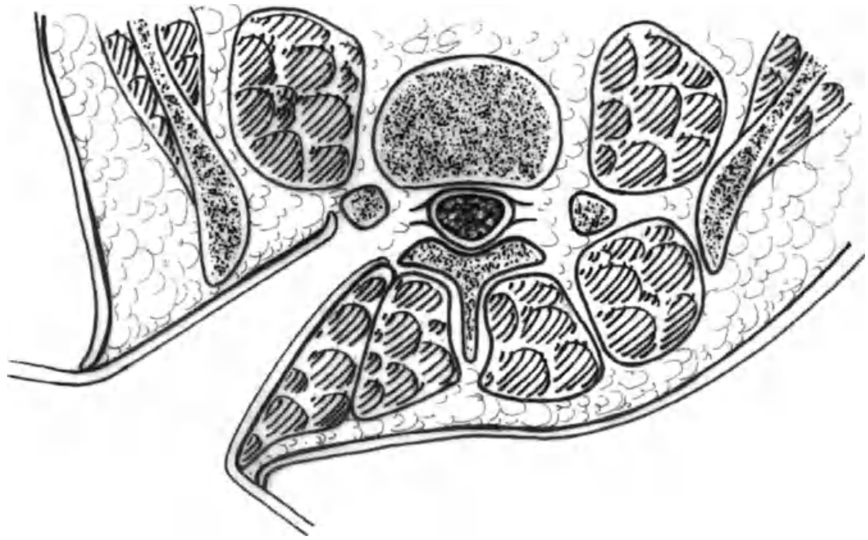


Fig. 16.45. *Paralateral approach. Following skin incision at 10 –16 cm from the midline, the thoracolumbar fascia is incised and carried deep down with blunt dissection between the iliocostalis and quadratus lomborum muscles, until the tip of the transverse process is palpated.*

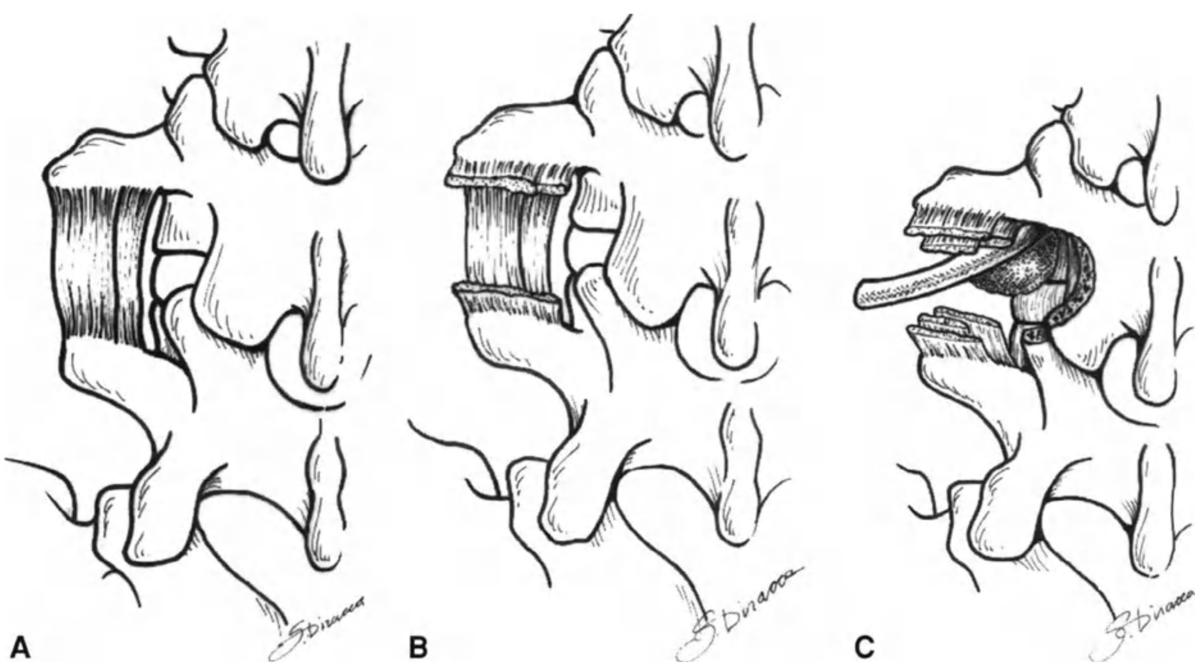


Fig. 16.46. *Paraspinal approach.* (A) *Exposure of the transverse processes and the intertrasversarii muscles.* (B) *Excision of the muscles and intertransverse ligament.* (C) *Following retraction of the nerve root, the disc is exposed and the extruded or migrated disc fragment is seen.*

With extravertebral approaches, there is less risk of affecting the stability of the motion segment, but greater risk of leaving behind a migrated intraforaminal disc herniation when the free fragment extends considerably into the vertebral canal. Furthermore, the extravertebral approaches do not allow for elimination of a concomitant nerve-root canal stenosis, not rarely present in patients with a lateral herniation (Fig. 16.47). On the other hand, with combined approaches, operative time is longer, and surgery is more demolitive and appears to be associated with a higher rate of unsatisfactory results compared with the extravertebral approaches performed singly (20); furthermore, combined approaches, compared with the interlaminar approach alone, may more easily lead to interruption of the pars interarticularis and complete arthrectomy.

Extravertebral approaches are electively indicated in contained or extruded extraforaminal herniation and

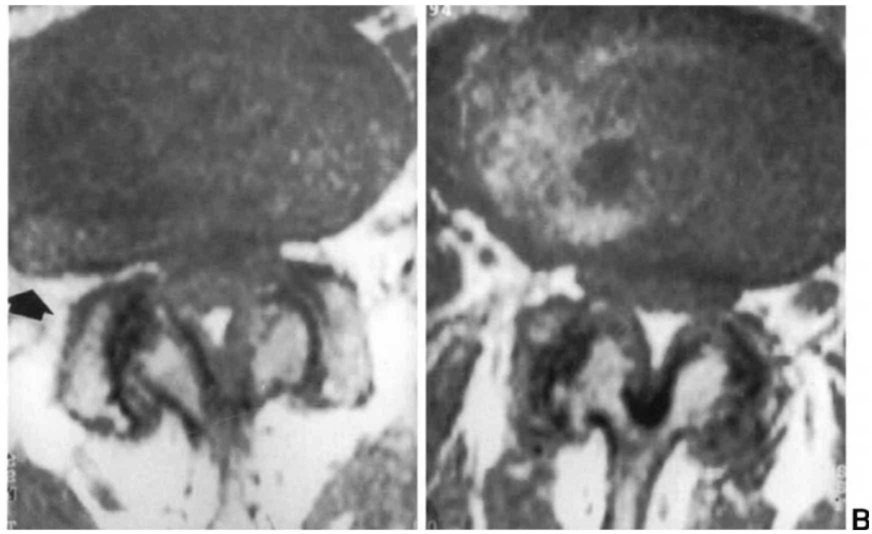


Fig. 16.47. *MR images of a patient with an extraforaminal disc herniation and spinal canal stenosis.* (A) *Spin-echo T1-weighted axial image showing L4-L5 extraforaminal herniation on the right (arrow).* (B) *Spin-echo T1-weighted axial scan clearly showing stenosis of the spinal canal at the same level as the herniation.*

in the rare cases in which a disc fragment is migrated to a large extent, or entirely, outside the intervertebral foramen. In the majority of intraforaminal herniations, the operation of choice is microdiscectomy through an interlaminar approach. In these herniations, however, not only is the surgical technique important, but also a precise preoperative diagnosis. The latter, in particular, should exactly determine: the type of herniation (contained, extruded or migrated) ; in case of migrated herniation, the location and size of the fragment; and whether a stenotic condition is present. When this is the case, the interlaminar approach should be preferred, regardless of the type of herniation. A combined approach should be carried out only when one approach or the other appears to be, during surgery, unexpectedly unable to eliminate the pathology.

Closure

As in conventional discectomy, there appears to be little indication for the application of a fat graft and instillation of morphine or cortisone after microdiscectomy through an interlaminar approach.

The shorter the skin incision the more difficult the closure of the deep layers, due to the little space available. A medium size needle should be used and, in the obese patient, it may be helpful to use the microscope also during closure to better see the fascia and the needle itself. We perform a continuous suture of the fascia with slowly dissolvable thread and a subcuticular suture with thin, quickly dissolvable thread. The ends of the thread emerging from the skin are cut at 8–10 days after surgery.

Postoperative management

Postoperative treatment is similar to that carried out after conventional discectomy, but accelerated compared with the latter. The patient remains in bed for 8–24 hours and is then invited to walk for a few minutes several times a day. He/she is usually discharged on the day after surgery. Patients with mild postoperative low back pain may be discharged on the same day as surgery, if submitted to a short general anesthesia or operated under spinal or local anesthesia. Discharge may be deferred to the second or third day if the patient lives further than 200 km away. Treatment with cortisone for the first 4–6 days after surgery may be useful to decrease symptoms due to postoperative radicular irritation.

Once at home, the patient should get up 8–10 times a day, for 10–30 minutes each time, during the first postoperative week. Thereafter, he/she begins to go out of the house for short walks. The surgical wound is checked 8–10 days after the operation and, if healing proceeds normally, postoperative exercises are commenced. These are deferred in the presence of radicular pain at rest or while performing exercises. The patient is allowed to drive the car 10 days, and to return to sedentary work 2 weeks, after surgery.

Anterior discectomy

Discectomy through an anterior approach is generally performed to carry out an anterior interbody fusion in patients with various pathologic conditions, such as segmental instability, spondylolisthesis or degenerative disc disease. Anterior discectomy, performed to excise a herniated disc with no spine fusion is, instead, an unusual procedure. It was first described by Nakano (52) and then performed by other Japanese surgeons (78, 79).

Operative technique

The operation is carried out in the supine position. Muscle relaxants may be administered to decrease tension of the abdominal muscles. Skin incision is 6–8 cm long. It is generally performed on the left side, but may also be carried out on the right for L5-S1 level, taking, as reference, the line joining the umbilicus to the anterosuperior iliac spine. For L4-L5 level, the skin is incised in the center of this line, whilst for the levels above or below, the incision is placed, respectively, at the level of the outer or inner half of this line (Fig. 16.48).

After dissection of the subcutaneous tissue, the external aponeurosis of the rectus abdominis muscle is sectioned along the line of the skin incision and the muscle bundles of the obliquus externus, obliquus internus and trasversus abdominis (79). Alternatively, the external aponeurosis of the rectus abdominis is sectioned almost vertically, the muscle is retracted medially and the internal aponeurosis is then incised (53). Beneath the muscle layer, the peritoneum, which should be carefully preserved, becomes apparent; if incidentally incised, it should be immediately repaired. As the peritoneum and abdominal viscera are retracted medially, the vertebral column can be palpated. The iliac vein and/or the vena cava are retracted medially and the

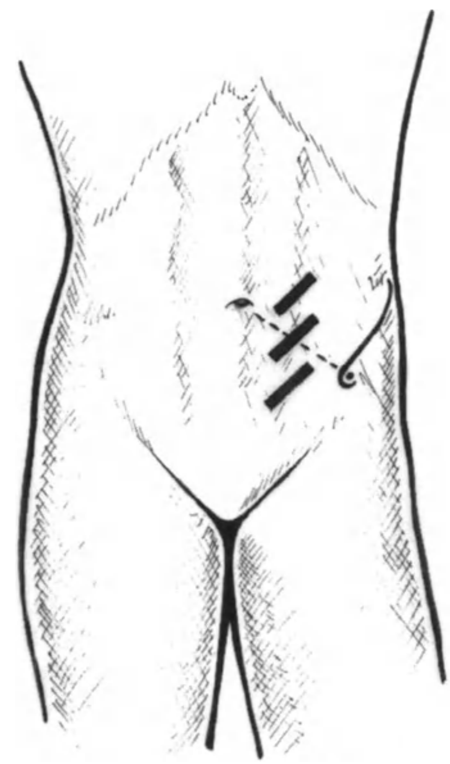


Fig. 16.48. *Anterior discectomy. The drawing depicts the skin incisions made, proceeding craniocaudally, for L3-L4, L4-L5 or L5-S1 discectomy.*

psoas muscle laterally, thus exposing a limited area (1 or 2 × 2 cm) of the involved disc (Fig. 16.49). Lumbar vessels do not need to be ligated, since only the disc is exposed. The sympathetic chain is not mobilized, since

Fig. 16.49. *Anterior discectomy. Once the retroperitoneal space is reached, the disc involved is exposed by retracting the psoas muscle laterally and the large abdominal vessels medially.*

it runs along the lateral aspect of the spine, whereas the communicating branches with the hypogastic plexus should be identified and retracted.

The anterior longitudinal ligament and annulus fibrosus are sectioned in a 30° oblique direction with respect to the sagittal plane. The nucleus pulposus and posterior annulus fibrosus are excised using pituitary rongeurs, bone rongeurs and a long curved curette, which is introduced behind the vertebral end-plates to remove possible extruded fragments of disc. The jaws of the pituitary rongeurs should have a smooth tip to decrease the risk of damage to the neural structures and, during discectomy, fluoroscopy may be useful to avoid invasion of the spinal canal (79).

After the operation, nutrition is given via the parenteral route until postoperative ileus resolves. Elastic stockings are always worn and anticoagulant therapy is indicated in patients with a risk of venous thrombosis. The patient may assume any position and gets up after 1–2 days.

Advantages and drawbacks

The extraperitoneal approach is almost bloodless, is quickly performed and avoids formation of scar tissue in the spinal canal. Furthermore, it may be easier to carry out in patients previously operated on through a posterior approach.

The main drawbacks of anterior discectomy with no interbody fusion are: impossibility to remove disc fragments migrated at a distance from the interspace and to decompress the neural structures in the presence of concomitant stenosis, as well as the possibile negative effects upon vertebral stability. With the modern imaging techniques, it is generally easy, before surgery, to demonstrate the presence of a disc fragment migrated beyond the limits of the interspace or nerve-root canal stenosis in association with herniation. Occasionally, however, these conditions represent an unexpected intraoperative finding. In these cases, anterior discectomy may easily lead to surgical failure. In a series of 80 patients, Tsuji et al. (79) reoperated five patients (6%) through a posterior appoach due to the presence of a migrated herniation or concomitant lumbar stenosis. To perform anterior discectomy, the anterior longitudinal ligament is sectioned and a large part of the anterior and posterior annulus fibrosus is excised. This probably causes a more marked decrease in vertebral stability than discectomy through a posterior approach, particularly when the articular processes are only moderately resected, as usually occurs when the operating microscope is used.

Indications

Anterior discectomy with no interbody fusion might be indicated in a midline contained herniated disc, or extruded herniation provided the fragment has remained in front of the interspace, occurring in young or middle-aged patients with bilateral radicular symptoms and no clinical and radiographic evidence of vertebral instability. In these cases, discectomy through a posterior approach may require a bilateral access, which has a similar effect to anterior discectomy upon vertebral stability and produces abundant scar tissue in the spinal canal. With the exclusion of these cases, anterior discectomy does not seem to offer any advantages with respect to discectomy through a posterior approach. The anterior approach is contraindicated when there is any doubt, even vague, that a migrated disc fragment, nerve-root canal stenosis, or instability of the motion segment may be present. In patients with vertebral instability, anterior discectomy must be associated with an interbody fusion.

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·CHAPTER 17·

POSTOPERATIVE FUNCTIONAL RECOVERY

F. Postacchini, S. Gumina

Surgical treatment

Satisfactory surgical outcome

Physical activities

In the first month after surgery, the patient should avoid strenuous physical activities, such as lifting or carrying weights, and limit the number of long-distance car journeys. During this period, it is useful to walk and exercise by cyclette. Both activities were found to be helpful in increasing oxygen consumption and tolerance to pain, as well as improving general physical condition (6). Males can resume sexual activity 3 weeks after surgery and females even earlier.

During the second month, the patient may begin to lift and carry weights not exceeding 15 kg, do some gardening, without bending the trunk while standing, and ride a bicycle. In general, the patient can resume all activities requiring moderate physical effort which he / she feels able to do, whereas activities and postures causing pain should be avoided.

In the third month, all non-sporting activities (excluding swimming) which do not involve lifting weights of more than 25 kg may be gradually resumed.

Exercise therapy

Aims

Exercise therapy has several goals in patients who have undergone surgery for lumbar disc herniation: to strengthen weakened muscles of the lower limbs, as well as abdominal, gluteal and trunk muscles; to stretch lower limb muscles and mobilize the decompressed nerve root in order to reduce periradicular adhesions; to mobilize the lumbar and thoracic spine; and to enable full functional restoration of the musculoskeletal system in order to resume physically demanding jobs or sporting activity. These aims are slightly different from those pursued in patients with disc herniation treated conservatively or in those with chronic low back or lumboradicular pain. The modalities of exercise therapy are, thus, different and include exercises both of flexion and extension of the trunk. The extension exercises are usually well-tolerated by operated patients and significantly increase spine flexibility (27).

Methods

In the past, we recommended to start the exercise therapy 2 or 3 days after surgery (38). This often led to delay in wound healing due to accumulation of serum in the suprafascial space. Furthermore, many patients could not withstand exercise therapy or carried it out with difficulty due to low back and / or radicular pain, often quite severe in the first few days following surgery. We thus postponed the beginning of exercise therapy to the 10th–12th day after surgery, when the wound has healed and the postoperative lumboradicular pain has considerably decreased. When healing of the surgical wound is delayed, exercises are started only after complete healing. In some centers, however, exercise therapy is started only 4 to 5 weeks after surgery (28).

The exercise program is structured so as to become progressively more intensive. The type of surgery – whether conventional discectomy or microdiscectomy – does not significantly affect the program. However, patients undergoing microdiscectomy tolerate exercise therapy better in the first few weeks after surgery and are usually able to perform the more demanding exercises earlier. The rehabilitation program lasts 1 to 3 months, depending on the patient's age, the speed with which adequate functional recovery is obtained, the patient's desire to continue exercising and his / her occupational and / or sporting demands.

Some of the exercises taught are shown in Figs. 17.1–17.14. They are illustrated in progressive order of difficulty, both for the whole body and the spine. The first exercises are carried out in the first few weeks, whilst the last ones are peformed in the final phase of the rehabilitation program.

First 2 weeks. The first exercises are aimed at strengthening the muscles of the lower limb, particularly those which may be weak due to nerve-root compression, stretching the posterior and anterior muscles of the limb, strengthening the abdominal and gluteal muscles, and mobilizing the spine. In addition, the patient is taught to perform exercises aimed at obtaining a correct posture of the trunk by decreasing lumbar lordosis and

Fig. 17.1. *Flexion of the knee and hip until the thigh is approached to the chest. The exercise is performed on both sides.*

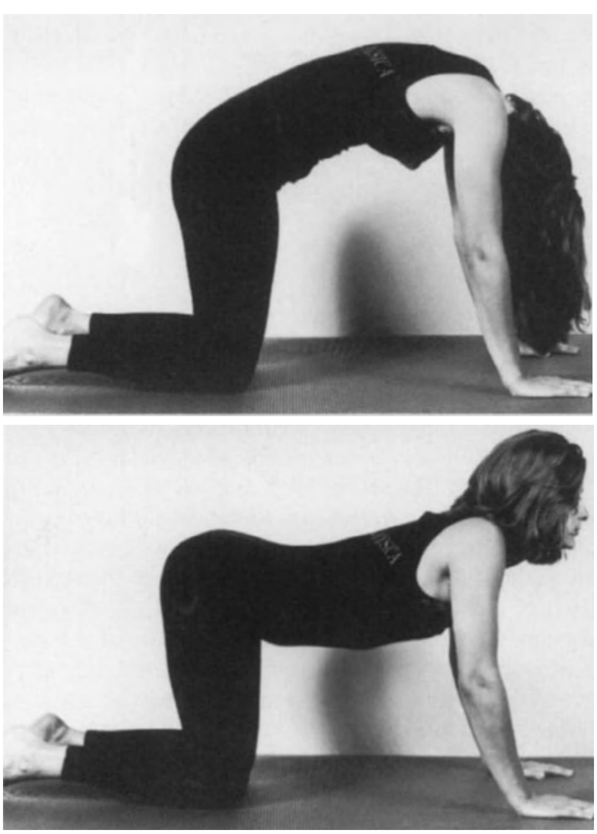

Fig. 17.2. *The lumbar spine is kyphosed by contracting the abdominal muscles. These are then relaxed and the lumbar spine is flattened.*

Fig. 17.3. *Egg-like posture, starting from the standing position.*

Fig. 17.4. *Rising on tiptoes.*

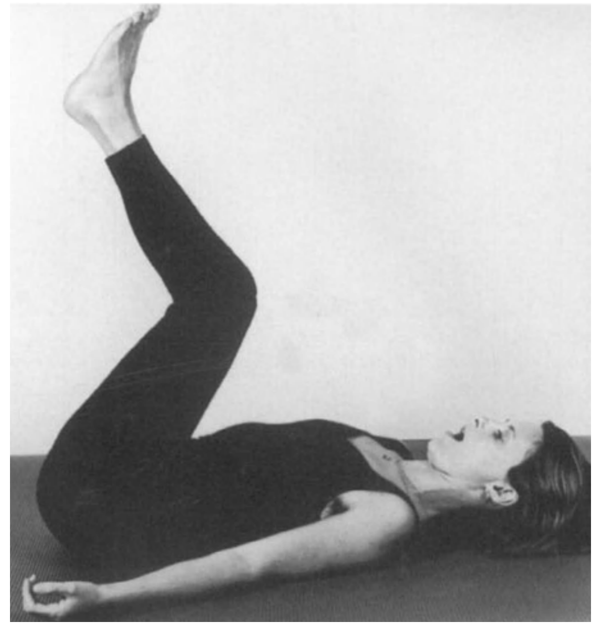

Fig. 17.5. *The thighs are approached to the chest, keeping the knees together and flexed.*

Fig. 17.6. *Rising from a chair levering on only one limb. The exercise is then performed on the opposite side.*

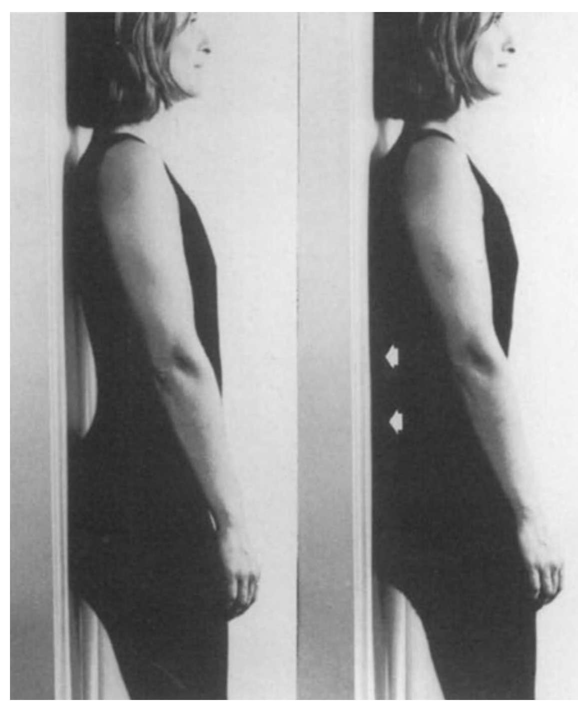

Fig. 17.7. *Pelvic tilt in the standing position.*

tilting the pelvis. The program also includes breathing exercises. The session begins with the latter and continues with specific exercises for the spine and lower limbs. In this phase, the exercises are not very demanding and the majority are carried out in the lying, sitting,

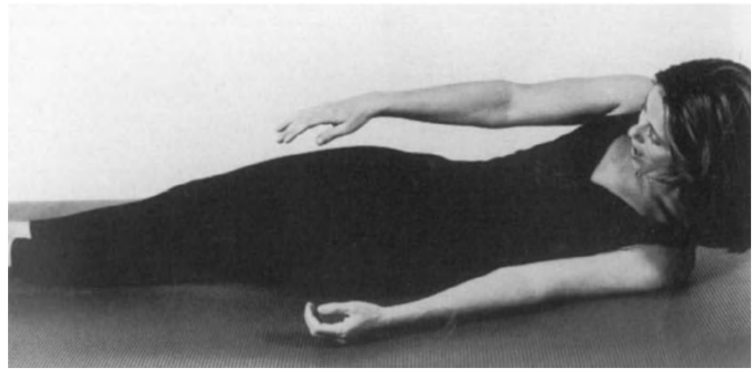

Fig. 17.8. *Rising of the trunk while keeping the left upper and lower limbs adherent to the floor. The exercise is then repeated on the opposite side.*

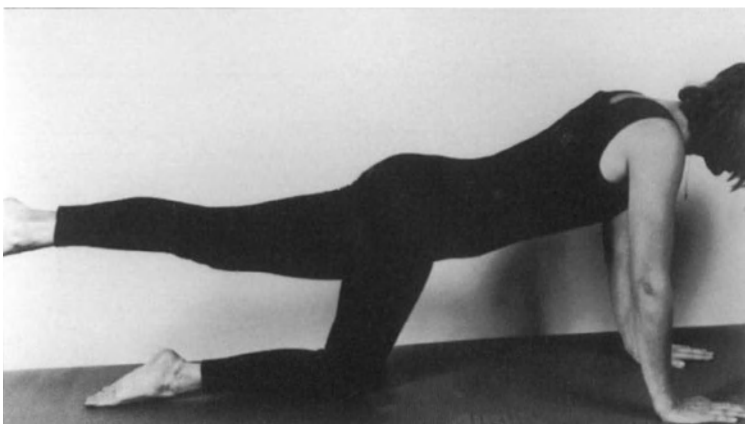

Fig. 17. 9. *Starting from the kneeling position, the lower limb is extended to the horizontal plane. The exercise is performed on both sides.*

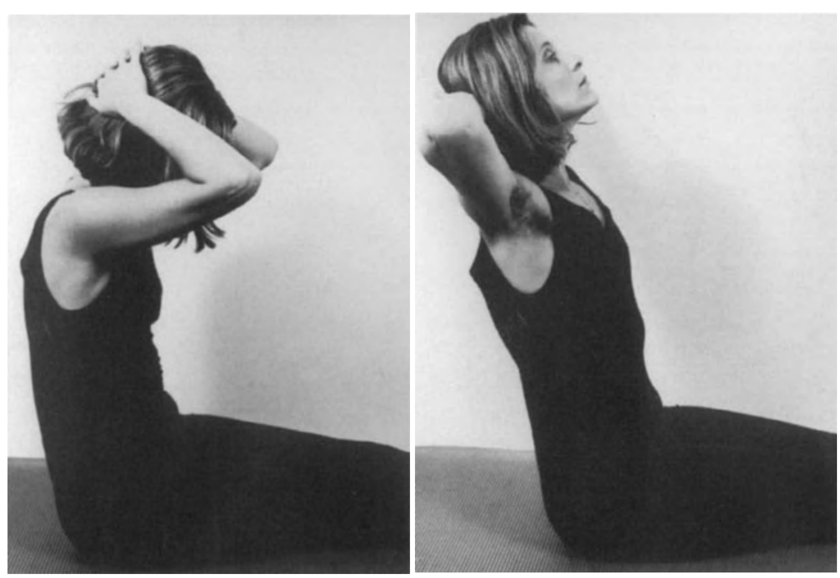

Fig. 17.10. *Trunk extension and forced external rotation of the abducted arms in the sitting position.*

or on all fours position. The sessions last 5 to 10 minutes and are repeated twice or more times a day.

Third and fourth week. The exercises become more demanding and have, on the one hand, the same objectives as those of the previous phase and, on the other hand, the aim of strengthening the paraspinal muscles and mobilizing the trunk in extension and lateral bending. The sessions last 15 to 20 minutes and take place twice a day. During the third week, the first half of the session is dedicated to the exercises from the first phase and, the second half, to new exercises. During the

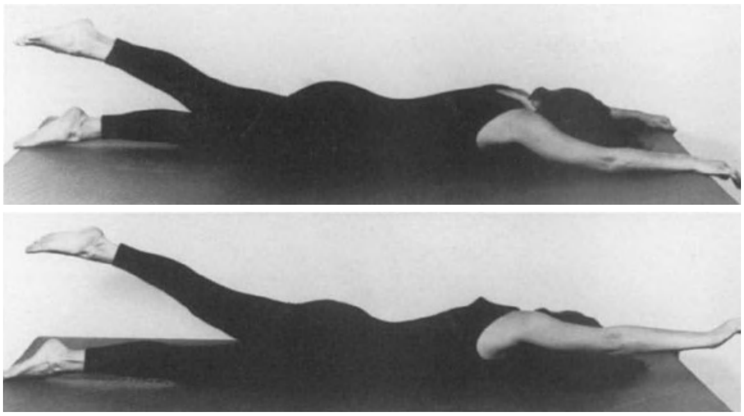

Fig. 17.11. *Extension of a lower limb in the prone position and, then, rising of the opposite upper limb. The exercise is performed on both sides.*

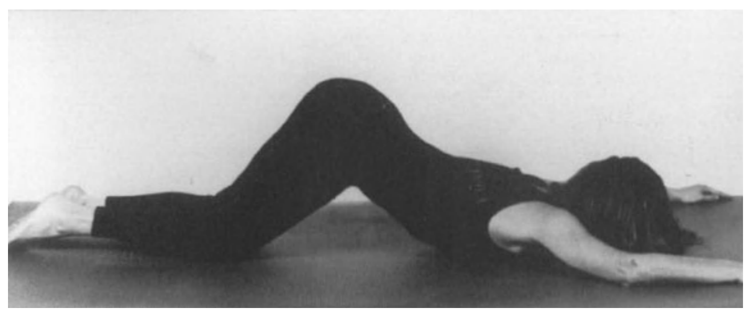

Fig. 17.12. *Forwards sliding of the trunk until the chin reaches the floor.*

fourth week, only the new exercises from the second phase are done and the number of repetitions of each exercise is increased gradually. Exercises to control trunk posture are incremented in this phase.

Second month. There is only one session lasting at least 20 minutes. Young and middle-aged patients are advised to prolong exercise therapy up to 30 or 40 minutes. This holds paticularly for those who perform manual labour or intend to resume sport.

During the initial 2 weeks, the first half of the session is dedicated to the exercises taught in the previous phase and the second half to new exercises. These are isotonic exercises aimed at stretching abdominal, gluteal and paravertebral muscles, strengthening the anterior and posterior muscles of the lower limbs and abdominal and trunk muscles, and increasing spine mobility both in flexion and extension. Exercises of lateral bending of the trunk are also carried out. During the session, exercises to control trunk posture are repeated many times. The patient avoids the exercises causing low back or radicular pain and suspends all exercises for a few days in case of persistent pain.

Where to exercise

Postoperative exercises may be done at a functional rehabilitation center or independently by the patient at home, or a mixed approach can be adopted. The former approach is preferable by far, since the exercises are carried out under supervision by a physiotherapist, but it may present some drawbacks. The patient must go to a rehabilitation center daily or even twice a day; this involves wasting time for the patient and companions, as well as use of specialized staff and relatively high costs, if the exercise therapy is completely individualized.

Following the second approach, the patient may be given a pamphlet, illustrating the exercises to be done (37). This method is simpler and cost effective. In our experience, the large majority of patients are able to do the exercises independently and almost all do so, at least during the first few weeks after surgery, although with varying commitment and frequency. An analysis of the compliance in performing exercise therapy carried out by means of a questionnaire filled in periodically by 100 patients submitted to microdiscectomy,

Fig. 17.13. *Lateral bending towards the wall, while pushing the pelvis with the hand placed on the flank.*

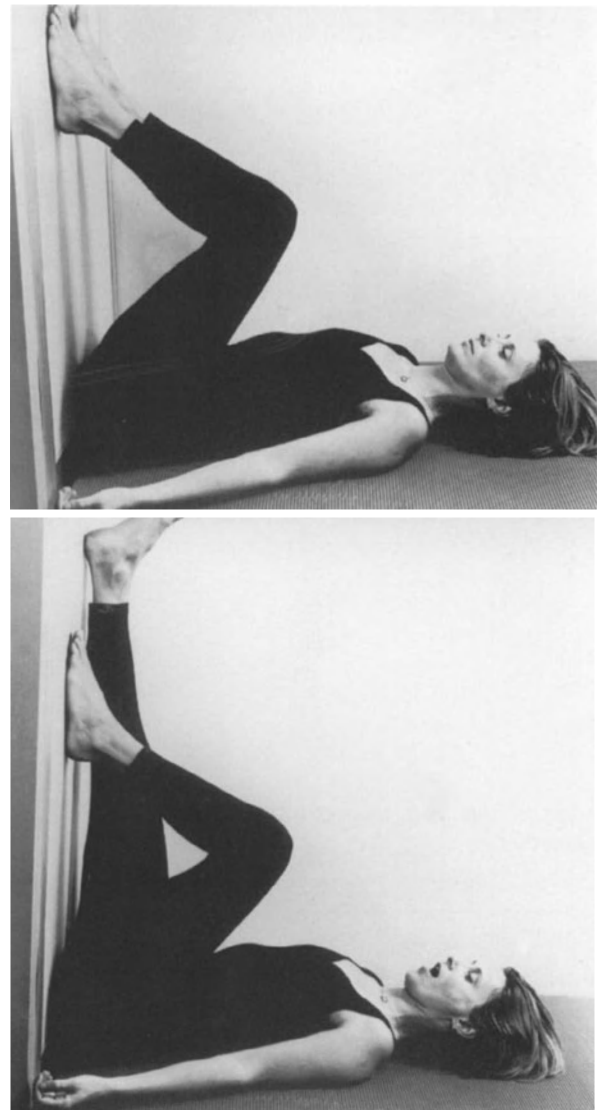

Fig. 17.14. *From the starting position, with the hips and knees flexed and pressed against the wall, the limbs are alternately extended.*

revealed that almost all felt able to do the exercises independently and the vast majority performed the exercise therapy during the first 4 weeks, whilst only 64% continued during the second month. Males, young patients, and those with a higher level of education showed more compliance. The negative aspect to this approach is that it is not possible to check whether patients perform the exercises correctly.

The most suitable method seems to be the mixed approach. This involves the patient exercising at home independently, but also visiting a rehabilitation center once or twice a week, so that a physiotherapist can check the exercises are being done correctly. This approach, compared with the completely autonomous method, also has the advantage of reinforcing medical instructions and stimulating the patient to continue the rehabilitation program.

Candidates for exercise therapy and tailoring of exercises

All young or middle-aged patients are able to do post-operative exercise therapy, in the absence of particular neurologic or osteoarticular pathologic conditions. In addition, many elderly patients are not only able, but often eager, to participate in an exercise program. The latter, however, may at times be superfluous or inadvisable in patients over 70 years old, due to advanced age or cardiovascular disorders.

The majority of patients under the age of 60 are able to do all the exercises in the rehabilitation program, unless they have other specific pathologic conditions. However, it may at times be necessary to modify the standard program or increase the time dedicated to a few exercises. For example, if a patient has recurrent pain while doing a particular exercise, this should be suspended. The same holds for the exercises in the advanced phase of the rehabilitation program, which a few patients may not be able to do; or, in the presence of severe deficit of a muscle group, more time should be dedicated to doing exercises aimed at activating those weak muscles.

Elderly patients should generally perform only the exercises of the first 4 weeks of the re-education program, in a single daily session.

Effects of exercise therapy

At the first postoperative follow-ups, patients who perform exercise therapy usually complain of less back pain than those who do not. They often report that, after the exercise session, back pain improves or disappears, or that they feel more backache when, for whatever reason, exercise therapy is stopped for a few days.

Exercise therapy accelerates recovery of trunk mobility in flexion and extension, even if the latter is largely influenced by the patient's constitutional muscle elasticity. At 30- to 45-day follow-up, the majority of patients who regularly follow the exercise program report that their trunk flexibility is comparable to that they had before the onset of symptoms due to disc herniation. Similarly, patients with long-standing preoperative sciatic scoliosis recover normal alignment of the spine faster than patients who do not perform exercise therapy. We did not carry out any comparative analysis of patients who follow an exercise program with respect to those who do not, since all our patients with a normal postoperative course are invited to perform exercise therapy. However, the occasional observation of patients who do no exercises, has shown that these patients tend to recover vertebral mobility and normal posture (if they presented severe preoperative sciatic scoliosis) 1 or 2 months later compared with those who carry out exercise therapy.

The intensity of the postoperative rehabilitation program seems to influence its therapeutic efficacy. In a randomized study (28), the results of a traditional rehabilitation program consisting of mild, generally mobility-improving exercises within pain limits were compared with those of a program of high-intensity dynamic exercises with the occurrence of back pain being the limiting factor. At 6- and 12-month follow-ups, the patients who had done the more strenuous exercises had less lumboradicular pain, less physical disability and better working ability levels.

Continuation of rehabilitation program

After the second month following surgery, patients who do not report a long preoperative history of low back pain are not invited to continue exercising, unless they wish to do so or they still complain of significant back pain. The latter patients are advised to continue exercise therapy for at least 1 more month. The same holds for those with a long preoperative history of back pain, who are invited to continue exercising for at least a few months and, often, also to attend a low back school. In these cases, we often advise the patients to do the postural exercise therapy performed by patients treated conservatively.

Physical therapy

No form of physiotherapy is usually needed in patients with successful surgical outcome and a normal postoperative course, except for those with preoperative motor loss in the lower limb. In these patients, it is generally useful to carry out electrotherapy of muscle stimulation, associated with massage and active assisted exercises, since the first few days after surgery. Before starting treatment, an intensity/duration electrodiagnostic test should be carried out to measure the intensity and duration of the electric stimulus to be applied to the muscle (36). Usually, the duration of the sessions should not exceed 10–15 minutes, since, subsequently, muscle fatigue appears, which may not allow valid contractions. Electrotherapy should be continued until clear clinical and/or electromyographic findings appear, indicating advanced functional recovery.

The muscles which most often need electrotherapy are the tibialis anterior, the peronei, the triceps surae and the quadriceps. The extensor hallucis longus does not usually need electrotherapy, both because it does not have a primary functional role and it may be difficult to carry out a selective electrostimulation of this small muscle.

Return to work

There are no definite time limits as to when to resume work after surgery for lumbar disc herniation. Numerous factors may influence postoperative sick-leave, besides the patient's ability to return to work (page 514).

Patients who do a sedentary job can generally return to work 3 to 6 weeks after surgery. Those who return earlier should work on a part-time basis in the first few weeks. Prolonged sitting may cause back pain; in this event, the patient should frequently get up and move around or do some exercises. On the other hand, patients whose jobs require prolonged standing should have the possibility of sitting frequently for a few minutes.

Patients who do moderately heavy work (frequent lifting or carrying objects weighing 15 kg and/or occasional lifting of no more than 25 kg at a time) (52) should not resume work before 6 to 8 weeks after the operation. During the first month, they should carry out a semi-sedentary job or at least not lift objects weighing more than 10–15 kg. Driving a heavy vehicle is comparable to moderately heavy work: during the first month back at work, patients should not drive more than 4 to 6 hours a day. If the hours driven are consecutive, the patient should get out of the vehicle and have a brief stroll or do some simple exercises.

Those who do heavy or extremely heavy work (frequent lifting or carrying of objects weighing 25 kg or more and/or occasional lifting of 50 kg or more at a time) (52) should not return to work before 3 months after the operation. These patients should also do a lighter work for a few weeks before returning to their usual activity.

Patients who do moderately heavy or heavy work should attend a low back school and continue to regularly perform the exercises taught for at least 3 to 6 months after returning to work.

Sport

Some surgeons recommend swimming, rather than exercise therapy, after the operation. Swimming may be beneficial for functional recovery, however it cannot substitute exercises for many reasons. Swimming activates limb and trunk muscles, but does not improve trunk mobility. Many patients find it more difficult to go a swimming pool than do exercises at home or at a rehabilitation center and, thus, they are more likely to give up swimming rather than exercise therapy. Elderly patients are less likely to go swimming and if they do, they often limit their activity to a few movements in the water, rather than performing true swimming. Attending a swimming pool is more expensive than exercise therapy autonomously performed at home, and probably also than exercising adopting the mixed approach.

Swimming can be performed 3 to 4 weeks after the operation. It is useful particularly in young patients, after the first month following surgery, as a sport activity integrating exercise therapy or preparation before returning to competitive sport.

Jogging may be resumed 3 months after surgery, starting with periods of 5 to 10 minutes, which may be increased by 5 minutes every week, provided the activity causes no back pain. The same time intervals are valid for tennis. Competitive sport should not be taken up before 3 to 5 months following the operation. These time limits are completely arbitrary, since no study has specifically analyzed this aspect of postoperative re-education. Our experience indicates that it is not necessary to delay return to sporting activity for a long period, however starting competitive sport too early exposes the patient to greater risks of episodes of acute low back pain and increases the probability of early recurrence of disc herniation.

In patients who intend to return to sport, it is advisable to start a supplementary rehabilitation program 2 months after surgery, aimed at restoring muscle coordination and endurance. This holds in particular for those who are returning to competitive sport. This program lasts 1 to 2 months and should be carried out at a rehabilitation center under the supervision of a physiotherapist.

The exercise program aimed at reconditioning to sporting activity includes exercises directed at strengthening trunk and upper and lower limb muscles, stabilizing the pelvis, speeding up muscle contraction and preparing the patient for specific situations in sport activity, such as falling or physical contact. The exercise program should gradually be incremented as far as concerns the difficulty of exercises, the number of repetitions and the duration of sessions. For competitive sport, the rehabilitation program precedes return to specific sport training.

Persistent lumboradicular pain

We refer to the persistence of radicular pain 1 to 3 months after the operation, or the presence of only low back pain of greater severity than the normal pain that patients feel in the first postoperative months.

Physical activities

The functional rehabilitation program is similar to that outlined for patients with a satisfactory outcome.

When lumboradicular pain is moderate or severe, it may be advisable, in the first few weeks after surgery, to let the patient stay in bed for some hours during the day. Subsequently, in the absence of specific causes for pain, patients should be stimulated to gradually resume activities implying limited physical effort, like walking, using a cyclette or swimming. This is useful in order to avoid both physical deconditioning and the onset or worsening of psychologic disorders, which tend to make chronic both the symptoms and physical disability. During the third month after surgery, patients should be encouraged to take up moderately heavy physical activities, such as lifting or carrying weights of a few kilograms.

Exercise therapy

After the operation, some patients continue to complain of moderate radicular pain for a few weeks. In these cases, the usual postoperative exercise program, or any exercises, should be avoided not to run the risk of an increase in leg pain. Alternatively, patients can be invited to perform the postural exercise therapy that is done by patients with disc herniation treated conservatively. Exercises, in fact, may improve low back pain and, at times, also radicular pain caused by initial periradicular adhesions or persistent nerve-root irritation, either spontaneous or related to surgical trauma. After an initial period of postural exercise therapy, the usual postoperative exercise program may be started, if radicular pain has improved or disappeared.

In patients with severe postoperative radicular pain, exercises should be avoided. The same holds in the presence of severe back pain, particularly when post-surgical complications are suspected.

Medical and physical therapy

Anti-inflammatory drugs are often less effective on radicular pain than in non-operated patients. Nevertheless, in the presence of severe leg pain, it is advisable to administer analgesics for 2 to 3 weeks following removal of skin suture. If pain is moderate, it is usually sufficient to reassure the patient by explaining that occasionally the symptoms regress slowly, over a period of a few weeks.

Massage and various types of physical therapy are often prescribed to patients who still complain of low back or lumboradicular pain a few weeks after the operation. However, there are no reliable studies, as far as concerns the methodological quality, on the effects of these treatments in patients with persistence of lumboradicular symptoms a few weeks after surgery. In our experience, massage and other forms of physical therapy have little or no effect on radicular pain. However, they may often improve a specific back pain. Of the various forms of physical therapy, the most effective are electrotherapy, particularly TENS, and ultrasounds. Some forms of exogenous thermotherapy, such as infrareds, may be used in preparation for massage.

Physical therapy is indicated in patients with moderate or severe back pain showing no improvement with exercises or when the latter are avoided. Usually, treatments are started 3 to 4 weeks after surgery and last for 2 to 6 weeks.

Corsets

In the past, many surgeons, regardless of the presence of residual symptoms, prescribed a corset for a few months after surgery and many still continue to do so (3, 10, 21). In our opinion, this therapeutic practice is useless in patients with a normal postoperative course, also taking into account that studies on the action of corsets show that these orthoses have little biomechanical effects on the lumbar spine. However, in patients with persistent postoperative back pain, not relieved or exacerbated by exercising, it may be useful to wear a lumbosacral canvas corset for 1 to 3 months, if it relieves pain. Subsequently, the corset should be left off because of the negative effects it may have on trunk muscle tone.

The use of a rigid corset may be indicated only in patients with proven postoperative vertebral instability.

Return to work

In patients with persistent lumboradicular pain, return to work should be delayed compared with patients presenting a normal postoperative course. As for the latter, there are no definite time limits for work resumption, which largely depends on the type of activity and the physical demand. Work should possibly be resumed once symptoms have considerably decreased or disappeared. It has been shown that return to work before 3 months, in the presence of persistent lumboradicular symptoms, negatively affects the long-term results of surgery or chemonucleolysis (51). In this respect, however, many factors, such as the patient's will to return to work and the cause of persistent lumboradicular symptoms, may play a relevant role. Sick-leave of more than 4 months is generally unjustified in the absence of clear evidence of a pathologic condition responsible for an abnormal postoperative course and, thus, for persistent symptomology.

Percutaneous procedures

Chemonucleolysis

The modalities and timing of rehabilitation treatments following chemonucleolysis are different from those carried out after surgical discectomy. The main reason is that patients undergoing nucleolysis tend to complain of more severe postprocedural back pain compared with those treated surgically, and that radicular pain often persists for some weeks. This requires a more prolonged rest during the first few weeks following the procedure and a more gradual return to normal physical activities.

In the fourth week after chemonucleolysis, the patient who complain of little or no lumboradicular pain should be encouraged to walk, use a cyclette, and swim, if desired. Until the sixth week, patients should avoid frequent long-distance car journeys, medium physical efforts (lifting 15 kg), prolonged standing or sitting (more than 5 hours) with no pause of rest, and frequent trunk flexion, extension or lateral bending. In patients with severe lumboradicular pain, the level of physical activity is conditioned by the intensity of pain: patients should perform only activities that cause little or no discomfort.

In patients complaining of moderate or severe lumboradicular pain, it may be useful to prescribe physiotherapy 3 to 4 weeks after nucleolysis. The type of physical therapy most commonly used by us is massage and infrareds (in preparation for massage), TENS and ultrasounds. Vertebral mobilization is also advised by some authors (43). However, it should be taken into account that these types of treatment are more effective in low back, than radicular, pain. They are thus indicated particularly in patients who complain only or prevalently of back pain.

Exercise therapy is usually begun 5 to 6 weeks after chemonucleolysis. If started earlier, exercises may easily cause, or exacerbate, low back or radicular pain, thus not only causing negative psychologic effects on the patient, but also slowing down the process of functional recovery. Furthermore, at least initially, the exercises are different from those recommended to operated patients. During the first 4 weeks, patients perform the postural exercise therapy taught to patients with lumbar disc herniation treated conservatively. The exercises are done under the supervision of a physiotherapist, autonomously by the patient or, preferably, by using the mixed approach, as described for patients treated surgically. The exercise sessions take place either once or, preferably, twice a day. In the former case, the session lasts 20 to 40 minutes, whilst in the second, each session lasts 20 minutes. Exercises which cause pain are either eliminated from the program or suspended, if the majority of exercises cause or exacerbate low back or radicular pain. After the phase of postural exercise therapy, muscle strengthening and stretching exercises, similar to those performed by patients treated surgically, are usually carried out, particularly in young or middle-aged patients. This second phase lasts 1 month, or longer if the patient has persistent back pain which improves with exercises.

Moderately heavy work may be resumed 2 months after the procedure if lumboradicular pain has disappeared or is very mild. If moderate or severe lumboradicular pain persists, it is advisable to delay return to work for at least 1 month. For heavy or very heavy work, the indications are the same as for patients treated surgically.

Swimming may be resumed 3 to 4 weeks after chemonucleolysis. Other sports may be performed 2 to 4 weeks earlier with respect to patients treated surgically, if the lumboradicular symptoms have disappeared or only occasional backache persists. Otherwise, the indications outlined for patients treated surgically are valid.

Other procedures

Postprocedural radicular symptoms in patients undergoing automated percutaneous nucleotomy, manual percutaneous nucleotomy or laser discectomy are comparable to those in patients submitted to chemonucleolysis, except for back pain, which is often more severe following nucleolysis. The limitations of physical activity, treatments and time off work are related to the type and severity of symptoms and are similar to those described for chemonucleolysis.

Chronic postoperative pain

Some of the patients submited to surgery or percutaneous procedures complain of chronic low back or lumboradicular pain in the absence of definite pathologic conditions, or in the presence of conditions requiring no repeat surgery or for which the patient refuses invasive treatments. These conditions, as well as numerous other lumbar pathologic conditions, are the cause of "the failed back syndrome". This may be treated with numerous rehabilitation therapies, which, however, often fail or provide only partial or temporary pain relief.

Physical therapy, manipulation and acupuncture

All patients with chronic postoperative pain undergo some form of physical therapy sooner or later. Some patients have no benefit, whilst others obtain pain relief of varying duration. However, little is known on the real therapeutic efficacy of most forms of physiotherapy. This is true in absolute, but particularly for operated patients, since studies on the efficacy of these therapeutic modalities have rarely distinguished between operated and non-operated patients. The few studies carried out using rigorous methodologies have provided conflicting results even for the most common and most studied forms of treatment, such as traction and TENS (7, 22, 29, 49). The conclusion is that for no form of physical therapy is there irrefutable proof of therapeutic efficacy. Manipulation was found to be more effective than placebo and other forms of treatment, such as analgesics, massage and low back school

(2, 13, 17, 19, 20, 45, 50). However, these findings refer almost exclusively to non-operated patients or patients for whom no mention is made on whether surgery had, or had not, been carried out. In one of the few studies which analyzed patients operated for lumbar pathologic conditions (22), electroacupuncture was found to be significantly more effective than TENS and placebo in relieving low back pain and increasing trunk extension strength at 3- and 6-month follow-ups.

Exercise therapy

Usually exercises have little or no effect on chronic radicular pain, whilst they represent one of the keystones in the treatment of patients with low back pain. Exercises should be done daily, for at least 20 minutes a day, for long periods of time. In our experience, the most suitable method is the mixed approach, i.e., the exercises are done at home and once or twice a week at a rehabilitation center under the supervision of a physiotherapist. This method stimulates the patient to continue treatment and makes it easier to perform exercise therapy, particularly if the latter should be continued for a long time. Usually the efficacy of exercises can be noted 2 to 4 weeks after the onset. Only following this period should the exercise program be suspended, if the symptoms are not relieved.

We start with the postural exercise therapy performed by patients with disc herniation treated conservatively, and then we advise more strenuous, dynamic exercises, aimed at strengthening and stretching the anterior and posterior muscles of the trunk and lower limbs.

Numerous randomized studies have compared the effects of an exercise program with those of other conservative treatments in operated and non-operated patients with chronic low back pain (7, 12, 15, 23–25, 30, 39, 40, 50). In the majority of studies, exercises were found to be more effective than control treatments (physical therapy, rest, behavioral therapies, placebo or no treatment). In a meta-analysis of the literature, no significant differences emerged, in terms of therapeutic efficacy, between the various types of exercises (9).

Low back school

Back schools may be useful in patients with chronic lumboradicular pain. However, it is still unclear whether the benefits are essentially due to the exercise therapy or whether the implementation of correct postures plays a relevant role in this respect. Furthermore, it is unknown whether low back schools are equally effective in operated, as in non-operated, patients. None of the many prospective randomized studies carried out to evaluate the effectiveness of this form of treatment have specifically analyzed patients with chronic postoperative pain.

Psychologic therapy

Psychologic therapies carried out in patients with chronic lumboradicular pain are essentially represented by operative behavioral, and cognitive behavioral, treatments.

Operative behavioral treatments are aimed at eliminating maladjustment to pain (for instance, reduction of general level of physical activity and refusal of activities causing pain) and at promoting well-being behaviors (increased level of physical activity or return to work). One of the methods to increase physical activity is to progressively modify the duration of periods of rest and physical activity. For instance, initially the patient is encouraged to perform exercises for 15 minutes every hour. Subsequently, the period of activity is increased progressively, whilst the period of rest is proportionally decreased. The same schedule may be applied to the uptake of analgesics. Another method is to provide social support in the form of appreciation and attention by the physician or the therapist when positive behavior is shown, and to reduce social support when excessive pain is manifested.

Cognitive behavioral treatments include various therapeutic modalities, such as muscle relaxation, diversion of attention, imaginative activities and active strategies to cope with pain. Of the various muscle relaxation techniques, the most commonly used is teaching the patient to relax various muscle groups in a progressive order and symmetrically, with or without the use of biofeedback techniques. Diversion of attention from pain may be obtained by means of mental concentration on specific thoughts or physical activities, such as walking or exercising. Imaginative activities consist in concentrating the mind on pleasurable or gratifying images or transforming the perception of pain into another sensation, for instance a warm sensation. The strategies to cope with pain are aimed at transforming negative thoughts and attitudes into rational ideas in order to minimize the importance of the painful stimuli.

The majority of studies (1, 8, 11, 18, 24, 33, 34, 42, 46–48) that have analyzed the efficacy of behavioral therapies, have shown that these are effective in reducing chronic low back pain, however almost all prospective randomized studies present methodological flaws, and this leaves many doubts on the real efficacy of these forms of treatment. Furthermore, it is not clear whether operated patients have similar results to those not operated on.

Functional restoration programs

At the beginning of the 80's, Tom Mayer developed a multidisciplinary program for physical, occupational and psychosocial restoration in patients with chronic low back pain at the Productive Rehabilitation Institute of Dallas for Ergonomics (PRIDE). The program, realized under the guidance of physicians, psychologists, physiotherapists and occupational therapists, lasts 8–10 hours a day for 3 weeks, and then continues for 1 and a half days a week for a maximum of 6 weeks, depending on the level of functional restoration attained during the intensive phase. The program starts with patient's functional, occupational and psychologic assessment. After this phase, three types of treatment are carried out: physical reconditioning of the whole body by means of exercises of increasing difficulty, occupational therapy carried out through simulated work activity (for example, lifting objects of increasing weight, climbing stairs, sitting in front of a computer for progressively longer periods of time) and psychologic therapy or support, aimed at modifying behavioral distorsions and conflicts in the familial and social environment. In addition, principles of postural education and ergonomics, as well as active strategies to cope with acute pain, are taught.

Other functional restoration programs have been developed, based on the PRIDE program (5, 16, 35, 44). All the programs are directed primarily at returning the patient to a productive workplace.

Few studies have evaluated the results of the functional restoration programs. In most of the trials (5, 16, 31, 32, 44), it was found that a large proportion of patients who participated in the programs obtained pain relief, a decrease in physical and psychologic disability, and an increase in physical performance. Furthermore, the majority of patients (56%–87%) returned to work, whereas less than half (27%–41%) of the control patients did. In the only study reporting negative results, 23% of patients had resumed work 18 months after the end of the program (35).

Work disability

A patient who develops lumbar disc herniation as a result of an accident at workplace may have a permanent partial decrease in working ability. The degree of impairment depends on numerous factors, such as the type of treatment (conservative or surgical) and the quality of outcome, the type of work, the pre-existent degenerative vertebral changes and the nature and severity of the possible neurologic lesions.

The Social Security Rulings in the United States (41) attributes patients with disc herniation a permanent disability rate of 0 to 25%, depending on the type of treatment and residual symptoms. These rulings establish that a patient with disc herniation should do less physically strenuous work than a patient with no pathologic lumbar condition. This is conceivable, taking into account that a patient operated on for disc herniation is more likely to have low back pain if he/she is engaged in a heavy or very heavy work. Neurologic lesions are generally evaluated separately from vertebral impairment. According to the *Guides to the Evaluation of Permanent Impairment* of the American Medical Association (14), the percentage of permanent partial impairment of the lower limb for a complete neurologic deficit of L3-S1 nerve-roots ranges from 24% to 40%. By means of conversion tables, these percentages are transformed into percentages of disability of the whole person. The AMA Guides are based on the concept that every part of the body is a portion of the whole person, and the percentage assigned to each part is based on the notion of function. The spine contributes a maximum of 60% of the functions of the whole person.

The *Barème des accidents du travail et maladies professionnelles* (4) assigns a percentage of disability of 10%–60% for disc herniation with monolateral sciatica and 40%–85% when sciatica is bilateral. The percentages vary depending on the severity of pain, the degree of vertebral range of motion and the severity of neurologic deficit.

In Italian industrial injury legislation, rating of physical impairment caused by disc herniation is not provided for. In the *Tabelle delle valutazioni del grado di invalidità permanente*, which evaluate the degree of permanent impairment and are attached to the Industrial Injury Act, the percentages of impairment produced by disc herniation or nerve-root lesions are not listed (26). The percentages of disability for peripheral nerve lesions range from 15% to 50% for monolateral paralysis of the posterior tibial nerve and sciatic nerve, respectively. Evaluation of permanent neurologic lesions caused by disc herniation can be based on the degree of loss of function of the respective peripheral nerve or nerves.

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·CHAPTER 18·

COMPLICATIONS OF SURGERY

F. Postacchini, G. Cinotti

Morbidity and mortality

The incidence of surgical complications has been reported to range between 1.6% and 9.1%, in series in which more than 1500 cases have been analyzed (23, 100, 114, 137). The complications have a slightly higher incidence in women and increase in proportion to the patients age; in patients over 65 years old the complication rate is more than twofold compared with patients aged less than 40 years (23). The incidence of complications is significantly higher in reoperated patients (114), in those with lumbar stenosis and in patients submitted to spinal fusion (23). No difference in the complication rate has been reported between patients operated on by orthopaedic surgeons or neurosurgeons (100). The most frequent complications are: hemorrhages or hematoma infections (superficial or deep), dural sac or nerve-root injuries, cardio-pulmonary disturbances and urinary and gastrointestinal dysfunctions.

In a series of 22,888 operations for herniated discs reported by 53 studies, Spangfort (124) found a mortality rate of 0.3%, while in a series of 2504 cases analyzed by the author, the mortality rate was 0.1% (Table 18.1). In a multicentric study of 3032 cases, Oppel (88) reported an incidence of 0.29%. In studies carried out more recently, however, a markedly lower mortality rate has been reported: 0.013% of 68,329 cases analyzed by Wildförster (137), 0.017% of 17,058 patients reported by Roberts (102), 0.059% of 28,395 cases analyzed by Ramirez and Thisted (100) and 0.07% of 18,122 lumbar spine operations (84% of which performed for disc herniations or lumbar stenosis) analyzed by Deyo et al. (23). In the last series, the mortality rate during hospitalization reached 0.6% in patients older than 75 years.

The most frequent causes of death are cardiac, vascular and respiratory complications, and severe infections with septicemia.

Cardiovascular complications

Cardiac complications

The reported incidence of myocardial infarction ranges from 0.002% to 0.15% (100, 114, 137). Together with injuries to abdominal vessels, myocardial infarction is the most frequent cause of intraoperative or early post-operative mortality. In one series (100), 52% of patients who had a heart attack died. A similar mortality rate due to myocardial infarction is reported for others

Table 18.1. *Percent of mortality in operations for lumbar disc herniation.*

Author	No. of operations	% of mortality
Love (1947)	1217	0.2
Busch et al. (1950)	1200	0.3
Gurdjian et al. (1961)	1176	0.2
Semmes (1964)	5000	0.0
Spangfort (1972)	2504	0.1
Oppel et al. (1977)	3032	0.29
Roberts (1988)	17,058	0.017
Ramirez et al. (1989)	28,395	0.059
Wildförster (1991)	68,329	0.013
Deyo et al. (1992)	18,122	0.07

non-cardiac operations (43). Less frequent and less fatal cardiac complications are represented by congestive heart failure and atrium or ventriculum arrhythmia.

Thrombophlebitis and pulmonary embolism

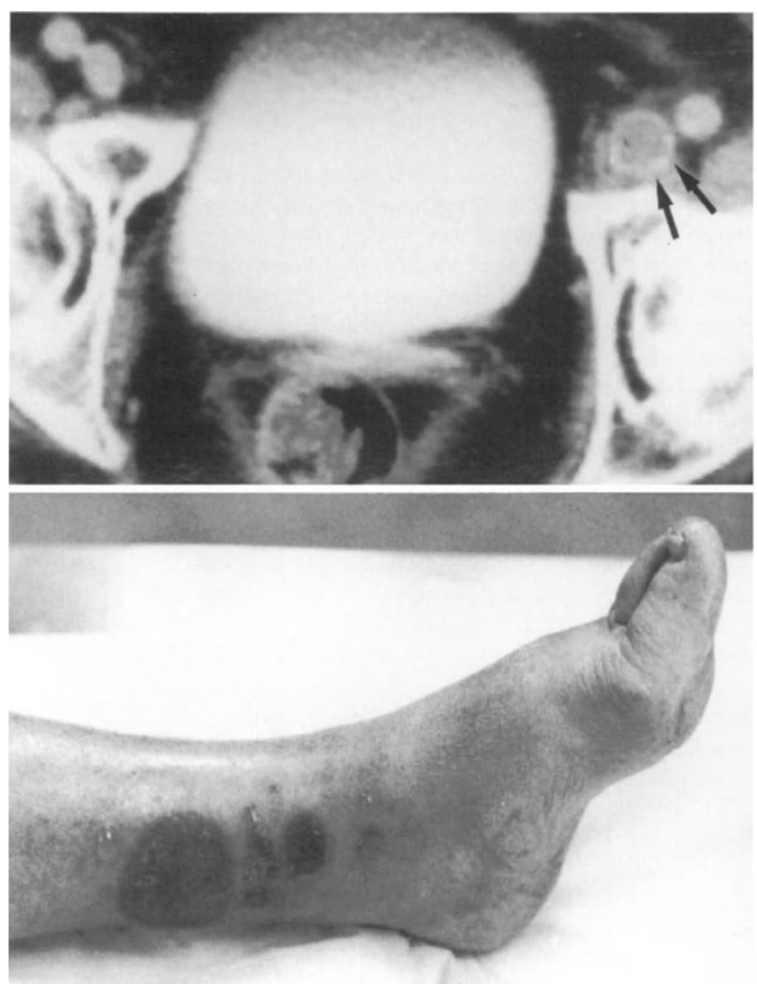
Thrombophlebitis in the lower limbs is reported as having an incidence ranging from 0.1% to 1.4% (23, 24, 38, 39, 114, 124). The incidence is higher in patients submitted to spinal fusion. Usually this complication becomes evident within 2 weeks of surgery. In exceptional cases an extensive thromboflebitis may occur (Fig. 18.1).

The incidence of pulmonary embolism in patients who undergo discectomy ranges between 0.008% and 0.8% (12, 24, 100, 114, 124, 137). In one series (124), pulmonary embolism was diagnosed in more than one third of patients who had thrombophlebitis. In a series of 28,395 patients analyzed by Ramirez and Thisted (100), a fatal pulmonary embolism occurred in 0.01% of cases; such a low rate indicates that discectomy should be included among the operations presenting a low risk of fatal pulmonary embolism.

Due to the low incidence of thrombophlebitis, a prophylactic treatment with heparin is not usually needed after discectomy. However, an antithrombotic prophylaxis, including the application of elastic stockings during the operation and/or administration of heparin, is recommended in elderly patients, particularly if the operation is of long duration (stenosis associated with arthrodesis), and it is always necessary if the patient is left in bed for a few days after surgery.

Cerebral circulatory disorders

The reported incidence of strokes and cerebral ischemia is 0.02% and 0.005%, respectively (100, 137). The inci-



A

B

Fig. 18.1. *Severe iliofemoral thrombophlebitis (flegmasia alba dolens) following laminotomy for disc herniation.* (A) *Axial CT scan at the level of the hip joint showing a thrombotic occlusion of the left external iliac vein (arrows).* (B) *Marked swelling of the left inferior limb with large cutaneous lesions on the medial aspect of the distal portion of the leg.*

dence of strokes in patients who undergo discectomy is slightly but not significantly higher than that reported for the general population under 75 years of age (100).

Superficial infections

Superficial cutaneous and subcutaneous wound infections are reported with an incidence of 2%–3% (100, 124). In effect, if mild infections which resolve in a few days are also taken into account, the incidence is probably higher. The complication is considerably more frequent in diabetic than non-diabetic patients. Often the infection is associated with a dehiscence of the cutaneous wound, which takes 1 or 2 weeks longer than it normally would, to heal.

In the presence of a superficial wound infection, systemic antibiotic therapy is not generally necessary. Frequent dressing and cleaning of the surgical wound is needed as well as moderate rest to reduce mechanical stresses on the cutaneous wound.

Spondylodiscitis

Terminology

Three different pathologic conditions should be distinguished: discitis, spondylitis and spondylodiscitis. Discitis is a condition in which the infective process does not spread through the end-plates of the adjacent vertebrae and does not extend to the bone tissue of the vertebral bodies. If the infection spreads to the vertebral bodies, a spondylodiscitis develops. Spondylitis, or vertebral osteomyelitis, is a condition in which the infection initially develops in one or more vertebral bodies; often the infective process subsequently spreads to the disc and causes, in this case also, a spondylodiscitis. This sequence is probably the rule in primary vertebral infection, while in postoperative infections it is theoretically possible, but probably is extremely rare. The vast majority of – or probably all – postoperative vertebral infections, begin as discitis and then usually become spondylodiscitis. Aseptic discitis, or aseptic vertebral necrosis, is a condition characterized by pathologic changes similar to those caused by infective discitis, but it is not caused by bacterial agents.

Incidence

In many series, the incidence ranges between 0.1% and 3%. (11, 12, 15, 21, 27, 36, 46, 65, 68, 72, 89, 94, 99, 101, 106, 108, 109, 111, 129, 131, 134, 136) (Table 18.2). In most series, however, the incidence is less than 2%.

The type of discectomy, i.e., partial or complete, does not seem to influence the incidence of infective complications. In some microsurgical series (129, 141), the incidence of spondylodiscitis was higher than that reported after standard discectomy, whilst in other series the opposite was found (21, 42). Overall, there does not seem to be a significant difference between the two surgical techniques. This seems to be in contrast with the finding that in the microscope wrap analysed at the end of 412 discectomies, various types of germs were detected in 12% of cases (134).

Etiopathogenesis

Staphylococcus aureus and epidermidis are the micro-organisms more frequently identified in patients with postoperative spondylodiscitis (20, 27, 72, 93–95, 101, 127). These bacteria are probably responsible for 80%–90% of spondylodiscitis. In the remaining cases, E. coli and Streptococci (faecalis, haemolyticus, viridans) are the micro-organisms most frequently involved.

Two pathogenetic hypotheses have been put forward to explain infective postoperative spondylodiscitis: a direct contamination of the disc space during surgery, or a diffusion of bacteria into the disc by a hematogenous route. In the latter case, the bacteria may originate from endogenous infective foci or they may be intro-

Table 18.2. *Incidence of spondylodiscitis after operations for lumbar disc herniation.*

Author	No. of operations	No. of cases	Incidence
Turnbull (1951)	300	3	1.0%
Brussatis (1954)	2000	4	0.2%
Lenschock (1956)	2000	3	0.1%
Salvi (1962)	2916	27	0.9%
Ruggeri (1965)	4962	16	0.3%
Bosch (1965)	1250	26	2.1%
Savini (1968)	2076	20	1.0%
Pilgaard (1969)	502	15	3.0%
Teng (1972)	917	3	0.3%
Greiner (1974)	1492	23	1.5%
El-Gindi (1976)	650	5	0.8%
Salenius (1977)	886	4	0.5%
Marchetti (1980)	6473	27	0.9%
Lindholm (1982)	3576	27	0.8%
Bouillet (1983)	613	5	0.8%
Rawlings (1983)	4500	11	0.2%
Puranen (1984)	1100	8	0.7%
Dauch (1986)	481	8	1.6%
Frank (1988)	6632	14	0.2%
Stolke (1989)	412	4	1.0%
Pappas (1992)	654	3	0.4%
Tronnier (1992)	412	1	0.2%

duced during the injection of drugs for anesthesia or other procedures. Whatever the pathogenetic mechanism involved, the infection could be favored by a decreased effectiveness of the immune system as a result of prolonged treatments with corticosteroids or non-steroidal antiinflammatory drugs (93).

The possibility of a hematic contamination, though attractive, is not supported by convincing data, particularly when no extravertebral infective foci have been detected. Presumably, spondylodiscitis usually originates from a direct contamination of the disc by micro-organisms which eventually spread to the adjacent vertebral bodies. This hypothesis is supported by the observation that in 17% of patients who had undergone discectomy without infective complications, various types of bacteria were found in samples of tissue excised from the disc at the end of surgery (134). When an osteomyelitis is present, the micro-organisms may reach the vertebral venous system and spread to other vertebrae. This mechanism may explain very rare cases of multiple vertebral infection (Fig. 18.2).

Postoperative aseptic spondylodiscitis has been hypothesized to explain cases with normal or slightly high values of ESR and CRP and no evidence of the typical histologic changes of infection, nor of bacterial growth in the material obtained with biopsy (35, 140). In these forms, bony destructive processes are generally mild, whilst there can be evident sclerotic reactions of the vertebral bodies (140). In our experience, postoperative forms of this condition are very rare whereas, primary forms are less rare. Aseptic spondylodiscitis might be due to inflammatory processes, of mechanical origin, both of the disc and the vertebral end-plates.

Clinical presentation

Usually, postoperative spondylodiscitis appears clinically within the first 10 days after the operation. Prior to the clinical onset fever is frequently present, but is usually mild.

The main symptom is a more severe low back pain than in the normal postoperative course. Normally, postoperative low back pain is mild and tends to progressively diminish after surgery. The presence of disci-

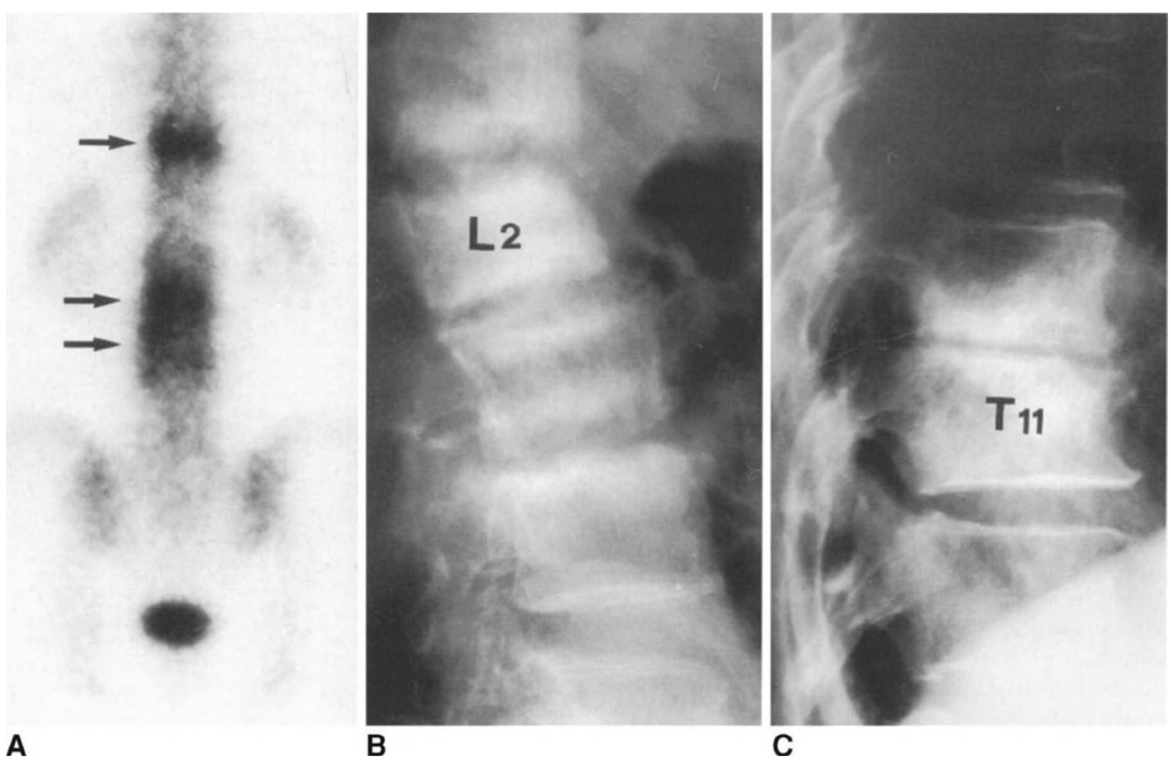


Fig. 18.2. *Patient submitted to laminectomy at L2-L4 levels and discectomy at L2-L3 with postoperative plurisegmental spondylodiscitis and diffusion of the infective process to the thoracic spine. Radiographs were negative 25 days after surgery while TC 99 bone scan* (A) *showed an increased uptake at L1-L3 and T10-T11 levels (arrows). Sixty days after surgery* (B), *radiographs showed spondylodiscitis at L1-L2, L2-L3 and L3-L4 levels with destruction of the anterosuperior aspect of the L2 vertebral body, resulting in segmental kyphosis at L1-L2 level. At T10-T11 level* (C) *a marked reduction in the disc height with irregularity of the vertebral end-plates and subchondral bone sclerosis were present.*

tis is characterized either by the persistence of intense low back pain immediately after surgery or, more frequently, by the appearance of severe pain after an initial period of well-being or by an unexplainable and progressive daily worsening of the normal postoperative low back pain. The pain increases both in the standing and sitting position and upon trunk movements. For this reason, the patient, who has started to get up several times a day during the first postoperative days, gets up less and less willingly and eventually refuses to get up at all. Even bed movements are painful and become increasingly difficult. Radicular pain, on the other hand, is not usually characteristic of discitis.

The fever is variable. In the first few days after the clinical onset of spondylodiscitis, it is often present, but rarely exceeds 38°C. Subsequently, it disappears or a light persistent fever may be present for variable periods of a few days or weeks. However, the presence of fever alone, without low back pain, is never a characteristic feature of discitis, while the absence of fever does not exclude discitis.

The surgical wound is rarely entirely normal, though it is also true that marked signs of cutaneous infection are seldom present. Generally, the skin is slightly swollen and reddened, and scant serous-purulent material may leak out if pressure is exerted around the wound. The wound may take a normal amount of time to heal, or it may take a few days, or in rare cases weeks, to heal.

Generally, 2–3 weeks after the onset of clinical symptoms, the patient complains of extremely severe low back pain, which is accentuated by even the slightest trunk movements. Often the pain radiates to the abdomen or more rarely to the groin. Severe spasm of the paravertebral muscles is present as is, in some cases, postural scoliosis in the standing position. Usually, there is no fever and the surgical wound is healed.

Some authors (72, 111) have described subacute and chronic forms of postoperative spondylodiscitis. The subacute form usually appears 2 to 4 weeks after surgery and is characterized by milder low back symptoms with respect to the forms with an earlier onset. The chronic form usually manifests itself 1–2 months after the operation, with mild low back pain. These forms may be due to low-virulence micro-organisms; a more convincing hypothesis, however, is that in most cases they are the result of spondylodiscitis being diagnosed late. Postacchini et al. (95, 96) reported on two groups of patients with spondylodiscitis who were analyzed retrospectively and prospectively. In the retrospective group, two thirds of the patients related the onset of the first symptoms back to 3–4 weeks after the operation. Instead, in the group analyzed prospectively, all the patients showed a deviation from the normal postoperative course 3 to 9 days after surgery. This finding suggests that an infective complication is usually already clinically manifest during the first few days after the operation, but it can initially be overlooked if the immediate postoperative course is not carefully observed.

Spondylodiscitis very rarely causes meningitis or septicemia. In the first case, the clinical picture is that typical of meningitis, with which encephalitis may be associated. Septicemia may occur in debilitated patients.

Diagnosis

Laboratory investigations

Various studies (8, 55, 59, 96) have analyzed the ESR values in patients submitted to discectomy who had not had postoperative infective complications. In the majority of cases, ESR does not increase after the operation. In a minority of patients, however, the ESR values increase, sometimes even considerably. This tends to occur particularly in patients showing a high preoperative ESR (normally less than 25 mm/h) or when a spinal fusion is performed. In these cases, however, ESR very rarely exceeds 70 mm/h and almost always tends to return to the preoperative values in the second or third week after the operation. In no case, however, has a tendency towards increasing ESR values been found after the first postoperative week. Of the 70 patients analyzed by Postacchini et al. (96), who underwent an uncomplicated discectomy, 14 showed a sharp increase in ESR 1 week after surgery, whilst after 2 weeks, the ESR values had decreased in all but two cases.

In patients with spondylodiscitis, ESR almost constantly increases from the 10th day after surgery. The most characteristic finding, however, is that the ESR value tends to increase further 2 to 3 weeks after the operation. Subsequently, it remains stable for a few weeks and then tends to gradually decrease with the resolution of the infective process. The maximum values usually range from 60 to 120 mm/h. Therefore, a marked increase in the ESR after discectomy should be considered suspect, particularly if the value exceeds 70 mm/h in patients with normal pre-operative values. In these cases, the ESR should be evaluated 2 weeks after surgery. If the value increases further, it is probable that discitis is present and this becomes a clinical certainty if it is accompanied by fever and/or abnormally severe low back pain.

C-reactive protein (CRP) usually increases after a discectomy without infective complications. It reaches the maximum value (about 30 mg/l) on the second postoperative day and returns to normal values within the first week after the operation (59). In patients with spondylodiscitis CRP generally shows a marked increase in the first postoperative days. High CRP concentration usually persists for a few weeks and then tends to decrease to normal values more rapidly than the ESR. CRP shows higher specificity in diagnosing an infective process compared with ESR.

Only a minority of patients with spondylodiscitis present hematic leukocytosis and, usually, this is of mild entity. Sometimes, in patients with high fever, a blood culture may allow detection of the micro-organism reponsible for the infective process.

Imaging studies

Radiography

Radiographs are negative in the first 4–6 weeks after the operation. This interval corresponds to the time needed for the occurrence of osteolytic changes in the vertebral bodies adjacent to the affected disc. One month after surgery, irregularities in the profile of the vertebral end-plates are initially visible, followed by areas of erosion in the subchondral bone (Fig. 18.3). Successively, if the infection has not been stopped, the destructive process involves the trabecular bone of the vertebral body, which may undergo severe or even massive osteolytic changes. Generally, one vertebral body is affected to a greater extent than the other. Moreover, the anterior part of the vertebral body usually shows a more marked destruction. In the course of 2 or more months the intervertebral disc usually shows a decrease in height, often of marked entity. In the late phase, sclerotic changes of the portion of the vertebral bodies adjacent to the disc are visible.

Tomography. Anteroposterior and lateral tomograms may reveal the initial changes of the vertebral end-plates only 3–5 weeks after the onset of the infective process. Hence, tomography has a higher diagnostic value than plain radiographs, but it entails exposure to a high dose of radiation.

Bone scanning

Although not very specific, bone scan is very effective in identifying a spondylodiscitis (Fig. 18.2). The investigation should be carried out with TC 99 or GA 67 (page 271). With the advent of MRI, however, the diagnostic utility of the bone scan has considerably decreased. It may, in fact, become positive after a discectomy without any infective complication (119) and it does not usually become positive earlier than MRI.

Computerized tomography

CT scans may show: osteolytic lesions, usually multiple, of the vertebral bodies; inflammatory reactions in the prevertebral and/or laterovertebral soft tissues, along with obliteration of the fat tissue or formation of perivertebral abscesses; and edema or purulent epidural collections (Fig. 18.4). The latter are more evident when the investigation is carried out after intravenous injection of contrast medium and they may represent the first changes that can be seen on CT scans, being

A B

Fig. 18.3. *Patient with isthmic spondylolisthesis of L5 and L5-S1 disc herniation submitted to discectomy and unilateral foraminotomy. The preoperative radiograph* (A), *revealed the isthmic lesion and a mild olisthesis; the height of the disc space was about half that of the adjacent disc. Two weeks after surgery the patient complained of a worsening of back pain, which persisted during the following weeks. The radiographs were negative until 50 days after the operation. At that time* (B), *they showed irregularities and erosions of the vertebral end-plates at L5-S1. A further reduction in the disc height and an increase in the olisthesis of L5 occurred.*

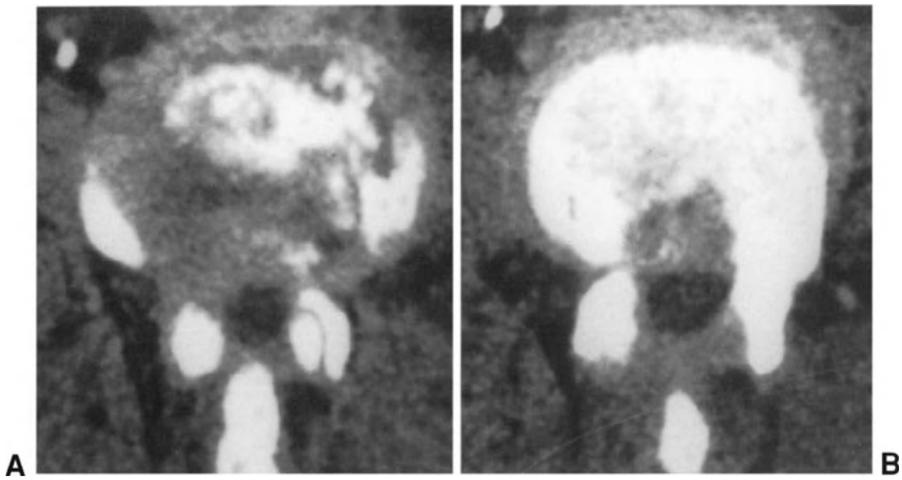


Fig. 18.4. *CT scans in a patient with spondylodiscitis following laminotomy and discectomy at L3-L4 level. The CT scans show a marked destruction of the L4 vertebral body, with diffusion of the infective process to the soft perivertebral tissues* (A) *and a large erosion of the posterior portion of L3 vertebral body* (B).

already visible just 2 weeks after surgery (45). However, CT scans do not show a high specificity since similar changes to those found in spondylodiscitis can be noted in other conditions, such as fractures, tumours or marked degenerative changes of the vertebral bodies. A discitis can be diagnosed on CT images only when all the three typical changes characteristic of spondylodiscitis are present (61).

Magnetic resonance imaging

Numerous studies have analyzed the role of MRI in diagnosing a primary spondylodiscitis (3, 37, 82). However, little is known on MRI changes, and its diagnostic accuracy, in postoperative spondylodiscitis.

In patients with spondylodiscitis, MRI shows two types of change: a decreased signal intensity of the disc and adjacent vertebral bodies on T1-weighted sequences; and an increased signal intensity of the disc and the adjacent portion of the vertebral bodies invaded by the inflammatory process on T2-weighted images (Fig. 18.5). On T1-weighted images, the reduction in signal intensity, presumably due to a decreased vascularization of the vertebral body, may involve the whole vertebral body or only a part of it; furthermore, on T1-weighted sequences it is often impossible to distinguish the disc from the vertebral body. (Figs. 18.5 and 18.6). On T2-weighted images, the signal hyperintensity may involve the whole disc or only a part of it; moreover, the disc does not show the normal band of nuclear hypointensity (intranuclear cleft) (Fig. 18.6). In these images, the vertebral body may show an extensive increase in signal intensity or, more frequently, localized areas of hyperintensity, often in continuity with the disc.

In postoperative spondylodiscitis the first changes are already visible 3 weeks after the operation (95).

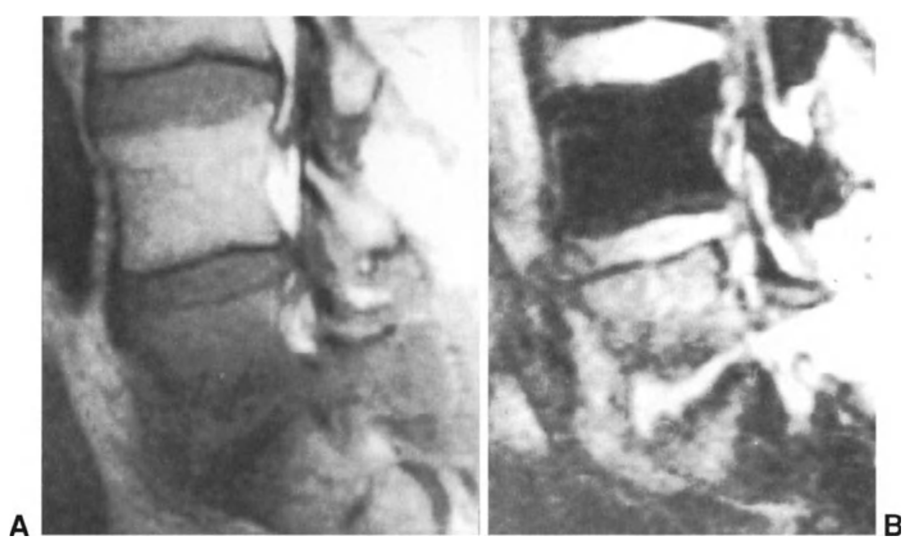


Fig. 18.5. *MRI scans in a patient with postoperative spondylodiscitis at L5-S1.* (A) *Spin echo T1-weighted sagittal image showing a diffused reduction in the signal intensity at L5 and S1 vertebral bodies. The L5-S1 disc is also hypointense and cannot be distinguished from the adjacent vertebral bodies.* (B) *Spin echo T2-weighted sagittal image which reveals an increase in the signal intensity of the disc and the adjacent vertebral bodies. Moreover, erosions of the ventral half of the vertebral end-plates of L5 and S1 are visible.*

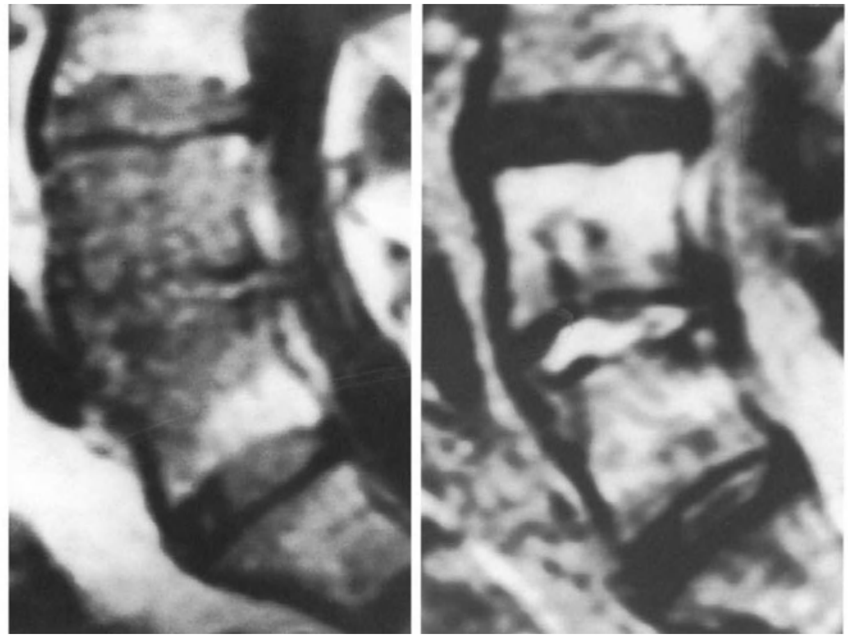


Fig. 18.6. *MRI scans in a patient with postoperative spondylodiscitis at L4-L5 level.* (A) *Spin-echo T1-weighted sagittal image showing a decreased signal intensity of the L4-L5 disc and most of the adjacent vertebral bodies. Note that the disc is no longer distinguishable from the L4 and L5 vertebral bodies.* (B) *Spin-echo T2-weighted sagittal image demonstrating an increase in signal intensity of the L4-L5 disc.*

A

B

With the resolution of the infective process, the changes in the signal intensity slowly disappear; this occurs more rapidly in the disc than in the vertebral bodies.

Biopsy

In many series, the proportion with which a biopsy has allowed the identification of the micro-organism involved ranges from 33% to 82% (8, 20, 35, 93, 95, 101, 132), but only in three of these (20, 93, 95) did this occur in more than half of the patients. On the other hand, no significant differences were found in the average duration of the antibiotic treatment between patients who underwent biopsy and those who did not (20, 32, 95, 132). On the basis of these findings, we believe that the decision both to carry out biopsy and to avoid it may be justified. The latter strategy has the advantage that antibiotic therapy can be administered earlier, as soon as an infective complication is suspected.

Our current approach is to always carry out a CT-guided needle biopsy under local anaesthesia when spondylodiscitis is thought to be present, once the antibiotics administered for the postoperative antibacterial prophylaxis have been discontinued for at least 3 days. If the bacteriological culture is negative and the antibiotics successively administered have not led to a significant improvement in the clinical picture or normalization (or tendency to normalization) of the laboratory tests after 4 weeks of treatment, the antibiotic therapy is discontinued for at least 8 days and a second biopsy is carried out. In this case, we use a trocar with a 5–7 mm caliber to collect an adequate amount of disc tissue and bone from the adjacent vertebral bodies.

Treatment

Conservative treatment

The conservative treatment is based on the administration of antibiotics and immobilization of the lumbar spine. Although in the past a few studies (94, 127) have questioned the usefulness of antibiotic therapy in postoperative spondylodiscitis, the therapeutic efficacy of second-generation antibiotics renders useful, if not mandatory, a treatment with antibacterial agents. When the culture of the material obtained from biopsy has identified the micro-organism responsible for the infection, there are usually no doubts regarding the antibiotics to be used. They should be chosen among those which result as being more effective against the identified germ, which are capable of penetrating the intervertebral disc (page 426) and have a low general toxicity. Furthermore, an antibiotic which can be administered both intravenously and intramuscularly should be preferred, so as to commence the treatment intravenously for 1–3 weeks and then continue it intramuscularly.

When the micro-organism is unknown, two antibiotics should usually be used, one active against Staphylococci i.e., the bacteria responsible for almost all postoperative spondylodiscitis, and one with a wide spectrum. Since some strains of Staphylococcus are resistant to penicillin and its derivatives, it is preferable to use antibiotics, such as teicoplanin, which are active against penicillin-resistant Staphylococci also. When choosing a wide-spectrum antibiotic – usually a cephalosporin – one which can be administered orally should be preferred considering the long duration of the treatment. In particular cases, an antibiotic specifically active against gram-negative micro-organisms can be administered for a few weeks at the beginning of the treatment.

The antibiotic treatment should be prolonged until the ESR has retuned to normal or nearly normal values or pain has disappeared. This usually occurs within a few weeks if the antibiotic is chosen on the basis of an antibiogram. When the germ is unknown, the duration of the treatment depends on how rapidly the diagnosis has been made and an adequate antibiotic administered. If the treatment is started within the first 10 days of the operation, 4–8 weeks of antibiotic therapy are usually necessary; if the beginning of the treatment is delayed, it usually lasts longer than 2 months (95, 96).

Immobilization of the lumbar spine with a plaster cast, a plastic corset or a canvas corset considerably decreases low back pain. The choice depends on the severity of the symptoms and the destructive vertebral lesions. Immobilization should last at least until the most painful symptoms have been resolved.

A suspected aseptic spondylodiscitis should be treated as an infective form, since the certainty that the clinical and radiographic picture is not caused by a bacterial agent is rarely obtained. On the other hand, if the ESR is normal, the antibiotic treatment should last no more than 30–40 days. If the painful symptoms recur once antibiotics have been discontinued, the treatment should be resumed, since it is unlikely that an aseptic form is present.

Clinical and radiographic evolution

The time necessary for the infective process to resolve varies from a few weeks to several months. The resolution is decidedly more rapid when the diagnosis has been made in the first postoperative days and the antibiotic treatment is both early and energetic (95). This is true when appropriate antibiotics are used, even if the pathogenic germ has not been identified, and mainly when the treatment is based on the results of an antibiogram. In these cases, a marked resorption of the disc is likely to occur and almost always osteolytic changes are visible in one or both of the adjacent vertebral bodies; such changes, however, are usually of mild entity (Figs. 18.7 and 18.8).

When a late diagnosis has been made and/or an inadequate antibiotic treatment administered, the infective process usually resolves in 3–6 months. In these cases, marked osteolytic vertebral changes often occur in addition to constant disc resorption (Fig. 18.9). Furthermore, since the infective process more frequently and markedly involves the anterior portion of the vertebral body, a kyphosis of the affected motion segment very often occurs (Fig. 18.2 B).

Spontaneous interbody fusion of the vertebral motion segment frequently occurs over time. This is more likely to take place in the presence of osteolytic changes of the vertebral bodies. A solid fusion generally

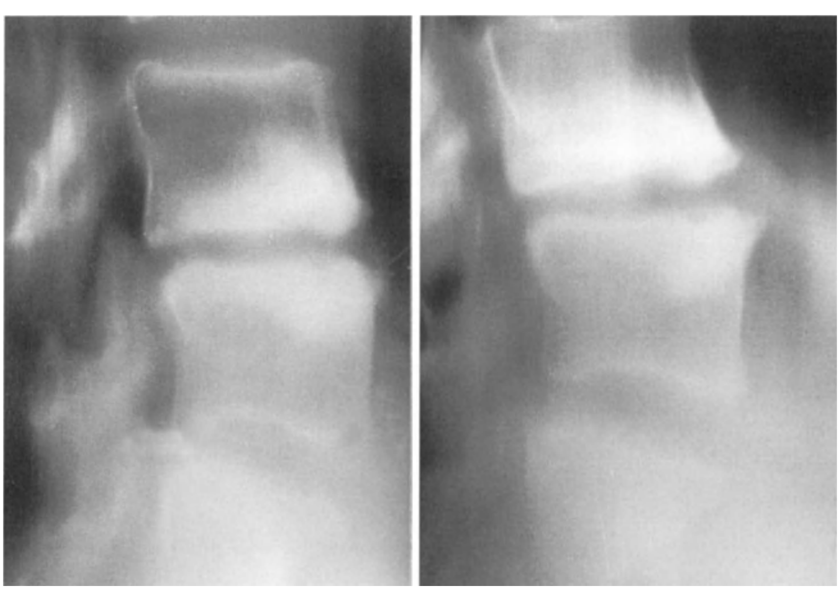


Fig. 18.7. *A patient with postoperative spondylodiscitis at L4-L5 level submitted to early antibiotic treatment. Tomographic scans carried out 5 months after the operation reveal small erosions of L4 and L5 vertebral end-plates and subchondral bone sclerosis, which is localized more extensively in the anterior half of the vertebral bodies.*

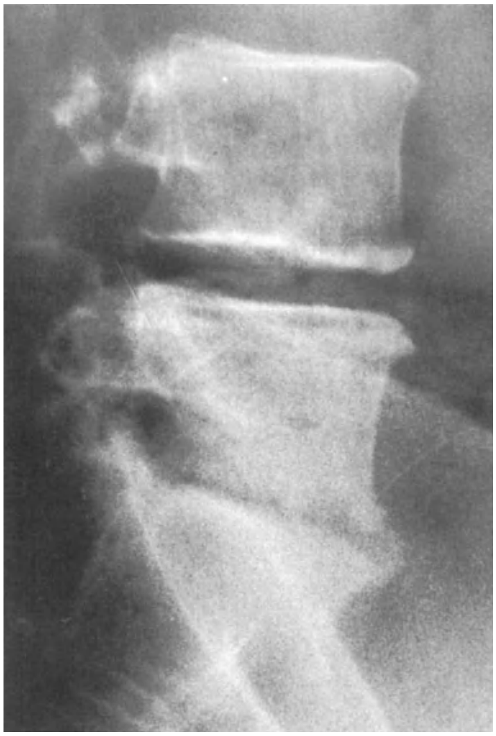


Fig. 18.8. *Postoperative spondylodiscitis at L5-S1 level in a patient who had undergone early antibiotic therapy. The radiograph shows a marked decrease in disc height at the operated level and erosions of L5 and S1 vertebral end-plates.*

develops over a time interval ranging from 1 to 3 years (Fig. 18.10).

The evolution of the painful symptomatology is closely related to that of the infective process. When the latter is resolved, moderate low back pain often persists, mainly when a marked destruction of the vertebral bodies has occurred. The low back symptoms tend to disappear when an interbody fusion takes place. However, chronic low back pain may persist if kyphosis of the motion segment has developed.

Exceptionally, spondylodiscitis may reactivate even several years after the quiescence of the infective process. Mansour et al. (71) described the case of a patient in whom a staphylococcical vertebral osteomyelitis reactivated after 34 years causing a psoas abscess.

Surgical treatment

Surgical treatment can be carried out either in the early stage, i.e., the first weeks after discectomy, or after 2 or more months.

Some authors have performed an early surgical treatment to evacuate the infective material in all cases (27) or occasionally (127, 130, 132). Surgery has led to a rapid and marked improvement of the clinical picture in all the patients treated by El-Gindi et al. (27), but in only one of the three patients operated on by Sullivan et al. (130).

In the presence of postoperative spondylodiscitis, it is often very difficult to decide whether to carry out conservative therapy obstinately or to perform an early operation. Even after surgery, in fact, a vigorous and prolonged antibiotic treatment should be carried out, along with spinal immobilization, as in conservative therapy. A reoperation is almost always advisable in the presence of further complications, such as an epidural abscess, meningitis or a cerebrospinal fluid fistula. It is never recommended, however, when a biopsy has identified the micro-organism involved and the antibiotics to which the germ is sensitive.

When a needle biopsy is negative, the aims of the operation can be: to obtain an adequate amount of infective material so as to increase the chances of a positive culture; to favor both the penetration of the antibiotics into the disc and their action against the bacteria, by removing the necrotic material and curetting the vertebral end-plates; and to reduce pain. However, the abundance of infective material does not significantly increase the probability of obtaining a positive culture; on the other hand, some of the second-generation antibiotics have been found to be able of penetrating the disc even when the cartilaginous end-plate is intact (page 421) and the operation, in any case, does not guarantee a reduction in the low back symptoms. Therefore, an early operation may be appropriate only when, despite an adequate antibiotic therapy lasting a few weeks, extremely severe pain persists and the diagnostic investigations show, or suggest the possible occurrence of, an extensive destruction of the vertebral bodies.

In a late phase, surgical treatment may be useful to eliminate a persistent infective process and avoid severe kyphosis of the motion segment in the presence of an extensive destruction of the vertebral bodies. In these cases, an interbody fusion should be carried out without instrumentation, after a partial removal of the vertebral bodies until healthy tissue is definitely reached. Even in postoperative spondylodiscitis, as in primary forms (28), a solid fusion generally occurs in the usual time.

Dural tears

Incidence

Dural tears are among the most frequent complications of surgical treatment. The incidence varies from 1.6%

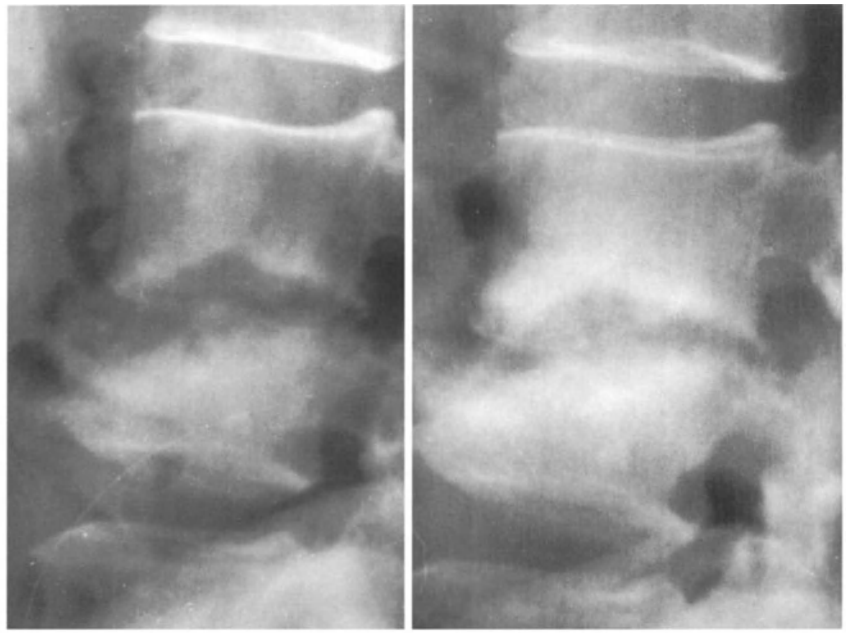

A B

Fig. 18.9. *Severe postoperative spondylodiscitis in a patient in whom a delayed and inadequate antibiotic treatment was administered. Massive destruction of the anterior superior portion of L4 vertebral body* (A) *and marked erosion of L3 vertebral end-plate occurred. Nine months after surgery* (B) *the radiograph shows a partial reconstitution of the anterosuperior part of L4 vertebral body and a tendency towards a spontaneous interbody fusion.*

to 7.5% (4, 24, 25, 39, 62, 87, 124, 129, 137) and is higher in reoperations.

There does not seem to be a significant difference between patients submitted to either standard discectomy or microdiscectomy. In fact, in some studies in which the two techniques were compared, the rate of this complication was higher in patients who underwent microdiscectomy (4, 135), whilst in other studies the opposite was found (129). Probably the incidence of the injury is more related to the surgeon's skill than to the surgical technique.

Pathogenesis, site and dimensions

The dural sac is very rarely injured when the ligamentum flavum is divided. Lesions caused by the Kerrison or pituitary rongeur are also rare. In most cases, the injury occurs during the dissection of the emerging nerve root and the thecal sac from adhesions with the herniated disc tissue or, in the case of reoperations, from the scar tissue around the nervous structures. In the presence of stenosis, the probabilities of a dural injury are higher, due to the possible adhesion of the

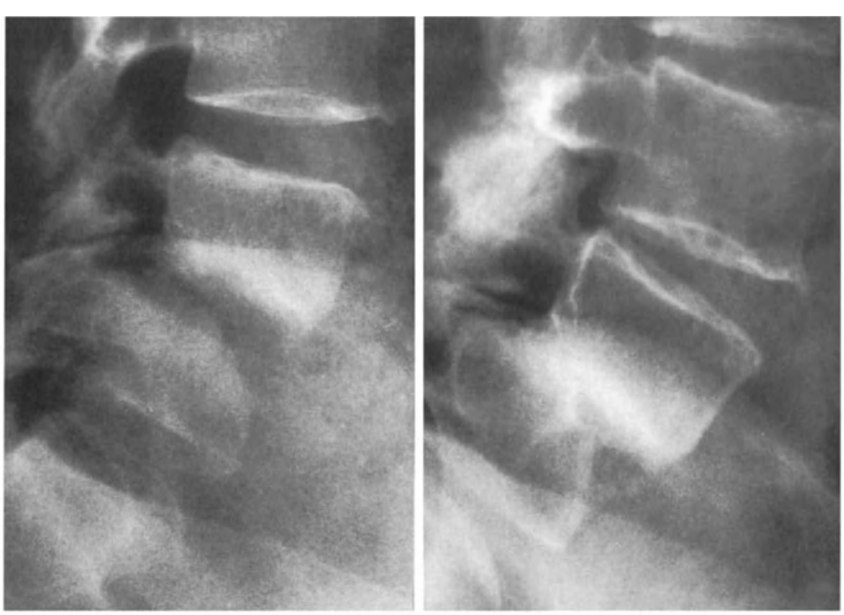

A B

Fig. 18.10. *Patient with spondylodiscitis following L4-L5 laminectomy and posterolateral fusion due to degenerative spondylolisthesis of L4. Three months after the operation* (A), *the radiograph revealed a marked destruction of the anterosuperior aspect of the L5 vertebral body. Sixteen months after surgery* (B), *a collapse of the L4-L5 disc had occurred leading to spontaneous interbody fusion and segmental kyphosis.*

Fig. 18.11. *Schematic drawing showing the most frequent sites of intra-operative dural tears.*

ligamentum flavum to the dura mater and the thinning of the dura in the areas subjected to long standing-compression (64).

Usually, the lesion is detected some time after its occurrence, due to the sudden leaking of cerebrospinal fluid. At times an incomplete dural tear is produced, which then becomes complete as a result of the continued manipulation of the nerve structures. An incomplete injury, from which there is no or very little leaking of cerebrospinal fluid, is dangerous, as the surgeon can overlook it and, if it is not treated, it can develop into a complete tear in the immediate postoperative period.

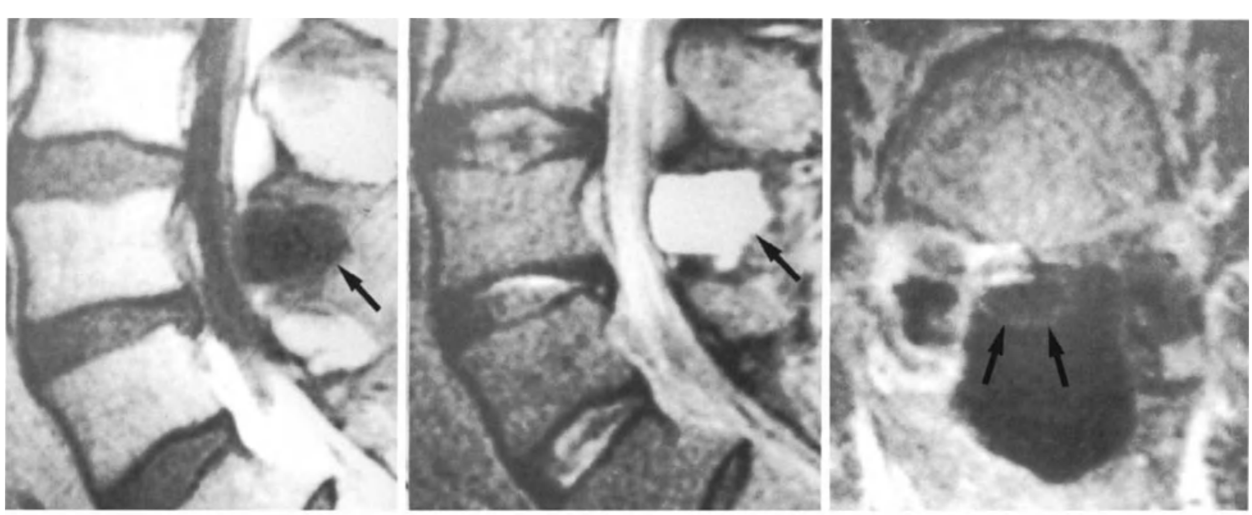
The most common sites for a dural tear are: the anterolateral aspect of the thecal sac proximally or at the level where the nerve root emerges, the lateral portion of the nerve-root sleeve where it emerges from the thecal sac and the lateral portion of the thecal sac distally to the site where the nerve root emerges (Fig. 18.11). Fortunately, injuries to the anterior portion of the thecal sac, which are poorly visible and reparable, are rare to occur.

Usually the lesion is a linear tear, 3 to 5 mm long. Less frequently, longer tears or irregular lacerations occur. Injuries causing a loss of dural substance are very rare.

Pseudomeningocele and duro-cutaneous cerebrospinal fluid fistula

An unrepaired dural tear through which CSF leakage continues after surgery may cause a pseudomeningocele or a duro-cutaneous fistula. Overall, these complications have been reported with an incidence ranging from 0.01% to 0.5% (89, 100, 114, 124).

Pseudomeningocele is a condition in which the CSF collection does not communicate externally. The fluid collection can be localized only in the spinal canal or



A B C

Fig. 18.12. *MRI scans of a patient with pseudomeningocele after bilateral laminectomy and discectomy at L4-L5 level.* (A) *and* (B) *Spin-echo T1-weighted and T2-weighted sagittal images, respectively, demonstrating a fluid collection at the operated level (arrows).* (C) *Spin-echo T1-weighted axial image which shows the close relationship between the liquid collection and the posterior portion of the thecal sac (arrows).*

it can be extraspinal. In the latter case, it may not exceed the fascial plane, or it may extend into the subcutaneous space. A CSF collection located only in the spinal canal is rare. The collection, usually of small entity, may not cause any symptom or it may compress the thecal sac and/or the emerging nerve root and produce radicular symptoms; the same applies for a subfascial pseudomeningocele (26, 81, 85, 92). Both conditions can be diagnosed by CT or MRI (Fig. 18.12). When the fluid collection exceeds the fascial plane, a fluctuating swelling measuring a few centimeters in diameter develops in the area of the cutaneous wound. In these cases, the differential diagnosis is with a serous subcutaneous collection. This is usually smaller than a pseudomeningocele and a clearly serous fluid is collected by puncturing the swelling area. In the presence of pseudomeningocele, on the other hand, the leaking fluid is tendentially white; in addition, the subcutaneous swelling tends to reform within a few hours of the fluid's evacuation. It is often the case that a definite diagnosis can only be made by using imaging studies. These show a subcutaneous fluid collection, which extends deeply into the spinal canal.

In the majority of cases, a CSF leakage occurs through a dehiscence of the cutaneous wound, forming a duro-cutaneous fistula. Due to the external communication, an infective process can develop which may cause spondylodiscitis and/or meningitis (26). Usually, when abundant CSF with the characteristic aspect of crystal clear water leaks externally, the diagnosis is easily made. However, the diagnosis is more difficult, when a dural tear has occurred but not been detected by the surgeon, or when the leaked CSF, mixed with blood, assumes a reddish-white color. This can occur in the first few postoperative days. As the days pass by, not only does the leakage of CSF continue, but it tends to become whiter. Moreover, the patient often complains of headache, particularly in the upright position, and persistent fever may be present. If there are diagnostic doubts, chemical analysis of the fluid may be carried out to identify the typical components of the CSF. In the early stage, even MRI may not aid diagnosis due to the difficulty in differentiating a CSF collection from a hematoma or a serous collection.

Treatment

In the presence of an incomplete dural tear, it is sufficient to apply one or two overlapping flaps of hemostatic sponge on the injured area and to keep the patient at bed rest for 2–3 days after the operation.

The treatment of a complete dural tear depends on the width and the site of the lesion. For tears no longer than 5 mm, two overlapping flaps of hemostatic sponges can be applied to occlude the lesion. This is particularly true for those areas where suturing the tear is demanding or even impossible, such as the ventral portion of the dural sac or the medial aspect of the emerging nerve-root sleeve. Alternatively, the tear can be sutured with one or two 5–0 silk stitches. In both cases, the surgeon should be certain that once the dural tear has been closed, the CSF leakage will stop. This can be done by positioning the patient in the anti-Trendelemburg and asking the anesthetist to increase the depth of breathing, and/or by carrying out the Valsalva manoeuvre. If hemostatic sponges are used, the patient should be left in bed in the horizontal, or slight Trendelemburg, position for 4–5 days and should be asked not to lie on the side corresponding to the dural injury; successively, only 3–4 short walks are allowed daily until the 7th postoperative day. With this treatment, carried out by us in numerous cases of small dural tears, we have always obtained the healing of the lesion. When the dural tear has been sutured, the patient is left in bed for 4 days after the operation. Experimental studies, in fact, have shown that a sutured dural lesion is already healed after 4 days (18).

Fibrin glue can be used in place of hemostatic sponge. It is prepared when needed and drops of the liquid solution obtained are put in the site of the dural tear and on the adjacent portion of the dural sac. The substance strongly adheres to the dura mater, forming an impermeable layer which resists to significantly higher pressures than the simple dural suture (18). After a few days the fibrin glue is invaded by a granulation tissue and resorbed. The substance may also be used in addition to the suture, particularly when this is not tight. Whatever the method of repair used, the thoracolumbar fascia should be seal sutured so as to obstacle the possible flow of CSF into the subcutaneous layer (26, 104).

For dural tears exceeding 5 mm, the treatment of choice is the suture of the lesion. Three conditions can be distinguished: linear tears which can be easily sutured due to their position; wide tears with tissue loss, in which a direct suture may not be possible; and tears which cannot be sutured due to their position.

The first-type lesions can be sutured either with isolated stitches or a continuous suture. The latter provides a better seal, but may be more difficult to perform due to the restricted space of the laminotomy. One of the main difficulties in suturing a dural tear, in fact, is the limited operating field in which it is to be accomplished. This is particularly true when microdiscectomy is carried out. In these cases, it may be advisable to enlarge both the skin incision and

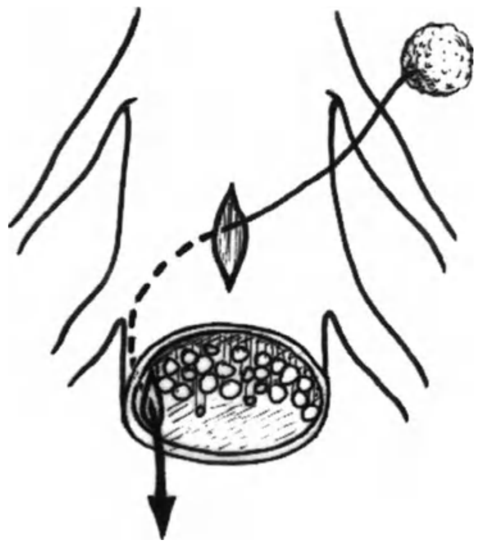


Fig. 18.13. *Repairing of an anterior dural tear: a small incision in the posterior aspect of the thecal sac is carried out and a fragment of fat or muscle graft is introduced through it. The graft is then attracted towards the lesion so as to occlude it.*

muscle disinsertion, and the laminotomy before carrying out the dural suture. Care should be taken in suturing so as not to catch intrathecal nerve roots.

In the presence of the second-type lesions, it may be necessary to close the tear with a flap of thoracolumbar fascia or with lyophilized dura. The margins of the lesion should be trimmed and sutured to the borders of the flap of the chosen material with discontinuous stitches. After the operation, the patient should be left in bed for 5–8-days depending on the seal of the suture.

When injuries occur in inaccessible zones (third type), a division of the thecal sac in its posteromedial portion can be performed in order to introduce a small fragment of fat or muscle graft into the dural tube. The fragment will be attracted towards the tear and will therefore occlude it (26, 27) (Fig. 18.13). This procedure, however, may be extremely demanding, whereby it may be preferable to occlude the tear externally with hemostatic sponge and apply a catheter cranially to the lesion.

Pseudomeningocele and cerebrospinal fluid fistula

A subfascial pseudomeningocele which is asymptomatic does not usually require any treatment. In the presence of lumboradicular symptoms, surgical treatment is indicated. Surgery should always be carried out when the pseudomeningocele extends subcutaneously. The operation consists in opening the CSF collection, identifying the dural tear, and closing it.

A CSF fistula can be treated surgically or by subarachnoid drainage. Surgical treatment should always be performed when there are clinical signs of an infective process, due to the potential risk of septic meningitis. As an alternative, before considering surgery, it may be indicated to attempt a simpler treatment, such as the application of a subarachnoid drainage. This holds particularly when it is known that the lesion, already identified intraoperatively, is located at an inaccessible site, or when the surgeon is not aware that a dural tear has occurred during the operation. In this case, in fact, there is a risk that the dural tear, although small, may be located at a hidden site, thereby its suturing could require an extensive resection of the posterior vertebral arch or an intrathecal approach.

Subarachnoid drainage

This treatment, first described by Mc Callum et al. (78), consists in introducing an epidural catheter into the subarachnoid space and leaving it for a few days so as to allow the dural tear to heal spontaneously.

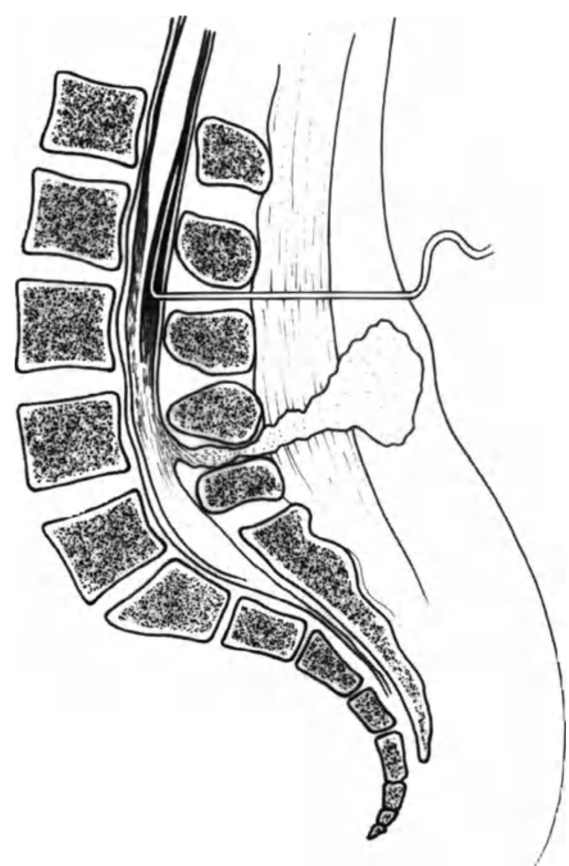


Fig. 18.14. *Treatment of a dural tear by placing an epidural catheter in the subarachnoid space cranially to the lesion.*

A 22 G or 25 G catheter is usually inserted at L2-L3 level with the same technique used for the application of an epidural catheter (Fig. 18.14). The external extremity of the catheter is connected to a sterile blood-collection bag to collect the leaked CSF. Usually 100–300cc of CSF are collected during 24 hours. The patient is maintained in the supine position and a cytochemical analysis of the collected fluid is carried out daily or every other day so as to detect any possible signs of infection (58). The catheter is maintained in place for 4–7 days. Subsequently, the patient is kept in bed for at least 1 day to allow the healing of the entrance hole of the catheter. Possible complications include nausea, vomiting and intrathecal infection. The former two are treated with intravenous hydration and reduction of the CSF leakage by raising the level of the collection bag. If any evidence of infection is present, the catheter is removed and intravenous antibiotics are administered.

With this method, Kitchel et al. (58) obtained the healing of the dural tear in 82% of 17 patients with CSF fistula following fractures or surgery at the cervical, thoracic or lumbar spine, in whom a drainage was left in place for 4 days. We have used this method in two patients with cerebrospinal fluid fistula following lumbar spine surgery, in whom a dural tear had not been detected intraoperatively. In one case the catheter was applied 10 days after the operation and maintained for 5 days; in the second case, the catheter was positioned 14 days after the operation and was left in place for 7 days. In both cases the CSF fistula healed.

Two hypotheses have been put forward to explain the mechanism of action of this procedure (58). The first is that eliminating the CSF leakage from the dural tear allows spontaneous healing of the lesion. The second is that the external leakage of cerebrospinal fluid decreases the pressure on the thecal sac; this, in turn, reduces the distension of the dura and leads to a contraction of the defect, thus bringing together the margins of the lesion, which is more likely to heal.

Nerve-root injuries

Isolated nerve-root injury

Contusion, compression, stretching

The radicular nerve – or nerve root in the extrathecal course – can be injured by the Kerrison rongeur during laminotomy or by the blunt dissector used to retract the nerve root during the removal of herniation. The latter mainly occurs in the presence of a large herniation. A third possibility is the occurrence of a deep postoperative hematoma, which causes a severe compression of the nerve structures. Cabezudo et al. (17) described a case of nerve-root compression produced by an epidural fat graft. In our experience, the presence of stenosis increases the risk of postoperative radicular deficits (Table 18.3), particularly if laminotomy has been carried out (97).

The effects of the trauma can vary from a mild and transitory functional impairment of the nerve root to a complete radicular paralysis. The severity of the deficit, on the other hand, is related to the entity of preoperative nerve-root dysfunction. Radicular paralysis, in fact, mainly occurs in the presence of a severe preoperative deficit. The nerve root which is by far the most frequently affected is L5, followed by L4 and S1 roots. The reason why the L5 root is the most often involved is unclear: it may be due to the high frequency with which this nerve root is compressed by a herniated disc or, especially, to the fact that the myotome supplied by the L5 root has, to a large extent, a monoradicular innervation.

The mildest and most frequent postoperative functional deficit is the onset of sensory disturbances with a

Table 18.3. *Clinical data of the patients with postoperative radicular deficit operated by one of the authors (F.P.).*

Cases	Sex	Age	Diagn.	Level	Postop. deficit	Nerve root	Type of surgery	Recovery	Recovery time
1	F	72	Hernia-stenosis	L4-L5	Paralysis	L5	Laminot.	No	–
2	F	29	Hernia	L4-L5	Paralysis	L5	Hemilam.	Complete	4 m
3	F	56	Hernia-stenosis	L3-L4 L4-L5	Paresis	L4	Multiple laminot.	Complete	2 m
4	F	74	Hernia-stenosis	L4-L5	Paresis	L5	Laminec.	No	–
5	F	58	Hernia	L3-L4	Paralysis	L4	Laminot.	Complete	7 m
6	F	52	Hernia-stenosis	L4-L5	Paresis	L5	Laminot.	Complete	5 m

dermatomal distribution, or a marked accentuation of preexistent sensory deficits. Normally, hypoesthesia considerably diminishes or completely disappears in the course of 1–3 months.

A more severe postoperative neurologic deficit is the onset or accentuation of moderate motor deficits, usually associated with sensory impairment. Even this condition usually resolves completely or almost completely in the course of a few weeks or months.

To detect a complete radicular paralysis after surgery is a dramatic event for the surgeon, who often is not aware of the occurrence of any significant nerve-root trauma during surgery. In these cases, it cannot be excluded that radicular ischemia caused by the surgical trauma, rather than a marked mechanical compression of the nerve root during the operation, is responsible for the functional impairment. The prognosis of a postoperative paralysis probably depends on various factors, such as the pathogenetic mechanism (often unknown), the patient's age and the severity of the preoperative deficit. In the vast majority of cases, radicular paralysis regresses completely, or almost completely, over 2–6 months. In our experience, this holds particularly for young or middle-aged patients with minor or moderate preoperative deficits. Elderly patients have less chance of a functional recovery, particularly if severe and long-standing preoperative deficits were present. There is very little probabilities of a functional recovery if a complete motor loss persists after 4 months, and almost none after 6 months.

Laceration

Laceration of the nerve root is usually provoked by the Kerrison rongeur when, at the beginning of the arthrectomy, it is introduced deeply to the ligamentum flavum and the facet joint. The injury occurs more rarely at the time of disc incision or during the removal of disc tissue with the pituitary rounger. The nerve is usually injured shortly after the site where it emerges from the thecal sac and often at its posterolateral portion, whereby the sensory nerve root is more likely to be damaged. The injured nerve tissue is recognizable due to its string-like shape, its yellow-white colour and encephalon-like consistency. CSF can leak out from the tear of the dural sleeve when the lesion is near the thecal sac.

The consequences on the nerve-root function depend on which portion of the nerve has been damaged. When only the sensory root has been injured, the patient complains of paresthesias, disesthesias and/or hypo-anesthesia in the distal portion of the dermatome. The disturbances, initially marked, often tend to regress, at least partially, within the course of a few weeks. Therefore, a severely disabling outcome is not usually observed. When a motor nerve root is involved, on the other hand, the functional consequences are much worse, since the motor deficit does not usually improve with time.

Incidence

The incidence of isolated nerve-root injuries, in the series in which it is reported, varies from 0.1% to 0.9% (76, 79, 100, 129, 137). Stolke et al. (129), in a series of 412 patients, observed three cases (0.7%) of postoperative worsening of radicular deficits. Two of the patients had undergone conventional discectomy whilst the third had undergone a reoperation; no cases, however, were found in the group of patients submitted to microdiscectomy. It can be supposed that microdiscectomy, because it allows a better vision of the anatomic structures than a standard discectomy, is less likely to cause nerve-root injuries. The few data available, however, do not allow any conclusions to be drawn in this regard.

In the series of one of the authors (F. P.), six cases of postoperative radicular paresis or paralysis occurred in patients who had mild or moderate motor deficits preoperatively (Table 18.3). Four of these patients had been submitted to conventional discectomy and two to microdiscectomy. The cause of the complication was identified with certainty in only one case, in whom postoperative MRI revealed an epidural hematoma.

Case reports (Table 18.3)

Case 1. *In 1981, a 72-year-old woman underwent a left laminotomy at the L4-L5 level for a contained disc herniation in a stenotic spinal canal. The preoperative muscle strength of the left tibialis anterior and EHL was 3/5 and that of the peroneal muscles was 4/5. The operation was made difficult by the narrowing of the spinal canal and abundant epidural bleeding. However, bleeding was mild at the end of surgery and therefore a drainage was not applied. After surgery the patient showed a complete paralysis of the left L5 nerve root. An ecchymotic cutaneous area surrounded the surgical wound. The patient underwent prolonged physiotherapy with no improvement of the motor loss. A mild recovery of the sensory deficit occurred after a few months. The neurologic deficit was probably due to the surgical trauma and/or the postoperative hematoma.*

Case 2. *In 1983, an obese 29-year-old woman underwent discectomy for an L4-L5 right disc herniation responsible for* *a moderate deficit of the right EHL and tibialis anterior (3/5 both muscles). Initially, the L3-L4 level was erroneously explored. Once the mistake had been detected, the right L4 lamina and the ligamentum flavum at L4-L5 were entirely removed and a large extruded disc fragment was removed. This was accomplished through a relatively narrow space, because the L5 lamina had not been excised. Moreover, the entire operation was made difficult by abundant epidural bleeding. A drainage was not applied. After the operation the patient presented a complete sensory and motor paralysis of the right L5 nerve root. Recovery of the nerve-root function was found to begin 40 days after surgery. After 2.5 months a moderate motor loss and sensory deficit were present. The functional recovery continued and became complete 4 months after surgery. The neurologic deficit was probably due to the surgical trauma, accentuated by the abundant epidural bleeding.*

Case 3. *A 74-year-old woman underwent a bilateral laminectomy and unilateral left discectomy for degenerative spondylolisthesis of mild entity, lumbar stenosis and central disc herniation at L4-L5 level. The patient had a moderate deficit of the left tibialis anterior and EHL (both 3–4/5) muscles since more than 1 year. During the operation, which was carried out without any complications, the left L5 nerve root was extensively decompressed and a wound drainage was applied at the end of surgery. After surgery, the strength of both the tibialis anterior and EHL muscles was 1–2/5 and a mild hypoesthesia, preoperatively absent, was present in the L5 dermatome. One year after surgery the patient did not show any significant recovery of the motor and sensory deficits. The only possible explanation for the increased radicular deficit was the occurrence of an excessive surgical trauma on a nerve root with a long-standing moderate deficit.*

Case 4. *A 58-year-old-patient with a right L3-L4 herniation migrated caudally underwent microdiscectomy in 1990 for severe low back and radicular pain and a severe deficit of the right quadriceps (2–3/5) which had been present for 2 months. Once a right laminotomy had been carried out at L3-L4 level, the disc was identified and, caudally to this, a fragment migrated ventrally to the L4 nerve root, which appeared markedly compressed. The nerve root was then retracted medially and the migrated fragment removed. Subsequently, the L3-L4 disc was excised. The epidural bleeding was more profuse than normal during surgery, but at the end of the operation it was scarce and thus a wound drainage was not applied. After surgery the patient had a complete paralysis of the right quadriceps and anesthesia in the anterior aspect of the right thigh and leg. Five days after the operation, lumbar MRI was performed, which showed a blood collection at the level of the laminotomy, with compression of the thecal sac on the right.*

The patient underwent reoperation. At the site of the laminotomy, a partially coagulated blood collection was found. The collection did not appear to be large enough to justify the neurologic deficit. After removal of the hematoma, the spinal canal was explored, but no pathologic condition was found. Two months after surgery the first signs of an improvement in the motor loss were noted. After 4 months the motor deficit had partially recovered (muscle strength 3/5), while a marked hypoesthesia persisted. The sensory and motor recovery was complete after 7 months.

Cauda equina syndrome

Incidence

This syndrome has been observed with an incidence ranging from 0.01 to 0.2% (76, 80, 102, 124). In a series of 28,395 patients operated on for disc herniation in the U.S.A. in 1980, the incidence of the syndrome was 0.08% (100). It is not known whether the use of an operating microscope influences the incidence of this condition.

Etiopathogenesis

This complication can be caused by an excessive trauma to the thecal sac during surgery (80), an epidural hematoma responsible for compression of the thecal sac (41, 74), an epidural fat graft slipped into the spinal canal (98), or medullar ischemia resulting from a radiculomedullary artery injury (139). The latter pathogenetic mechanism can be hypothesized when myelography or MRI reveal no compression of the thecal sac in the thoracic or lumbar spine. We have observed a case of cauda equina syndrome in a patient with disc herniation in a stenotic spinal canal, in whom a wide dural tear occurred during surgery, with a massive herniation of the intradural nerve roots.

In many of the reported cases, stenosis of the spinal canal was present at the level of the herniated disc (80), whilst in others, disc herniation (9, 105), stenosis (9) or an intradural tumour (63) was present proximally to the site of discetomy. When stenosis or constitutional narrowing of the spinal canal coexists at the level of the herniation, the syndrome can be due to an increased compression of the nervous structures, due to the edema resulting from the surgical trauma (80). This is more likely to occur if a narrow laminotomy has been carried out and a marked compression of the thecal sac is present. When there is a pathologic condition proximally to the herniated disc, the onset of the syndrome may be related to an increased compression on the nervous structures due to intraradicular edema or disturbances of the epidural venous circulation (9).

Onset and treatment

The syndrome can appear upon the patient's awakening from the anesthesia or after a time interval ranging from a few hours to some days. Usually the neurologic deficits are already present upon the patient's awakening, or they appear in the first 48 hours after surgery.

MRI of the lumbar and thoracic spine should be immediately carried out as soon as cauda equina syndrome is suspected. If imaging studies show no significant compression of the nervous structures, conservative treatment should be perfomed. It should be based on the administration of high doses of corticosteroids and vasodilatory medication. In these cases, a mild recovery of the neurologic deficits may be expected in the course of a few months.

When MRI scans show compression of the nervous structures, an extensive decompression of the thecal sac should be carried out through a bilateral laminectomy. This should be performed within 48 hours of the diagnosis. As in the case of primary cauda equina syndromes, an immediate operation may not provide higher chances of recovery of the neurologic function than an operation performed after a few days. However, given the severity of the clinical presentation, the sooner surgery is carried out, the higher the chances of obtaining a satisfactory result. Of the few patients in whom the surgical outcome has been accurately reported (9, 80, 98, 105), approximately one fourth experienced a complete disappearance of the neurologic deficits; most of the remaining patients obtained a considerable improvement or complete disappearance of the sphincter dysfunction and a mild to moderate recovery of the motor deficits. The degree of functional recovery, however, was related to the severity of the syndrome.

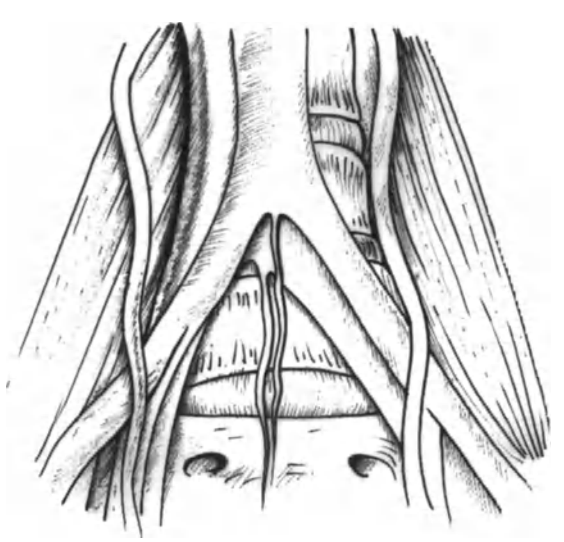


Fig. 18.15. *Relationship between the big endoabdominal vessels and the lumbar spine. In the majority of subjects the abdominal aorta bifurcates between the third and fourth lumbar discs.*

Injuries to abdominal structures

Vascular injuries

Incidence

The first case of an injury of the retroperitoneal vessels was reported in 1945 (69). In 1959, De Saussure (22), by sending a questionnaire to more than 3000 orthopaedic surgeons or neurosurgeons, learned of 106 intraoperative injuries to abdominal vessels. In 1969, Birkeland and Taylor (6) reported on four cases of their own and 44 cases found in literature. Since then, numerous other reports including isolated cases or small series have been described (5, 14, 19, 29, 30, 31, 33, 44, 49, 54, 56, 66, 73, 75, 84, 86, 89, 100, 107, 112–114, 118, 124, 128, 137, 138).

In series including more than 1500 cases (2, 88, 100, 114, 124, 137), the incidence of this complication ranged from 0 to 0.17%; in three of these (88, 114, 137) including the one (137) with the highest number of patients (68, 329), the percentage ranged between 0.045% and 0.06%. Thus, on average, an injury to abdominal vessels occurs approximately in 1 out of 2000 patients. Between 1954 (48) and 1991 (137), the mortality rate due to these injuries dropped from 65% to 12% (6, 22, 48, 137). It is probable that, in recent decades, the more widespread knowledge that these lesions may occur has lead to an earlier diagnosis and treatment, thus leading to a considerable decrease in the mortality rate.

Site and type of lesion

The abdominal aorta runs close to the midline on the left side and close to the anterior longitudinal ligament. In the vast majority of subjects, it bifurcates between the third and fourth lumbar discs (Fig. 18.15). The common iliac arteries cross the L5 vertebral body and, at the level of the caudal portion of the L5-S1 disc, give origin to the internal and external iliac arteries. The left common iliac vein runs ventrally and medially to the homonymous artery, whereas the right common iliac vein runs first dorsally and then dorsolaterally to the respective artery. The two common iliac veins join the inferior vena cava posteriorly to the proximal portion of the right common iliac artery. Anda et al. (2) analyzed the vascular prevertebral anatomy on CT scans in 50 adult subjects. They found that in most cases the

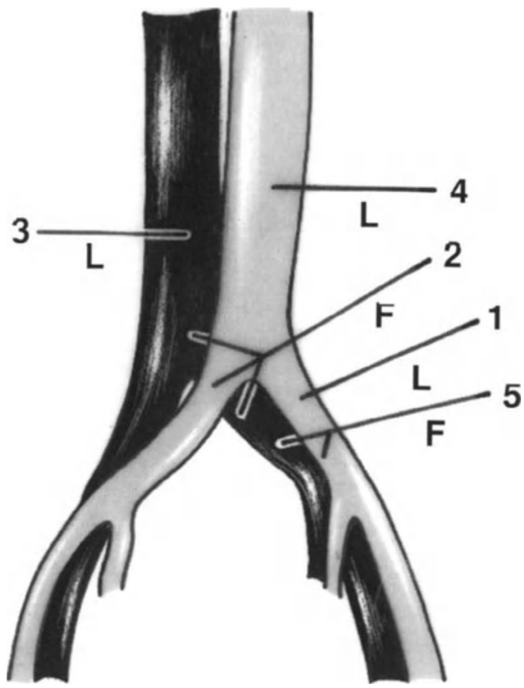


Fig. 18.16. *Sites and types of the most frequent injuries to abdominal vessels during lumbar discectomy. The most frequent is an isolated injury of the left common iliac artery* (1L) *followed, in order of frequency, by arteriovenous fistula between the right common iliac artery and the left common iliac vein or the vena cava* (2F), *isolated injury of the inferior vena cava* (3L), *the aorta* (4L), *and arteriovenous fistula between the left common iliac artery and the left common iliac vein* (5F).

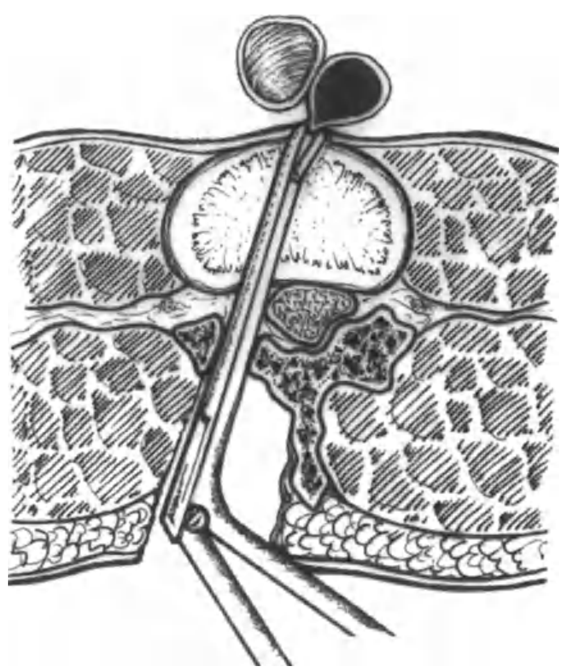


Fig. 18.17. *Pathomechanism of a big vessel injury during lumbar discectomy (From Ref. 83).*

inferior vena cava is adjacent to the aorta at the level of the L3-L4 disc. At L4-L5 level, various anatomic configurations may be present. The most common, which are present in two thirds of subjects, are: the right common iliac artery entirely overlapping the inferior vena cava, or the left iliac artery partially overlapping the inferior vena cava. The latter forms a wide vascular band ventrally to the disc. At L5-S1 level, the vast majority of subjects show common iliac vessels situated ventrally to the anterolateral portion of the disc.

Abdominal vessels which can be damaged during discectomy are the aorta, the inferior vena cava, the common iliac and, exceptionally, the internal or external iliac, vessels and the sacral middle artery. The injury may consist in a laceration or contusion of an isolated vessel or an arteriovenous fistula. A complete injury of the vessel wall causes an immediate hemorrhage, which is usually massive if the vessel is arterious and less severe if a vein has been injured. A trauma or an incomplete lesion of an artery may cause weakening of the vessel wall, which may eventually lead to a complete rupture resulting in a massive hemorrhage, or it may cause a moderate hemorrhage with the formation of a hematoma and subsequent pseudoaneurysm (128). An arteriovenous fistula occurs when two contiguous vessels are damaged concomitantly.

The most frequent lesion seems to be an isolated injury to the left common iliac artery: this accounted for more than half of the isolated arterial injuries reported by Birkeland and Taylor (6). These are followed, in order of frequency, by arteriovenous fistula between the right common iliac artery and left common iliac vein or vena cava, and isolated injuries to the inferior vena cava (Fig. 18.16). In De Saussure's series (22), arteriovenous fistula represented only 17% of all the vascular injuries reported by the interviewed surgeons. However, of the 48 cases analyzed by Birkeland and Taylor (6), 44 of whom were collected from the literature, 69% were arteriovenous fistulae. This discrepancy might be due to the fact that the cases reported in the literature are more likely to be those with unusual clinical characteristics, which are more common in patient with arteriovenous fistula.

Vascular injuries more frequently occur in patients submitted to discectomy at L4-L5 level (6). The second, in order of frequency, is the L5-S1 disc, followed by the L3-L4 disc, which is by far the most rarely involved. Often the vascular injury occurs on the side opposite to the discectomy.

Causes

The injury is caused by the perforation of the anterior wall of the annulus fibrosus and the anterior longitudinal ligament by a surgical instrument, usually a pituitary rongeur (Fig. 18.17).

Marked degenerative changes of the anterolateral annulus fibrous may render the perforation by a surgical instrument more likely. This probably occurs more frequently than is commonly thought. Solonen (123), by performing an intraoperative discography at the end of disc excision, found the contrast medium to leak through the anterior annulus in 12% of 25 patients, none of whom had shown a leakage of contrast medium at preoperative discography. An anterior perforation of the disc might occur more easily in the presence of an anterior disc herniation. Another predisposing factor is a surgical position causing compression of the patient's abdomen, since in this case the retroperitoneal vessels may be in closer contact with the lumbar spine. The variability of the anatomic relationships between the retroperitoneal vessels can explain the injury to one vessel rather than another, or the occurrence of an arteriovenous fistula instead of an isolated vessel injury.

The main cause of a vascular injury, however, is an excessively vigorous discectomy and especially a violent trauma caused by the pituitary rongeur to the anterolateral annulus fibrosus or discectomy carried out too ventrally. The best ways to prevent an annular perforation are to avoid forcefully penetrating the disc with the pituitary rongeur, particularly at the beginning of the discectomy, when the opening made in the posterior annulus is still narrow, and to avoid even touching the anterior wall of the annulus fibrosus with the pituitary rongeur during the removal of tissue in the disc space. Furthermore, it is advisable to open the pituitary rongeur immediately after this has been introduced into the disc space: it is in fact easier to perforate the anterolateral annulus fibrosus when the jaws are closed than when they are open (6). Another precaution may be that of applying a mark (a metallic collar or thin strip of plastic material) on the pituitary rongeur, indicating the safety depth when penetrating the disc space (51). Such depth would be of about 3 cm (2).

Clinical presentation and diagnosis

The two main clinical signs of an abdominal vessel injury are: an abundant hemorrhage from the disc space and an unexplainable arterial pressure drop during or immediately after the operation.

Vascular injury should be suspected in the presence of profuse bleeding from the disc space and is certainly present when a stream of blood comes out from the interspace. The color of the extravasated blood has little diagnostic value, since venous blood is highly oxygenated during anesthesia (83). An arterial injury causes an acute hemorrhagic shock. A venous injury leads to a hypovolemic shock which may be evident only a few hours after surgery, since blood extravasation may occur slowly due to the low venous pressure and the hematoma may reduce the hemorrhage. In both cases, a myocardial infarction or prolonged hypoxia should be considered in the differential diagnosis.

Additional clinical elements, which may be detected in the postoperative period, may be: reduction or absence of the femoral pulse together with pallor and a decreased temperature in the lower limbs, on one or both sides; abdominal distension accompanied by nausea, vomiting and abdominal pain which persist for more than 24 hours after the operation; the presence of a palpable hematoma in the retroperitoneal space; and clinical signs and symptoms of lumbosacral nerve-root compression.

The clinical presentation of an arteriovenous fistula is more subtle and multiform. During the operation there may not be a hemorrhage from the disc space or, if there is, it may be mild; very often, however, there is a drop in the arterial pressure along with an increase in the pulse frequency. After the operation the patient may present palpitations, pallor, ileus and abdominal pain. Physical examination reveals congestive heart failure, which may eventually be associated with cardiomegaly; an increase in the systolic and a decrease in the diastolic pressure, due to reduced peripheral arterial resistance; direct local signs (vessel fremitus or murmur) and indirect signs (edema in one or both lower limbs, vascular peripheral insufficiency, pulsating varices). Given the relatively poor initial clinical presentation, an arteriovenous fistula is often diagnosed late (6, 22), sometimes after years (13, 126) and not rarely the patient is treated for thrombophlebitis. Diagnosis is made by arteriography and CT and/or abdominal MRI.

Treatment

If vascural injury is detected during surgery, the disc space must be filled with hemostatic material and abundant blood transfusions or hematic substitutes administered. If the general condition of the patient appears to be very serious, the skin should be rapidly closed with sparce stitches, the surgical wound protected with two adhesive plastic sheets and the patient prepared for laparotomy. The latter should be carried out by the orthopaedic surgeon or neurosurgeon only if there is a high risk of the patient's immediate death and a vascular or general surgeon is not immediately available. In this case, the surgeon should only clamp the injured vessel and wait for a vascular surgeon who can adequately repair the lesion. Usually, however, the operation should be postponed until the arrival of a vascular surgeon; this holds particularly when the diagnosis has been made in the postoperative period. An arteriovenous fistula should not usually be treated as an emergency.

If the vascular injury is diagnosed and treated early, the mortality rate is very low. In DeSaussure's series (22), the mortality rate, in cases treated within 24 hours of the operation, was little more than half of that in patients treated later. A fatal outcome mainly occurs in patients with severe injuries to the aorta or vena cava, who may decease during, or shortly after, the end of surgery. The mortality rate for arteriovenous fistula is lower than that for isolated vessel injuries, but a peripheral vascular insufficiency persists in some of the patients treated surgically.

Ureter injuries

These injuries are very rare (10, 22, 51, 57, 84, 90, 110, 137). Wildföster (137) found only one case in a series of 68,329 herniated discs operated on in 37 hospitals. This injury can occur during discectomies carried out either at L4-L5 or L5-S1 level. In some cases it was associated with vascular injuries. The right ureter, in fact, runs close to the vena cava and the left ureter is close to the aorta.

Borski and Smith (10) positioned three marks in the L4-L5 disc in a cadaver, in order to simulate the course of a pituitary rongeur introduced into the disc on the right side. The subsequent abdominal exploration showed that two of the marks were close to the common iliac artery and the third was in contact with the left ureter. According to the authors, an ureter injury tends to occur more easily on the opposite side to that in which the discectomy is carried out.

This complication usually becomes manifest a few days after the operation with variable symptoms, including hematuria, fever, flank pain and abdominal pain associated at times with a paralytic ileum. The diagnosis is made with an intravenous urogram or a retrograde ureterogram, which reveal a leakage of the contrast medium from the ureter. The treatment is surgery.

Bowel injuries

Approximately 10 cases of this complication have been described (7, 22, 48, 60, 89, 115, 117, 120, 121), some of which were associated with vascular injuries (7, 22). In most cases the lesion occurred during an L5-S1 discectomy. Generally, the small intestine was injured.

The surgeon realizes that an injury to the bowel has occurred when a fragment of mucosa or smooth muscle tissue is removed from the disc space with the pituitary rongeur. If adipose tissue is excised, a bowel injury is very likely. In the majority of the reported cases, however, the surgeon did not realize that a bowel injury had been provoked.

The injury may cause, since a few hours after the operation, a clinical picture of acute abdomen with peritonitis or abdominal distension associated with gastric disturbances (7). In some of the cases reported, the injury caused a deep infection and was diagnosed late (117, 120). In one case, the intestinal injury (appendix avulsion) was recognized during the repairing of an arteriovenous fistula (7).

In the presence of persistent abdominal disturbances after surgery, the possibility of bowel injuries should be considered. In these cases it may be useful to take a radiograph of the abdomen to detect the presence of free gas and the postoperative clinical course should be carefully monitored. The subsequent appearance of signs of deep infection can confirm the suspected bowel injury.

The treatment includes an exploratory laparotomy and repairing of the lesion.

Complications due to patient's wrong positioning

Peripheral nerve injuries

Brachial plexus and nerves of upper limbs

Brachial plexus injuries can be due to nerve stretching or compression. They occur when the limb is positioned at 90° abduction, extrarotation and extension. In these position, the humeral head protrudes into the axilla and may lead to stretching of the brachial plexus and compression of the axillary nerve. Nerve stretching increases further if the neck is tilted towards the opposite side. These injuries usually occur in the supine or lateral position (91), but they can exceptionally happen in patients placed in the prone position. The probability of a plexus injury, as well as any peripheral nerve injury, increases in proportion to the duration of surgery. Usually, the neurologic deficits recover in a time lapse ranging from a few days to several months; however, they can be also irreversible (91).

The ulnar nerve can be compressed in the epitrochlea-olecranon groove due to malpositioning of the elbow on the arm support. The anterior interosseous nerve of the forearm can be compressed with the same mechanism. In this case, the clinical picture is characterized by difficulty in the flexion movements of the distal interphalangeal joint of the index finger and the interphalangeal joint of the thumb, and by reduced strength of the pronator quadratus (better evaluated with the elbow completely flexed); the lesion can be favored by anatomic anomalies of the nerve or perineural structures.

Sciatic nerve and peroneal nerve

The sciatic nerve can be compressed, in patients operated on in the kneeling position, by the support lying on the gluteal region, if this is a bar. The latter can compress the nerve when it is positioned at the level of the inferior portion of the glutei or at the proximal extremity of the thigh.

Case report

A 57-year-old woman underwent discectomy for a contained herniated disc at L4-L5 level on the right. The operation was performed in the kneeling position with the glutei held up by a metal bar 8 cm high, padded with foam rubber. The operation was carried out without complications. After surgery, the patient presented a paralysis of the right sciatic nerve. When she was examined by one of us 10 days after the operation, a marked hypoesthesia was found in the entire sciatic nerve dermatome, as well as marked to complete motor loss of all the leg muscles and flexor muscles of the thigh, and mild deficit of the gluteus maximus and medius. No sphincter dysfunction was present. MRI of the lumbar spine showed the presence of granulation tissue in the laminotomy area, but no significant compression of the nervous structures. A probable compression of the sciatic nerve caused by the gluteus support during the operation was diagnosed.

The patient underwent physiotherapy and neurotrophic medication. Six weeks after the operation the neurologic deficits began to regress and completely disappeared over 3 months.

The peroneal nerve may be compressed when a lateral decubitus position is used (91). This complication can be avoided by placing a pad under the knee lying on the operating table.

Femoral cutaneous nerve

This nerve can be compressed due to an excessive flexion of the hip in the knee-chest position or in the lateral decubitus position (102). The most common cause, however, is an excessive compression at the level of the anterior superior iliac spine in the prone position. This can occur when the Wilson frame is used, if the iliac supports are not sufficiently padded. The patient complains, immediately after the operation, of hypoesthesia in the lateral or anterolateral region of the thigh, which in a few cases is accompanied by burning pain.

Usually the disturbance decreases progressively until it disappears over 2–7 days. At times the hypoesthesia can last for some weeks, but in our experience it disappeares in all cases. No treatment is necessary.

This complication, which is rather frequent when the Wilson frame is used, can be avoided by adequately padding the iliac supports or, in obese patients or those submitted to long operations, by placing a small soft pad or a thick layer of cotton on the support.

Cutaneous injuries

An excessive pressure on a limited cutaneous area can cause edema or necrosis of the skin. This can occur on the thorax, scrotum, penis, on the face and on the knees during operations performed in the prone position, and on the trochanteric region when surgery is performed in the lateral decubitus (103, 122). If the Wilson frame is used, the skin of the abdomen or the scrotum may get stuck in the rack at the base of the frame when the iliac rests are raised.

Ocular injuries

The prone position, whatever type of operation is performed, exposes the patient to the risk of ocular complications (67). These are usually represented by excoriations and contusions of the eyelids. In rare cases, a compression of the eyeball occurs, which may lead to transitory or permanent decrease in, or loss of, vision (50, 53, 103, 125, 133). The pathogenetic mechanism, in the most severe cases, is a thrombosis in the central artery of the retina, which causes a retina ischemia. If a complete ischemia occurs for more than 15–20 minutes, it causes irreversible damage to the retina associated with atrophy of the optic nerve and permanent blindness. Arterial thrombosis can occur more easily if the operation is carried out under hypotensive anesthesia (67). The ocular injury becomes manifest with exophthalmos, which is already present upon the patient's awakening, or appears 1 hour after the end of the operation, with visus loss. The possible recovery of the sight occurs during the first 4–6 weeks.

The injury can occur when either a horseshoe head holder for cervical spine surgery is used or the patient's head lies on the operating table in a twisted position. In the first case, eyeball compression can occur even bilaterally (103); in the second, the compression can more easily occur in patients with a marked stiffness of the cervical spine. This complication can be prevented by taking extreme care when positioning the head, using a soft pad when the head is placed on the operating table, checking for possible head displacement from the pad during surgery (for instance if the patient moves due to lightening of the anesthesia) and by frequently evaluating the ocular region during the operation.

Case report

A 63-year-old patient, 1.85 m tall and weighing 115 kg, underwent a bilateral laminotomy at L4-L5 and L3-L4 levels and bilateral discectomy at L4-L5 level, due to a central disc herniation in a constitutionally stenotic spinal canal. The patient complained of chronic cervical pain and had a considerable rigidity of the cervical spine due to spondyloarthrosic changes. The operation was carried out in the prone position, using a Wilson frame. The patient's head was turned towards the right and rested on a foam rubber ring. The operation was performed without any particular difficulty and controlled hypotension was not carried out.

When at the end of surgery the patient was placed in the supine position, a semicircular ecchymosis in the medial region of the left orbit was noted. After 20 minutes, a considerable edema in the left eyelids appeared together with a progressive exophthalmos. The patient had a complete visus loss. Furthermore, he had paresthesias, hypoesthesia and mild motor deficits with a C6 and C7 radicular distribution. An ophthalmologist diagnosed the presence of a cornea abrasion and probable thrombosis of the central artery of the retina. CT scans of the left orbit showed a marked exophthalmos due to a retroeyeball edema and a dysmorphia of the eyeball (Fig. 18.18). The patient was treated with high doses of vasodilators, heparin and corticosteroids. The radicular disturbances disappeared in the course of 2 days. The eyelid edema and the exophthalmos regressed within 3 weeks, but the patient had a complete and permanent loss of sight of the left eye.

Probably, the marked stiffness of the neck did not allow an adequate axial rotation of the head during surgery, whereby the malpositioning of the head had favored the eyeball compression.

Cervical neurologic injuries

In patients with marked arthrosic changes in the cervical spine, hyperextension and/or a marked axial rotation of the neck in the prone position can cause spinal cord compression or accentuate a preexistent one, or lead to a compression of the cervical nerve roots. The radicular disturbances, including hypoesthesia and

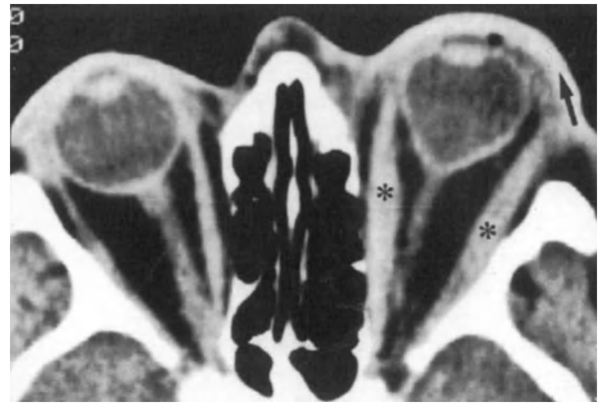


Fig. 18.18. *Axial CT scan at the orbital level in a patient with severe exophthalmos of the left eye which occurred after excision of a disc herniation in a stenotic spinal canal. The image reveals a thickening of the rectus medialis and lateralis muscles (asterisks), of the left subpalpebral tissue (arrow) and dysmorphy of the eyeball.*

motor loss, generally resolve within 1–2 days. In patients operated on in the lateral decubitus position, a Horner syndrome can occur due to the stretching of the cervical sympathetic chain when the neck is excessively flexed laterally (40).

Retention of foreign bodies

In two very large series, the incidence of this complication was 0.07% (100) and 0.012% (138), respectively. These rates, however, are probably lower than the true incidence of the complication, since foreign bodies that do not cause any symptoms are not usually detected.

Cottonoids and hemostatic gauzes

A cottonoid or hemostatic gauze left in the surgical wound can provoke a foreign body inflammatory reaction responsible for a fistula from which serous-purulent material leaks out. This can occur even a few months after the operation (34). Occasionally, the foreign body may compress a nerve root, with consequent persistent radicular symptoms; these can be caused either by nerve-root compression or the aseptic inflammatory reaction produced by the foreign body.

Case report

A patient who underwent excision of a disc herniation at L5-S1 level in 1989 continued to complain of radicular symp-

toms as severe as prior to the operation, from the first postoperative day. The symptoms regressed with the administration of corticosteroids, but they recurred as soon as the therapy was discontinued. The cutaneous wound healed in the usual time without complications. Successively, the patient underwent prolonged physiotheraphy with no improvement.

The patient was seen by one of us 4 months after the operation. The clinical picture suggested an incomplete removal of disc herniation. The patient underwent CT of the lumbar spine, which revealed a round formation about 1cm in diameter, which was interpreted as a disc fragment, situated caudally to the L5-S1 disc. During the second operation, a fragment of hemostatic gauze was found, wound up in the S1 radicular canal, without any apparent local inflammatory reaction. The foreign body compressed the S1 root, to which it was loosely adherent. It was removed without difficulty, leading to a complete resolution of the symptoms.

Prevention

The first preventive measure is to avoid excessive bleeding during surgery and to have adequate lighting of the surgical field. In addition, the use of short hemostatic gauzes should be avoided as should their tight packing at the site of the surgical field without leaving one extremity of the gauze protruding externally. During the operation, in fact, a hemostatic gauze can easily be forgotten, because it is difficult to be detected once it is soaked in blood. Likewise, cottonoids, or portions of cottonoids, without identification threads should never be used. At the end of the operation, the surgical field has to be carefully inspected and all the material used, including cotton swabs, hemostatic gauzes and cottonoids, carefully counted to ensure that all of it has been removed.

Metallic fragments

The metallic fragments that are most easily left in the surgical wound are tips or eyes of suture needles. These fragments usually remain in the subcutaneous tissue and are completely harmless. In rare cases, screws or broken fragments of a Kerrison rongeur can be lost in the surgical wound. Equally rare is a scalpel breaking during incision of the annulus fibrosus (34). In this case, the broken fragment may fall into the disc space and with great difficulty can be retrieved, even using a magnet. To eliminate this complication, the use of scalpels with interchangeable blades should be avoided; the safest instrument in this regard is a tenotome.

Intraoperative hemorrhage

The amount of epidural bleeding is extremely variable. It is often abundant, especially with arterial hypertension patients or in those with coagulation defects, but it is never uncontrollable for a sufficiently expert surgeon. In our series of patients operated on for disc herniation, blood transfusion has never been necessary. In the series of Stolke et al. (129), abundant intraoperative bleeding was found more often during conventional discectomies than microdiscectomies.

The bleeding should be carefully controlled, particularly at the end of surgery, since the persistence of an abundant hemorrhage after closing the thoracolumbar fascia can cause a postoperative epidural hematoma responsible for compression of the nervous structures. This complication should be prevented by coagulating the largest epidural vessels, using hemostatic material, tamponing tightly the bleeding vessels for a few minutes before suturing and applying a wound drainage.

Urinary retention

Many patients have urinary retention during the first few hours after surgery. This can be due to the postoperative pain, the horizontal position in bed and, mainly, the functional inhibition of the smooth musculature of the bladder caused by the drugs used for general anesthesia. In the vast majority of cases, the urinary retention rapidly resolves. In a few cases, however, it persists, despite attempts to urinate in a standing position. This usually occurs in patients with prostatic hypertrophy, and its incidence increases proportionally to the duration of the anesthesia. This complication has been reported with an incidence ranging from 0.45% to 11% (12, 23, 62, 79).

Postoperative urinary retention can be prevented by applying a bladder catheter immediately before or after the operation when the patient is under anesthesia. This should be done if an operation longer than 3 hours is foreseen, and independently of the duration of surgery, in patients with known prostatic hypertrophy. Therefore, when collecting the clinical history, elderly patients should be specifically asked if they have this condition.

A young patient with urinary retention usually urinates easily once he/she is in an upright position. If the urinary retention does not resolve, a bladder catheter should be applied. This holds particularly for patients who may have a prostatic hypertrophy. When the patient is able to regularly assume the upright position, the catheter should be removed to reduce the risk of urinary infection. If urinary retention occurs again, a urological examination should be carried out.

Gastroenteric disturbances

Gastric disturbances are not rare in patients who undergo antiinflammatory therapy after surgery. This therapy should be avoided in patients with ulcer; in those with gastritis or duodenitis, the therapy should be associated with gastroprotective drugs, such as famotidine.

Postoperative paralytic ileus is rarely observed in patients operated on for disc herniation. The syndrome usually resolves rapidly with laxatives and the application of a rectal probe.

A very rare complication (52) is pseudo-obstruction of the colon or colonic ileus. This condition is characterized by distension of the ascending and transverse colon, which may suggest a mechanical obstruction; the clinical presentation includes abdominal distension, crampy abdominal pain and hypoactive abdominal sounds. The syndrome can be favored by the abuse of laxatives and the use of medication (opiate analgesics associated with anticholinergic drugs) capable of reducing the intestinal peristaltic activity. The differential diagnosis includes postoperative ileus and surgical injuries to intestinal loops. The condition may require surgical treatment.

Deyo (23) reported on a case of colon diverticolosis in a 84-year-old patient who had a fatal intestinal perforation as a result of surgery. In one series (12), two patients (0.3%) showed an acute abdomen due to unknown causes, which required laparotomy.

Miscellanea

Defects in the healing process of the cutaneous wound. A delay in the healing of the cutaneous wound has been observed in about 3% of cases (129). A dehiscence of the wound has been found in 0.2% of cases (23); this figure, however, is probably lower than the true incidence of the complication. In our experience, as well as in that of others (129), a defect in the cutaneous healing occurs less frequently after microdiscectomy than conventional discectomy.

Algodistrophy. This complication has been observed after surgery in 0.01% of cases (102). The syndrome is initially characterized by excruciating pain and edema in the affected limb and subsequently vessel spasm, cyanosis, and cutaneous atrophy. The cause is unknown. The treatment includes physiotherapy and sympathetic block.

Meningism. A postoperative meningitic reaction has been reported in 0.8% of cases (12). However, it is probable that the complication was a result of preoperative myelography rather than surgery.

Arachnoiditis. This is often reported as one of the complications of surgical treatment. However, many of the cases described in the past were probably due to multiple myelographies. We feel, however, that arachnoiditis should be considered a surgical failure rather than a complication of surgery.

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CHAPTER 19

RESULTS OF SURGERY

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Evaluation of the results

Numerous studies have analyzed the outcome of surgery in lumbar disc herniation (1, 4, 5, 8, 12, 15, 18, 20, 22, 26, 31–33, 35, 36, 38, 39, 43, 46, 64, 67, 68, 71–73, 75, 77, 79, 83, 84, 88, 95, 97–99, 105, 106, 112, 116, 128). However, it is extremely difficult to compare the results of the various studies, since the methods of surgical treatment, the criteria of evaluation of the results or the categories into which they are divided lack uniformity. For instance, some studies classify the results into three categories (good, fair, and poor), and others into four (excellent, good, fair, and poor). Some studies analyze the outcome considering low back pain and radicular symptoms separately, whilst others evaluate the overall result. Some authors report the parameters used in the assessment of the results, whereas others make no mention of the evaluation criteria. In many studies, particularly the less recent, there is no statistical analysis and, thus, any evaluation of the significance of the data. In some studies, both the objective clinical data and patient's subjective evaluation of the result are taken into account, whilst in others the results are assessed only by a self-administered questionnaire. On the other hand, it has been shown that the rating of the outcome may vary considerably depending on the characteristics of the questionnaire and, more in general, on the criteria of evaluation of the results (47).

In the analysis of the outcome of surgery, we preferably referred to the more recent studies, particularly those describing the methods used in the assessment of results and providing statistical significance of the data. Furthermore, the good results of the series in which the surgical outcome are assigned to one of three categories, have been equalized to the excellent and good results of the studies in which outcome is assigned to one of four categories.

Definition of terms

There is no agreement, in the literature, regarding the time limits which characterize a short-term or long-term result of surgery in lumbar disc herniation. Five different postoperative periods can be identified: immediate, short-term, medium-term, long-term and very long-term period (89). The immediate postoperative period corresponds to the first 3 months after surgery, whilst the short-term period refers to the interval between the fourth month and the end of the second year (Table 19.1). The medium-term period refers to the third and fourth postoperative year and the long-term period to the fifth to the tenth year, after which, the very long-term period begins. Although these time limits are arbitrarily determined, they correspond to different stages in the evolution of the clinical outcome and the pathologic changes which characterize disc disease.

Immediate postoperative period

In the first few days after surgery, the patient complains of moderate low back pain. The pain is generally more severe in patients who have undergone conventional discectomy, particularly when a complete arthrectomy was carried out. In a comparative study (7) of patients submitted to microdiscectomy and patients operated on conventionally, it was found that, in the immediate postoperative period, those in the former group took a tenth of the analgesics compared with the patients in

Table 19.1. *Postoperative periods.*

Immediate	0–3 months
Short-term	4th month–2nd year
Medium-term	3rd–4th year
Long-term	5th–10th year
Very long-term	>10 years

the latter group and were generally afebrile, whilst most patients in the conventional surgery group were febrile in the early postoperative days. Severe low back pain, compelling the patient to remain in bed or making him unwilling to get up, may be an expression of spondylodiscitis. However, also in these cases, pain is often as intense as usually in the first postoperative week.

Radicular pain is generally slight or absent in the first 2–4 days after surgery, particularly if steroids are administered. Pain may subsequently increase, but usually remains of mild entity. In most cases, the more severe the preoperative nerve-root compression, the quicker and more complete the disappearance of pain. In patients with slight radicular compression, pain in the lower limb may persist, or sometimes increase in severity, in the first few postoperative days. This rarely occurs in patients with severe preoperative nerve-root compression. Persistence of severe pain after the 4th–6th postoperative day, may be an expression of persisting radicular compression.

In the first few days after surgery, the patient may complain of hypoesthesia with a dermatomal distribution or, rarely, of paresthesias which were absent, or less severe, before the operation. Both sensory disorders are more frequent in patients with mild preoperative nerve-root compression and when the root has been excessively traumatized during surgical maneuvers. Usually these disturbances decrease considerably or disappear in the course of 3–6 weeks. In the first days after surgery, preoperative motor loss shows no improvement; this usually begins to occur after the first postoperative month.

Immediate results

One month after surgery, the majority of patients, regardless of the surgical method employed, have low back pain, particularly when making physical efforts, even if slight. The pain tends to be less severe in patients submitted to microdiscectomy or, anyhow, in those in whom the interlaminar access, and particularly arthrectomy, were less wide. Mild and / or inconstant radicular pain is present in at least one third of patients, the most common site being the buttock and the upper portion of the thigh. At this time, the sensory disorders present before surgery have usually disappeared; slight motor deficits have considerably improved or disappeared, whereas more severe motor loss has only slightly improved or remained unchanged. Many self-employed workers with a sedentary job have returned to work. This holds, particularly, for patients who have undergone microdiscectomy.

Two months after surgery, the majority of patients with a satisfactory result complain of slight, often intermittent, low back pain. Radicular pain, as well as sensory disturbances, have usually disappeared. Motor deficits have considerably improved or disappeared, except for severe preoperative motor loss, which may show only partial improvement. The majority of sedentary workers, motivated to return to work, have resumed their preoperative job.

At 3 months, mild low back pain still persists, although it is generally occasional. Severe motor loss has usually regressed, however not entirely. At this stage, significant differences between those patients who have undergone microdiscectomy and those submitted to conventional discectomy are no longer appreciable, unless in the latter, subtotal or complete arthrectomy was carried out. The majority of motivated patients have returned to work.

A retrospective study (43) analyzed the improvement after surgery, as assessed by the patient, in 166 cases submitted to conventional technique, at 10–30 days, 2 months and 3 months post-op. At the first follow-up evaluation, 73% of patients had considerably improved or were asymptomatic, whilst at 2 and 3 months, the percentages had risen to 81% and 88%, respectively. Spangfort (112), in a series of 2504 cases studied retrospectively, found a progressive decrease in the percentage of patients with complete relief of radicular pain between the follow-up performed in the first 2 weeks (95%) and those carried out from more than 2 months onwards (73%).

In a prospective analysis (2) of 513 patients who underwent microdiscectomy or conventional discectomy, assessed 3 months after surgery, it was found that 79% were not limited by residual symptoms and their level of activity was similar to that before the onset of disease. Postacchini et al. (91) analyzed the results of microdiscectomy in 87 patients with disc herniation at a single level, 1 month and 3 months after surgery. At 1-month follow-up, the outcome was excellent in 32% of cases, good in 53%, fair in 13% and poor in 1%. At 3-month evaluation, the proportions were 63%, 26%, 9%, and 2%, respectively.

In almost all studies which compared patients submitted to either surgical technique, the postoperative hospital stay was significantly shorter after microdiscectomy (9, 55, 78, 131). The latter, in the vast majority of studies, led to a faster return to work, usually being 4 to 10 weeks after surgery. However, a randomized prospective study (124) of 30 patients treated by microdiscectomy and 30 operated conventionally, revealed no significant differences between the two groups, also as far as concerns the length of hospital stay and the duration of sick-leave, which was approximately 10 weeks in both groups. No significant differences emerged between the series in which partial discectomy was performed and those in which discectomy was complete or radical. In the majority of the series, however, complete discectomy was carried out.

Results in the longer run

Short-term results

In most studies (2, 28, 40, 53, 101, 108, 130) reporting on short-term results after conventional discectomy, the percentage of satisfactory outcomes ranges from 70% to 95% (Table 19.2). Weir (130) studied prospectively, for 1 year after surgery, 100 patients treated by conventional discectomy. Of the patients who evaluated the outcome based on a self-administered questionnaire, 63% reported complete disappearance of low back pain and 73% complete resolution of radicular pain. Improvement in lumbar and radicular symptoms was rated as partial by 29% and 22% of patients, respectively; 93% of patients were glad to have undergone surgery and 12% occasionally assumed analgesics in the first postoperative year. The mean time off work was 33 days in those patients without workmen's compensation and 66 days in those with compensation.

The percentage of satisfactory results after microdiscectomy varies, in the majority of studies, between 86% and 98% (7, 61, 78, 91, 108, 124) (Table 19.2). However, in several studies, no significant differences were found between the results of conventional discectomy and those of microdiscectomy at 1- to 2-year follow-ups (2, 91, 108, 124). Comparable results were also observed after microdiscectomy or limited disc excision, consisting in partial discectomy carried out through a small laminotomy (55, 114).

Table 19.2. *Percentages of satisfactory results at short term after conventional discectomy or microdiscectomy.*

Author	No. of patients	Satisfactory results
Conventional discectomy		
Gutterman (1973)	69	78%
Weir (1979)	100	73% [a]
Eie (1978)	191	88%
Silvers (1988)	270	95% [a]
Junge (1995)	328	79%
Abramovitz (1991)	338	79%
Salenius (1977)	656	70%
Microdiscectomy		
Tullberg (1993)	29	86%
Nystrom (1987)	56	95%
Postacchini (1992)	91	91%
Andrews (1990)	112	97%
Kotilainen (1993)	237	92% [a]
Silvers (1988)	270	98% [a]

[a] Percentages referring to radicular symptoms.

Medium-term results

Medium-term results do not differ significantly from short-term outcomes. In most series, the percentage of excellent or good outcomes is 80% to 90% (9, 82, 99, 120). In one study, comparing patients treated with conventional discectomy and patients submitted to microdiscectomy, the proportion of satisfactory results was slightly, but not significantly, higher in the latter group (60). The comparison between different series of patients submitted to either method leads to similar conclusions.

In one study (85), professionals, patients with a high cultural level and self-employed workers obtained a higher rate of satisfactory results, at medium term, than other social categories. In factory workers, the proportion of satisfactory outcomes was 74%, whilst in the others it reached 96%.

Long-term results

In a retrospective analysis (101) of 695 patients submitted to conventional surgery 6 to 11 years before, only 56% were found to have little or no pain. The symptoms were unchanged in 36% of cases and had worsened in 8%. Only 36% of patients had returned to work and this had occurred faster in those with a short period of inability to work (less than 3 months) before surgery. More encouraging results emerged from a prospective study carried out by Weber (128); he assessed, 1, 4 and 10 years after surgery, 59 patients with a doubtful indication for surgical treatment, who underwent conventional discectomy. The proportion of satisfactory outcomes was 91% at 1 year, 85% at 4 years and 91% at 10 years, with no significant changes, at the various follow-ups, in the ratio between excellent outcomes (obtained in approximately two thirds of patients) and good outcomes. Similar percentages were also found in retrospective studies (42, 43) (Table 19.3).

In a prospective study (67), 83 patients were evaluated, by a questionnaire, 1 year and 5–10 years after surgery. At 1-year follow-up, complete or partial relief of low back pain was reported by 63% and 29% of patients, respectively, and complete or partial resolution of radicular pain by 74% and 22%. At long term, low back pain had completely or partially disappeared in 62% and 29% of cases, respectively, and the corresponding proportions for radicular pain were 62% and 27%. The symptoms were similar to, or more severe than, those present preoperatively in 14% of cases. Repeat surgery had been performed in 18% of patients, in most cases (73%) at the same level and on the same side as the first operation, after an average of 2 years. A retrospective analysis (129) of surgical outcomes in 71 patients, 10 years after surgery, showed that 80% were satisfied with treatment and 79% had resumed their preoperative work. In apparent contrast with this satisfaction, it was found that 18% of patients had undergone reoperation during the first postoperative year, and 38% over the following years. Such a high incidence of reoperations, however, has not been reported in any other long-term study. In numerous European series, the percentage of reoperations ranges from 4% to 9% (43, 77, 78, 99, 102, 128).

Very long-term results

Very long-term results of surgery remain to be fully elucidated, since few studies have assessed patients after more than a decade and all studies are retrospective (Table 19.3). Naylor (77) analyzed the results of surgery in 204 patients (all by a questionnaire and just over 50% by clinical evaluation) 10-25 years after hemilaminectomy or complete unilateral laminectomy: 38% had no symptoms, 41% complained of mild symptoms, mostly represented by occasional low back pain or paresthesias, 18% had improved, but still complained of symptoms requiring some form of treatment and 3% had no improvement. Low back pain was the most common residual symptom and its presence appeared to be related to degenerative vertebral changes present before, or developed after, surgery. Jacchia et al. (49) reported satisfactory results in 84% of 681 patients, followed for 12 years, on average. Comparable results were found in a study of 970 patients, followed for a mean period of 10.8 years (20).

An analysis of surgical outcomes, assessed by a questionnaire, in 575 patients operated 4 to 17 years previously, showed that 70% complained of low back pain, which was continuous in one third of the cases, whilst 45% had radicular disturbances and 14% were receiving a disability pension (25). Furthermore, one third of patients were undergoing some form of treatment for lumboradicular symptoms. No significant differences emerged in the results between patients in whom the operation was considered justified (based on the records in the clinical chart) and those with an unjustified surgical indication.

Table 19.3. *Percentages of satisfactory results at long term and very long term after conventional discectomy.*

Author	No. of patients	Satisfactory results
Long term		
Weber (1983)	59	91%
Weinstein (1986)	71	80% [b]
Lewis (1987)	83	89%
Hagen (1977)	89	85%
Hakelius (1970)	138	88% [a]
Zerbi (1980)	579	80%
Salenius (1977)	620	56%
Very long term		
Naylor (1974)	204	79%
Jacchia (1980)	681	84%
Davis (1994)	970	89%

[a] Percentage referring to radicular pain.
[b] Patients satisfied with treatment.

Recurrences of acute pain

In the years following surgery, some 20% of patients have episodes of acute low back pain or, more rarely, lumboradicular pain, often following physical efforts. This occurs particularly in the first few years after surgery. Usually, the pain resolves in the course of 1–2 weeks with bed rest, medical therapy and physiotherapy, and rarely lasts for more than 3 weeks.

Radicular symptoms, when present, usually involve the preoperatively symptomatic side and originate from the vertebral level operated upon, however there is no objective evidence of this. In most cases, in fact, the radicular syndrome is irritative in nature and is presumably due to periradicular scar tissue or persistent annular bulging, recurrent disc herniation rarely being present. The latter, on the other hand, produces motor deficits more rarely than a primary disc herniation and the absence of a reflex is of little diagnostic value if the reflex was abolished, or there is some doubt that it was absent, before surgery. In these cases, the clinical features that should lead to suspect nerve-root compression, rather than an irritative radicular syndrome, are duration of radicular symptoms for more than 3 weeks, the considerable severity of the radicular pain and marked positivity of nerve-root tension tests.

Deterioration of the results with time

Various data indicate that the results of surgery tend to deteriorate in the long and very long term. Deterioration is usually due to recurrence of, or increase in, low back pain (27, 43). However, it is worthwhile pointing out that in all the longitudinal studies carried out so far, the results were evaluated clinically, but plain radiography, CT or MRI were not carried out to determine the nature and severity of postoperative degenerative vertebral changes.

Deterioration of the results with time may be due to degenerative vertebral changes at the level where surgery was carried out and/or degenerative changes of discs or facet joints at different levels from that operated on. Epidemiologic studies (92) have shown that a constitutional predisposition to degeneration of intervertebral discs exists, as suggested by the frequent detection, on MR images, of degenerative changes of multiple discs, in patients with a single-level disc herniation. This tends to suggest that the persistence or recurrence of low back pain is often due, also or only, to degenerative changes at levels different from that operated on.

Teenagers

Immediate or short-term results are satisfactory in almost all patients. The percentages reported are usually over 90% (11, 21, 27, 29, 80, 102) and only a small minority of patients have a poor outcome. Sensory and motor deficits almost always disappear and vertebral rigidity resolves within a few weeks. The majority of subjects return to preoperative sporting activities a few months after the operation (70).

In contrast, conflicting results have been reported regarding the long-term and very long-term outcomes. Savini et al. (102) evaluated 101 cases, 2 to 22 years after surgery, and personally examined 84 of them. In the latter group, the results were rated as excellent in 79% of cases and good in 18%; both patients with a poor outcome had an L5-S1 disc herniation and spondylolysis of L5, which had transformed into spondylolisthesis at the time of follow-up. Of the 101 patients, only three had undergone repeat surgery for disc disease (one with recurrent disc herniation at the same level and two with herniation at a different level). Similar results were observed in other studies, in which small groups of patients were followed-up at medium, long or very long term (13, 57, 80, 100, 125). The results of two studies carried out at very long term, in a same hospital, were less encouraging. In one of these two sudies (21), 50 patients were evaluated, on average, 19 years after surgery: 24% had been reoperated and the result was rated as poor in 26% of cases. In the other study (27) (probably including all, or some of the patients in the previous study), after a mean of 18 years, 16 (20%) patients out of 74 had undergone discectomy and/or fusion, mostly at the same level as the initial operation, and seven had a third or fourth operation. However, after all treatments, results were excellent in 57% of cases, good in 38% and poor in 4%. A similar proportion of reoperations (18%) to that reported in the latter study, was found by Taylor (119) in a series of 39 patients assessed, on average, 5 years after surgery.

Also in the past, discectomy has rarely been associated with fusion in patients under the age of 20 years. The results, in patients submitted to fusion, did not differ significantly from those in patients who had no arthrodesis (14, 27, 57).

Elderly patients

The proportion of satisfactory results at short-medium term in patients over the age of 60 years is similar to that in middle-aged subjects.

Maistrelli et al. (69), who evaluated 32 patients aged over 60 years, found an excellent or good outcome in 87% of cases and no poor results. Comparable percentages of satisfactory outcomes (88% and 90%) had previously been reported by other investigators, who had assessed only patients over 60 years (109) or aged 50–72 years (86). An et al. (6) found satisfactory results in 92% of 50 patients aged 50 to 78 years, followed-up at short or medium term. Most of the patients had an extruded disc herniation and one fifth also a concomitant stenotic condition.

Lateral herniations

Many studies (1, 24, 30, 34, 51, 87, 93, 103, 107) have selectively analyzed the results of surgical treatment in intraforaminal and extraforaminal disc herniation (Table 19.4). In the majority of cases, the outcome, regardless of the type of surgical approach (interlaminar or extravertebral), was, on average, not as satisfactory as that generally reported for other types of disc herniation.

In a short-term analysis of 16 patients treated by the interlaminar approach, it was found that 62% had satisfactory results (51); in one of the two cases with a poor outcome, the extraforaminal disc herniation had not been excised at surgery. The same occurred in two patients, out of 60, in another series (30), in which the herniation was removed by an interlaminar approach and a partial (47%) or total (53%) arthrectomy; in this series, only one patient required fusion due to post-surgical instability. However, in the largest reported series (1), including 138 cases operated through an interlaminar approach, a satisfactory result was obtained in 82% of patients.

Postacchini et al. (90) evaluated the outcome of surgery in 43 patients with intraforaminal (34 cases) or

Table 19.4. *Percentages of satisfactory results in intraforaminal or extraforaminal disc herniation.*

Author	No. of patients	Satisfactory results
Postacchini (1979)	9	77%[a]
Faust (1992)	12	92%[c]
Jackson (1987)	16	62%[a]
Darden (1995)	25	80%[c]
Donaldson (1993)	29	72%[d]
Siebner (1990)	40	70%[c]
Postacchini (1995)	54	89%[b]
Epstein (1990)	60	95%[a]
Abdullah (1988)	138	82%[a]

[a]Conventional discectomy.
[b]Microdiscectomy through an interlaminar approach.
[c]Extravertebral approach.
[d]Combined interlaminar and extravertebral approach.

extraforaminal (9 cases) disc herniation excised through an interlaminar approach using the operating microscope. Posterolateral disc protrusion or spinal stenosis was present at the level of the lateral herniation in four and seven cases, respectively. In intraforaminal herniations, the results were satisfactory in 88% of cases at 3-month follow-up and 91% at 2-year follow-up. In extraforaminal herniations, an excellent or good outcome was obtained in 89% of cases in the immediate postoperative period and in all cases at 2-year follow-up. In only one patient was total arthrectomy carried out inadvertently. In no case, did surgery cause vertebral hypermobility.

The results of operations performed through extravertebral approaches do not appear to be better than those carried out through an interlaminar approach (19, 24, 107). In a short-term study (107) of 40 patients operated through a para-articular approach using the operating microscope, the result was satisfactory in 70% of cases; of the six patients with a poor outcome, five had persistent or recurrent herniation and one of these also had stenosis of the radicular canal. A similar rate of satisfactory results (72%) was obtained in a study on medium-term results in 29 patients operated through a combined interlaminar and para-articular approach (24). In contrast, Faust et al. (34) found a satisfactory outcome in 92% of 12 patients with extraforaminal or intraforaminal herniation, operated through a paraspinal, or occasionally a combined, approach.

In our experience, the use of the operating microscope makes the operation through the interlaminar approach considerably easier and also increases the percentage of satisfactory results. However, the rate of excellent or good results is higher in patients with migrated or extruded herniation than in those with contained herniation. The patients with a contained or extruded extraforaminal disc herniation tend to have a better outcome than those with an intraforaminal disc herniation of the same type.

Discectomy at multiple levels

Little is known concerning the quality of the surgical results in patients operated on at multiple levels, compared with those submitted to surgery at a single level. In a study on teenagers (21), it was found that of the patients operated on at two or more levels for excision of multiple disc herniations or only surgical exploration, almost half underwent repeat surgery over the next few years. The available data on adult patients with disc herniation at multiple levels are too few and incomplete to draw any definite conclusions. This holds particularly for patients with a symptomatic disc herniation and an asymptomatic annular bulging or a small contained herniation. These conditions are frequently observed with the modern imaging studies, but the surgical indications are often uncertain, due to the lack of data on the long-term clinical evolution in patients in whom also the asymptomatic disc is excised, compared with those undergoing removal of only the symptomatic herniation.

Discectomy through an anterior approach

In a series of 80 patients, Tsuji et al. (123) carried out repeat surgery through a posterior or anterior approach in nine cases. In the remaining patients, followed-up at short and long term, the percentage of satisfactory outcomes was 93% at short term and 91% at long term; no patient had a fair or poor result. The operated disc showed an average decrease in height of 2 mm 3 years after the operation, and of 3 mm at long term. Similar results were reported by Nakano and Nakano (76), who observed an excellent outcome in 90%, and a good outcome in 6%, of 304 cases, half of whom were followed for more than 5 years after surgery. In this series, so gratifying for the surgeons, poor results were reported in only 0.6% of patients.

Discectomy and fusion

Several studies have found higher rates of satisfactory outcomes in patients submitted to discectomy and vertebral fusion than in those undergoing only discectomy (66, 75, 126, 132). However, a large number of investigations indicate that, in patients with disc herniation, arthrodesis does not provide significantly better results than discectomy alone (8, 35, 39, 64, 105, 122). In patients undergoing only discectomy, the proportion of reoperations over the following years tends to be higher than in fused patients (122, 126). Despite this advantage, in patients undergoing arthrodesis the rate of postoperative complications is higher, the hospital stay is longer and the treatment is more expensive (23). These findings indicates that arthrodesis should not be used as a matter of routine in patients with a clinical syndrome typical of disc herniation. Fusion may be recommended in selected cases, together with, or following, discectomy.

Recovery of neurologic deficits

Slight or moderate motor deficits, in the absence of a cauda equina syndrome, usually recover completely within 1–3 months after surgery. Severe motor loss, instead, may recover only partially or may remain unchanged. This occurs in 10%–20% of cases (36, 78, 101, 113). The frequency of complete recovery of motor deficits was found to be higher in patients undergoing microdiscectomy compared with those operated conventionally (78).

Usually, the greater the preoperative deficit, the slower the recovery. The entity of recovery depends on the severity and duration of the deficit before surgery. Severe muscle weakness may not improve, if it is of long duration (77). Unfortunately, the time limit beyond which the probability of recovery decreases considerably or chances become nil, is not known. Certainly, the limit varies in different individuals and may depend on either the patient's age or the muscle group, and thus the root, involved. Elderly patients appear to have less ability to recover motor loss than young subjects. The quadriceps rarely presents severe weakness and only exceptionally remains considerably impaired; this is likely to be due to the pluriradicular innervation of the muscle. The extensor hallucis longus is the muscle which most frequently presents a partial recovery; however, an even severe weakness of this muscle is almost never disabling. The tibialis anterior and peronei muscles are, after the extensor hallucis longus, those most frequently showing an insufficient, or even no, recovery, usually leaving the patient, in this case, with a disabling functional deficit. The triceps surae muscle rarely remains weak, but when this occurs the patient is considerably disabled.

In our experience, in the presence of severe muscle weakness (strength equal to, or less than, 2/5) lasting less than 1 month, there is a high probability of complete or almost complete recovery; the probability is fairly low when the deficit lasts since 1–4 months and the chance then progressively decreases, until it disappears, after 8–12 months. Usually, a partial recovery is clinically appreciable after the second postoperative month. If there is no clinical evidence of improvement 3–4 months after surgery, an adequate recovery is unlikely to occur and the probability will progressively decrease with increasing time.

Sensory deficits recover to a large extent or completely in the majority of patients (36). If recovery is only partial, hypoesthesia is usually limited to a narrow area in the distal part of the dermatome. The areas where most frequently hypoesthesia persists are the big toe, the lateral border of the foot and the heel.

Osteotendinous reflexes do not usually return when they were absent preoperatively (36, 59). When they are decreased, they often normalize, even if with some delay.

Cauda equina syndrome

The results of surgery regarding bladder function depend on the severity of sphincter dysfunction, which is strictly related to the rapidity of onset of the syndrome. In the presence of an abrupt onset, which tends to be associated with bladder paralysis and bilateral perianal anesthesia, sphincter function recovers completely in half to two-thirds of cases (63, 113). Patients with a slow onset of the syndrome and / or bladder dysfunction and unilateral perianal anesthesia or bilateral hypoesthesia nearly always recover complete bladder function. There is no correlation between preoperative duration of the syndrome and quality of the results (37, 52, 63, 81, 113). In the series by Kostuik et al. (63), no significant differences emerged between patients operated within 48 hours and those operated 3–5 days after the onset of the syndrome. Spännare (113) reported better results in patients treated surgically after the first week compared with those operated within the first few days (who had greater degrees of bladder dysfunction). Usually, in patients with a satisfactory final outcome, bladder function is partially recovered within the first 2 weeks and completely restored between 2 and 5 months after surgery; occasionally, however, longer intervals, even of years, may be necessary (3, 118).

Sexual dysfunction often persists, particularly in males. This may consist in a decreased sensitivity of the penis or sexual impotence; this residues in approximately a quarter of cases (63).

Preoperative motory deficits recover completely in the vast majority of patients, but, if severe, they may improve only partially or persist unchanged. There is no correlation, also for muscle weakness, between quality of the results and rapidity of intervention, if surgery is carried out within the first few weeks after the onset of syndrome. Sensory deficits recover less frequently, and in longer periods of time, compared with motor loss (118).

Return to work

Return to work after surgery for lumbar disc herniation depends on various factors, which are not only medical, or however vertebral. They are essentially represented by: the patient's will to resume work; the type of work; the patient's cultural level; and the possibility of obtaining workmen's compensation. The variability of these factors may affect the percentage of patients who return to work and the average time off work, in different historical periods and different countries.

Of 695 Scandinavian patients (101) treated surgically between 1960–1965 and followed-up at long term, 66% had returned to preoperative work, 8% had changed to a lighter work, 2% had resumed a heavier work, 7% were not working and 17% had a disability pension.

In various long-term studies (65, 67, 129) carried out in North America and Europe, approximately 90% of patients had resumed the same work, or a lighter work (10–30%). In Switzerland, in the long or very long term, 14% of patients were partially or totally unable to work (25). Similar proportions of work resumption and working inability were found in studies on patients treated surgically over the last decade (26, 60, 124), and assessed at short or medium term.

The mean time off work varies, in the majority of reports, between 6 and 12 weeks. However, various factors affect the rapidity with which a patient returns to work. Usually, sedentary workers resume work before manual workers, and the latter before those doing a heavy job. In a prospective study (130), the average time off work after surgery was found to be 15 days for professionals, 30 days for office workers and housewives, 46 days for manual workers and 51 days for heavy manual workers; these figures, however, are lower than those commonly reported for the various categories of workers. There is strong evidence indicating that patients with a shorter duration of preoperative pain (less than 2 to 6 months, depending on the studies) return to work faster than patients who have a longer period of illness (43, 58, 60, 77). However, a too fast return to work, in the presence of persistent lumboradicular symptoms, might negatively affect the long-term results of surgery (129). Several studies (10, 78, 131) have revealed that patients submitted to microdiscectomy resume work quicker than patients operated conventionally; Tullberg et al. (124), instead, found no significant differences between the two procedures.

Spondylotic changes

In many patients with disc herniation, the herniated disc presents a decrease in height of varying degree. However, conflicting data exist on the prevalence of this change, the percentages ranging from 30% (77) to 98% (44). After surgery, the operated disc often decreases in height, or shows a further decrease, usually of mild entity. Kambin et al. (56) analyzed the spondylotic changes (decrease in disc height, marginal osteophytes, hypertrophy of the facet joints) appearing after surgery in 39 patients, who showed no appreciable changes on preoperative radiographs. An average of 5 years after surgery, 61% of patients had mild to severe spondylotic changes. Of these patients, 30% showed a decrease in height also of the disc above. Naylor (77) observed that in 50% of 72 cases followed for 10–25 years, the operation had no effect on the onset or increase in severity of the spondylotic changes. The result of surgery, however, does not appear to be influenced by the spondylotic changes present before surgery or developed subsequently (44, 77).

Predictive factors of the outcome

Many studies have attempted to determine which factors may be of prognostic value regarding the result of surgery. Two factors were found to be predictive in almost all studies: the duration of preoperative pain and type of herniation. A third factor – the degree of positivity of the straight leg raising test – was predictive in the majority of studies in which the prognostic value of the test was analyzed (Table 19.5).

Patients with long-standing low back and / or radicular pain tend to have less favorable results than those with a short painful period before surgery, as already observed by Mixter and Barr (74). The time limit beyond which the result is negatively affected has not been well defined. In some studies, it was found to be very short – 2 or 3 months (43, 48, 61, 117) – and in others rather long – 1 year or more (16, 65, 67). Presumably, the limit is 4–8 months and it is shorter for patients with continuous pain than for those with intermittent pain. Surin (117) analyzed the chronic history of lumboradicular pain preceding the episode which had led up to surgery, but no significant differences emerged, regarding the duration of postoperative inability to work, between patients with a short, and those with a long, history of pain.

In patients with contained disc herniation and, more so, in those with annular bulging or negative surgical findings, the percentage of satisfactory results, evaluated clinically or on the basis of the length of the time off work after surgery, is significantly lower than in patients with extruded or migrated herniation (48, 65, 67, 112, 115, 117). No significant difference would appear to be present between the latter two conditions.

Table 19.5. *Predictive factors of the surgical result.*

Highly predictive factors
Duration of preoperative symptoms
Degree of limitation of SLR
Type of disc herniation
Moderately predictive factors
Age
Neurologic deficits
Obesity
Diabetes
Nicotinism
Fibrinolytic activity
Type of work
Social and psychologic factors
Workmen's compensation
Duration of sick-leave
Other painful areas in the body
Width of surgical approach

The volume of disc tissue removed at surgery does not seem to affect the outcome of surgery (104).

In the majority of studies analyzing the relationship between the degree of positivity of the SLRT and the proportion of satisfactory surgical results, a close correlation was found between the two parameters (2, 45, 48, 65, 127, 130). Moreover, it was noted that a positive crossed SLRT (45) or absence of low back pain in raising the leg (2) is predictive of a satisfactory outcome. In a few investigations, however, no relationship emerged between positivity of the SLRT and quality of the result, whilst in others (67) a short-term, but not a long-term, correlation was found.

Considerable doubt still exists concerning the influence of many other factors upon outcome, namely, age, neurologic deficits, obesity, diabetes, nicotinism, fibrinolytic activity, type of work, social and psychologic factors, compensation, total duration of sick leave in the years preceding the operation, presence of other painful areas in the body, and width of the approach to the spinal canal (Table 19.5).

In a few studies (2, 61, 65), the age at the time of surgery was not found to affect the result. In other studies (43, 46, 48, 101), patients under 40 years of age presented a higher rate of satisfactory results than older patients. Spangfort (112) reported that the proportion of patients with complete relief of radicular pain after surgery progressively decreases with increasing age, but this holds only for patients with contained disc herniation, annular bulging or negative surgical findings. On the other hand, it is worthwhile pointing out that the studies which analyzed only elderly patients report comparable proportions of satisfactory results to those in which patients of all ages were included.

The presence of motor and/or sensory deficits was found to be predictive of a good surgical result in some studies (115), but not in others (10, 65). In a prospective survey (2), it was observed that the presence of preoperative muscle weakness implies an increased probability of failure in the resolution of the radicular syndrome, whereas the presence of sensory deficits increases the probability of persistent postoperative low back pain.

Obesity appears to play a role on the outcome of surgery according to some authors (48), but not according to others (65).

In a retrospective study comparing diabetic and non-diabetic patients with disc herniation, it was found that the rate of satisfactory results was considerably lower in diabetics (35%) than in non-diabetics (96%) (110); similar findings were obtained in stenotic patients. The cause of failure in diabetic patients has been related to the coexistence of diabetic neuropathy or microangiopathy. However, Cinotti et al. (17) did not observe significant differences in the results of surgery between stenotic patients with or without diabetes; the failures in diabetics were due to errors in identifying the etiology of the clinical syndrome (diabetic neuroangiopathy, rather than stenosis).

In heavy smokers, the outcome tends to be worse, as far as concerns the relief of low back pain, than in non-smokers (44).

Normal fibrinolytic activity (evaluated from euglobin clot lysis time and concentration of plaminogen activator inhibitor 1) seems to favor satisfactory surgical results, unlike reduced fibrinolytic activity (41). A defect in fibrinolytic activity, in fact, might imply inadequate removal of fibrin deposits, and lead to chronic inflammation and more abundant formation of peridural scar tissue (94).

Data on the relationship between the type of preoperative work and the outcome of surgery are also conflicting. A few investigators found a weak correlation between these two factors (48). Other investigators (10, 35, 65, 111) observed that sedentary workers obtain much more satisfactory results than manual workers. In a prospective study of 100 patients assessed 1 year after surgery, Weir (130) observed comparable results in sedentary and manual workers, except for postoperative low back pain, which was more frequent in manual workers. The latter return to work, on average, after a longer time interval and less often than sedentary workers (101).

In a prospective survey (48) of 357 patients, evaluated 1 month and 6 months after surgery, it was found that social factors, such as the desire to resume work after the operation, marital status (normal marital life compared with divorce or widowhood) and patient's satisfaction with his/her own life situation, were positively correlated to the quality of the result, whilst depression, hypochondriasis and somatization were negative prognostic factors. These findings are in keeping with the observations of Spengler et al. (115), who found that patients with abnormal scores on MMPI tended to have less satisfactory results, regardless of the surgical findings. These observations have been confirmed in numerous other studies (page 323). However, it has been claimed that psychologic examination of the patient may not be necessary, since the prognostic evaluation can be carried out on the basis of the standard clinical data (2).

The possibility of obtaining workmen's compensation is generally considered as a negative prognostic factor as far as concerns a satisfactory surgical result (38, 71, 96). Various authors (85, 108, 130), however, found no significant differences between patients with compensation claims and those without such problems, except for the duration of the time off work.

It has been noted (117) that patients with an abnormally long total period of absence from work due to lumboradicular pain over the years preceding surgery, tend to have rather unsatisfactory results and an abnormally long period of sick-leave in the years following the operation. In two prospective studies (53, 54), which evaluated various clinical and sociodemographic factors, it was found that the most important predictive factors of an unsatisfactory result were a long preoperative inability to work and the presence of other painful areas in the body.

A few studies have shown that a wide access to the spinal canal is associated with a higher percentage of unsatisfactory outcomes (16, 48). This finding is in keeping with the observation that arthrectomy increases the probability of surgical failure due to persistent low back pain (2). However, the rate of satisfactory results after bilateral laminectomy was found to be similar to that usually obtained after unilateral hemilaminectomy (50). Furthermore, it has been stated that bilateral laminotomy would increase the probability of a satisfactory outcome (42).

Conclusions

The results, 2–3 months after surgery, are satisfactory in approximately 85% of patients. In the short term, the percentage of satisfactory results ranges, in the majority of studies, from 75% to 95%. At medium term, the results do not significantly differ from the short term results. In the long term, surgical results tend to deteriorate in a limited number of cases, due to recurrence of radicular pain, or exacerbation or recurrence of low back pain. At this stage, approximately 10% of patients have undergone repeat surgery, because of degenerative conditions at the same level as the previous operation or at different levels. The few data available for the very long term seem to indicate that less than half of the patients are asymptomatic. The remaining patients complain of some symptoms, usually in the low back area, the presence and severity of which seem to be related to degenerative vertebral changes, apparently independent of the operation.

With microdiscectomy, the postoperative hospital stay may be of 24 hours or less (133). This is possible on account of the mild postoperative low back pain, due to the limited extent of muscle dissection and moderate excision of the laminae and, particularly, the facet joint. Better vision of the deep surgical field allows more complete removal of the herniated tissue, with less trauma to the nervous structures. Reduced pain permits a more rapid functional recovery in the immediate postoperative period and a faster return to sedentary work. The advantages of using the operating microscope are no longer evident a few weeks after the operation. Indeed, after 6–12 weeks, the results of microdiscectomy are similar to those of conventional surgery, provided the arthrectomy is only slightly wider than that currently performed with the microscope.

Elderly patients have the same probability of surgical success as younger patients.

Motor or sensory deficits of slight or moderate severity usually recover completely after surgery. Severe impairment, instead, may recover only partially or remain unchanged. The probability of recovery is inversely proportional to the severity and duration of impairment. In the presence of severe deficits lasting more than 1 month, the higher the number of months elapsing from their onset, the lower the chances of complete recovery.

Recovery of bladder function is obtained in approximately 60% of the patients with a cauda equina syndrome presenting bladder paralysis and saddle anesthesia. Patients with partial bladder dysfunction, instead, nearly always achieve a good functional recovery. The time interval (in terms of days or weeks) between the onset of the syndrome and surgical treatment does not affect the outcome. Nevertheless, in the presence of a cauda equina syndrome, it is advisable to carry out surgery rapidly, even if not as an emergency, in order to avoid partial sphincter and motor or sensory dysfunction becoming worse and, thus, decreasing the chances of a complete postoperative recovery.

The vast majority of patients return to their preoperative, or a lighter, work. This usually occurs 8–10 weeks after surgery, and earlier for sedentary, than manual, workers.

Three factors seem to significantly affect the result of surgery, particularly regarding radicular signs and symptoms. These are the preoperative duration of the clinical syndrome, the surgical findings and the degree of positivity of nerve-root tension tests. Patients with pain lasting more than 6 months before surgery and those with annular bulging or contained disc herniation tend to present less satisfactory results than patients with a shorter duration of pain and/or a migrated disc herniation. A satisfactory result is more often associated with a marked, rather than a weak, positivity of nerve-root tension tests. A clear-cut prevalence of low back pain with respect to leg pain implies a high risk of an unsatisfactory outcome.

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SPINAL FUSION AND DISC PROSTHESIS AT PRIMARY SURGERY

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Spinal fusion

Indications

In past decades many surgeons, particularly in North America, used to perform spinal fusion in all the patients submitted to lumbar disc herniation. In recent years, the vast majority of surgeons does not carry out fusion in patients submitted to primary surgery for disc herniation. In effect, while most of the patients with disc herniation do not need fusion, this may be indicated or even necessary in a limited number of cases.

In patients with disc herniation, fusion may be necessary in the following conditions: degenerative changes of discs and/or facet joints; intraoperative iatrogenic instability; retrolisthesis and conditions such as stenosis, spondylolisthesis or scoliosis. The latter group is analyzed in chapter 21.

Discogenic low back pain

Candidates for fusion

Spinal fusion may be indicated in patients in whom low back pain is the only symptom, or is the clearly predominant symptom with respect to radicular pain, as well as in those with a typical clinical presentation of disc herniation and a long history of back pain.

Some patients in whom the neuroradiologic investigations show a herniated disc may not complain of radicular pain, because the herniation does not cause any compression of the neural structures. In these cases, the pathologic condition cannot be considered as a disc herniation, at least from a clinical point of view, but it should be regarded as disc degeneration with an associated herniation. This distinction is important, since it is well known that in most patients complaining of low back pain only, discectomy alone leads to unsatisfactory results. The reason is unknown, but it is probably related to several factors. In these patients low back pain may be due to structural changes of the whole disc rather than mechanical stimulation of nociceptors located in the annulus fibrosus and posterior longitudinal ligament by the herniated tissue. Alternatively, disc degeneration may cause segmental microinstability, which may cause low back pain, even if no vertebral hypermobility is detectable on flexion-extension radiographs. In both cases, the excision of the nucleus pulposus will not improve the low back symptoms, which may worsen as a result of the increase in segmental instability caused by the discectomy. Furthermore, patients with the typical symptoms of disc herniation, in whom discectomy relieves the radicular pain but leaves the low back symptoms unchanged, are more likely to tolerate residual back pain after surgery than those whose predominant symptom before the operation is back pain, which has not improved after discectomy. In these patients, the surgical failure may lead to a negative psychologic reaction or accentuate a preexistent psychologic instability, which may contribute to worsening of the low back syndrome. Similar considerations are valid for patients complaining of preoperative lumboradicular pain in whom low back pain is the predominant symptom. In both these categories of patients surgery is rarely indicated; however, if an operation has been planned, fusion of the vertebral motion segment should usually be performed.

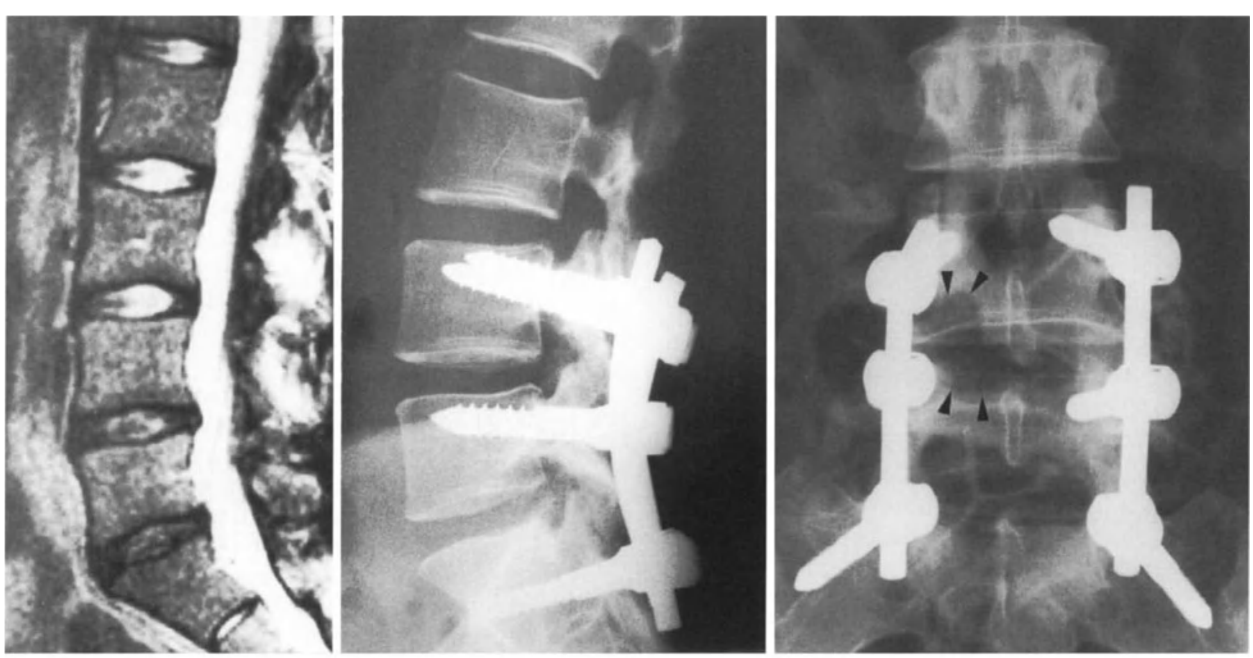
Some patients complain of frequent or persistent low back pain for several years before the onset of the lumboradicular syndrome caused by the herniated disc. Usually, in these cases, disc excision eliminates the additional symptoms caused by the herniated disc, but not the low back pain. The latter, however, is often mild and is likely to improve with conservative treatments. In rare cases of severe low back pain, fusion may be indicated.

In conclusion, the prerequisites which should be considered in deciding whether to perform a fusion are: the presence of low back pain for at least 2 years; persistent or frequent pain (more than one third of the days per year); and symptoms of such severity as to severely restrict the patient's occupational or non-occupational activities.

Diagnostic algorithm

When the clinical history and objective findings suggest that a spinal fusion may be indicated, the first step in the diagnostic algorithm is the evaluation of plain radiographs of the lumbar spine. If the radiographs show a decreased disc height or spondyloarthrosis at multiple levels, there is no indication for spinal fusion and, therefore, other diagnostic investigations are not necessary. If radiographs show no changes, or disc degeneration only at the level of the herniated disc or at an adjacent level, MRI study should be performed.

The main question which should be addressed by MRI studies is whether degenerative changes are present in the discs adjacent to the herniated one. If degenerated discs are present at multiple levels, fusion is seldom indicated, either because it may be difficult to determine whether the vertebral levels not to be included in the fusion area are partially responsible for the low back symptoms or because the increased mechanical stresses at the levels adjacent to the fusion may accelerate any preexisting degenerative changes, whereby the adjacent disc may eventually become symptomatic. Usually, spinal fusion is indicated only in patients showing one or two degenerated discs including the herniated one (Fig. 20.1). In these patients, the



A B C

Fig. 20.1. *Thirty-nine-year-old female with marked low back pain and mild radicular pain on the right side. Spin-echo T2-weighted sagittal MR scan* (A) *showing a small contained herniation at L4-L5 level and disc degeneration at L4-L5 and L5-S1 levels. An instrumented posterolateral fusion at L4-S1 levels* (B) *and* (C) *was performed along with laminotomy and discectomy on the right (arrowheads).*

possibility of carrying out flexion-extension radiographs and discography should be evaluated.

Flexion-extension radiographs should be taken in the presence of traction spurs at the level of the herniated disc or at the adjacent levels and when plain radiographs suggest that vertebral instability may be present. The presence of vertebral hypermobility at one of the levels adjacent to the herniated disc, should suggest either that this level has to be included in the fusion area or that fusion should be avoided.

Discography is indicated when MRI scans show two non-adjacent degenerated discs. Usually one of the two, often that most proximal, is asymptomatic and should not be included in the fusion area. Likewise, in a patient with disc herniation at L4-L5 level, in whom MRI shows a mild or uncertain reduction in the signal intensity of the L5-S1 disc on T2-weighted sequences, discography may be carried out to determine whether the disc is normal or degenerated and, thus, whether it should be included in the fusion area or not. In the remaining cases, discography may not be necessary, particularly when MRI scans show disc herniation at one level and normal discs at the adjacent levels.

Patients with chronic low back pain may show abnormalities in their psychologic profile more frequently than those with a typical syndrome of a disc herniation. Therefore, if spinal fusion is indicated, the possible influence of psychologic disturbances on the patient's symptoms should be assessed by means of psychometric tests. If the latter clearly show a functional component in the patient's complaints, fusion should be avoided, whereas mild changes in the psychologic profile might not represent a contraindication to fusion, particularly when only some of the psychometric tests reveal abnormalities.

Wearing a rigid corset or a plaster jacket for 2–4 weeks – the so-called trial corset – is a diagnostic test sometimes used in candidates for spinal fusion. The test is positive when more than 50% of low back pain is relieved. The rationale of the test is that the corset should provide a comparable immobilization of the lumbar spine to that achieved by fusion. In effect, the efficacy of a lumbar corset (a plaster jacket should have similar effects) in decreasing vertebral motion, particularly at the two lower lumbar levels, is not well known (page 364). On the other hand, to associate an immobilization of a hip joint with a lumbar brace extended to the thigh does not seem to significantly increase the efficacy of the brace. In our experience, a trial brace is more reliable in patients with segmental instability than in those with discogenic low back pain. In the latter, the trial may be useful when there is a functional component in the patient's complaints. If the patient tolerates the corset for only a few days or hours, there are high chances that the pain may be, at least in part, psychosomatic in nature. On the other hand, if the patient shows a complete tolerance of the corset and spinal immobilization causes a significant decrease in low back symptoms, spinal fusion may well be successful. Similar considerations are valid for the application of an external fixator, which, however, we do not use.

Assessment of indication for spinal fusion

In patients who have the prerequisites for spinal fusion, several factors may render surgery more or less appropriate.

In subjects aged less than 30 years, fusion is seldom indicated due to their long life expectancy and, hence, higher chances that degenerative changes may develop at the adjacent vertebral motion segments as a result of fusion. Fusion is also rarely indicated in subjects over 65 years old, since discogenic low back pain is more likely to be tolerated by elderly patients due to the decrease in physical activity which occurs with aging. Patients aged between 45 and 60 years are the best candidates for spinal fusion since they are physically active, but have a life expectancy of a few decades.

In assessing the indication for fusion, the morbidity associated with the operation and the limitations of physical activities during the first postoperative months should be taken into account. These factors should be taken into consideration particularly in patients with a typical syndrome of disc herniation and chronic low back pain, in whom the surgical alternative is discectomy alone, which entails a short operative time, a low morbidity and a postoperative course without significant limitations of physical activities. On the other hand, it should be borne in mind that fusion does not guarantee a complete relief of low back pain and that the effectiveness of discectomy alone in relieving low back pain may not be predicted.

Severe osteoporosis may be a contraindication for fusion because, during the subsequent years, the bone mineral density of the vertebral motion segments included in the fused area tends to decrease as a result of the reduced mechanical stresses, whereas the adjacent motion segments may be more exposed to pathologic fractures as a result of the increased mechanical stresses occurring at these levels. Likewise, the presence of a lumbar scoliosis cranially to the levels which should be fused may be a contraindication for arthrodesis due to the possible worsening of the spinal curve as a result of the increased mechanical stresses caused by fusion.

In patients complaining of chronic pain in the cervical and thoracic spine also, fusion is generally less indicated than in those complaining of pure low back pain because, in the former, a hidden distress status or a fibromyalgic syndrome which negatively affects the result of spinal fusion may be present, or because the resolution of low back pain only may be of little satisfaction to the patient.

Type and extension of fusion

It is commonly believed that solid fusion, by eliminating vertebral motion, avoids mechanical stresses on the intervertebral disc and might thus relieve discogenic low back pain. However, it has been shown that in patients with a solid posterior or posterolateral fusion who complain of persistent low back pain, discography of the discs included in the fused area may reproduce the low back symptoms (40, 52). This finding suggests that in these patients an interbody fusion performed through an anterior or posterior approach or a circumferential fusion would be more appropriate than a posterolateral fusion. In effect, the possibility that discogenic low back pain may persist in the presence of a solid posterolateral fusion is based on findings which are too rare to be accepted as a realistic event. It is presumable that a posterolateral fusion eliminates the low back symptoms when these are caused by a disc which has been included in the fused area, providing that a solid fusion has been achieved.

Instrumented fusion with pedicle screw fixation has become widely used due to the advantages provided by the instrumentation. In patients with discogenic low back pain, in whom the vertebral motion segment is not preoperatively unstable, a unilateral instrumentation may be indicated. Interbody cages may be used in performing posterior interbody fusion to avoid a rigid immobilization of the lumbar spine after surgery. These devices may also be implanted through an anterior laparoscopic approach.

Usually, the vertebral motion segments to be included in the area of fusion should encompass the herniated disc and the adjacent levels showing disc degeneration. However, the intervertebral level adjacent to the herniation, when showing a marked decrease in height due to severe disc resorption, does not need to be included in the fused area if discography fails to provoke the patient's symptoms. This situation is more likely to occur at the L5-S1 level in the presence of disc herniation at L4-L5. In this case, there may be a risk of persistent pain after surgery, originating from the posterior joints of the unfused vertebral motion segment. However, in the authors' experience this risk is very low. On the other hand, the advantage of limiting the extension of the fused area is to decrease the mechanical stresses on the adjacent vertebral motion segments and, thus, the possibilities that subsequent degenerative changes may develop. Furthermore, the chances of obtaining a solid bone mass do not decrease when a "floating" fusion is performed (5, 29).

Results

Numerous studies have analyzed the results of discectomy alone compared with discectomy and fusion, in patients submitted to primary disc excision (chapter 19). However, no study has analyzed prospectively the results of the two procedures in patients with discogenic low back pain in whom the degree of degeneration of the discs and facet joints adjacent to the level of herniation had been assessed prior to surgery.

Vaughan et al. (51) performed L4-L5 fusion, in patients with disc herniation at this level, only when discography showed no degenerative changes of the disc above or below. The retrospective analysis of these patients, compared to those submitted to discectomy alone, revealed that, after a mean of 7.3 years, the proportion of satisfactory results was significantly higher in the fused group (85%) than in the non-fused group (39%). In the latter, the most frequent causes of failure were the occurrence or progression of disc degeneration (as seen on plain radiographs) and recurrent herniation; in the fused group, pseudarthrosis and donor site pain were the most frequent causes of failure. However, even this study does not address the question of the role played by fusion in these patients, i.e., whether they have a significantly greater improvement of low back symptoms than non-fused patients.

In our experience, patients with long-standing and severe low back pain, in whom preoperative MRI and/or discography do not show any degenerative changes at the levels adjacent to the fused area, usually report a greater improvement of low back symptoms compared with non-fused patients. This holds particularly when fusion is performed at a single level. Failure in resolving low back pain after a spinal fusion may be due to pseudarthrosis or a wrong surgical indication. Pseudarthrosis is the first condition which should be investigated in patients complaining of persistent low back pain, even though it is well known that pseudarthrosis is not necessarily associated with a poor clinical result (10, 20, 45, 49). Surgical failures in the presence of a solid fusion may be due to a wrong preoperative diagnosis or concomitant psychologic or psychosocial dysfunction which may negatively affect the clinical outcome.

Zygoapophyseal arthrosis

Clinical relevance and diagnosis

In the presence of disc degeneration, particularly when associated to a decrease in disc height, degenerative changes of the facet joints are often present. However, the role of this condition in the etiology of low back symtpoms is controversial. Degenerative changes of the facet joints, in fact, are essentially an age-related phenomenon: 50 –90% of the subjects over 45 years old show evident degenerative changes at one or more levels, the entity of which tends to increase with aging (25, 36). On the other hand, in patients with disc degeneration, and even more in those with symptomatic disc herniation, it may be difficult or even impossible to determine the role played by degenerated facet joints in the pathogenesis of low back pain.

Plain radiographs and CT scans may show arthrotic changes of the facet joints (hypertrophy, osteophytes and irregularities of the joint surface), but they may also show normal findings. In a series of 12 patients submitted to fusion for chronic low back pain presumably due to a facet syndrome, Eisenstein (13) did not find radiographic changes in the posterior joints; in all cases, the histologic analysis revealed chondromalacic changes of the joint cartilage. To diagnose the source of pain, arthrography of the posterior joints may be carried out. Arthrography may reproduce the patient's typical symptoms, which may improve after intra-articular injection of local anesthetic (15). In effect, this procedure is of little diagnostic value, particularly in a patient with a concomitant disc herniation.

Indications for fusion

In patients with severe and long-standing low back pain who show marked arthrotic changes of the facet joints in addition to a herniated disc, doubts may arise on whether discectomy should be associated to fusion In our experience it is extremely rare that spinal fusion is indicated in these cases for several reasons: 1) It is very rare that zygoapophyseal arthrosis causes severe low back pain and that the latter cannot be resolved with conservative treatment. 2) In most cases arthrotic changes involve several lumbar motion segments and the possibility that the motion segments not included in the fused area are symptomatic cannot be ruled out; on the other hand, fusion tends to increase degenerative changes at the adjacent non-fused levels. 3) Patients with marked arthrotic changes are mainly elderly subjects for whom fusion is seldom indicated. Younger adults with severe arthrotic changes usually show associated conditions, such as scoliosis or degenerative spondylolisthesis, implying specific diagnostic and therapeutic evaluations (chapter 21).

Fusion may be indicated in middle-aged or early-senile patients with marked arthrosis of the facet joints affecting only the level of the herniated disc or, at the most, the first adjacent level, when the degenerative changes are the result of peculiar pathologic conditions, such as congenital anomalies, old fractures or infective diseases.

Results

Little is known on the results of spinal fusion in patients with degenerative changes of the facet joints without associated spinal conditions, such as scoliosis or spondylolisthesis. This is probably due to the fact that previous studies carried out in patients submitted to fusion for degenerative changes of the lumbar spine did not specifically assess this condition. Of the 12 patients submitted to fusion by Eisenstein and Parry (13), two had previous failed back surgery and one had degenerative scoliosis. One patient was reoperated on for pseudarthrosis, but all of them reported a considerable improvement in low back pain.

Iatrogenic instability

Stability and instability of vertebral motion segment

A vertebral motion segment may be stable, potentially unstable or really unstable. The concept of spinal instability has not yet completely been elucidated and the assessment of vertebral mobility on flexion-extension radiographs is the only clinical investigation used to demonstrate spinal instability. The vertebral motion segment is considered to be stable when it does not show any angular or translatory hypermobility and unstable when an excessive and/or abnormal angular motion or sagittal translation is present (11). A condition of potential instability occurs when a vertebral motion segment has higher chances of becoming unstable or of developing vertebral slipping, compared to a normal vertebral motion segment, once the integrity of the stabilizing structures of the spine has been compromised. For instance, in the presence of lumbar scoliosis, particularly of the degenerative type, there are higher chances that a unilateral facetectomy may cause vertebral hypermobility and/or lateral displacement of the affected vertebra than in a normal spine. A vertebra which shows an initial tendency to olisthesis due to degenerative changes is potentially unstable: in this case, even a limited impairment of the stabilizing spinal structures may accelerate vertebral slipping and render the motion segment really unstable. Degenerative spondylolisthesis represents a condition of potential instability if the slipped vertebra does not show any hypermobility on flexion-extension radiographs, or a condition of true instability if the olisthetic vertebra is hypermobile.

Biomechanical in vitro studies (1, 24) have demonstrated that, in a stable vertebral motion segment, laminotomy and partial facetectomy performed unilaterally or bilaterally do not affect spinal stability. Clinical experience, on the other hand, demonstrates that bilateral laminotomy does not make the operated vertebral motion segment unstable even when a bilateral discectomy is carried out, particularly if the central portion of the posterior annulus and the posterior longitudinal ligament are preserved. However, spinal stability is significantly reduced in vitro after total facetectomy performed unilaterally or bilaterally (1).

When the vertebral motion segment is potentially unstable, disc excision may critically reduce spinal stability, already decreased by the laminoarthrectomy. This holds particularly if a bilateral discectomy or total unilateral facetectomy has been carried out. Likewise, when the vertebral motion segment is preoperatively unstable, any decompressive surgery, particularly if associated with discectomy, tends to increase spinal instability.

Instability after surgery for disc herniation

When disc herniation is associated with other spinal conditions, such as stenosis, isthmic spondylolisthesis or scoliosis, decompression of the nervous structures is likely to cause spinal instability. These conditions are analyzed in chapter 21.

However, postoperative instability rarely occurs when disc herniation is the only spinal condition present, with the exception of possible disc pathologies at other lumbar levels. In this case, the vertebral motion segment at the level of the herniated disc is usually stable and the laminotomy and discectomy do not affect postoperative stability. Spinal instability may occur when a unilateral or bilateral total facetectomy has been carried out.

A unilateral total facetectomy may be performed deliberately to remove an intraforaminal or extraforaminal disc herniation, or it may occur accidentally, mainly at the upper lumbar levels, where the facet joints have a sagittal orientation. In most patients submitted to unilateral total facetectomy, postoperative low back pain is more severe than usual, however only in the first few months after surgery, and flexion-extension radiographs show no vertebral hypermobility. Probably, in these cases, the vertebral motion segment was preoperatively stable and the instability caused by surgery is of moderate entity and gradually decreases until it becomes asymptomatic or only slightly symptomatic as the reparative processes in the excised disc take place. In the few patients in whom flexion-extension radiographs show postoperative vertebral hypermobility, severe low back pain may persist even in the long term: this possibly occurs only when the vertebral motion segment is preoperatively unstable. The chances of postoperative instability increase if laminotomy and discectomy have been carried out on the opposite side also.

A total bilateral facetectomy performed at the same level as disc excision, very often determines vertebral hypermobility and low back pain due to spinal instability, even when the vertebral motion segment is preoperatively stable; this is particularly true when discectomy has been carried out bilaterally. A bilateral total facetectomy, however, is an extraordinary event in patients with a herniated disc only.

Indication for fusion

When a total facetectomy has been planned preoperatively or carried out accidentally during surgery in patients with a herniated disc only, there may be doubts on whether fusion needs to be performed. Many surgeons feel that fusion is necessary when a total facetectomy along with ipsilateral discectomy has been performed. In the authors' experience, fusion is not necessary when flexion-extension radiographs show no evidence of potential instability. Such evidence, however, cannot be represented exclusively by traction spurs, since the clinical relevance of this finding remains uncertain.

When a total facetectomy has been carried out accidentally, the opportunity to perform fusion during the same procedure should be carefully evaluated. The patient, in fact, may subsequently object against spinal fusion if he / she had not been informed preoperatively that fusion might be necessary. Since opinions on the need for fusion after a unilateral total facetectomy and ipsilateral discectomy are controversial, it is usually prudent to avoid fusion if the patient has not given an informed consent prior to surgery.

Fusion is advisable when a total facetectomy and discectomy have been performed on one side and laminotomy with partial facetectomy and discectomy have been carried out on the contralateral side. Fusion, however, is necessary when a total facetectomy and discectomy are performed bilaterally. If this procedure has not been planned before surgery, but it is found to be necessary during the operation, the surgeon is justified in carrying out a fusion, even if the patient had not been informed preoperatively, due to the high chances that a symptomatic postoperative instability may occur.

Retrolisthesis

Retrolisthesis, i.e., a posterior slipping of a vertebra with respect to the one below, occurs more rarely than spondylolisthesis (isthmic or degenerative) and in most cases the vertebral displacement is of mild entity. The most frequent retrolisthetic vertebra is L5 (33); very rarely are two or more retrolisthetic vertebrae present. The etiopathogenesis of retrolisthesis remains to be elucidated, but the condition appears to be related to degenerative changes to the disc below, which usually shows a varying decrease in height. Disc herniation, when present, is usually located at the level below the retrolisthetic vertebra (Fig. 20.2). This condition is commonly regarded as a type of segmental instability (21, 47). In effect, the retrolisthetic vertebra rarely exhibits an abnormal angular motion or sagittal translation on flexion-extension radiographs.

Effects of discectomy

Disc excision below a retrolisthetic vertebra may cause a slight increase in the retrolisthesis, probably due to a loss of disc height after surgery. However, we have never found vertebral hypermobility on flexion-extension radiographs after discectomy for a herniated disc below a retrolisthetic vertebra when the operation has consisted in laminotomy and unilateral discectomy. Moreover, in these cases, the degree

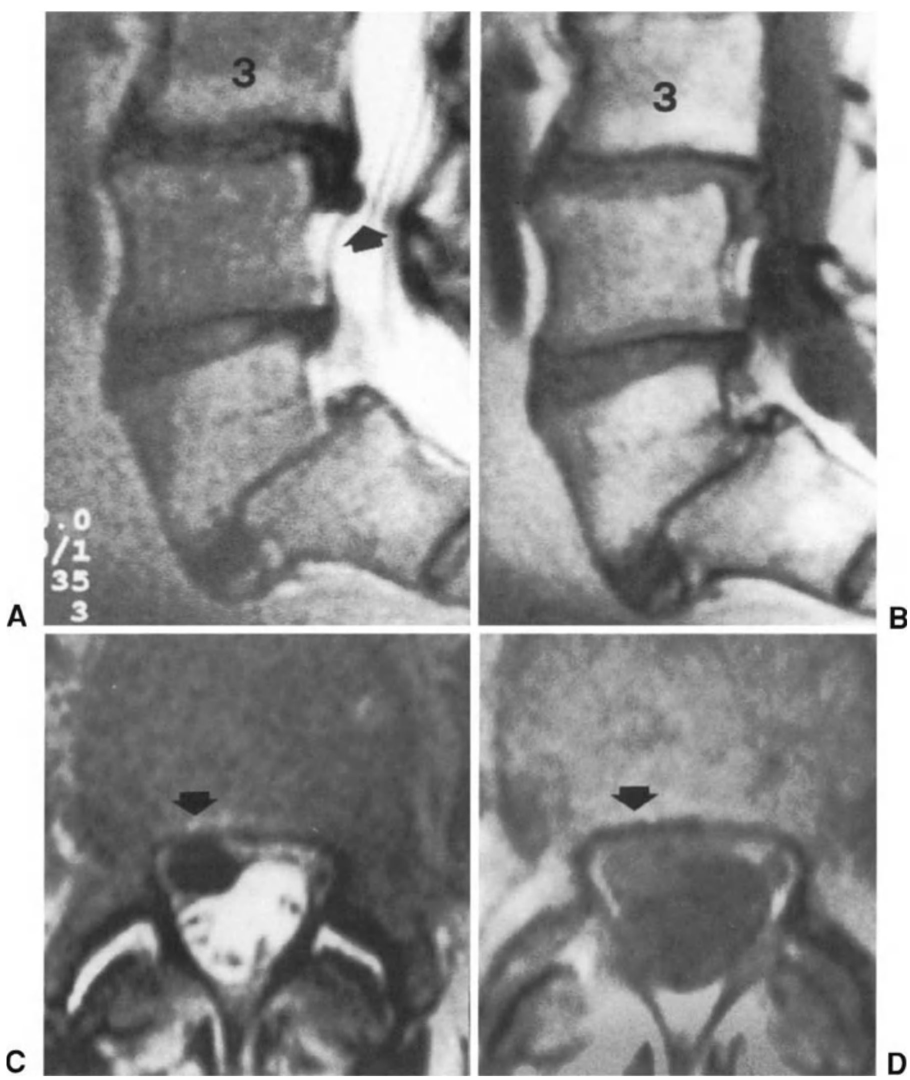


Fig. 20.2. *A patient with retrolisthesis of L3 and disc herniation at L3-L4 level.* (A) *and* (B) *Spin-echo T2-weighted and T1-weighted sagittal MR scans, respectively, showing marked retrolisthesis of L3 and extruded herniation at the level below (arrow). Mild retrolisthesis of L4 and isthmic spondylolisthesis of L5 are also present.* (C) *and* (D) *Turbo spin-echo T2-weighted and T1-weighted axial MR scans, respectively, revealing extruded disc tissue in the right nerve-root canal of L3 (arrows). The patient underwent laminotomy and discectomy with complete resolution of the symptoms.*

of postoperative low back pain was not different, on average, with respect to patients without retrolisthesis (Fig. 20.2). In the only patient who showed a marked worsening of retrolisthesis, as well as vertebral hypermobility after surgery, a bilateral laminotomy and discectomy along with a wide facetectomy on one side had been performed.

Indication for fusion

In patients with retrolisthesis and disc herniation, fusion may be taken into consideration for two reasons: 1) to avoid an increase in the posterior slipping and/or postoperative vertebral hypermobility when the herniation is located in the disc below the retrolisthetic vertebra; 2) as a possible treatment of chronic low back pain already present prior to the appearance of disc herniation, which may be located in the disc above or below the retrolisthetic vertebra.

The former should lead to perform fusion when, for any reason, a bilateral laminoarthrectomy and discectomy have been carried out, whereas there is no motive for carrying out fusion after a unilateral laminoarthrectomy, particularly when less than the medial one third of the facet joint has been excised. The latter should induce the surgeon to perform fusion in those rare cases in which preoperative flexion-extension radiographs show hypermobility of the retrolisthetic vertebra. The presence of retrolisthesis only, does not justify fusion, even in the presence of chronic and severe low back pain, since there are no proofs that posterior vertebral slipping may in itself be a cause of low back pain.

Types of fusion

The most common techniques used for spinal fusion will be described briefly, since they are extensively reported in numerous articles and books.

Posterolateral fusion (non-instrumented and instrumented)

It may be carried out through the posterolateral approach described by Wiltse (55) or the posterior approach. The former allows a better exposure of the fusion area and reduces intraoperative bleeding. Moreover, pedicular screw fixation is more easily performed with this approach. The posterior approach is generally used when fusion is associated with decompression of the nervous structures. With this approach, the skin incision should be extended one or two levels proximally and distally to the fusion area, to allow an adequate muscular retraction to expose the transverse processes. Once the laminae have been cleared, the insertions of the longissimus thoracis muscle are sectioned at the level of the lateral aspect of the articular processes using the diathermy blade. At this stage two arteries are found, one located laterally to the pars interarticularis and the other at the intersection between the superior border of the transverse process and the pedicle. Both arteries can be easily coagulated using bayonet forceps. The lateral portion of the articular processes is then palpated with the index finger until the transverse process is identified. The transverse process is then exposed subperiostally, taking care to avoid fracture.

Decortication of the fusion area can be performed either manually or by using a high speed burr. We prefer the manual decortication, since the high speed burr can cause thermic necrosis of the bone at the site of the graft bed. The pars interarticularis and the lateral aspect of the superior articular process can be decorticated with a curved osteotome or a large curette, whereas a bone rongeur should be used initially to interrupt the thin cortical wall of the transverse process to avoid causing its complete fracture. The decortication is then extended to the entire transverse process with a small curette. The preparation of the bed graft is completed when bleeding bone has been exposed throughout the fusion area and when soft tissues which might interpose between the bone graft and the decorticated bone have been carefully removed.

Small bone chips obtained from the iliac crest are placed in the bed graft, taking care to place a layer of cancellous bone graft directly in contact with the decorticated bone. Paraspinal muscles are then repositioned over the bone graft, taking care to avoid displacement of the bone chips into the spinal canal. To prevent this from occurring, the dural sac should always be protected with hemostatic sponges prior to the positioning of the bone graft.

If pedicle screw instrumentation has been planned, the entry point for the screw insertion is located at the intersection between a horizontal line located in the middle of the transverse process and a vertical line which may be located either at the inferolateral border of the superior facet or slightly lateral to this point, depending on whether the screw is to be inserted with a sagittal or an inward orientation, respectively. The advantage of positioning the screw with a sagittal orientation is that a larger area for bone grafting is available in the lateral portion of the articular process and there is a lower risk of causing nerve injuries. However, a lateral entry point associated with an inward screw orientation has the advantage of increasing the stiffness of the spinal fixation and decreasing the risk of injuring both the neural structures and the abdominal vessels. A screw insertion at the middle point between the two techniques is the authors' preferred method. Two further aspects should be taken into account: 1) the preservation of the cortical wall at the screw entry point increases the stiffness of the implant; 2) once the screw has been inserted into the pedicle, it may be difficult to perform an accurate decortication of the residual portion of the articular processes and the transverse process. Therefore, it may be advisable to prepare the hole for the screw first and then carry out the decortication, taking care to leave a small area of cortex around the hole. Once the decortication has been completed, the pedicle screws and bone graft are positioned.

In a historical cohort study including more than 2000 patients submitted to posterolateral fusion with pedicle screw instrumentation, intraoperative complications have been recorded in 5% of cases (58). The most frequent complication, i.e., pedicle fracture, occurred in 1.2% of patients. Nerve and vascular injuries were found in 0.4% and 0.1% of cases, respectively.

Interbody fusion

Posterior. The laminoarthrectomy should be extended laterally and as much of the lateral and anterior annulus as possible should be removed. An interlaminar retractor is positioned to achieve an adequate visualization of the disc space. The vertebral end-plates are excised initially with an osteotome and subsequently with a small curette until bleeding bone is exposed, but without extending too deeply in the subchondral bone. This reduces the bleeding in the disc space and preserves the subchondral trabecular bone, thus decreasing the risk of bone collapse. It is advisable to leave a bony edge of 2 mm along the posterior and posterolateral borders of the vertebral bodies in order to limit the chances of a posterior dislocation of the graft. The bone graft should be thick enough to be inserted into the disc space with little resistance and as long as possible, considering that the anterior and posterior extremity of the graft should be located 3–4 mm within the external border of the vertebral end-plates.

The bone graft may be rectangular or cylindrical in shape, or may consist of bone chips which are packed into the disc space. Usually, two to four rectangular bicortical or tricortical bone blocks are used. The advantage of using only two bone blocks, one on each side, is that displacement of the graft is less likely to occur; however, they should be larger than when three or four bone blocks are used and, therefore, there is a higher risk of damaging the nervous structures during their insertion in the disc space or performing a total facetectomy. These risks are reduced by using three or four bone blocks of a smaller size: once the first bone block has been positioned, it is shifted to the middle of the disc space with a small osteotome and then a second bone block is positioned laterally to the former.

As an alternative, cylindrical or rectangular titanium or carbon fibre cages filled with cancellous bone may be used. The use of such devices should allow a more rapid functional recovery after surgery and eliminate the risk of the bone graft collapsing (3, 39, 57). However, it is often necessary to perform an extensive or even total facetectomy to insert these devices with safety. This is more frequently the case at the upper lumbar levels, where the facet joints show a sagittal orientation and the emerging nerve root is less mobile. When a total facetectomy has been performed, a spinal fixation with pedicle screws should be associated (Fig. 20.3). If a total

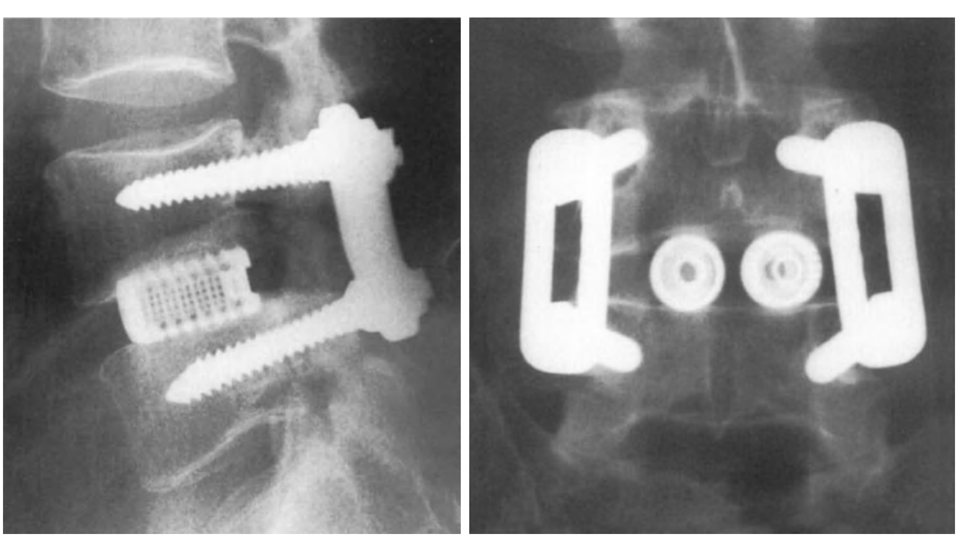


Fig. 20.3. *Posterior interbody fusion with cages. A left total facetectomy was necessary for the positioning of the cage, whereby a pedicle screw instrumentation was associated.*

facetectomy has been carried out on one side only, it may be sufficient to associate a unilateral instrumentation on the same side.

The most severe intraoperative complication is injury to the neural structures while positioning the bone graft or cages. In one series this occurred in 19% of patients and, in 75% of these, the neurologic deficits did not recover (50). The risks of such a complication may be reduced by performing an extensive or, if necessary, a total facetectomy.

Anterior. The anterior approach to the lumbar spine is usually carried out through a retroperitoneal approach on the left side. The patient is placed in the supine position with a small sandbag under the left buttock. In addition, a lumbar support which may be elevated when the bone graft is introduced into the disc space is used, in order to achieve an adequate opening of the disc space. Alternatively, the caudal part of the operating table may be tilted downwards.

To expose the lumbar discs adequately, the big vessels need to be mobilized and retracted and this may require the ligature of one or more intersegmental vessels or the ascending lumbar vein. At L5-S1 level, the midsacral vessels should be isolated and ligated, taking care to avoid any injury to the presacral plexus. Once the big vessels have been mobilized, they are retracted using cross-pins inserted in the adjacent vertebral bodies near the disc space. The anterior longitudinal ligament and the annulus fibrosus are divided parallelly to the vertebral end-plates. The anterior longitudinal ligament may also be sectioned on the midline to obtain two flaps, which may be sutured over the bone graft inserted in the disc space.

The bone grafts may be cylindrical or rectangular. The former can be introduced with a precise fit into the disc space; however, the dowel cutter usually removes a large amount of subchondral bone in the vertebral bodies above and below and this might increase the risk of bone graft collapsing. Rectangular bone blocks occupy a larger area of the intervertebral space and preserve the subchondral bone to a greater extent; both factors decrease the risk of bone graft collapsing and increase the chances of obtaining a solid fusion. As an alternative to the corticocancellous bone graft, titanium or carbon fiber cages filled with cancellous bone may be used.

A major intraoperative complication is an injury to the big abdominal vessels. In one series this occurred in 18% of cases (2). During the learning phase, the mobilization and retraction of the big vessels should be carried out together with a vascular surgeon. However, even when the orthopedic surgeon or neurosurgeon has become familiar with this approach, a vascular surgeon should be rapidly available during the operation. Preoperative CT and MRI may be useful in detecting vascular anomalies which may require a different surgical strategy. Retrograde ejaculation is a rare complication when the retroperitoneal approach is used.

Laparoscopic interbody fusion

The patient is placed in the supine position with the head down at approximately 30° of Trendelemburg to facilitate upward displacement of the bowels. The authors suggest the use of shoulder-padded supports to stabilise the patient. It is also recommended to use calf-muscle stimulators during the procedure, since the incidence of deep venous thrombosis following laparoscopic surgery seems to be higher than with open techniques. This may reflect the potential compression of the large abdominal veins by the use of carbon dioxide. Before beginning the procedure, the patient is catheterised. An initial dose of intravenous cephalothin and gentamicin is given at the time of induction of the anesthesia. It is useful to have two monitors, so that the surgeon and the assistant can have comfortable vision both on the left and right side of the patient. The authors prefer standing on the right side of the patient with the assisting general surgeon on the left.

A standard laparoscopy is performed using carbon dioxide and an initial umbilical portal. Once the abdomen is distended, a standard umbilical 30° angled laparoscope is inserted and two working portals are made above the iliac crests bilaterally. The lumbosacral promontory is then identified and the parietal peritoneum over the lumbosacral disc is carefully divided; the midsacral artery and veins are identified and clipped. Care is taken to avoid any injuries to the presacral plexus which may result in retrograde ejaculation.

The intended lumbar disc is then exposed and two curved retractors are used from each of the lateral working portals to protect the common iliac veins and arteries. In most cases this allows an adequate exposure of the lumbosacral disc for the insertion of two standard cylindrical 15 mm cages.

Using long peanuts and specially-designed Cobb elevators, one long Steinmann pin is inserted through a suprapubic small stab incision under laparoscopic control, using fluoroscopy. The purpose of inserting the pin is to achieve an ideal placement of the skin incision for the main suprapubic working portal, through which the cages should be introduced with a correct orientation in both the frontal and sagittal planes. Ideally, the initial pin should be in a central position in relation to the intervertebral disc, both in the frontal and sagittal planes. Once the surgeon is satisfied that the position of the wire is central and parallel to both end-plates, a small transverse incision is made to

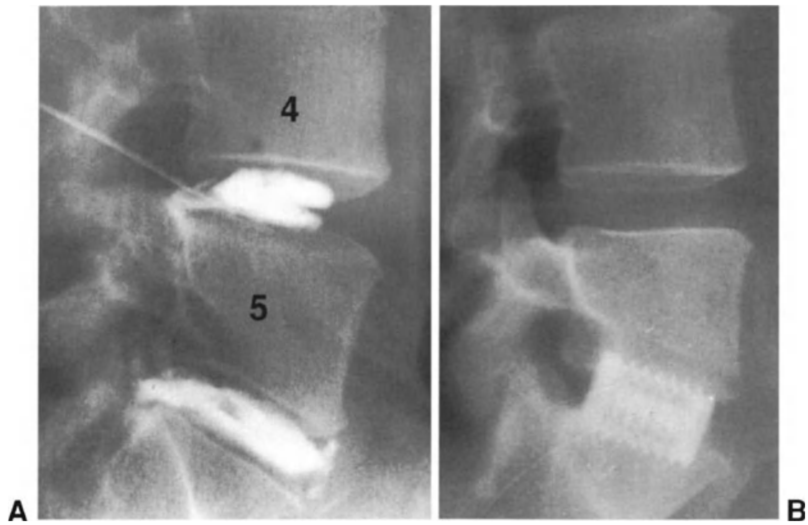


Fig. 20.4. *Laparoscopic interbody fusion.* (A) *Preoperative discogram with reproduction of the patient's typical symptoms at L5-S1 level.* (B) *Postoperative radiograph after laparoscopic interbody fusion with threaded titanium cages.*

allow the insertion of the 18 mm working cannula which is used for the removal of the disc and insertion of the cages. Using a special caliper, two marks, equidistant from each other, are made on each side of the central pin to identify the ideal site for the insertion of the two cages.

The disc is then entered with an initial sharp tubesaw, which cuts a window into the anterior annulus. Under laparoscopic vision, using specially-designed pituitary and Kerrison rongeurs, the anterior annulus and nucleus pulposus are removed prior to the insertion of specially-designed spacers. The procedure is repeated on both sides prior to the insertion of the cages. Following subtotal excision of the intervertebral disc, the site for the cages is prepared using specially-designed burs, which cut a cylindrical groove into the end-plates of L5 and S1. A tap is then employed and the threaded cage of the selected length and width is inserted after having been filled with autogenous cancellous bone from the iliac crest.

The parietal peritoneum is sutured using a specially-devised instrument and the suprapubic portal is closed with interrupted reabsorbable sutures. Prior to the removal of the laparoscope, the abdomen is deflated and the surgeon checks for any potential bleeding which may have been masked by the raised intra-abdominal pressure.

Patients are allowed to stand up as soon as they regain trunk control and are able to roll in bed from side to side. A soft lumbar corset is used for the first 6 weeks after surgery and, in most cases, after a standard one-level procedure, the patient is discharged between 6 and 12 hours after the completion of surgery. AP and lateral radiographs are taken prior to discharge and the patient is followed for 2 to 6 weeks after surgery with repeat radiographs (Fig. 20.4).

Among the possible intraoperative complications, a potentially immediate one is a iatrogenic injury to the abdominal aorta when inserting the cannula for the distension of peritoneum. This is unlikely to happen if the procedure is carried out by an experienced laparoscopic surgeon. Vascular complications can occur when inserting the cages and/or prepearing the disc, due to an insufficient retraction of the common iliac veins and/or an inadequate preparation of the midsacral vein and artery. When approaching the L4-L5 space, one has to be aware of the position of the ascending lumbar vein, as in standard retroperitoneal open procedures. At all stages, the surgeon has to be prepared to convert the laparoscopic procedure into an open one, if warranted by excessive bleeding.

Another potential complication may be caused by an inadequate clearance of the intervertebral disc with a consequent posterior displacement of disc material upon insertion of the implant. This may be compounded by a lateral placement of the cage with secondary nerve-root compression at the level of the intervertebral foramen. It is paramount, therefore, to carry out a complete clearance of the disc prior to insertion of the implants, to check the position of the cages on both the AP and lateral view, and to ensure that they are parallel to each other and within the boundaries of the intervertebral disc space proper. For the first few operations, it is useful to perform a postoperative CT scan to confirm the positioning of the cages, although this is not warranted on a routine basis.

Postoperative complications include deep infections, displacement of the cages, ongoing instability due to inadequate bone ingrowth into the implant, non-union, fibrous union and retrograde ejaculation. In the authors' experience, deep infections are rare with titanium-threaded cages and their incidence is minimized by the routine use of prophylactic antibiotics, a meticulous surgical technique and careful postoperative monitoring (39, 58). Malpositioning of cylindrical cages might lead to a rotation of the implants and secondary instability.

Effects of fusion on adjacent vertebral motion segments

Many studies indicate that fusion favours the occurrence of several conditions such as disc degeneration, facet joint arthrosis, stenosis, segmental instability or spondylolisis, in the motion segments adjacent to the fused area (4, 9, 19, 20, 27, 30, 34, 35, 37, 43, 45, 53).

In a series of patients with degenerative conditions, submitted to disc excision with or without fusion and followed-up 10 years after surgery (20), those who had had fusion showed a significantly higher incidence of asymptomatic degenerative changes in the motion segments proximal to the fused area, including vertebral osteophytes, reduced disc height and vertebral hypermobility. These changes were four times more frequent at L4-L5 level when fusion was performed at L5-S1 than at L3-L4 level when the two lower lumbar levels were fused. Lehman et al. (34) analyzed 62 patients submitted to fusion, an average of 33 years after surgery; moreover, 33 of these had radiographs or CT scan at the last evaluation. Of the latter, 45% showed segmental instability at the level above the fusion and 42% had stenosis, which was severe in one third of cases. The incidence of stenosis was higher at the levels above than at those below the fusion. However, the clinical results did not appear to be related to the radiographic and CT findings, since the large majority of patients were satisfied with the operation. It should also be considered that these patients had undergone a posterior fusion, which is the type of arthrodesis that causes the largest mechanical stresses on the adjacent non-fused levels compared with posterolateral or interbody fusion (31). In a series of 19 patients who complained of new symptoms an average of 8.5 years after fusion (30), the most common conditions at the levels adjacent to the fused area were facet joint arthrosis (88% of cases) and stenosis (44%), whilst a marked disc degeneration was present in 27% of cases. However, in none of the patients of these series was the degree of degeneration of the disc adjacent to the fusion evaluated by discography, nor were the dimensions of the spinal canal assessed before surgery. Furthermore, in none of the patients was the disc adjacent to the fused area evaluated at follow-up by MRI or discography.

A retrospective study (51) analyzed the results of discectomy and posterolateral fusion at L4-L5 level after a mean of 7.3 years, in patients in whom a preoperative discography had shown a normal disc at the level adjacent to the area to be fused. In no patients were significant degenerative changes or instability detected at the motion segments adjacent to fusion. Cinotti et al. (9), analyzed 48 patients submitted to posterolateral fusion after 7.4 years, on average; 14 of these underwent CT or MRI. Of the latter, two patients showed degenerative changes at the disc above the fusion, and two other had stenosis and degenerative spondylolisthesis, respectively.

In a recent investigation, 110 patients who had undergone posterolateral fusion were analysed after an average of 22.6 years and compared to a control group of nonoperated patients (54). Narrowing of the disc above the area of arthrodesis was found in 19% of cases and of the first non-adjacent disc in 21%, whereas, in the control group, the incidence was 23% and 14%, respectively. Degenerative spondylolisthesis was found at the level adjacent to an L4-S1 or an L5-S1 fusion in 11% and 14% of cases, respectively, whilst in the control group the incidence was 11% and 2%, respectively. Segmental instability was observed in 9% of patients at the level adjacent to the fused area and in 11% at the first non-adjacent level; similar rates were found in the control group. The clinical outcomes did not appear to be related to the radiographic findings. Penta et al. (41) carried out MRI studies in 52 patients who had been submitted to interbody fusion 10 years before and who had undergone discography before surgery. Degenerative changes at the levels adjacent to the arthrodesis were observed in 32% of patients, who also showed a significantly higher incidence of multiple disc degeneration in the lumbar spine compared with patients who had a normal disc at the level adjacent to the fused area. This findings suggest that degenerative changes of the disc adjacent to the fusion do not strictly depend on the increased mechanical stresses which occur at these levels, but they are probably related to a constitutional predisposition.

Conclusions. The data available seem to indicate that in the first decades after spinal fusion only a small proportion of patients develops degenerative changes at the level or levels adjacent to the fused area, as a result of fusion. The most common changes are facet joint arthrosis, segmental instability and disc degeneration. These changes are probably more marked in patients who, before surgery, already have degeneration of discs adjacent to the area to be fused. It is possible that in patients who exhibit no degenerative changes at the levels adjacent to the area to be fused, degenerative processes may occur due to aging or constitutional predisposition rather than as a result of fusion. On the other hand, in the majority of patients these degenerative changes are asymptomatic.

Instrumented fusion

The occurrence of degenerative changes at the level adjacent to the fused area is probably related to the amount of mechanical stresses which take place at these levels. The association of spinal instrumentation decreases the rate of pseudarthrosis (56), but increases the stiffness of the fused area and, hence, the mechanical stresses at the adjacent levels. This, in turn, should increase the incidence and/or severity of degenerative changes at the motion segments adjacent to the fusion. Moreover, the presence of stiff implants may cause a decrease in the bone mineral density in the vertebrae included in the fusion area due to a stress-shielding phenomenon (23, 38). No study has analyzed, at long- or very-long term, patients submitted to instrumented fusion compared with patients who underwent noninstrumented fusion. In a study carried out at medium term, however, it has been found that patients with an instrumented fusion showed significantly earlier degenerative changes at the adjacent levels than patients submitted to noninstrumented fusion (28).

The disadvantages associated with an excessive stiffness of the fused area may be avoided by: removing the instrumentation once a solid fusion has been achieved; using a unilateral instrumentation, which seems to provide a similar rate of solid fusion to bilateral instrumentation (8, 29); or using less rigid devices. However, even for these methods of spinal instrumentation, there are no data regarding the long-term effects of fusion on the adjacent segments.

Disc prosthesis

Rationale

In the past, fusion was the only surgical option in treating severe degenerative conditions of peripheral joints. In the last 20 years this procedure has been replaced, with few exceptions, by artifical joint replacement. The latter not only eliminates pain, but also allows recovery of joint motion to a large extent, thus improving the functional result and avoiding a mechanical overloading of the adjacent joints.

The success of peripheral joint prosthesis has encouraged the design and use of devices to replace the intervertebral disc. Spinal fusion, in fact, entails several disadvantages: a solid fusion is not always achieved; the mechanical stresses at the levels adjacent to fusion are increased; high rates of pseudarthrosis are reported when fusion is performed at multiple levels; a prolonged spinal immobilization is needed after surgery. The latter has been eliminated with the use of spinal instrumentation which, however, increases the mechanical stresses at the adjacent levels.

These drawbacks might be overcome by using disc prostheses. Such devices may improve low back symptoms by removing the affected disc and, by preserving vertebral motion, may avoid abnormal mechanical stresses at the adjacent levels. Moreover, disc prosthesis would allow the management of patients with multiple disc degeneration without compromising spinal mobility.

Models of artificial disc

More than 20 models of artificial disc prostheses have been designed, the majority of which have not been implanted in man. They are designed to replace the nucleus pulposus only or variable portion of the whole disc.

The first artificial disc implanted in man was the spherical metal ball spacer designed by Fernström (17), a primitive model which should have allowed a wide mobility in each plane of motion. In the 50's and 60's, this prosthesis was implanted in a large number of patients. However, 4–7 years after surgery, the majority of the metal balls had migrated into the vertebral bodies with subsequent collapse of the disc space; the author was then compelled by the medical authorities to interrupt these operations. Thereafter, models which replace the nucleus pulposus with a remotely fillable flexible bladder with end-plate anchoring pins (18), with silicone fluid contained in a plastic tube (16), with a silicone nucleus placed between two metallic plates (12), or with semipermeable tubes filled with hygroscopic gel (44) were proposed. These prostheses, none of which has been used in man, have the advantage that they may be inserted through a posterior approach. However, if the implant is not well fixed to the annular tissue and vertebral end-plates, it might dislocate into the spinal canal. Very little data have been published so far on the biomechanical behavior of these implants (22).

Prostheses which entail the replacement of the whole disc have been tested and a few of these have been implanted in man through an anterior transperitoneal or retroperitoneal approach.

Hedman et al. (26) have designed an artificial disc, which should allow a similar vertebral mobility to that of normal vertebral motion segments. The prosthesis consists of two metallic plates with an external porous coating, linked with a posterior loose hinge. Two metallic springs are sited in the anterior half of the metallic plates. A screw is used to augment the fixation to the vertebral body above and below. This prosthesis allows an angular motion of 15°–20° in the sagittal plane and of 3°–6° in the coronal plane.There are many doubts regarding the mechanical strength of the metallic springs, the tendency to produce metallic debris, and the possibility that soft tissue may penetrate within the springs, thus reducing the mobility of the prosthesis. This device has only been implanted in animals so far.

The Steffee artificial disc (48) is made of a silicone rubber disc and two titanium end-plates with an external porous coating. On the external surface of each metallic end-plate are four cone-shaped posts to enhance mechanical fixation. Experimental tests have shown that the weak point of the prosthesis is the rubber-titanium interface. However, in the six patients who had this prosthesis implanted, the only mechanical failure found was within the rubber core (14).

The Charitè SB prosthesis is the artifical disc most widely used in man so far. The SB III Charité is the evolution of two previous models (6). It is made up of two CrCoMo metallic end-plates with a smooth external surface, presenting small teeth to anchor the implant to the vertebral end-plates. The polyethylene core has a convex surface above and below, which slides on the concave surface of the metallic end-plates. This device should provide a range of motion of 12°–14° in flexion-extension and unlimited motion in axial rotation. The latter may cause a functional overloading of the facet joints. Further concerns are related to the wear of the polyethylene core and the production of wear debris.

Lee et al. (32) have designed an artificial disc, the biomechanical characteristics of which should reproduce those of the human disc. This model includes three components corresponding to the nucleus pulposus, the annulus fibrosus and the vertebral end-plates, all made of urethane elastomers, but with a progressively higher stiffness in the three components. The annulus fibrosus is reinforced by fibers of urethans and dacron with a spatial orientation similar to that of annular fibers.

Clinical results

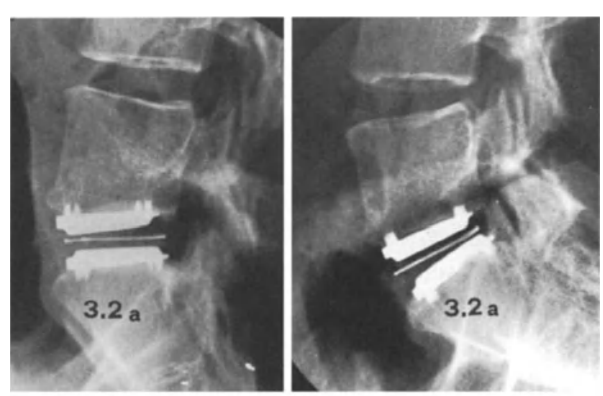
Few clinical investigations have been carried out on patients with disc prostheses. Moreover, they provide little data on the effectiveness of these implants, due to the scant information regarding the surgical indications and the methods used for the evaluation of the clinical outcomes.

Buttner-Janz (6) analyzed 50 patients with an age ranging between 26 and 59 years, in whom a Charité SB I or II prosthesis was implanted. Two-thirds of the patients had a herniated disc and / or narrowing of the spinal canal and a few of them had spondylolisthesis. After an average of 14 months from the operation, the clinical outcome was rated as very satisfactory in 47% of cases. An improvement of the preoperative symptoms was obtained by 12% of patients, whereas 26% and 2% were unchanged or had worsened, respectively, compared to the preoperative status. A high proportion of patients showed a subsidence of the implant in the vertebral bodies (31%) or a complete failure of the metallic end-plates (5%) only a few months after surgery. The average vertebral motion at the operated level was 8.8° before surgery and 5.2° at follow-up.

The results of the Steffee disc prosthesis have been analysed in six patients (aged 33–75 years) a minimum of 3 years after surgery (14). The preoperative diagnosis was disc degeneration, which involved a disc adjacent to a fused area in four cases. The clinical result was rated as satisfactory in three patients.

A multicentric study has evaluated the results of 234 patients with an age ranging between 25 and 59 years in whom a Charité disc prosthesis was implanted (46). In 19% of patients intraoperative or postoperative complications occurred, including injuries to iliac vessels repaired intraoperatively, thrombosis of the iliac veins, temporary sexual dysfunction, and temporary bladder and bowel disturbances. The clinical result was rated as satisfactory in 73% of cases. A marked subsidence of the prosthesis in the vertebral bodies and an anterior dislocation of the implant was found in eight and nine patients, respectively; however, these complications did not influence the surgical outcome. In six cases a partial intervertebral ossification was noted. Eight patients underwent fusion due to persistent pain. In no case did a failure of the polyethylene core occur, and none of the removed implants were found to be cracked or worn.

Postacchini and Cinotti (7, 42) analysed 46 patients in whom a Charité SB III disc prosthesis was implanted by Thierry David. There were 21 men and 25 women, with an average age of 36 years (range 27–44 years) at



A B

Fig. 20.5. *Flexion* (A) *and extension* (B) *radiographs in a patient who underwent disc prosthesis at L5-S1 level. The angular motion at the operated level is 13°.*

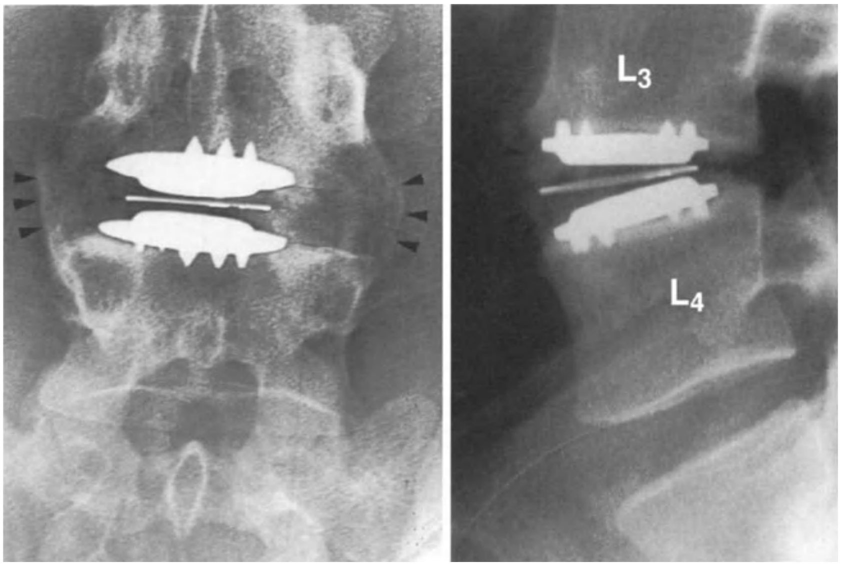


Fig. 20.6. *Patient submitted to L3-L4 disc prosthesis. An ossification of the anterior and lateral annulus fibrosus is visible (arrowheads).*

the time of surgery. The preoperative diagnosis was low back pain due to disc degeneration or a previous discectomy. The artificial disc was implanted at one level in 36 cases and at two levels in 10. The patients underwent clinical and radiographic evaluations on average 3.2 years after surgery (range 2.1–5.3 years). The clinical result was rated as excellent or good in 63% of cases, fair in 30% and poor in 7%. Of the eight patients who obtained unsatisfactory results, all but one underwent spinal fusion without removing the prosthesis. The clinical results were satisfactory in 69% of patients who had the disc prosthesis at one level and in only 40% of those who had the prosthesis at two levels. Satisfactory results were obtained by 48% of patients who had previous failed back surgeries and by 78% of those who had not. The vertebral motion at the operated level as seen on flexion-extension radiographs was, on average, 8.2°. The better results were obtained in patients in whom a prosthesis larger than 80% of the sagittal length of the adjacent vertebral bodies was positioned at the middle of the disc space (Fig. 20.5). In no patient was a dislocation of the implant observed. A subsidence of the implant into the vertebral body above or below was found in four patients in whom an undersized prosthesis was inserted. In seven patients an annular ossification or a spontaneous fusion was found (Fig. 20.6). These poor radiographic outcomes, however, did not influence the clinical results.

Indications

Patients with a disc degeneration unresponsive to prolonged conservative treatments should be the best candidates for disc prosthesis. The cases of disc herniation in which fusion is indicated may represent a further indication for disc prosthesis.

When deciding whether a disc replacement may be indicated or not, a careful preoperative evaluation of the vertebral structures which will be directly or indirectly affected by the presence of the artificial disc should be carried out. The presence of osteoporosis contraindicates artificial disc replacement, due to the risk of subsidence or dislocation of the implant. Likewise, arthrotic changes of the facet joints may contraindicate surgery, since they may be a cause of residual pain, particularly when the vertebral motion segment regains part of its mobility. The height of the disc space does not appear to influence the surgical outcome; however, it may be advisable to avoid implanting a disc prosthesis in a disc space which is markedly decreased and thus responsible for a severe reduction in the vertebral motion. A disc prosthesis is also contraindicated in the presence of segmental instability, both because it may persist along with back pain after surgery and because the abnormal mechanical stresses at the affected motion segment increase the chances of mechanical failures of the prosthesis (dislocations, subsidence, wear or failure of the polyethylene core).

Young adults with an isolated disc degeneration appear to be the best candidates for disc prosthesis. On the other hand, artificial discs are not indicated in elderly patients, due to the high chances that they may have severe degenerative changes of the facet joints and vertebral osteoporosis.

It should be taken into account, however, that disc prosthesis is still a procedure in a phase of clinical testing which has been performed in a limited number of patients and that few data are available on the clinical results obtained. In particular, the long-term results of disc prosthesis are entirely unknown. The experience with hip arthroplasty has shown that the effectiveness of the implants should be assessed at least 10 years after surgery. This holds particularly for artificial disc replacement, since this is indicated in active young adults and should, thus, last even longer than hip or knee prostheses, which are usually implanted in elderly patients. Prospective randomized studies with long-term follow-up should be made to assess whether patients with prosthesis may have clinical results as good as those of patients submitted to spinal fusion and whether the potential complications related to disc replacement are offset by lower adverse effects at the adjacent nonoperated levels.

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·CHAPTER 21·

DISC HERNIATION ASSOCIATED TO OTHER CONDITIONS

F. Postacchini, G. Cinotti

Lumbar stenosis

Clinical presentation

The clinical presentation of central stenosis associated with marked annular bulging or disc herniation is extremely variable. In some cases, signs and symptoms differ from those typical of lumbar stenosis: chronic symptoms with a predominance of radicular disturbances with respect to low back pain; bilateral radicular symptoms, even if often predominant on one side; no symptoms at rest; sensory, astenic or, less commonly, painful intermittent claudication; and negative nerve-root tension tests. A clinical presentation typical of stenosis is usually observed when the disc condition is represented by slight annular bulging. In the presence of a herniated disc, signs and symptoms are more often those typical of disc herniation: recent onset or exacerbation of symptoms; predominance of radicular pain with respect to sensory and motor dysfunction; unilateral radicular symptoms; pain at rest; no or essentially painful intermittent claudication; and positive nerve-root tension tests. The latter, however, tend to be slightly positive, particularly in elderly patients, who are those most frequently presenting stenosis. A third type of clinical picture is a combined presentation, in which either the typical symptoms of stenosis or those of disc herniation may prevail. In these cases, the patients usually complain of chronic radicular disturbances of mild entity, which have recently exacerbated; radicular symptoms are bilateral, however predominant on one side, and are not relieved by rest; different types of intermittent claudication may be present; and the nerve-root tension tests are slightly positive.

Isolated nerve-root canal stenosis often becomes symptomatic in the presence of annular bulging or a herniated disc. The symptoms of also this form of stenosis can be variable. Usually, however, the clinical presentation is that typical of pure stenosis in the presence of annular bulging, and that observed in patients with a herniated disc when the latter is present. In the former case, the patients report long-standing radicular symptoms, which worsen or appear during walking, the nerve-root tension tests are negative or slightly positive, and the motor deficits are of mild severity. In the latter case, even a small herniated disc may cause a clinical picture of acute nerve-root compression, usually associated with mild low back pain.

In stenosis of the intervertebral foramen associated with a pathologic disc condition, the clinical presentation is similar to that of radicular canal stenosis.

Surgical treatment

Spinal stenosis

Constitutional stenosis

In this type of stenosis, the disc often plays a relevant role in the compression of the neural structures. The disc condition usually consists in annular bulging into

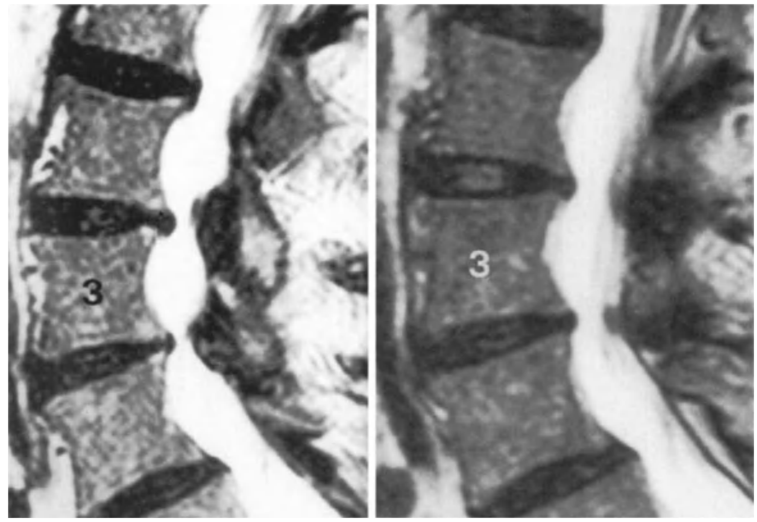

Fig. 21.1. *Constitutional spinal canal stenosis and disc bulging at multiple levels. Spin-echo T2- weighted sagittal MR images showing constitutional spinal canal stenosis at L2-L3 and L3-L4 levels; disc bulging is mild at L3-L4 level and more marked at L2-L3 level. Mild olisthesis of L4 is also present.*

the spinal canal (Fig. 21.1); when bulging is marked, it may be hardly distinguishable from a midline disc herniation. Occasionally, a midline herniation with concomitant bulging of the posterolateral portions of the annulus fibrosus is present. A lateral or posterolateral disc herniation is rarely associated with constitutional stenosis (Fig 21.2).

A classic concept in the surgical treatment of lumbar stenosis is that disc excision is not needed in the presence of annular bulging (3, 24, 26, 63, 79, 88). In effect, this is true only for mild bulging, when the disc is hard in consistency. If marked bulging is present, the disc has to be excised, particularly when it is soft (69, 68). This holds particularly when bilateral laminotomy, which is the treatment of choice in most constitutional stenoses, is carried out (75). Laminotomy, in fact, preserves spinal stability to a large extent, even if bilateral discectomy is performed, provided that the motion segment is preoperatively stable. If the disc is not excised, the preservation of the midportion of the posterior arch exposes to the risk of persistent compression of the thecal sac by the disc or, when this is soft, of possible formation of true herniation subsequently (74). Discectomy should be performed bilaterally when radicular symptoms are bilateral and/or when, after disc excision on one side, marked annular bulging

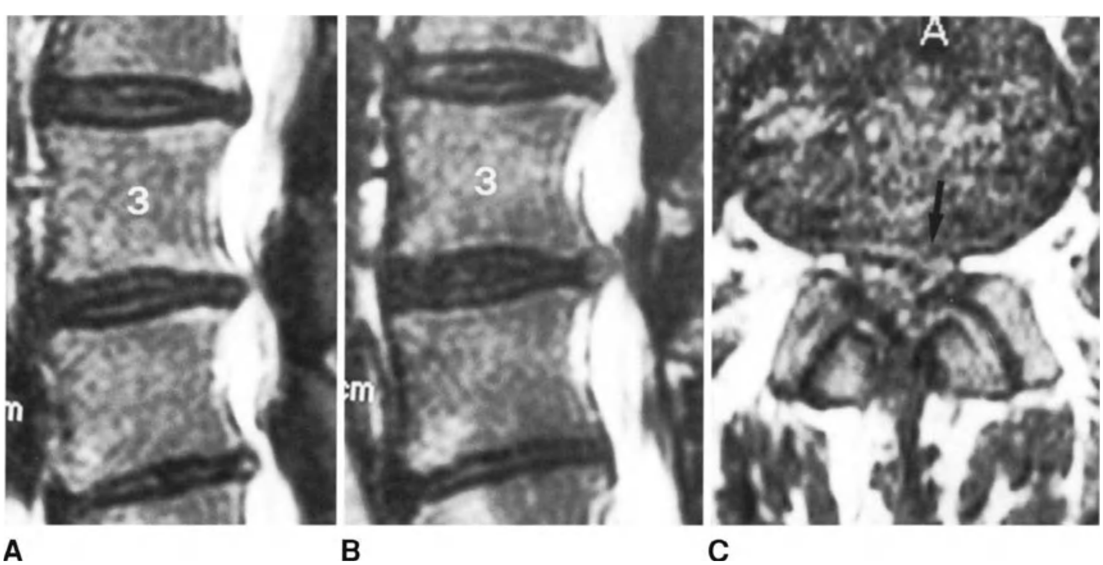

Fig. 21.2. *Constitutional canal stenosis of the spinal canal and disc herniation.* (A) *and* (B) *Spin-echo T2-weighted sagittal MR images revealing moderate stenosis at L2-L3 and L4-L5 levels and marked stenosis at L3-L4 level.* (C) *Spin-echo T1-weighted axial MR image at L3-L4 level showing disc herniation on the left.*

persists on the opposite side. In patients with two-level or three-level constitutional stenosis, a marked disc bulging is usually present at one level, very often where stenosis is most pronounced, whereas less severe bulging may be found at the adjacent levels. In these cases, discectomy should usually be performed only at the level where annular bulging is most marked.

When disc herniation is present, it is usually sufficient to perform discectomy on the side of herniation. Usually, in the presence of a midline disc herniation, the herniated tissue may be adequately removed through a unilateral approach.

Degenerative and combined stenosis

In these forms of stenosis, disc bulging is often mild and plays a secondary role in the pathomechanism of nerve-root compression. In these forms, as in constitutional stenosis, a true disc herniation is rarely present.

Discectomy should generally be avoided, particularly when annular bulging is mild and the disc is of hard consistency. On the other hand, if central laminectomy, which is often necessary in these cases (75), is carried out, a large space is created for the nervous structures, which may easily escape the mild compression exerted by the disc when the posterior arch is intact. However, disc excision should be performed in the presence of a marked disc bulging, to avoid any persistent compression of the nervous structures after surgery. Discectomy is even more indicated when bilateral laminotomy is performed or the disc is soft in consistency.

Disc excision should always be performed in the presence of disc herniation. If severe stenosis is present at the level of the herniated disc, and central laminectomy has been planned, discectomy should be carried out after bone decompression (94). Disc excision in a stenotic spinal canal, in fact, may expose to the risk of injuring the neural structures.

At times, preoperative imaging studies reveal both disc herniation and a moderate spinal canal stenosis of the degenerative or combined type. In these cases, the patient should generally be treated as if the spinal canal were of normal size, particularly when radicular symptoms are unilateral. Removal of the disc on only one side, in fact, may lead to adequate decompression of the nervous structures also on the opposite side (Figs. 21.3 and 21.4).

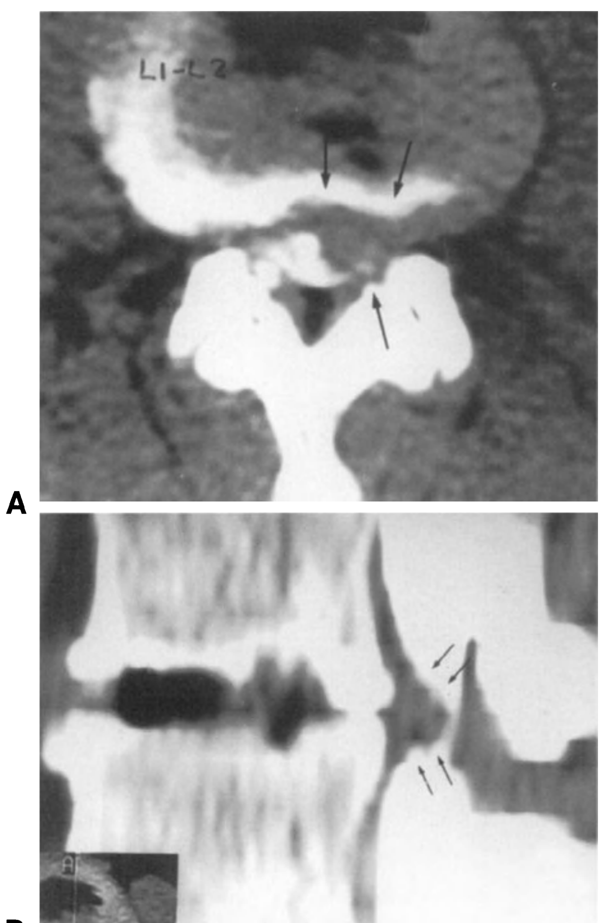

Fig. 21.3. *Combined stenosis of the spinal canal associated with disc herniation at L1-L2 level. Axial CT scan* (A) *and sagittal reconstruction* (B) *show an extruded herniation on the left (arrows) and a small-sized spinal canal. Laminotomy and discectomy were performed on the left side.*

Isolated nerve-root canal stenosis

In this type of stenosis, unilateral or bilateral laminotomy is usually performed. Discectomy should be carried out in the presence both of disc herniation and marked annular bulging (Fig. 21.5). The latter, in fact, may cause persistent, although mild, compression of the emerging nerve root. When deciding whether discectomy has to be performed, it should be borne in mind that not only preoperative imaging studies, but also intraoperative findings may not allow a small contained herniation to be distinguished from annular bulging. On the other hand, laminotomy and discectomy do not affect spinal stability, particularly when the procedure is performed unilaterally, as usually occurs in patients with isolated radicular canal stenosis who complain of radicular pain on only one side.

Laminotomy should extend from the distal one third of the vertebral body above to the proximal half of the pedicle below in order to encompass the entire intervertebral area (Fig. 21.6 D). Usually, it is not necessary to remove more than the medial half of the articular processes to obtain adequate decompression of the

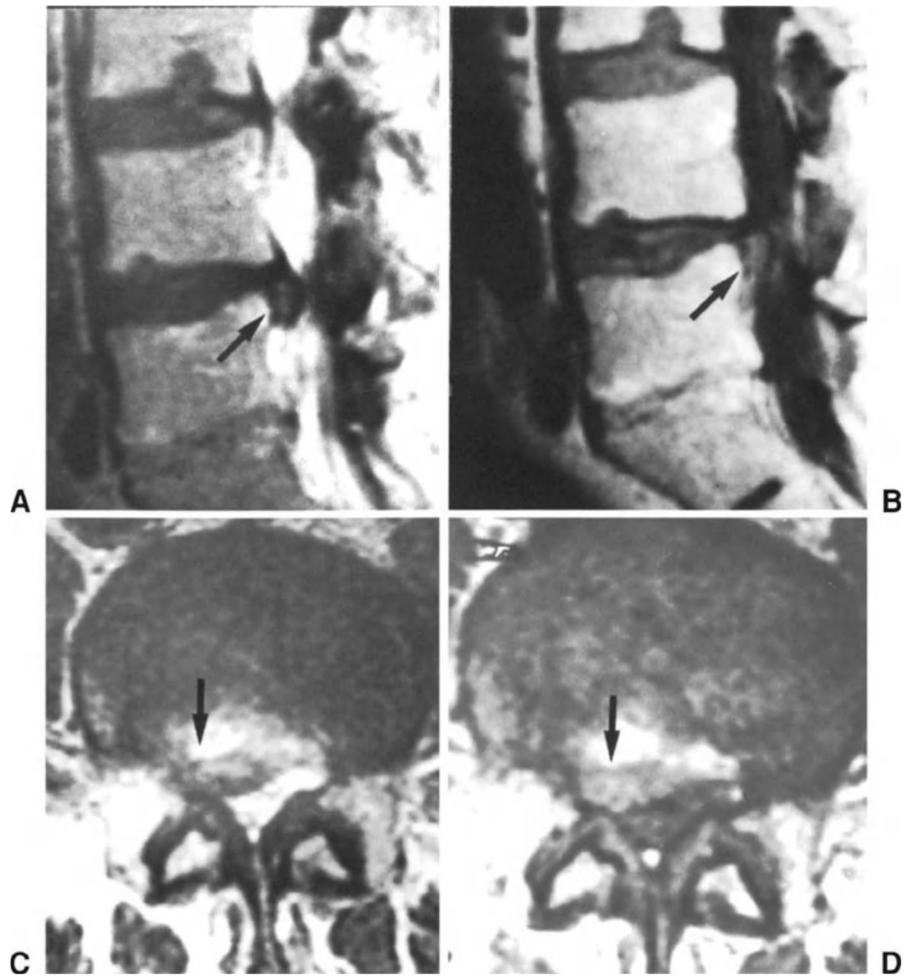

Fig. 21.4. *Disc herniation in a patient with combined spinal canal stenosis.* (A) *and* (B) *Turbo spin-echo T2-weighted and spin-echo T1-weighted sagittal MR images showing severe compression of the nervous structures at L4-L5 level due to an extruded disc herniation (arrows) in a spinal canal of small dimensions.* (C) *and* (D) *Spin-echo T2-weighted and T1-weighted axial MR images at L4-L5 level revealing a herniated disc on the right side (arrows). The patient underwent laminotomy and discectomy on the right.*

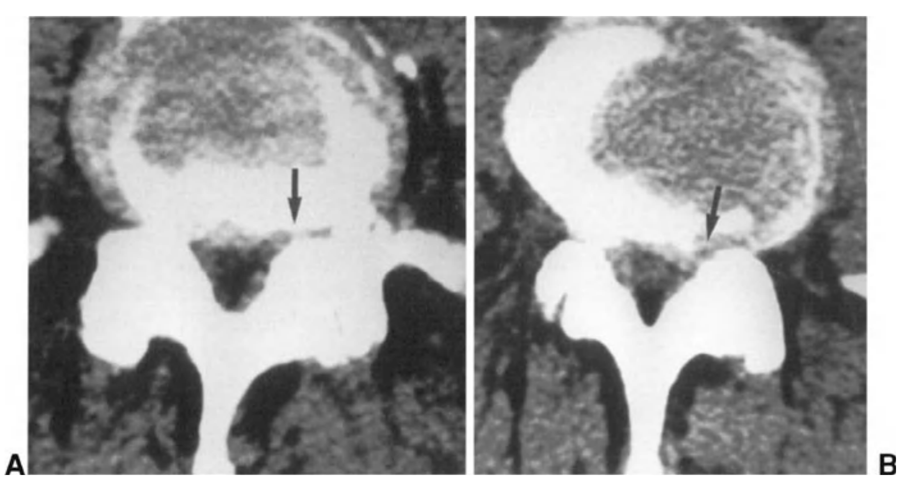

Fig. 21.5. *Disc herniation and nerve-root canal stenosis. CT scans showing bilateral stenosis of the nerve-root canal* (A), *more severe on the left side (arrow), and concomitant posterolateral and intraforaminal disc herniation* (B) *on the left (arrow). Laminotomy and discectomy were carried out on the left.*

emerging nerve root. The use of an operating microscope may be useful both to decompress the nerve root without removing too extensively the facet joint and to visualize and excise the herniated disc more easily (73, 99).

Stenosis of the intervertebral foramen

Stenosis of the intervertebral foramen, i.e., a narrowness responsible for nerve-root compression, is a rare condition, and even less common is the coexistence of a herniated disc at the same level. Annular bulging is more frequently observed, but it rarely contributes significantly to compress the nerve root running in the neuroforamen. CT and MRI studies often suggest foraminal stenosis, but most patients have only constitutional or degenerative narrowing of the neuroforamen, causing no compression of the nerve root. Usually this type of stenosis can only be diagnosed at surgery, by evaluating, with a Frazier probe, the space around the nerve root along its intraforaminal course.

In the presence of a contained or extruded herniation, or a disc fragment migrated proximally to the disc, surgical treatment is similar to that performed for a herniated disc not associated with foraminal stenosis. When the latter is suspected, an interlaminar, rather than an extravertebral, approach should be carried out, particularly when concomitant radicular canal stenosis is present or suspected. Laminoarthrectomy may be performed, as usually done, at the level of the herniated disc (L4-L5 interlaminar space for disc herniation at this level) or at the level above. In the former case, after removal of the herniation, one moves cranially to expose the nerve root above and performs a partial athrectomy in a mediolateral direction, until the root is entirely decompressed. In the latter case, starting from the interlaminar space above, the distal lamina and the articular processes compressing the nerve root are excised and, then, the herniation at the level below is removed. The former procedure, which is less invasive, should be preferred when the herniated disc is thought to be the primary or the only cause of nerve-root compression, or when concomitant radicular canal stenosis is present at the same level as the herniated disc. The second approach may be more appropriate when nerve-root compression is thought to be mainly caused by the osteoligamentous structures and / or in the presence of radicular canal stenosis at the level above that of herniation. In both cases, the use of an operating microscope may facilitate the decompression of the nerve root and decreases the risk of performing an unnecessary total facetectomy.

Indications for fusion after discectomy

In vitro biomechanical studies (1, 35) indicate that laminotomy with partial facetectomy, performed unilaterally or bilaterally, does not significantly affect spinal stability. However, spinal stability may be significantly impaired by even unilateral total arthrectomy or central laminectomy with partial arthrectomy. Disc excision, particularly if radical, significantly increases vertebral motion at the operated level (34). Clinical studies (44, 75) confirm that laminotomy preserves spinal stability to a greater extent than central laminectomy, but also indicate that a concomitant unilateral discectomy has little influence on spinal stability. Iida et al. (44) found postoperative instability in 11% of 35 patients who had undergone laminotomy, and 27% of the 11 who had had central laminectomy. However, in none of the patients was spinal stability assessed before surgery. In our experience, whether discectomy has been performed or not, the effects of surgical decompression are directly related to the degree of preoperative spinal stability (68).

When the motion segment is preoperatively stable, central laminectomy with partial or complete discectomy does not significantly impair spinal stability. This holds when at least the outer one third of the facet joint is preserved. However, if subtotal or total arthrectomy is performed, there are high chances of causing postoperative instability. Bilateral discectomy significantly increases the risk of instability. Bilateral laminotomy, which preserves the medial portion of the ligamentum flavum, as well as the interspinous and supraspinous ligaments, does not reduce stability even if a bilateral discectomy is carried out. In this case, care should be taken to preserve the midportion of the annulus fibrosus and the posterior longitudinal ligament. Complete unilateral arthrectomy with ipsilateral discectomy decreases spinal stability, however at medium and long term it is not generally associated with significant low back pain. Vertebral body osteophytes may produce spontaneous vertebral fusion, as often occurs in degenerative stenosis; this allows a wide decompression to be carried out with no significant compromise of spinal stability.

When the motion segment is potentially unstable, laminoarthrectomy with concomitant discectomy may reduce spinal stability to a critical extent. This is particularly true if discectomy is performed bilaterally or central laminectomy or complete unilateral arthrectomy are carried out. Likewise, when the motion segment is preoperatively unstable, any decompressive procedures tend to decrease spinal stability, particularly if associated with discectomy. Although the latter does not necessarily imply that low back pain will increase after surgery, there are high chances that this will occur.

Arthrodesis is usually not indicated in patients with preoperatively stable motion segments, unless bilateral arthrectomy has been performed. However, there may be an indication for fusion when central laminectomy with subtotal arthrectomy and bilateral discectomy has been carried out. Another possible exception is represented by patients with one-level or two-level stenosis, disc degeneration in the stenotic area and a chronic history of low back pain. In these cases, if no pathologic conditions are present proximally or distally to the stenotic area, arthrodesis may be performed to relief chronic low back pain.

When laminoarthrectomy and discectomy are performed in a potentially unstable spine, the possibility of performing a fusion should be carefully considered. Arthrodesis is generally indicated when central laminectomy, bilateral laminotomy and discectomy, or unilateral total facetectomy are performed.

Fusion should routinely be performed when the motion segment submitted to decompression and discectomy is preoperatively unstable. The only exceptions may be the patients with no history of chronic low back pain, in whom a unilateral laminotomy with minimal arthrectomy and discectomy are carried out.

Degenerative spondylolisthesis

The disc below a spondylolisthetic vertebra is consistently degenerated and often decreased in height. Usually the disc shows mild, if any, annular bulging, whilst a herniated disc is rarely present; the latter is more likely to occur in discs showing a normal, or moderately decreased, height (Fig. 21.6). Disc herniation may be central, posterolateral, or more rarely, lateral and is usually contained or extruded. We have never observed a tissue fragment migrated from the disc below a vertebra presenting degenerative spondylolisthesis.

As in disc herniation associated with stenosis in the absence of spondylolisthesis, the clinical presentation may be that typical of patients with disc herniation or stenosis, or mixed features may be present. Usually, the clinical picture resembles that of disc herniation when no stenosis is present, whilst it shows mixed features in the presence of a stenotic spinal canal.

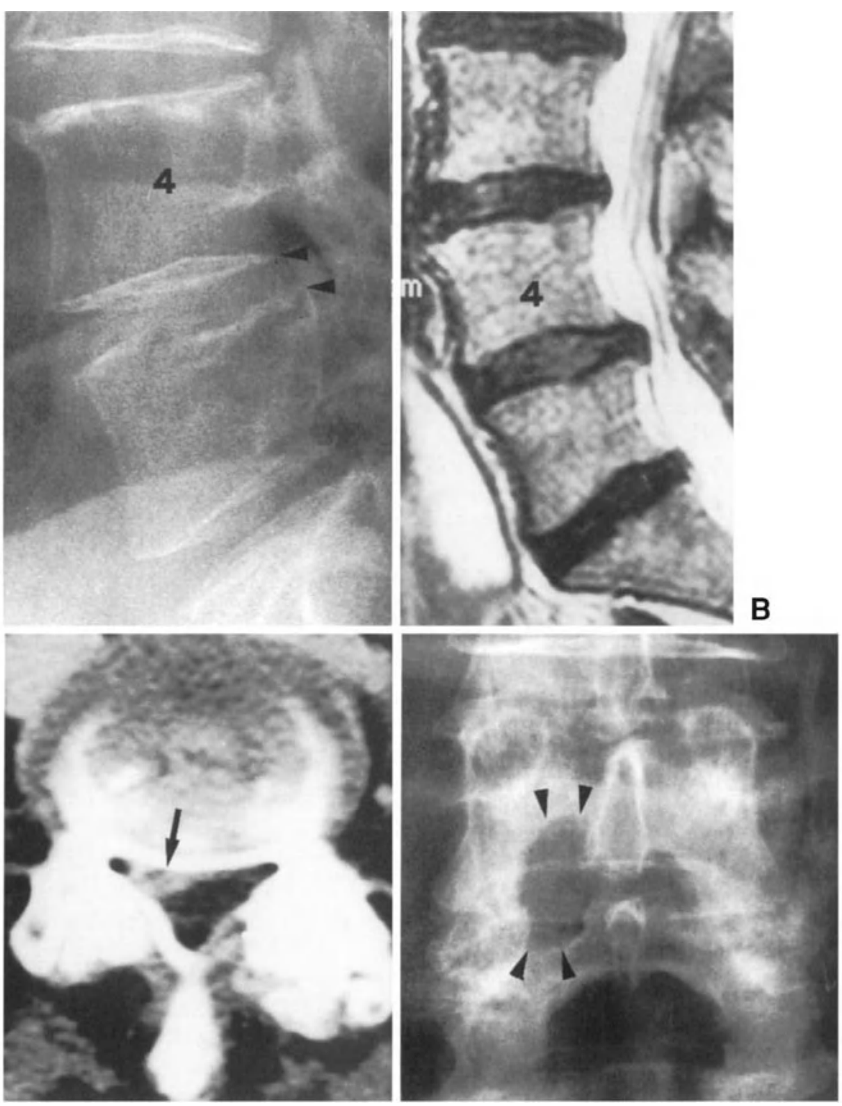

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Fig. 21.6. *Degenerative spondylolisthesis and disc herniation.* (A) *Lateral radiograph showing mild degenerative spondylolisthesis of L4.* (B) *Spin-echo T2-weighted MR sagittal image revealing compression of the nervous structures due to olisthesis of L4 and disc herniation at L4-L5 level.* (C) *Axial CT scan at L4-L5 level showing a small posterolateral herniation on the right (arrow).* (D) *Anteroposterior radiograph obtained after laminotomy and discectomy on the right. Laminotomy extends cranially until the distal third of L4 vertebral body and caudally to the distal portion of L5 pedicle (arrowheads).*

Surgical treatment

In patients with disc herniation and degenerative spondylolisthesis, the two decisions that should be made in the planning of surgical treatment are: the type of surgical decompression, i.e., unilateral or bilateral laminotomy versus central laminectomy; and whether fusion should be associated to decompression. Few studies (17, 72, 75, 76) have compared the results of bilateral or unilateral laminotomy with those of central laminectomy in degenerative spondylolisthesis, and no study has electively analyzed patients with a concomitant disc herniation. Postacchini et al. (72, 75) found that in patients with stenosis and mild spondylolisthesis, bilateral laminotomy may allow adequate decompression of the neural structures. However, in the presence of severe olisthesis (25% or more) or marked stenosis, an adequate surgical decompression may be achieved only by central laminectomy.

There are conflicting opinions on the need for spinal fusion in patients with degenerative spondylolisthesis. Although several authors have reported satisfactory results after decompression alone (23, 28, 43, 61, 76), other investigators have stressed the risk of an increase in olisthesis and vertebral hypermobility following decompression (42, 46, 52, 84, 88). This has led, in the last 20 years, to perform fusion more and more often in association with decompression (12, 17, 18, 30, 31, 39, 49, 50). Nevertheless, few studies have compared patients who had, or had not, undergone spinal fusion. In a study (53), satisfactory results were obtained by 80% of patients submitted to central laminectomy and 90% of those who had had no fusion. Herkowitz and Kurz (42), in a prospective study comparing 25 fused and 25 unfused patients, found the results to be satisfactory in 44% and 90% of cases, respectively.

Surgical options

Different surgical procedures may be performed in patients with degenerative spondylolisthesis, particularly when a concomitant disc herniation is present. The choice depends on several factors: type and severity of stenosis; presence of unilateral or bilateral radicular symptoms; severity of low back pain before the clinical manifestation of disc herniation; degree of olisthesis; degree of mobility of the olisthetic vertebra on preoperative flexion-extension radiographs; and presence of degenerative changes in the discs adjacent to the herniation.

At one extreme, there are the patients with signs and symptoms typical of disc herniation: no history of chronic low back pain, mild olisthesis with no vertebral hypermobility on flexion-extension radiographs, and no stenotic compression of the neural structures. In these patients, it is usually sufficient to perform a conventional laminotomy and discectomy or microdiscectomy, without arthrodesis (Fig. 21.6). After discectomy, olisthesis may increase, but this does not usually cause significant low back pain, nor stenosis, or symptomatic stenosis, on the contralateral side, at least for several years after surgery. However, the patient should be informed that this surgical option involves the risk that central, or contralateral, decompression and / or fusion may be needed in the following years. The advantages of this surgical strategy are the reduced morbidity and rapid functional recovery associated with discectomy alone, and the low chances of developing symptomatic degenerative changes at the adjacent levels.

At the opposite extreme, there are the patients with or without a history of chronic low back pain, who show marked olisthesis, vertebral hypermobility, severe stenosis of the spinal canal, and bilateral radicular symptoms. In these patients, central laminectomy or bilateral laminotomy and fusion should be carried out.

In the intermediate situations, there are various options: 1) Unilateral laminotomy and discectomy, associated with fusion, may be preferred in patients with chronic low back pain or hypermobility of the olisthetic vertebra, but no significant stenosis or radicular symptoms on the side opposite the herniation. 2) Bilateral laminotomy with unilateral or bilateral discectomy and fusion may be indicated in the presence of stenosis on the side opposite the herniated disc or of midline or bilateral herniation. In these cases, however, central laminectomy is usually preferable in order to achieve a more effective decompression of the neural structures, at least in the presence of central stenosis (75). This holds particularly if pedicle screw fixation, which increases short-term spinal stability, is carried out. 3) Bilateral laminotomy and unilateral discectomy without fusion may be carried out in patients with no chronic low back pain, who show moderate central stenosis or radicular canal stenosis on the side opposite the herniation, mild olisthesis without vertebral hypermobility, decreased height of the herniated disc, and / or marked degenerative changes or annular bulging in one of the discs adjacent to the herniation.

In patients with herniation of an adjacent disc to that below the olisthetic vertebra, the decision to extend the surgical procedure to the olisthetic level (decompression, arthrodesis or both) is based on the evaluation of the same factors as in patients with disc herniation immediately below the olisthesis. In these cases, the most important element in choosing the surgical procedure is the severity of stenosis and its possible effect on radicular symptoms over time. If an arthrodesis is performed, this usually includes the level where disc herniation is located.

Type and extension of fusion

The type of fusion depends, to a large extent, on the surgeon's preference. We prefer bilateral intertransverse arthrodesis with autologous bone graft augmented with pedicle screw fixation. The main goal of internal fixation is to avoid any postoperative rigid immobilization. Instrumented fusion allows a similar proportion of solid fusions to be obtained compared with non-instrumented arthrodesis and prolonged rigid post-operative immobilization. In the majority of studies, the percentage of solid fusions ranges from 91% to 100% after noninstrumented arthrodesis (30, 31, 53, 72) and from 87% to 100% after arthrodesis using pedicular fixation and autologous bone graft (12, 18, 19, 47).

Internal fixation with pedicle screws can be performed on one or both sides. Unilateral fixation may be sufficient in patients with mild olisthesis and no vertebral hypermobility who undergo arthrodesis at a single vertebral level (19); this holds particularly if unilateral laminotomy and discectomy are performed (Fig. 21.7). The advantage of using unilateral instrumentation is a decreased stiffness of the fused area, whereby the chances of degenerative changes at the adjacent motion segments will be reduced (20, 47, 70). Bilateral instrumentation should be preferred in the presence of severe olisthesis or hypermobility of the olisthetic vertebra, particularly if central laminectomy is performed (Fig. 21.8).

The alternative to posterolateral arthrodesis is posterior interbody fusion, using autologous iliac bone graft, bone fragments obtained from the excised portion of the posterior vertebral arch or allograft (10, 13, 21, 85). Unilateral or bilateral pedicle screw fixation may be associated to interbody fusion (14, 48, 86). The latter may also be carried out by packing bone graft into titanium or carbon fiber cages, implanted into the intervertebral space.

Anterior discectomy with interbody fusion (90) is justified only in the absence of stenosis or when this is

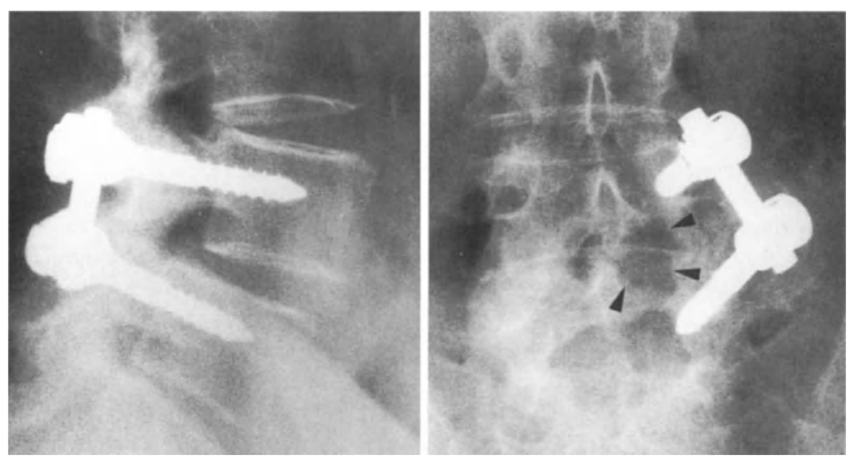


Fig. 21.7. *Postoperative radiographs of a patient with stenosis of the left nerve-root canal due to degenerative spondylolisthesis of L4 and posterolateral disc herniation at L4-L5 level on the left. Laminotomy (arrowheads), discectomy and unilateral intertransverse instrumented fusion was carried out on the left.*

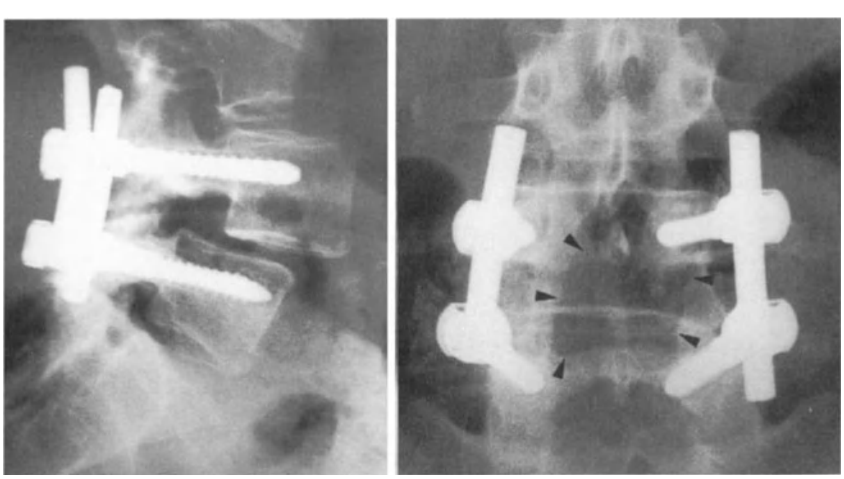


Fig. 21.8. *Postoperative radiographs of a patient with stenosis of the spinal canal caused by degenerative spondylolisthesis of L4. Central laminectomy (arrowheads) was performed along with bilateral intertransverse instrumented fusion.*

of mild severity and probably asymptomatic. In the remaining cases, there are high risks that radicular symptoms may persist after surgery due to persistent stenosis.

When the olisthetic vertebra is L4, or a vertebra above, fusion may be limited to the level of olisthesis ("floating" fusion), or extended to the sacrum. We always prefer a floating fusion, except when the disc or discs below the area to be fused show marked degenerative changes, which may increase in severity or become symptomatic as a result of the increased mechanical stress caused by the arthrodesis. A fusion extended to the sacrum exposes the last mobile motion segment to higher mechanical stresses than a floating fusion, with higher risks of disc degenerative changes and postoperative instability (71). On the other hand, with a floating arthrodesis, there are the same chances of obtaining a solid fusion as with arthrodesis extended to the sacrum (14, 47).

Reduction of spondylolisthesis

There is no evidence that reduction of vertebral slipping is beneficial in patients with degenerative spondylolisthesis undergoing posterolateral arthrodesis. In this condition, in fact, olisthesis is usually mild and never exceeds 50% of the sagittal diameter of the vertebral body below. Furthermore, there is no proof that patients who have undergone reduction of the spondylolisthesis have greater chances of achieving a solid fusion or a better clinical outcome than those undergoing no reduction of the slipping.

Spondylolysis

Spondylolysis without olisthesis is seldom observed in adulthood, particularly in subjects aged over 40 years. This condition does not appear to affect the incidence of disc degeneration at the level above the spondylolytic vertebra, whilst the disc below frequently shows mild degenerative changes. It is still unclear whether disc herniation occurs more likely in the disc below a spondylolytic vertebra, however, in our experience, spondylolysis does not predispose to disc herniation.

Surgical treatment

Disc excision below a spondylolytic vertebra may impair spinal stability and cause spondylolisthesis. The latter, however, almost invariably occurs over time (69), although this event is not necessarily associated with low back pain (32). Therefore, arthrodesis is not always needed when discectomy is carried out. Fusion is generally indicated when preoperative flexion-extension radiographs demonstrate hypermobilty of the spondylolytic vertebra, as well as in patients with chronic low back pain who show no degenerated discs other than the herniated one. When the disc above and/or below the herniation exhibits marked degenerative changes, arthrodesis may be extended to the adjacent level, or fusion should be avoided. We usually prefer the latter option, particularly in young patients in whom fusion may be performed subsequently, if the spondylolytic vertebra becomes unstable or the patient complains of severe back pain postoperatively.

An alternative to arthrodesis is the reconstruction of the isthmic defect. In this case, discectomy should be carried out through a limited facetectomy or by excising only the ligamentum flavum. This is more easily accomplished using the operating microscope. Thereafter, the pars interarticularis is exposed on both sides, the pseudarthrosis tissue is removed and the bone defect curetted; the isthmic defect is then filled with bone graft obtained from the iliac crest or the spinous process of the spondylolytic vertebra. The fixation of the loose vertebral arch may be achieved with a screw inserted into the posterior border of the lamina and passed through the isthmus up to reach the pedicle (15); with a wire anchoring the spinous process to the transverse processes (62) or to pedicle screws (78); or with transisthmic screws anchored to a laminar hook (59). The latter is the authors' preferred method. The percentage of successful isthmic reconstructions in patients with spondylolysis or spondylolisthesis (Mayerding grade I) (57) ranges from 67% to 100% (5, 8, 16, 45, 62, 65, 87, 92), with no significant differences between the various techniques.

In the presence of a herniated disc below the spondylolytic vertebra, isthmic reconstruction is indicated in patients showing one or more degenerated discs adjacent to the herniation, as well as in those with no adjacent degenereted discs who do not complain of significant low back pain. In both cases, isthmic reconstruction is aimed at avoiding the occurrence of spondylolisthesis, since preoperative low back pain may even not be relieved by the operation. However, it should be taken into account that in a study (83) carried out on young patients (mean age, 17 years), no significant differences in the clinical outcome were found between patients with or without degenerative disc changes at the level below the spondylolytic (or slightly spondylolisthetic) vertebra.

Isthmic spondylolisthesis

Disc herniation may occur at the interspace above or below an olisthetic vertebra, or at a different level.

In young patients, the disc below the spondylolisthetic vertebra was found to be usually normal in one study (89) and generally degenerated in another study (82). However, the disc is almost invariably degenerated in older patients (89, 87). This is particularly true in the presence of Grade II or III spondylolisthesis, in which the disc is usually narrowed; this is the rule in patients with Grade IV spondylolisthesis. Axial CT and MRI studies often show an apparent posterior or lateral annular bulging (Figs. 21.9 A and B), which may be incorrectly interpreted as disc herniation. Such a misinterpretation may occur because, on axial scans, the posterior annulus appears to be dislocated posteriorly with respect to the vertebral body above, which is slipped forwards. A true herniated disc is rarely observed before the age of 20 years (41). It is also rare in older patients and is usually associated with Grade I or II spondylolisthesis (6, 56, 58) (Fig. 21.9). In a study (95), 11% of 97 patients treated operatively for spondylolisthesis underwent discectomy due to a concomitant herniated disc. Possibly, however, discectomy was decided intraoperatively, rather than on the basis of preoperative imaging studies.

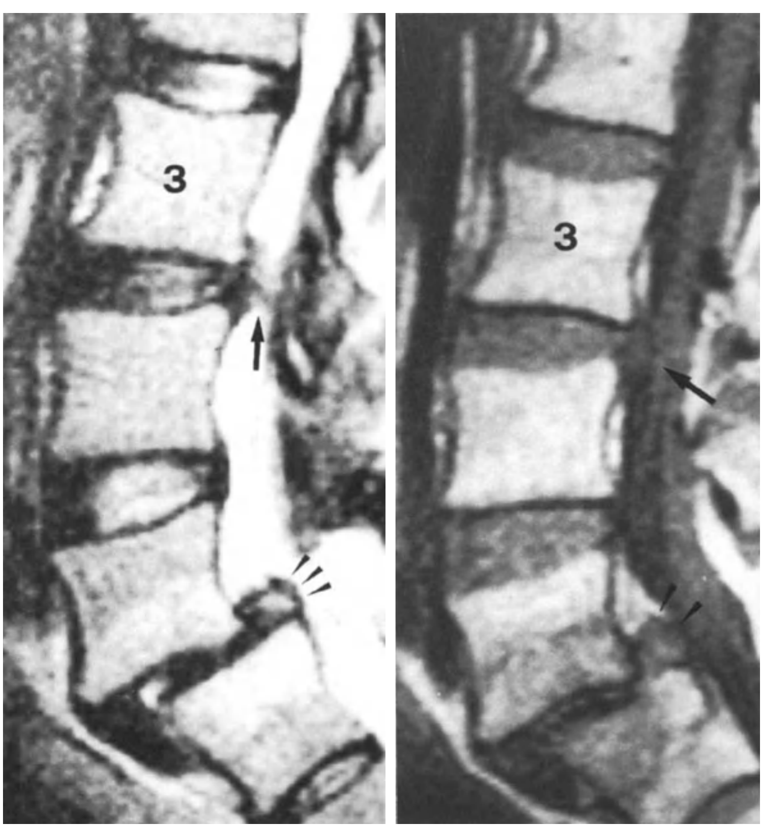
The disc above an olisthetic vertebra shows degenerative changes more often than discs at the same level in the absence of spondylolisthesis (82, 89). However, in our experience, the prevalence of disc herniation is not significantly different from that found in an homologous disc in patients with no spondylolisthesis. The discs located at a distance from spondylolisthesis are not affected by the vertebral slipping.

The herniation possibly found below an olisthetic vertebra is usually contained or extruded, whilst spondylolisthesis does not appear to influence the type of herniation which may be present at other vertebral levels.

Clinical presentation

It is well known that isthmic spondylolisthesis may be asymptomatic or may cause mild to severe low back and / or radicular pain, and that the severity of symptoms is related to the level of the olisthetic vertebra and the degree of vertebral slipping (4, 32, 33, 40, 80, 81, 95, 96).

In patients with concomitant disc herniation and spondylolisthesis, three different types of clinical history may be reported: 1) The patient, who had never suffered from low back pain, began complaining of back pain associated or not with radicular symptoms since a



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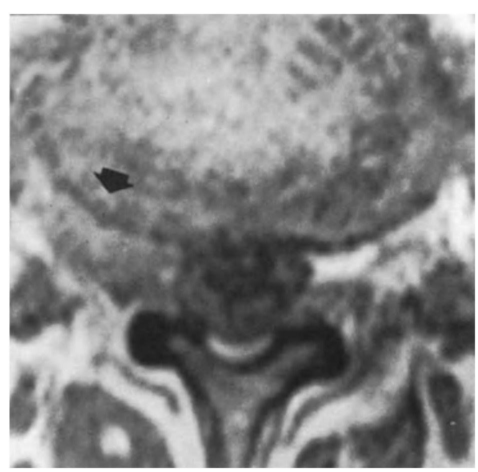

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Fig. 21.9. *Disc herniation and isthmic spondylolisthesis.* (A) *and* (B) *Turbo spin-echo T2-weighted and T1-weighted MR sagittal images showing disc herniation at L3-L4 level (arrow) and Grade II isthmic spondylolisthesis of L5. Note the disc below the olisthetic vertebra, which appears to protrude into the spinal canal (arrowheads).* (C) *Spin-echo T1-weighted axial RM image at L3-L4 level revealing an intraforaminal herniation on the right (arrow).*

few weeks or months. 2) The patient has been complaining of intermittent episodes of mild low back pain for several years, although the symptoms limited the patient's daily activities to a negligible extent, and medications were rarely needed. Recently, however, low back pain increased in severity and radicular pain appeared. 3) The patient reports a long history of continuous or very frequent low back pain, which has recently become worse and / or associated with radicular pain. The latter may have been present in the past, but it was of mild entity and presented different clinical features to that of recent onset.

The radicular signs and symptoms are similar to those of patients with no spondylolisthesis.

Diagnostic studies

CT and / or MRI studies usually allow a correct diagnosis to be made. However, in the presence of severe olisthesis, the axial images can be difficult to interpret, because of the geometric distortion of the spinal canal and the abnormal spatial relationships between the olisthetic vertebra and the vertebra below (77). Furthermore, since it may be difficult to obtain axial scans parallel to the disc when the slipped vertebra is tilted caudally, a multiplanar CT reconstruction or sagittal MRI scans should be evaluated.

Occasionally, doubts may arise regarding the role played by the spondylolisthesis and a concomitant disc herniation in the etiology of radicular symptoms. This mainly occurs in patients with Grade II or III spondylolisthesis, which can easily cause radicular symptoms. For instance, in a patient with an L5 radicular syndrome, who shows a severe spondylolisthesis of L5 and a small contained or extruded disc herniation at L4-L5 level, it may be difficult to determine whether the radicular pain is caused by the spondylolisthesis or the herniated disc. It is extremely important to clarify this diagnostic doubt, particularly when no fusion is planned, if the clinical syndrome appears to be caused by the herniation. Likewise, in patients with low back pain and radicular symptoms with no precise dermatomal distribution, in whom imaging studies reveal disc herniation at the L3-L4 level and a concomitant spondylolisthesis of L5, it may be difficult to determine the role of the spondylolisthesis in the etiology of the radiated symptoms (Fig. 21.10). In both cases, it may be useful to carry out discography, in order to provoke the pain usually felt by the patient. Occasionally, an anesthetic block of the radicular nerve may also be useful to establish the etiologic role of spondylolisthesis.

Myelography is of limited value, since the nerve root emerging at the level of the olisthetic vertebra (L5 root for spondylolisthesis of L5) may present a filling defect at the level of the isthmic lesion, even in the absence of radicular symptoms. However, myelograms may clearly show compression of the nerve roots emerging above or below the olisthetic vertebra. At times, despite all diagnostic studies, serious doubts on the origin of the


A B C

Fig. 21.10. *Disc herniation and isthmic spondylolisthesis.* (A) *and* (B) *Turbo spin-echo T1-weighted sagittal MR images showing an intraforaminal disc herniation and Grade I spondylolisthesis of L5.* (C) *Spin-echo T1-weighted axial MR image at L5-S1 level revealing an intraforaminal herniation on the left (arrow).*

radicular symptoms may persist in the presence of disc herniation and a concomitant spondylolisthesis.

Management

Percutaneous procedures

A few authors (25, 26, 64) have performed chymopapain injection in patients with a herniated disc below a spondylolisthetic vertebra (Grade I or II); the proportion of satisfactory results was found to be similar to that in patients without spondylolisthesis, and only in few cases was an increased olisthesis observed after the procedure. In our experience, a true herniation rarely develops in the disc below the olisthetic vertebra. In some of the patients submitted to nucleolysis, the satisfactory outcome might be attributed to the natural evolution of an irritative radicular syndrome, produced by bulging of the annulus fibrosus or the pseudarthrosis tissue. However, in the presence of a true herniation, there may be an indication for chemonucleolysis, particularly when radicular pain is the only or main patient's complaint. When the disc below the spondylolytic or spondylolisthetic vertebra shows a normal or slightly decreased height, it should be taken into account that olisthesis or vertebral mobility may increase following chemonucleolysis.

In the presence of a herniated disc above the olisthetic vertebra, the indications for chemonucleolysis or other percutaneous procedures are similar to those in patients without spondylolisthesis.

Surgical treatment

When spinal fusion is performed along with discectomy, laminoarthectomy may be even very wide or, in patients in whom radicular symptoms are attributable to the spondylolisthesis, the entire posterior vertebral arch may be excised. If no fusion has been planned, laminoarthrectomy should be of limited extent to reduce the risk of causing or accentuating spinal instability. In these cases, it is preferable to use the operating microscope, since it may allow disc excision through a smaller laminoarthrectomy than that performed with the naked eye. As in patients with herniation and no spondylolisthesis, a complete discectomy should be preferred.

Indications for fusion

Disc herniation below spondylolisthesis. To evaluate whether fusion may be needed, the following factors should be taken into account: severity and duration of low back pain; level of the olisthetic vertebra; degree of mobility of the slipped vertebra on flexion-extension radiographs; height of the disc where herniation has developed; and presence of degenerative changes in the intervertebral discs adjacent to the slipped vertebra.

Usually, arthrodesis is not indicated in patients with no history of low back pain or a history of occasional, mild pain. This holds particularly when: 1) The olisthetic vertebra is L5; this vertebra is intrinsically more stable than an L4 olisthetic vertebra (37) and is less likely to become unstable after discectomy. 2) The preoperative flexion-extension radiographs reveal no hypermobility of the slipped vertebra. 3) The disc where herniation has occurred shows a marked decrease in height; in this instance, there is little probability that the slipping will significantly increase after discectomy, since, in adulthood, the spontaneous increase in olisthesis over time parallels the decrease in height of the disc below and terminates when the disc is completely resorbed (55, 66, 69, 93). 4) Preoperative MRI demonstrates degenerative disc changes at the level above or below the herniation. After arthrodesis, in fact, the increased mechanical stresses on the degenerated disc tend to aggravate the degenerative changes; this may be avoided by extending the arthrodesis to the adjacent level(s), however an extended arthrodesis may not be desirable, particularly in young patients or those with mild low back pain.

Arthrodesis is generally indicated in patients who have been complaining of intermittent low back pain for years or decades. This holds particularly when: the disc where herniation is located shows a slight decrease in height; flexion-extension radiographs demonstrate hypermobility of the olisthetic vertebra; and no degenerative changes are present in the disc(s) adjacent to the slipped vertebra. The risk, if fusion is not performed, is that discectomy may lead to an exacerbation of low back pain due to the occurrence of, or an increase in, spinal instability.

Arthrodesis is generally indicated in patients with a long history of frequent or continuous low back pain. The procedure is contraindicated when multiple-level disc degeneration makes it difficult to determine the role played by the spondylolisthesis in the etiology of chronic low back pain. In these cases, discography may be carried out to establish whether a degenerated disc adjacent to the spondylolisthesis is symptomatic; in addition, the pars defect may be injected with local anesthetic to assess the role of pseudarthrosis tissue in the origin of low back symptoms (9, 87). However, the presence of disc herniation makes these diagnostic tests of uncertain interpretation and, thus, of little usefulness.

Disc herniation above spondylolisthesis. This condition usually consists in a herniation at L4-L5 level, in the presence of a spondylolisthesis of L5. In these cases, arthrodesis is rarely indicated. The indication essentially depends on the presence (or absence) and severity of chronic low back pain, since excision of the herniation does not affect the stability of the olisthetic vertebra, unless a subtotal or total L5-S1 foraminectomy is performed. Hence, the indication for fusion is, to a large extent, independent of the herniation and should be evaluated using the same criteria adopted in patients who have spondylolisthesis and no disc herniation. If fusion is carried out, it should usually be extended to L4. The coexistence of severe degenerative changes of the L3-L4 disc may represent a contraindication for arthrodesis, due to the increase in mechanical stress on this level following fusion.

Types of arthrodesis

A posterolateral arthrodesis, an anterior or posterior interbody fusion, or a circumferential arthrodesis, with or without instrumentation, can be performed; furthermore, an in situ fusion may be carried out, or the olisthesis may be reduced preoperatively or intraoperatively (8, 41, 55, 60). Posterolateral in situ fusion with pedicle screw fixation is the authors' preferred method in adult patients with Grade I-III spondylolisthesis. It is still unclear whether pedicle screw fixation significantly increases the proportion of solid fusions in patients with isthmic spondylolisthesis; pedicle screw fixation led to a higher rate of fusions in one comparative study (101), but not in another investigation (58). However, the use of internal fixation decreases the immediate postoperative back pain and, thus, the hospitalization time and, above all, avoids prolonged rigid postoperative immobilization. Intraoperative reduction of the olisthesis associated with circumferential arthrodesis may be considered in patients with Grade IV spondylolisthesis or in adolescents with Grade III or IV slipping.

Isthmic repair

This procedure is indicated in patients with Grade I spondylolisthesis. However, as in patients with spondylolysis, the resolution of chronic low back pain may not be the main goal of the procedure, when pain is due to degeneration of the disc below the slipped vertebra. Isthmic repair may be useful in patients with disc herniation below the slipped vertebra when fusion is not indicated, in order to avoid the progression of olisthesis and the possibile occurrence of postoperative instability.

Lumbar scoliosis

The prevalence of disc herniation does not seem to be affected by the presence of idiopathic lumbar scoliosis. This is also true for degenerative scoliosis, which may be associated more frequently with lumbar stenosis (2, 27, 38, 54).

In patients with idiopathic scoliosis and disc herniation, the clinical presentation does not differ from that of patients without scoliosis, although scoliotic patients are more likely to report a history of chronic low back pain. More often, patients with degenerative scoliosis present a clinical picture which is typical of stenosis.

Percutaneous treatments may be indicated in young patients with a spinal curve of less than 20°. In the presence of more severe scoliosis, narrowing of the radicular canal may be present, which increases the chances of failure after percutaneous treatments. Moreover, if chemonucleolysis is performed, the reduced disc height occurring after chymopapain injection may cause further narrowing of the intervertebral foramen, and lead to compression of the emerging nerve root. Furthermore the decreased disc height might decompensate the scoliotic curve.

Although in these cases discectomy is not technically different from that performed in subjects without scoliosis, care should be taken to avoid an excessively wide arthrectomy, which might compromise spinal stability to a greater extent than in non-scoliotic patients. Therefore, microdiscectomy seems to be particularly indicated in these patients, since it may allow excision of the herniated disc through a more limited facetectomy. There is no indication for fusing the operated level, unless a complete arthrectomy has been performed. In the presence of severe scoliosis, a single-level fusion exposes to the risk of increasing the spinal curve and/or causing rotatory instability of the motion segments adjacent to the arthrodesis.

In adults with severe and progressive scoliosis, who complain of intense low back pain prior to the appearance of lumboradicular symptoms caused by the herniated disc, correction of the deformity and fusion should be associated to discectomy. If posterior instrumentation is used to correct the deformity, a segmental fixation with pedicular screws may be advisable (54). With pedicle screw instrumentation one may obtain a better correction of the lumbar kyphosis, which is often responsible for the low back symptoms complained of by the patients who have lumbar scoliosis. In the presence of a marked and rigid kyphoscoliosis, an anterior, or combined, procedure may be indicated.

Cervical and thoracic disc herniations

Cervical and lumbar herniations rarely occur simultaneously. Even more rarely are a lumbar and a thoracic herniation found together, since the latter condition is uncommon in itself. The presence of disc herniations in different areas of the spine entails diagnostic and therapeutic problems.

Diagnosis

Diagnostic problems may arise in the presence of spinal cord compression causing symptoms which mimic those of a lumbar disc herniation, at least when the symptoms in the lower limbs are vague and bilateral, and sensory and motor impairment prevails on pain. This may occur, for instance, in the presence of a low thoracic herniation and a lumbar disc herniation located in the midline or associated with lumbar spinal stenosis.

Spinal cord compression shown by CT or MRI may be asymptomatic or symptomatic (Fig. 21.11). In the former case, the patient presents only the clinical signs and symptoms caused by lumbar herniation. In the latter, some or all of the typical signs of the various cervical or thoracic cord compression syndromes may be present. The correct diagnosis of the origin of the patient's signs and symptoms may be made from the evaluation of disturbances in the lower limbs. The presence of pain, particularly if it shows a dermatomal distribution, and monoradicular motor loss suggest a lumbar pathologic condition. This holds also for depression of the reflex activity on only one side. However, in the presence of asthenic intermittent claudication, it may be impossible to determine whether this is caused by compression of the caudal nerve roots or the spinal cord.

Sensory and / or motor evoked potentials can be useful in determining whether a subclinical myelopathy is present or evaluating the severity of a clinically overt myelopathy. EMG sudies may document the presence and severity of lumbar nerve-root compression. Discography or anesthetic nerve-root block may be useful when doubts persist as to whether the lumbar disc herniation is asymptomatic or responsible for the patient's symptoms.

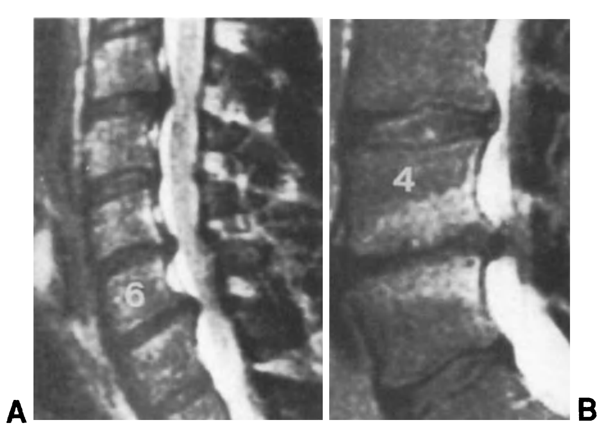

Fig. 21.11. *MR sequences of a patient with asymptomatic herniations in the cervical spine and a symptomatic herniation at L4-L5 level.* (A) *Turbo spin-echo T2-weighted sagittal image showing disc herniation at C3-C4 and C5-C6 levels and stenosis at C6-C7 level.* (B) *Turbo spin-echo T2-weighted sagittal image revealing stenosis of the spinal canal and disc herniation at L4-L5 level.*

The role of these investigations in the diagnostic path is demonstrated by the following cases.

Case 1. *A 38-year-old female complained, for several months, of sensory loss and paresthesias in the posterior aspect of the left thigh, and less frequently, the left leg, along with frequent pain in the posterior aspect of the limb and a sensation of asthenia and "difficulty in controlling" the lower limb. Physical examination revealed a moderate increase in reflex activity in both lower limbs, a negative Babinski's sign, and decreased abdominal reflexes on the left side. MRI showed a midline herniated disc at T9-T10 level and a small disc herniation at L5-S1 level, on the left. SEPs showed an increase in the central sensory conduction velocity. EMG revealed normal function of the S1 nerve root. Discography provoked no low back or radicular pain. The herniation at L5-S1 level was, thus, thought to be most probably asymptomatic and T9-T10 discectomy was carried out with complete and lasting relief of symptoms.*

Case 2. *A 62-year-old male had been complaining, for several months, of low back pain, as well as pain and mild hyposthesia along the posterolateral aspect of the thigh and the posterior aspect of the leg, on the left. Similar symptoms, however less severe, were present on the right side. The pain in the left leg considerably increased during walking, whereby the patient could walk only a few dozen meters. Physical examination revealed a marked symmetrical hyperreflexia on both lower limbs, a negative Babinski's sign, normal abdominal reflexes, absence of motor deficits in the lower limbs, a negative straight leg raising test, and a slightly positive femoral nerve stretch test, on the left side. Radiographs of the lumbar spine showed degenerative spondylolisthesis of L3. MRI revealed stenosis of the spinal canal and a left paramedian disc herniation at L3-L4 level , as well as a left paramedian herniation at T10-T11 level. SEPs were normal, whilst EMG studies showed slight impairment of the L5 nerve root on the left. The thoracic herniation was thought to be asymptomatic. Central laminectomy and left discectomy, as well as instrumented posterolateral fusion, were performed at L3-L4 level, with complete relief of symptoms.*

Management

Two main decisions should be made in the planning of surgical treatment: whether surgery should address only one condition or both; and, if surgery is performed on the lumbar spine, to make sure that the spinal cord compression will not become worse during the operative procedure. The latter situation may occur due to the patient position during surgery or alteration in the spinal cord blood supply in the presence of preoperative ischemia or edema of the spinal cord.

The first decision has to be made on the basis of the clinical features and the results of the electrophysiologic studies. Usually, only one of the two conditions is responsible for the patient's signs and symptoms and this is the first, or only, condition that should be treated surgically. However, if both conditions appear to be symptomatic, or it is unclear which one is responsible for the patient's symptomatology, both should be treated simultaneously. Alternatively, only the condition that is more likely to be symptomatic may be treated, after informing the patient that an additional operation may be needed, if required by the residual symptoms.

If surgery is initially performed on the lumbar region, SEPs should be recorded during the procedure, beginning immediately after patient positioning. In the presence of marked SEP abnormalities, the patient position should be modified and the blood pressure increased if hypotensive anesthesia is being performed, or the procedure should be discontinued.

Intradural tumors

The coexistence of a neurinoma of the cauda equina and a herniated disc is extremely rare. A neurinoma can be asymptomatic or symptomatic. While in the former case, symptoms are only due to the herniated disc, in the latter, the herniation may be an accidental finding or it may appear during the chronic course of the neurinoma (already diagnosed or undiagnosed), and lead to a change in the patient's symptoms.

If the neurinoma originates from an extrathecal nerve root and is asymptomatic, there is no indication for removing the tumor during discectomy. However, if there is any doubt about the origin of the radicular symptoms, both neurinoma and disc herniation should be excised. If the tumor is intrathecal, it is usually removed along with the herniation. In these cases, in fact, it may be extremely difficult, or even impossible, to determine which condition is responsible for the radicular symptoms. Morever, an asymptomatic intrathecal neurinoma is more likely to become symptomatic and require surgery over time. In the case of a combined procedure, the neurinoma should be removed before the herniated disc, since the surgical trauma caused to the emerging nerve root and thecal sac while removing the herniated disc can accentuate the compression of the intrathecal nerve roots by the tumor, with the possible appearance of neurologic deficits postoperatively. The same considerations are valid for other benign intrathecal tumors.

An ependymoma, or other intramedullary tumors located in the conus medullaris or the thoracic cord, may exceptionally be associated with lumbar disc herniation. When the diagnosis has been made preoperatively, surgical treatment should include the excision of the herniated disc if this appears to be symptomatic. If disc excision alone is carried out, SEPs should be monitored during surgery, since paraplegia or cauda equina syndrome have been reported in patients operated on for disc herniation, who presented a thoracic or high lumbar intradural tumor not diagnosed preoperatively (7).

Extradural meningeal cysts

Radicular meningeal cysts are usually asymptomatic. Therefore, it is generally unnecessary to excise a

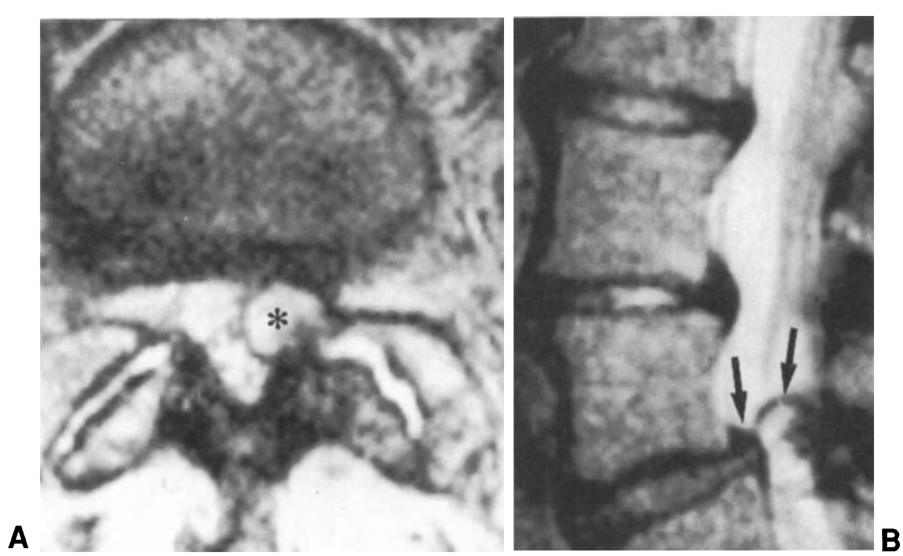

Fig. 21.12. *Synovial cyst of the facet joint and annular bulging.* (A) *Turbo spin-echo T2-weighted axial MR image at L5-S1 level revealing a large cyst (asterisk) of the left facet joint, compressing both the left S1 nerve root and the thecal sac.* (B) *Turbo spin-echo T2-weighted sagittal MR image showing the synovial cyst (arrow) and the concomitant annular bulging (arrow) at L5-S1 level. Mild olisthesis of L5 is also present.*

meningeal cyst of the emerging nerve root during discectomy. However, if the nerve root is compressed by the cyst due to its large dimensions and/or the presence of an anomalous nerve root, it is advisable to cut the cyst wall along the longitudinal axis of the nerve root and suture the two edges in order to eliminate the cystic dilation. Similar considerations are valid for the cysts of the thecal sac.

Periarticular cysts

Periarticular, synovial or ganglionic cysts mainly develop in arthrotic facet joints (100). Hence, this condition is not rare in patients with degenerative stenosis of the spinal, or nerve-root, canal and in those with degenerative spondylolisthesis (51). The coexistence of a herniated disc, with or without stenosis, is very rare. The presence of a cyst may easily render a small herniation or disc bulging symptomatic (Fig. 21.12). If surgery has been planned, the herniation should always be removed, while in the presence of a bulging disc the indications for discectomy are similar to those outlined for bulging in a stenotic spinal canal.

Chondral and osteochondral avulsion of vertebral end-plate

There are four distinct types of lesions in young and middle-aged subjects (page 112).

The signs and symptoms are similar to those of herniated discs. In adolescents, in whom the majority of these lesions are found, the clinical presentation is characterized by lumboradicular pain, markedly positive nerve-root tension tests, and mild neurologic deficits. In adults, the neurologic deficits tend to be more severe, especially in Type IV lesions (29).

Standard radiographs rarely reveal the avulsed osteochondral fragment. However, in a few cases, it may look like a wedge-shaped fragment located posteriorly, and often cranially, with respect to the vertebral plate from which it originates. CT and myelo-CT, as well as MRI, clearly demonstrate the avulsed fragment and the compression of the neural structures (22).

In Type I, II or III lesions, the cartilaginous fragment can be removed through a unilateral laminotomy. The latter may be extended more proximally than usual in order to adequately expose the caudal end-plate of the vertebra above, from which the cartilaginous fragment usually originates. In the presence of a large central fragment, it may be necessary to perform bilateral laminotomy or central laminectomy (91). When the avulsion is present for only a few weeks, the fragment is usually mobile and can be easily removed. However, in the presence of a long-standing lesion, the fragment may adhere strongly to the vertebral body. The posterior longitudinal ligament is usually intact and the cartilaginous fragment can be identified only after incision of the ligament. In many cases the fragment is not visualized in the surgical field, but is removed along with the disc tissue and is detected by handling an hard fragment within the excised tissue.

In Type IV lesions, in which the osseous fragment is large, it is often necessary to perform a central laminectomy. In the presence of a long-standing lesion, it may be impossible to remove the fragment. In these cases, only a posterior decompression can be performed in order to eliminate the stenosis created by the fracture of the vertebral body.

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CHAPTER 22

SURGICAL FAILURES

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Definition and classification

A failure in surgical treatment should be distinguished from a complication. The latter term – as currently used in medicine – includes extraordinary events, often unpredictable and sometimes correctable intraoperatively, which render abnormal the operative or postoperative course; however, complications do not necessarily affect the surgical outcome. A failure occurs when the expected result has not been achieved, due to events which may normally cause a deviation from the usual course. Failures may be the result of factors inherent to the treated condition, related to other conditions, or due to intraoperative or postoperative complications. The distinction between complications and failures is often difficult and at times arbitrary. However, it is important not only for taxonomic reasons, but also for the different therapeutic and legal implications that are involved in the two situations. In this chapter, we analyze the failures which are not related to surgical complications.

Recurrent herniations and new symptomatic herniations are generally reported as surgical failures (3, 8, 24, 25). This is certainly not appropriate for new herniations, which represent a pathologic condition that was not present at the time of the primary discectomy. However, it is not even appropriate for recurrent herniations, which, in the majority of cases, are due to factors for the most part unknown, rather than to a wrong planning or execution of surgery. Thus, we have not included these conditions among the surgical failures.

Failures in surgical treatment should not be identified with unsatisfactory outcomes. The latter, in fact, usually include the fair results, characterized by a moderate improvement in the preoperative clinical symptoms. On the other hand, patients with surgical failures cannot be considered as only those undergoing reoperation. This parameter is well-defined but too restrictive, since a patient with a surgical failure may refuse further surgery. Failures should be considered as all those cases in which surgery did not lead to a significant improvement or caused worsening of the preoperative clinical status. These cases correspond to those with outcomes that are usually rated as poor.

The failure may be due to persistence of low back or radicular pain (Table 22.1). Radicular pain may persist unchanged or decrease only slightly after surgery, or it may recur after a symptom-free period. This distinction is important, since, in the first case, surgery may have failed in decompressing adequately the neural structures, whilst in the second, the failure is usually due to a pathologic condition which developed after the primary operation. Severe postoperative low back pain may be due to a preexisting vertebral instability or be caused by surgery. However, in most cases, the causes may not be clearly defined and sometimes may be several. We refer to this type of low back pain as idiopathic, to underline that the etiology can often be suspected, but not proven.

Persistent radiculopathy

Wrong surgical indication

This represents a frequent, if not the most frequent, cause of surgical failure. The error usually consists in a too enlarged indication for surgery. This essentially occurs in three situations: in the presence of a slight compression of the neural structures responsible for

Table 22.1. *Classification of surgical failures.*

Persistent radiculopathy

Wrong surgical indication
- Mild radicular compression
- Psychogenic pain
- Long-standing neurologic deficits

Wrong preoperative diagnosis
- Stenosis
- Tumors
- Thoracic disc herniation
- Other pathologic conditions

Wrong surgical planning
- Concomitant herniation at another level
- Unilateral discectomy for bilateral herniation
- Concomitant stenosis
- Concomitant isthmic spondylolisthesis

Errors in detecting herniation
- Surgery at wrong level
- Surgery on wrong side

Defective surgical treatment
- Incomplete removal of contained or extruded herniation
- No or incomplete removal of migrated disc fragment
- Extrusion of residual disc fragment
- Persistent nerve-root canal stenosis
- Nerve-root injury

Recurrent radiculopathy after a pain-free interval

Epidural fibrosis
Arachnoiditis
Stenosis

Postoperative low back pain

Spinal instability
Discogenic low back pain
Facet joint osteoarthrosis
Pseudarthrosis
Psychogenic low back pain

mild radicular symptoms; when pain is mainly psychogenic in nature or a legal contention exists; and in the presence of long-standing neurologic deficits associated with no or mild radicular symptoms.

Unsatisfactory results are likely to be obtained in patients with annular bulging or a small contained or extruded herniation, who complain of mild radicular symptoms and/or symptoms limited to the proximal portion of the lower limb, and show negative or slightly positive nerve-root tension tests and no neurologic deficits. In these cases, pain is often relieved only slightly or persists unchanged after surgery, particularly in the short term. The cause of surgical failure in these patients is unknown. However, in many conditions in which pain is the main symptom, the quality of the surgical outcome is known to be related to the severity of the preoperative pathologic condition. Possibly, these patients have an abnormally low pain threshold, due to an insufficient production of endogenous opiates or other unknown causes, leading to an abnormal perception of pain before and after surgery.

The presence of psychologic disorders, such as depression, anxiety, hysteria and hypochondriasis, may considerably affect the surgical result (48, 58, 66, 72). The same is true for legal controversies directed at obtaining financial compensation or work disability. Certainly, even patients with disorders in their emotional profile may present entirely organic conditions, which resolve with surgery (54). However, in the presence of behavioral or clearly psychotic disorders, the indication for surgery should be carefully evaluated and psychologic tests performed prior to surgery. This is particularly true when diagnostic studies show a less severe pathologic condition than expected from the patient's complaints.

Radicular motor or sensory deficits, lasting for several months or years, have little possibility of recovering after nerve-root decompression. If the only reason for surgery is the improvement of neurologic deficits, there are high chances of failure. In these cases, the operative treatment is justified only if radicular pain or lumboradicular intermittent claudication is present, and the primary aim is the resolution of these symptoms, rather than of the motor deficits.

Wrong preoperative diagnosis

Approximately one fifth of asymptomatic subjects have a herniated disc in the lumbar spine. The presence of herniation may lead to ascribe the lumboradicular symptoms to this condition, whereas the cause of pain is another condition, such as stenosis or tumor, located at a different vertebral level from that of herniation.

A stenotic condition can be missed when the diagnosis is based only on clinical data, or when CT examination is not extended to the uppermost lumbar levels. After surgery, the radicular symptoms and neurologic deficits remain unchanged or may worsen in the presence of severe compression of the neural structures at the stenotic level. A wrong diagnosis should be suspected when preoperative CT shows a narrow spinal canal or marked osteoarthrotic changes of the facet joints.

All intraspinal or vertebral tumors in the lower thoracic or lumbosacral spine may mimic the clinical presentation of a lumbar herniated disc. The most frequently unrecognized tumors are cauda equina neurinomas (Fig. 22.1) and ependymomas of the lower thoracic or upper lumbar spine, whilst primary or secondary bone tumors are rarely a cause of diagnostic errors. When preoperative signs and symptoms are caused by the tumor, rather than the herniated disc, the clinical picture remains unchanged or may worsen after discectomy. The deterioration can vary from a mild worsening of the preoperative neurologic deficits to complete paraplegia. In these cases, MRI studies of

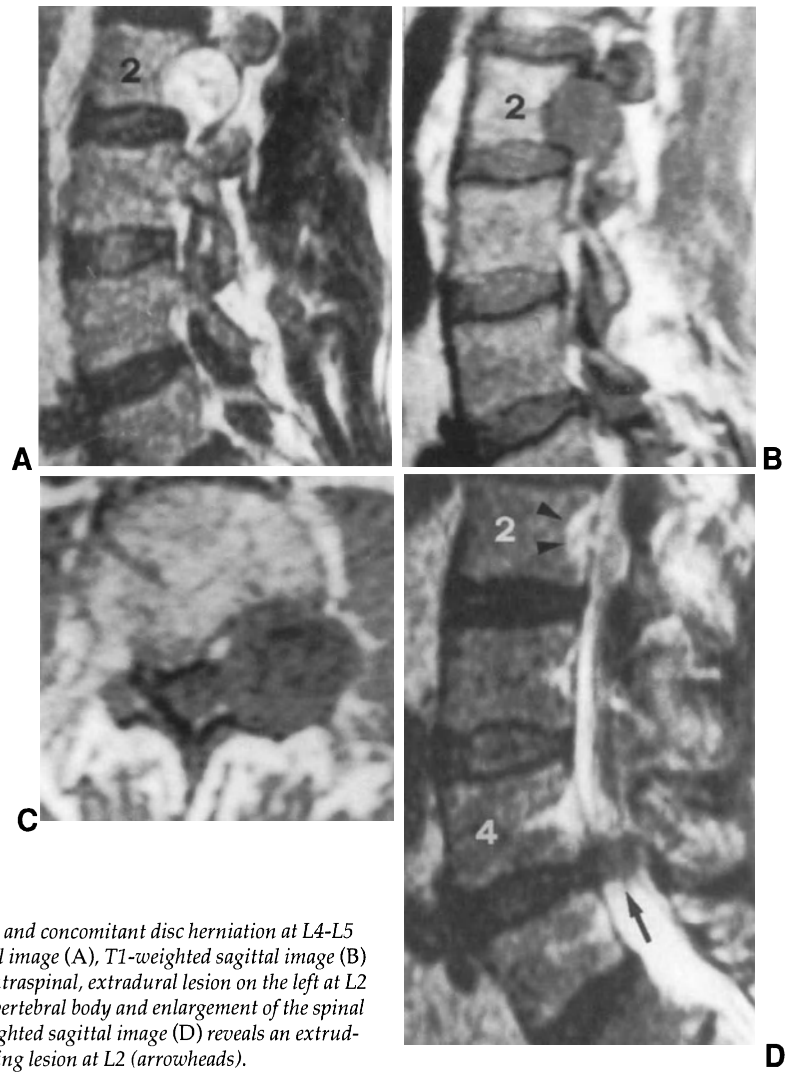

Fig. 22.1. *MR images of a patient with neurinoma at L2 and concomitant disc herniation at L4-L5 level, on the left side. The spin-echo T2-weighted sagittal image* (A), *T1-weighted sagittal image* (B) *and T1-weighted axial image* (C) *show an expanding, intraspinal, extradural lesion on the left at L2 level, which causes erosion of the posterior aspect of L2 vertebral body and enlargement of the spinal canal and intervertebral foramen. The spin-echo T2-weighted sagittal image* (D) *reveals an extruded disc herniation at L4-L5 level (arrow) and an expanding lesion at L2 (arrowheads).*

the thoracic and lumbosacral spine usually lead to detection of the tumor. The subsequent treatment will vary according to the type and spread of the tumor, and the severity of the neurologic deficits.

Disc herniation in the lower thoracic spine may cause lumboradicular symptoms similar to those produced by a lumbar herniated disc. The condition may be missed if neurologic examination reveals no signs of spinal cord compression, or these are not recognized by the examiner, and MRI studies are limited to the lumbar spine. After surgery, the clinical picture remains unchanged or may worsen due to spinal cord edema or ischemia, as a result of the patient positioning during surgery or intraoperative hypotension.

Many other vertebral or extravertebral conditions – such as synovial cysts of the facet joints or aneurysms of the abdominal aorta – may be responsible for diagnostic errors (Fig. 22.2). These conditions should be taken into consideration when CT and / or MRI of the lumbar spine reveal no pathologic conditions which can account for the patient's complaints.

Wrong surgical planning

Wrong planning of surgery is due to inadequate evaluation of the clinical data or diagnostic tests. This may lead to the clinical signs and symptoms of a different pathologic condition from that responsible for the patient's complaints, or to the role played by a given condition in the etiology of radicular pain, being underestimated. The result is an error in the surgical strategy and partial or no decompression of the involved neural structures.

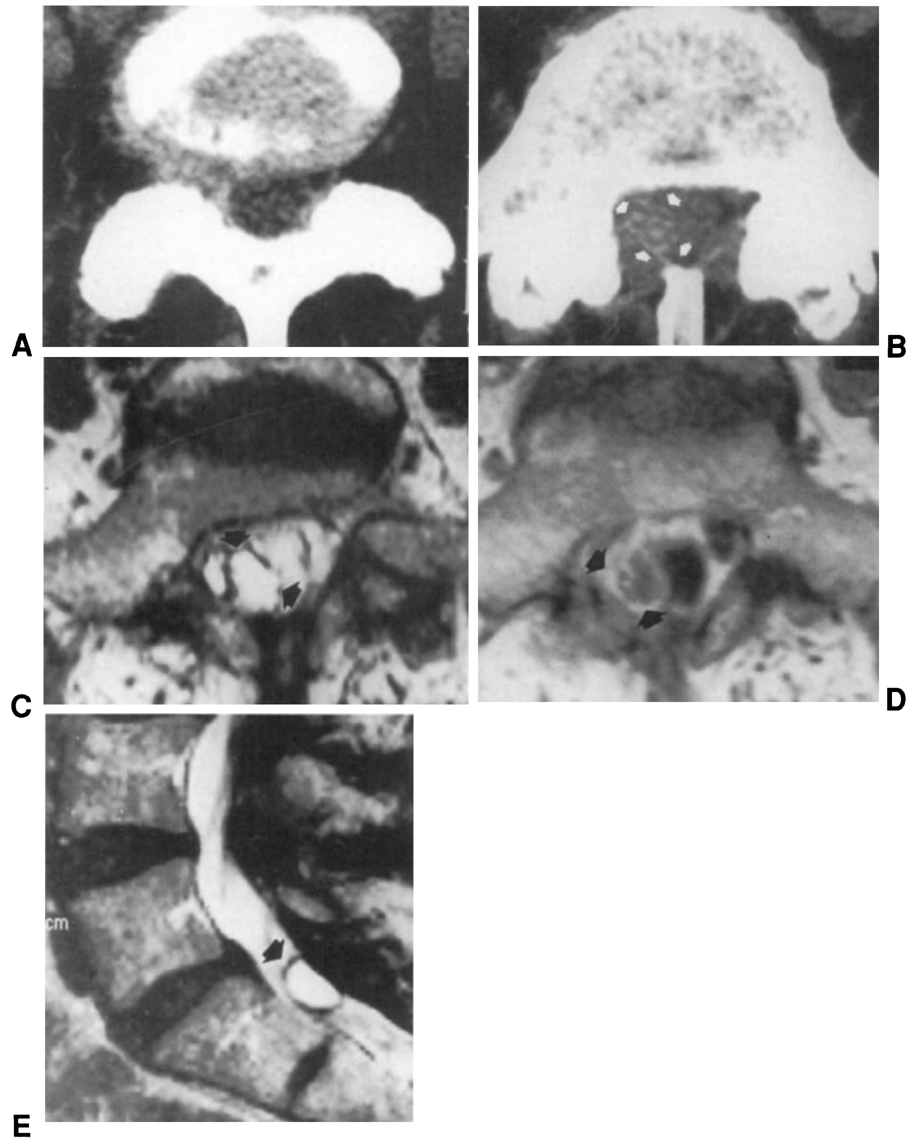

Fig. 22.2. *Synovial cyst of the right facet joint erroneously interpreted as an intraforaminal disc herniation.* (A) *Preoperative CT scan at L5-S1 level revealing tissue isointense to the disc in the right intervertebral foramen.* (B) *CT scan through the midportion of the pedicles showing a rounded lesion (arrows) compressing the thecal sac and S1 nerve root on the right. The patient underwent discectomy with slight relief of symptoms.* (C–E) *Axial MRI scans, respectively turbo spin-echo T2-weighted and T1-weighted, and sagittal turbo spin-echo T2-weighted image, obtained 4 months after surgery, showing a large cyst of the posterior joint on the right (arrows).*

Concomitant herniation at another level

Two situations may be identified: symptomatic disc herniation at two levels; and symptomatic herniation at one level with concomitant asymptomatic herniation at another interspace. The second condition is analyzed in the chapter dealing with recurrent herniation.

It is extremely rare that a symptomatic herniated disc is simultaneously present at two levels. On the other hand, it may be difficult to determine preoperatively whether both herniated discs are responsible for radicular symptoms, or which herniation is symptomatic. When only one of two symptomatic herniated discs, or only the asymptomatic herniation, is excised, the patient continues to complain of lumboradicular symptoms, which may be, respectively, less severe than, or similar to, those present preoperatively. In the former case, it is advisable to carry out conservative treatment for several weeks before considering repeat surgery. This holds particularly when the unexcised herniation is small and responsible for mild radicular symptoms. In these cases, in fact, not only may the residual symptoms gradually disappear, as occurs in patients who undergo successful conservative management, but there is also the risk that persistent symptoms may result from postoperative irritation of the decompressed nerve root rather than from the residual herniation and, thus, that further surgery is unnecessary. However, when severe symptoms persist unchanged for 2 weeks after surgery, repeat surgery should be planned, if postoperative MRI excludes other conditions or reveals an insufficient decompression of the neural structures at the operated

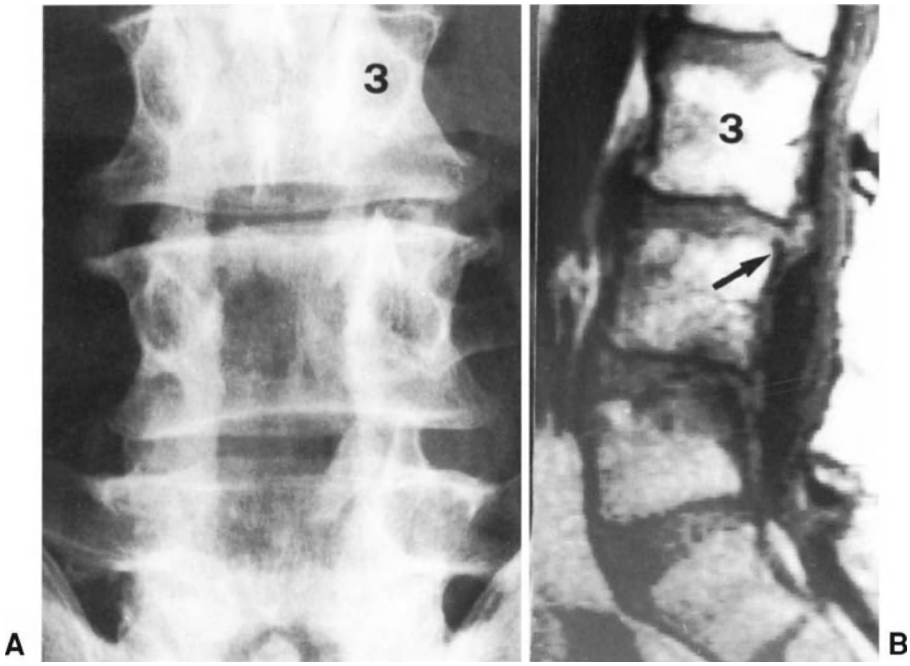

Fig. 22.3. *This patient* (A) *with spinal stenosis at L3-L5 and disc herniation at L3-L4 and L4-L5 levels had undergone L3-L5 central laminectomy and L4-L5 discectomy. MRI performed 3 months after surgery* (B), *due to persistence of radicular symptoms, showed compression of the neural structures by an L3-L4 herniated disc* (*arrow*) *not removed at initial surgery.*

level (Fig. 22.3). Only in the latter case may re-exploration of the operated level be indicated.

Unilateral discectomy for bilateral herniation

Bilateral herniation rarely causes compression of the nerve structures on both sides, particularly in the absence of nerve-root canal stenosis.

Wrong surgical planning may occur when: the contralateral herniation is not diagnosed preoperatively, and the radicular symptoms on the opposite side are felt to be caused by the midline or paramedian location of the herniation; or it is felt that the herniation on the opposite side can be removed by disc excision on the more symptomatic side. In both cases, after surgery, the patient continues to complain of radicular symptoms on the side opposite that operated on. In the majority of patients with bilateral herniation, the preoperative symptoms are predominant on one side, and the mild radicular pain which may persist postoperatively on the opposite side is usually well-tolerated and tends to disappear in a few weeks or months. This holds particularly when the contralateral herniation was identified preoperatively and accurate, radical disc excision was carried out. In these cases, prolonged conservative management should be carried out, before considering repeat surgery on the opposite side. In the presence of severe leg pain, which usually occurs in patients with nerve-root canal stenosis, reoperation should be planned after a short period of conservative therapy.

Concomitant stenosis

The removal of only the herniated disc, in the presence of symptomatic stenosis at another level, may leave the lumboradicular symptoms caused by stenosis unchanged. Similarly, when stenosis is present at the level of discectomy, the patient may continue to complain of radicular symptoms due to persistent compression of the neural structures. In effect, this rarely occurs when, prior to operation, radicular symptoms are present only on the operated side, since the decompression of the neural structures that laminotomy implies usually resolves the leg symptoms. However, in these cases, the patient may begin to complain of contralateral radicular symptoms, after an initial period of pain relief.

The opposite mistake is to overestimate the clinical significance of a narrow or stenotic spinal canal. This may lead to unnecessary decompression, causing radicular symptoms, generally transitory, due to the effect of surgical trauma on preoperatively asymptomatic nerve roots.

Concomitant isthmic spondylolisthesis

In a patient with disc herniation and isthmic spondylolisthesis, the radicular symptoms may persist after surgery if the role played by the spondylolisthesis in the patient's complaints was not determined preoperatively. The condition most frequently encountered is spondylolisthesis of L5 and concomitant herniation, or annular bulging, at L4-L5 level. Excision of the L4-L5 disc may only decrease or leave unchanged the radicular pain if this is partly, or entirely, due to spondylolisthesis. This possibility should not lead to indiscriminate decompression and/or fusion of the olisthetic vertebra in addition to disc excision, particularly when spondylolisthesis is long-standing, whilst radicular symptoms are recent in onset, and the patient reports no chronic history of low back pain.

Errors in detecting disc herniation

Surgery at wrong level

This is one of the most common mistakes in lumbar disc surgery. In the vast majority of cases, the error is recognized and corrected intraoperatively. Otherwise, after surgery, the patient continues to complain of the same symptoms as those present preoperatively. Occasionally, the symptoms improve for a few days after the operation due to a surgery-related placebo effect or the anti-inflammatory medication administered during the postoperative period. In a few cases, both pain and neurologic deficits are more severe immediately after surgery. This may be related to an increase in nerve-root compression due to the patient's position during surgery or to intraoperative bleeding, when the explored disc is adjacent to the herniated one.

Wrong level exploration at initial surgery has been reported in 2% to 9% of patients submitted to reoperation for surgical failure (13, 24, 26, 29, 61). Usually, the mistake can easily be detected postoperatively on an anteroposterior radiograph of the lumbar spine. The radiograph may not permit diagnosis or may leave doubts when only flavectomy, or an extremely limited laminoarthrectomy, has been performed. In these cases, the diagnostic doubt is easily resolved by MRI, which shows the changes in the epidural tissue and paraspinal muscles produced by the surgical approach. MRI should usually be given preference over CT, due to its greater ability in excluding errors in preoperative diagnosis.

If surgery at a wrong level is diagnosed after the operation, the patient should be immediately informed and reoperated on.

To avoid this error, some surgeons routinely perform an intraoperative lateral radiograph of the lumbar spine at the end of discectomy, placing a blunt dissector into the disc space. In our opinion, this procedure is useful if there is any doubt, even minimal, that a wrong level has been explored; however, it should be avoided, because of the time loss and radiation exposure, when the surgical findings leave no doubts that the pathologic disc has been operated on.

Surgery on wrong side

To perform disc excision on the side opposite the herniation, and not to recognize the error during surgery, is an extremely rare event: 0.8% in a series of 116 surgical failures analyzed by Zerbi et al. (74). In the presence of a contained, or a subligamentous or transligamentous extruded, herniation, the herniated tissue may even be removed from the opposite side, provided a complete or radical disc excision is carried out. Surgery on the wrong side, therefore, may occasionally be associated with the resolution of radicular symptoms. However, this does not occur when the herniation is extruded behind the posterior longitudinal ligament or a migrated disc fragment is present. Furthermore, in all these cases, transitory nerve-root impairment on the operated side may occur, due to manipulation of a preoperatively asymptomatic nerve root. The treatment required is an immediate reoperation.

Defective surgical treatment

Many patients complain of persistent radicular pain after surgery, particularly when no anti-inflammatory drugs are administered in the first postoperative days. Usually, pain is less severe than preoperatively and gradually disappears over several days or weeks. This persistent pain should not be considered as pathologic and the patient has to be reassured that it will gradually disappear.

The persistence of radicular pain as severe as, or only slightly less severe than, the preoperative pain, should suggest that a wrong surgical treatment has been carried out. The distinction between normal and abnormal postoperative pain is based on the evaluation of several factors, such as the patient's psychologic profile, the degree of positivity of nerve-root tension tests and, particularly, the correlation between the surgical findings and the condition diagnosed preoperatively.

Incomplete removal of contained or extruded herniation

This cause of failure has been detected in 2.5% of 116 patients with persistent radicular pain after discectomy (74). An incomplete removal of the herniation should be suspected when the preoperative neuroradiologic studies reveal no migrated disc fragment or nerve-root canal stenosis, or when the amount of disc tissue excised at surgery was less than expected. In these cases, radicular pain generally decreases after surgery, but only slightly.

There are two possible options when an incomplete removal of herniation is suspected: to carry out a neuroradiologic study aimed at demonstrating the possible persistence of the herniation and reoperate on the patient; or to obtain plain radiographs of the lumbar spine to exclude that surgery was performed at a wrong level and carry out a prolonged conservative therapy before considering further surgery.

The first choice is more appropriate when radicular pain is severe. Usually, however, it is advisable to wait at least 1–2 weeks after surgery, during which bed rest is advised and anti-inflammatory medication, possibly corticosteroids, is administered. If severe symptoms persist, repeat surgery should be planned, once a condition requiring surgery has been detected on CT or MRI. CT may be sufficient when MRI was performed preoperatively, whereas the latter should be performed when the preoperative diagnosis was made by CT; computerized tomography, in fact, may fail to detect non-discal conditions or pathologies located at the upper lumbar levels, which may be the true cause of the persisting symptoms. However, if only a disc condition is detected at the operated level, the therapeutic decision should be based on the clinical presentation, since CT or MRI findings may be difficult to interpret in the early postoperative period.

The second choice is justified when the postoperative symptoms are of a moderate severity and/or the surgeon feels that the neural structures were adequately decompressed. In these cases, it is advisable to perform an intensive conservative treatment, based on anti-inflammatory medication and physiotherapy, for 3–5 weeks, avoiding postoperative exercise therapy during this period. When radicular symptoms do not improve significantly, CT or MRI should be carried out according to the criteria previously outlined. If imaging studies reveal a persistent disc herniation which may be responsible for nerve-root compression, it is usually advisable to reoperate on the patient. To prolong waiting, in fact, not only may not lead to a sufficient pain relief, but may cause a long sick-leave as well as reduce the probability of a satisfactory outcome, if surgery is delayed excessively.

Failure to remove or partial removal of migrated disc fragment

This technical error has been detected in approximately 5% of patients operated for surgical failures (13, 15). It mainly occurs when the migrated disc fragment is not clearly shown by preoperative imaging studies, and particularly in small intraforaminal migrated herniations, in which an erroneous diagnosis of contained or extruded herniation may easily be made preoperatively. The possibility that a migrated fragment has been removed only partially should be taken into account when the excised fragment is smaller than suggested by the preoperative imaging studies and/or the fragment has been removed in small pieces.

When the entire migrated fragment has been left behind, the patient complains of radicular symptoms of a similar severity to those present preoperatively. Occasionally, in the first few days, pain and neurologic deficits may be even more severe, due to the additional trauma to the nerve root caused by the surgical maneuvers and intraoperative bleeding. When only a portion of the fragment was removed, radicular symptoms may be less severe after surgery, but in the first few weeks they are often unchanged. There are no clinical data which may lead to the suspicion of a missed migrated fragment, even if this possibility should always be taken into account in the presence of a partial or complete failure in relieving preoperative radicular symptoms. CT and, particularly, MRI usually demonstrate, even in the immediate postoperative period, the presence of a medium-sized or large migrated fragment not excised at surgery. However, a small fragment, or the residual portion of an incompletely removed fragment, may not be clearly shown by imaging studies.

Failure to remove a migrated fragment usually requires an immediate reoperation. The same is true for an incomplete removal of a migrated fragment, if the residual portion is large. However, if only a small portion of the original fragment (less than one fourth of the original size) was left in place, the evolution of symptoms should be carefully monitored during the following 3–6 weeks, before considering repeat surgery, particularly when operative treatment has considerably relieved the radicular symptoms. In fact, resorption of the residual fragment may gradually occur, with a complete resolution of symptoms.

If a reoperation is performed, the neural structures should be exposed more widely than at initial surgery, especially if microdiscectomy was carried out. However, the use of the operating microscope may facilitate the visualization of migrated disc fragments.

Extrusion of residual disc fragment

This event may occur in the presence of any type of disc herniation, particularly in patients with a markedly degenerated disc and/or a midline disc herniation. The condition is usually due to an incomplete excision of the herniated disc tissue or the contents of the disc space.

Typically, the patient reports a complete, or almost complete, relief of the radicular symptoms soon after surgery. A few days later, the symptoms recur, often abruptly, without any reason or following a mild physical effort. CT or MRI may reveal a disc fragment in the spinal canal or may even be uninformative. This occurs particularly in the first few days after surgery, due to the difficulty in differentiating the pathologic tissue from the postoperative hematoma or early scar tissue, or in distinguishing a pathologic annular bulging from the normal postoperative bulging of a disc where herniation was present.

When radicular symptoms recur in the first postoperative days, conservative treatment should initially be undertaken, since the recurrent radicular pain may only be due to a transient irritation of the nerve root. If pain has not decreased after a few days of conservative management, MRI should be performed. If it reveals a pathologic condition or suggests the extrusion of a residual disc fragment, a reoperation should be planned (Fig. 22.4). When symptoms are severe, repeat surgery should be carried out even if the results of the imaging studies are inconclusive, provided that the preoperative symptoms were clearly caused by the excised herniation and that, after surgery, the pain had disappeared or considerably decreased for at least a few days. In the presence of other vertebral conditions, such as disc bulging and/or stenosis, at an adjacent level to that operated on, surgical exploration should be extended to this level in the absence of any significant pathologic condition at the site of the previous discectomy.

Persistent nerve-root canal stenosis

This condition has been found in 2% of 92 patients submitted to repeat surgery (16). The rarity of persistent radicular canal stenosis is due to the fact that discectomy, in order to be easily performed without risking injury to the nerve roots, involves a wide enough opening of the spinal canal to eliminate any compression of the emerging nerve root by the osteoligamentous structures. Significant stenosis may persist when laminoarthrectomy has been abnormally limited or, more rarely, when the nerve root is compressed in the distal portion of the radicular canal. In these cases, the normal postoperative epidural fibrosis may contribute to nerve-root compression.

In patients with persistent stenosis, radicular symptoms, although improved, persist after surgery. Often,

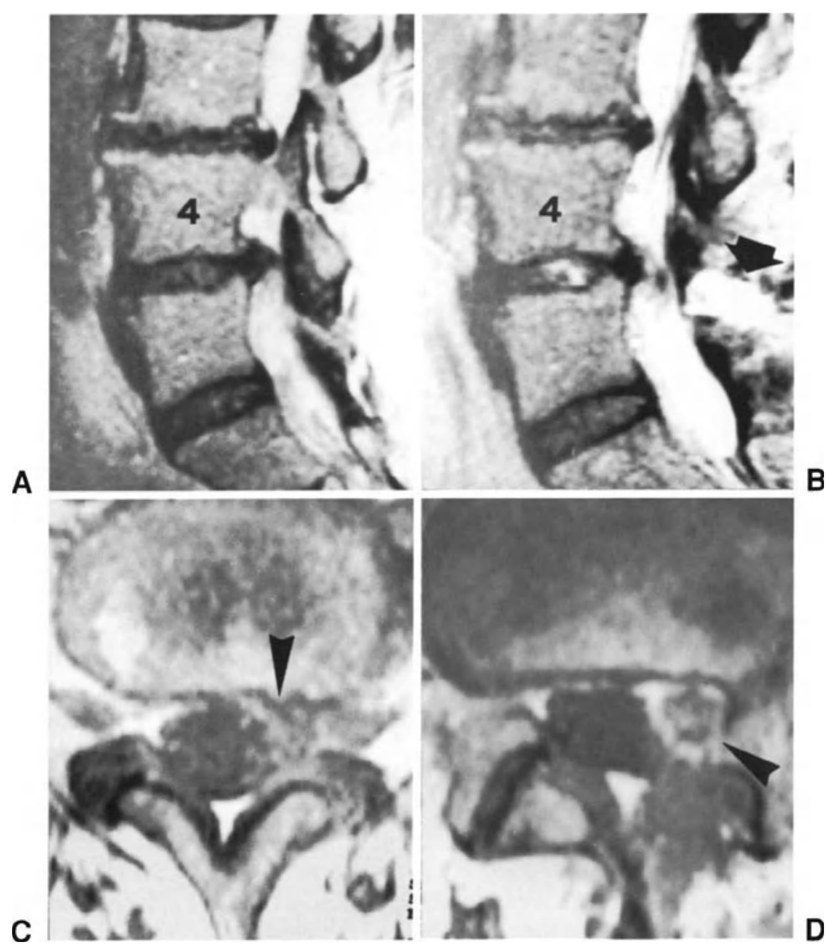

Fig. 22.4. *Extrusion of a residual disc fragment after discectomy. The preoperative MRI* (A) *of this 67-year-old female showed an extruded herniation at L4-L5 level on the left and a small asymptomatic herniation at L3-L4. The patient underwent an L4-L5 discectomy on the left with complete relief of radicular symptoms. Eleven days after surgery she experienced a sudden recurrence of radicular pain on the left. Postoperative MRI,* (B) *and* (C)*, revealed, at the site of surgery, a tissue of uncertain origin (arrowhead). After gadolinium injection* (D)*, the tissue showed a peripheral increase in signal intensity, whilst the central portion remained hypointense (arrowhead). The arrow in* (B) *indicates the hyperintense tissue present at the site of the surgical approach.*

the patient experiences an immediate pain relief, which, however, does not progress to a complete disappearance of the symptoms during the weeks following surgery. Radicular pain may be present even at rest or appear only during walking. Pain on walking may indicate persistent stenosis. In these cases, CT has a greater diagnostic ability than MRI, since it allows better visualization of the bony structures. It should be noted, however, that it may be difficult to determine whether nerve-root compression due to radicular canal stenosis is present at an operated level, except when stenosis is severe.

When imaging studies reveal, or strongly suggest, a persistent nerve-root canal stenosis, repeat surgery should be planned, if conservative management for at least 3 months has not relieved the radicular symptoms. If a definite condition has not been diagnosed, a reoperation may be justified when the patient complains of the typical symptoms of stenosis, and these are severe and not relieved by conservative treatment prolonged for at least 6 months.

Traumas to the emerging nerve root

Excessive retraction or traumatic manipulation of the nerve root in the extrathecal course may cause root edema or ischemia, responsible for persistent radiculopathy after surgery. Usually, the symptoms consist in sensory disturbances (hypoesthesia, paresthesias, dysesthesia), at times associated with a mild worsening of the preoperative motor deficit; even persistent postoperative radicular pain may be due to a battered root. The radicular symptoms usually regress over several weeks, but they may also persist in the long term (3). It is unclear whether traumatic manipulation may cause arachnoiditis of the nerve root in the extrathecal course, as a result of meningeal inflammatory reaction. This possibility, however, seems to be realistic and might explain the persistence of radiculopathy in patients with no apparent reason for surgical failure.

Recurrent radicular pain after a pain-free interval

Epidural fibrosis

Origin

Any surgery entailing the violation of the spinal canal produces epidural fibrosis. After laminotomy and discectomy, the area originally occupied by the ligamentum flavum and the portion of the laminae and facet joint excised at surgery is filled with scar tissue. Furthermore, the latter develops ventrally to the thecal sac and the emerging nerve root, particularly in the area adjacent to the disc, where it forms adhesions between the residual annulus and the neural structures.

Studies aimed at determining the origin of epidural fibrosis indicate that the connective tissue cells of the deep layer of the paraspinal muscles are the main source of epidural scar tissue (42). Within a few weeks, fibroblasts form a fibrous membrane which fills the surgical defect (laminectomy or laminotomy) and penetrates into the spinal canal, where it adheres to the thecal sac and emerging nerve roots. When discectomy is performed, even the anterior portion of the spinal canal is invaded by fibrous tissue (36, 65). The latter might also originate from cells of the annulus fibrosus, since the exploration of the spinal canal, with no lesion to the annulus fibrosus, does not seem to stimulate the formation of scar tissue in the ventral region of the canal (42).

Epidural bleeding seems to play an important role in the development of scar tissue. In an experimental study (1), the epidural scar tissue which developed in the animals in whom profuse bleeding had occurred during surgery, was more resistent to tensile stresses than that formed in animals with normal bleeding. It is still unclear, however, whether the formation of scar tissue is related to other factors, such as the entity of trauma to the epidural tissue during surgical maneuvers, the extent of the opening created in the annulus fibrosus or the individual tendency to form scar tissue.

Clinical relevance

Epidural fibrosis is often considered as a possible cause of surgical failure, responsible for the recurrence of radicular symptoms several weeks or months after surgery (25, 29, 74). The asymptomatic interval would correspond to the time necessary for the scar tissue to become dense and retracted enough to cause pathologic effects. A pure epidural fibrosis, however, has been found at reoperation even in patients with no pain-free interval after primary discectomy (34). The fibrous tissue might provoke: 1) Traction of the emerging nerve root, causing nutritional disturbances and impairment of nerve conduction and, thus, radicular pain (1). 2) Decreased mobility of the nerve root, resulting in a greater vulnerability of the root to compressive agents, such as recurrent herniation or stenosis (1, 40). 3) Constriction of the nerve root, which would be as enfolded in a rigid sleeve; in the presence of inflammatory processes of the nerve root, this rigid sleeve would cause root compression or ischemia of the neural tissue.

In effect, the clinical significance of epidural fibrosis remains to be elucidated. In particular, it is unclear whether epidural fibrosis may, in itself, determine traction-compression effects on the nerve root and whether these effects are related to the amount of scar tissue. Several findings suggest that the scar tissue, even when abundant, does not in itself cause pathologic effects. There is, in fact, no correlation between the clinical results of the operation and the factors that may favor the formation of scar tissue: patients presenting profuse intraoperative bleeding or a tendency to form keloid scars, have similar chances of obtaining an excellent surgical result as those with little bleeding and no tendency to form hypertrophic scars; postoperative CT and MRI show that, in patients with no radicular symptoms, the amount of epidural scar can vary considerably (2, 10).

Scar tissue is likely to favor the onset or persistence of radicular symptoms only when marked bulging of the annulus fibrosus persists after surgery or even a small recurrent herniation occurs. Fibrous tissue decreases the nerve-root mobility, thus favoring compression of the root by the discal pathologic condition.

Treatment

In patients with postoperative radicular pain in whom the imaging studies show only epidural fibrosis at the operated level, management should usually be conservative. Numerous studies indicate that, in these patients, reoperation often provides unsatisfactory results; the percentage of failure ranges from 33% to 92% (15, 19, 20, 22, 34, 44, 59), usually being around 50%. The proportion of unsatisfactory results is not decreased by the use of the operating microscope. In a few patients, the clinical picture improves in the first few weeks or months after reoperation, but then it worsens, becoming the same as, or at times even worse than, before surgery. Hence, before planning a reoperation, it is extremely important to determine whether epidural fibrosis is the only demonstrable pathologic condition. If this is the case, when severe radicular pain persists after prolonged conservative management, repeat surgery may be justified, however only when imaging studies do not exclude the possible presence of a concomitant recurrent disc herniation or nerve-root canal stenosis.

Adhesive arachnoiditis

In this condition, there is an inflammatory process of the arachnoid and pia mater, which leads to thickening of these membranes and adhesions of the nerve roots to each other and/or the arachnoid. Three types of arachnoiditis have been identified: in Type I, only the area where a single nerve root emerges from the thecal sac is affected; in Type II, the thecal sac presents an annular constriction and a central patent zone; in Type III, the thecal sac is completely obstructed (35). Arachnoiditis may involve one or more vertebral levels. Usually, it affects the entire terminal portion of the thecal sac. In long-standing cases, areas of calcification or ossification of the arachnoid may be observed.

Etiology and clinical presentation

Lumbar arachnoiditis is usually attributed either to the contrast media employed for myelography or to surgery; other causes may be traumas, subarachnoid hemorrhages, infections, tumors or unknown causes responsible for spontaneous arachnoiditis (4, 27, 28, 30, 31, 35, 57, 71). A role may be played by an intradural or systemic decrease in fibrinolytic activity (11).

Numerous experimental and clinical studies indicate that not only lipiodol, but also the hydrosoluble contrast media (at least the less recent ones) can cause arachnoiditis, particularly when blood penetrates into the thecal sac or several myelographies are carried out. With the advent of CT and MRI, this cause of arachnoiditis has almost disappeared, since myelography is now rarely performed. Surgery may cause arachnoiditis as a result of the operative trauma to the thecal sac or the emerging nerve roots. Predisposing factors to the development of the condition may be: a midline disc herniation, responsible for severe compression of the neural structures; central laminectomy or multiple-level surgery; intraoperative dural tears; and multiple operations (35, 58, 63, 71). In effect, the role played by surgery in causing arachnoiditis remains unclear. In many cases, postoperative arachnoiditis is likely to be caused by idiopathic factors, the surgical trauma being only a favoring or aggravating factor. On the other hand, in patients submitted to discectomy and no previous myelographic studies, adhesive arachnoiditis is exceedingly rare: 1.6% and 3% of cases in two series of patients who underwent postoperative MRI (21, 32).

This condition develops and progresses over 6–18 months (70). It may cause low back pain and radicular dysfunction including mono- and multiradicular pain, sensory disorders (paresthesias, hypoesthesia, dysesthesia), motor loss and, in rare instances, sphincter disorders. The condition, however, may be entirely asymptomatic – 50% of cases in Fitt and Stevens's series (21) – or the symptoms may gradually disappear with no specific therapy (71). Therefore, one should be very cautious in attributing recurrent lumboradicular symptoms occurring a few months after decompressive surgery to arachnoiditis; diagnosis of arachnoiditis can be made only when all other demonstrable causes of radicular compression have been excluded.

Treatment

In the vast majority of cases, management should be conservative: anti-inflammatory and anti-depressive medication, physiotherapy, acupuncture, functional re-education, low back school. The use of dorsal column stimulators placed subcutaneously or epidurally may be indicated when pain has not been sufficiently relieved by non-invasive treatments (56).

Surgical treatment consists in intrathecal neurolysis performed with the operating microscope; sensory rhizotomy may be carried out in association with, or instead of, neurolysis. Controversial results have been reported following neurolysis. In the majority of surgical series, the percentage of patients who had a significant relief of symptoms does not exceed 50% (33, 35, 63, 70); by comparison, conservative treatment led to satisfactory results in a similar or slightly lower proportion of cases (33, 63). Since symptoms may become even worse after neurolysis, and rhizotomy does not seem to be any more effective (70), surgical treatment should be considered only in extremely selected patients, who have severe pain and progressive neurologic deficits. This is especially true in the absence of other pathologic conditions. When a discal or stenotic condition coexists, surgery may be more indicated and give better results (7). In these cases, it is generally advisable to treat the associated condition without performing neurolysis.

Lumbar stenosis

An untreated, or inadequately treated, lumbar stenosis in a patient submitted to discectomy may be responsible for recurrent lumboradicular symptoms (Fig. 22.5). However, if stenosis has developed subsequently to disc excision, it cannot be considered as a surgical failure, since it could not have been treated at the time of primary surgery. Stenosis may involve, at a single level, the entire spinal canal or only the radicular canal, on one or both sides. Moreover, the condition may be present at the level of the previous discectomy and/or at a different level.

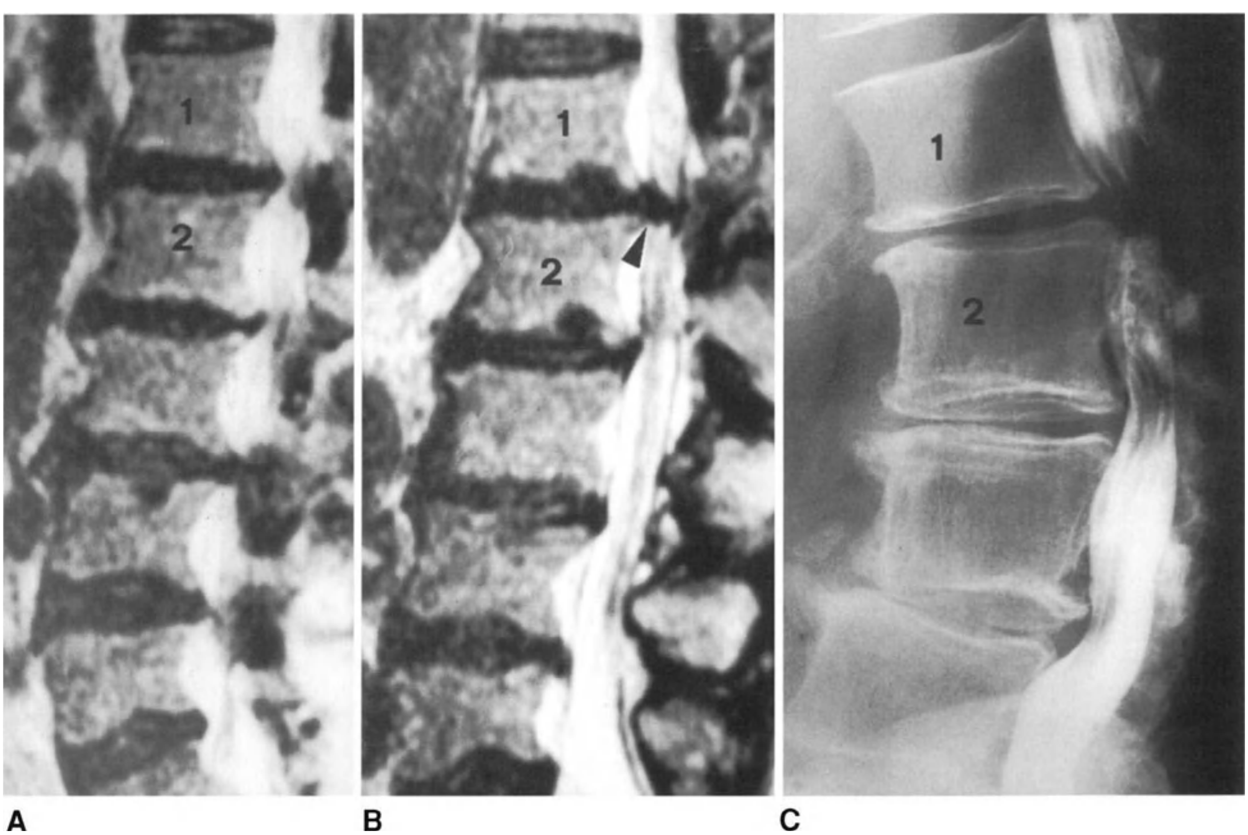

Fig. 22.5. *MRI scans and myelogram of a patient with lumbar stenosis who had inadequate surgical decompression.* (A) *Preoperative spin-echo T2-weighted sagittal image showing stenosis at multiple levels, between L1 and L5, and concomitant disc herniation at L3-L4 level. Bilateral laminotomy was performed at L2-L3, L3-L4 and L4-L5 levels, along with discectomy at L3-L4.* (B) *Turbo spin-echo T2-weighted sagittal image performed 11 months after surgery, showing compression of the nervous structures at L1-L2 level (arrowhead), due to stenosis of the spinal canal and disc herniation which were already present, although producing a less severe neural compression, prior to surgery.* (C) *Myelogram showing a complete block of the contrast medium at L1-L2 level.*

Incidence and clinical presentation

The incidence of spinal stenosis responsible for delayed surgical failure has been reported to vary from 41% to 71% (9, 34, 37); in two series, the ratio of spinal canal stenosis to radicular canal stenosis was 1:1 (34) and 6:1 (8), respectively. However, no studies report whether stenosis was present at the time of primary surgery or whether it developed subsequently.

In our experience, a preoperatively asymptomatic stenosis rarely becomes symptomatic after surgery. This probably occurs in less than 15% of surgical failures after discectomy, and the rate of spinal canal stenosis to isolated radicular canal stenosis is approximately 1:1. The frequency observed by us is comparable to that reported by Finnegan et al. (20) and Ebeling et al. (15), who found stenosis to be the cause of surgical failure in 2% and 19% of cases, respectively.

After discectomy, the asymptomatic interval or the period of clinical improvement ranges from a few months to many years, but it generally lasts a few years. The clinical picture is usually characterized by a predominance of radicular pain over low back pain. The radicular signs and symptoms are generally unilateral and involve more frequently the previously symptomatic side. They can have the typical features either of disc herniation or spinal stenosis.

Treatment

Usually, management should be obstinately conservative when imaging studies reveal a mild or uncertain stenotic compression of the neural structures. In fact, the difficulty in making a precise diagnosis, at least at the previously operated level, may lead to an overestimation of the clinical relevance of stenosis, which might not be the cause of radiculopathy. Wrong diagnosis might explain the high proportion of unsatisfactory results obtained by a few authors after repeat decompressive surgery (37, 68). In patients with severe compression of the neural structures, additional decompressive surgery (with or without fusion) usually leads to a considerable improvement in, or a complete disappearance of, the radicular symptoms, at least in the presence of a normal psychologic profile.

Postoperative low back pain

Normal low back pain

In the first postoperative months, the majority of patients operated on for lumbar disc herniation complain of intermittent or continuous low back pain, generally of a mild entity. Pain is almost invariably present upon awakening in the morning and is increased by physical efforts, whilst it often improves or disappears with exercise therapy. Low back pain is more frequent in middle-aged, than in young or elderly, patients. From the third month after discectomy, approximately half of the patients complain of low back pain, usually mild and discontinuous. After the sixth month, most patients do not suffer from low back pain or complain of occasional discomfort in the low back, which does not limit daily activities nor require any treatment. Low back pain is much more frequent in patients who have complained of back pain for years or decades before surgery than in those with a short history of pain. Rare episodes of acute low back pain, generally of a short duration, may occur either during or after the first postoperative year.

Up until the third month after surgery, low back pain should be considered as physiologic, even when it is persistent or frequent, but mild or moderate. Between the third and sixth month, mild and discontinuous low back pain requiring occasional medication should still be considered as normal. After the sixth month, low back pain is pathologic if it is mild but continuous, or when it is occasional but severe enough to limit daily activities or it requires treatment.

Spinal instability

The concept of spinal stability and the possible causes of instability following surgery for a herniated disc in a preoperatively stable or unstable spine are analyzed in chapters 20 and 21.

Clinical presentation and diagnosis

The clinical manifestation of segmental spinal instability is low back pain, which may or may not be associated with radiating pain. The typical features of low back pain due to spinal instability are: episodes of sudden pain upon trunk movements; alteration of the normal rhythm of trunk movement upon flexion and extension; occasional sensation of the lumbar spine "giving way"; and apprehension regarding the possible occurrence of either "giving way" or pain upon movements (53, 62). Furthermore, in many patients pain decreases or disappears in the supine position and appears or increases upon standing, particularly if prolonged. Often, however, low back pain due to spinal instability has no peculiar feature and it cannot be differentiated from low back pain caused by disc disease or spondyloarthrosis.

Instability can be demonstrated by flexion-extension radiographs. However, vertebral hypermobility does not necessarily cause low back pain, whilst, on the other hand, an occult symptomatic instability is likely to exist, whereupon flexion-extension radiographs show no hypermobility. The vertebrae of the unstable motion segment may show traction spurs, which have been interpreted as an indirect sign of vertebral instability (49). In effect, the diagnostic value of these osteophytes is still unclear, since they are often absent in unstable vertebrae, whereas they can be present in the absence of any clinical or radiographic evidence of instability. As an auxiliary diagnostic test, a plaster jacket or a brace may be applied for 2–4 weeks: a significant relief of low back pain may confirm the diagnosis of instability. Alternatively, an external fixator may be implanted, which more efficiently immobilizes the vertebral motion segment (17, 47, 50).

Treatment

In patients with chronic postoperative low back pain in whom flexion-extension radiographs show vertebral hypermobility of the operated motion segment, there is a clear-cut indication for spinal fusion. However, it can be difficult to make a decision in this regard when the clinical symptoms and plain radiographs (showing a subtotal or total, unilateral or bilateral, arthrectomy) suggest spinal instability, whilst flexion-extension radiographs show no hypermobility of the vertebrae involved. In these cases, it may be helpful to apply a trial plaster jacket and, if this improves the low back pain, arthrodesis may be indicated. When pain is not relieved, an external fixator may be applied. If the latter does not considerably reduce the patient's symptoms, the low back pain is highly unlikely to be caused by spinal instability.

Arthrodesis usually provides satisfactory results in patients with spinal instability. In one series (20), all patients with postoperative instability obtained good or excellent results following fusion. Boccanera et al. (6) reported satisfactory results in 80% of cases.

Discogenic low back pain

Pathogenesis

The majority of patients with pathologic postoperative low back pain, who have undergone discectomy without excessive resection of the facet joints, show no overt spinal instability, evident degenerative changes of the facets, or clear psychologic distress. They may have structural changes, often associated with a decrease in height, of the operated disc and/or degenerative changes of one or more adjacent discs. In these cases, it is logical to hypothesize that low back pain originates from the operated disc and/or the adjacent degenerated discs.

The reasons why a disc may cause low back pain after excision of its contents remain unclear. Pain might be due to structural and biochemical changes of the disc, similar to those responsible for chronic low back pain in non-operated patients with disc degeneration. Alternatively, low back pain may be the result of an occult instability caused by discectomy. Biomechanical in vitro studies, in fact, have shown that discectomy decreases spinal stability. It is possible that surgical destabilization is responsible for the early postoperative low back pain frequently reported by operated patients, and that the stability of the motion segment is gradually restored, although not completely, while the postoperative reparative processes take place in the outermost annulus fibrosus; this process would lead, in patients with a preoperatively stable vertebral motion segment, to a gradual resolution of low back symptoms. By contrast, in the presence of potential or occult preoperative instability, due to ligamentous laxity, abnormal orientation of the facet joints or other unknown causes, disc excision would increase spinal instability to a critical extent, even without making it patent, and would lead to persistent low back pain. On the other hand, the biochemical and structural changes which characterize disc degeneration might cause low back pain, due to a decreased stability of the motion segment. This hypothesis, based on pathologic observations (38), is supported by the results of biomechanical studies indicating that disc degeneration decreases the rigidity of the motion segment and causes changes in vertebral motion.

Clinical presentation and diagnosis

There are no clinical features peculiar to postoperative discogenic low back pain. Patients with discogenic lumbago often complain of pain after sleeping at night, while standing or sitting for a long time, upon trunk movements and, particularly, during heavy physical activities. At times, the clinical presentation is that typical of low back pain due to spinal instability. Episodes of acute pain that resolve in a few days or weeks are often present in the clinical history.

MRI of the lumbar spine may allow detection of disc degeneration at a different vertebral level to that at which surgery was performed. If the latter appears to be the only degenerated disc, it may be useful to perform discography as a pain provocation test; however, if the typical patient's symptoms are not elicited by discography, a discogenic origin of the pain cannot be excluded, particularly when an operated disc is injected. Immobilization of the lumbar spine with a trial plaster jacket, or an external fixator, may, or not, decrease low back pain. When discs other than that operated on appear to be degenerated, discography is the only diagnostic test able to determine which disc is responsible for the low back pain.

Treatment

In patients with discogenic low back pain, there can be an indication for fusion of the involved motion segment. However, spinal fusion is very rarely necessary, since in the vast majority of cases back pain is sufficiently relieved by conservative treatment, particularly exercise therapy, low back school and physiotherapy. Conservative management is indicated especially in patients showing disc degeneration at levels adjacent to that operated on. In these cases, in fact, it may be difficult to determine with reasonable certainty whether the symptomatic disc is that which has been operated on. Furthermore, the presence of degenerated discs at adjacent levels exposes to the risk of an increase in degenerative changes of these discs and a possible reappearance of low back pain after a few years.

Fusion may be indicated: in psychologically stable patients, who have not obtained sufficient pain relief from conservative management carried out for at least 1 year after surgery; and when no degenerative changes are detected in discs adjacent to that operated on or, if the latter is one of the two lowermost lumbar discs, only the other disc is degenerated. In this case, an L4-S1 fusion should be performed. The decision to perform spinal arthrodesis in patients aged less than 40 years should be carefully evaluated, due to the higher chances that patients with a long life expectancy may develop degenerative changes as a result of mechanical overloading of the motion segment adjacent to the fused area.

Facet joint osteoarthrosis

Clinical relevance

Chronic postoperative low back pain may be due to degenerative changes of the facet joints of the operated motion segment and/or the adjacent segments. A decrease in disc height is known to expose the posterior joints to abnormal mechanical stresses (14, 73), which may cause, or increase the severity of, degenerative changes of the facets. This may also occur as a result of the decrease in disc height, which often occurs following discectomy. On the other hand, degenerative changes of the facet joints may be present at multiple lumbar levels due to aging, a constitutional tendency to osteoarthrotic changes or an altered load distribution as a result of scoliosis, hyperlordosis or tropism of the articular facets. These degenerative changes can be responsible for postoperative low back pain independently of the discectomy. However, facet joints probably play a marginal role in the pathomechanism of postoperative low back pain. The degenerative changes of the facets and the subsequent articular and periarticular inflammatory processes may cause low back pain, which, however, is rarely severe, particularly when only the operated motion segment is involved.

Diagnosis and treatment

No well-defined clinical features are found in patients with low back pain due to degenerated facet joints, except for the little or no tendency for pain to decrease with rest and, on the other hand, its tendency to increase upon trunk extension (16). Osteoarthrotic changes, if severe, are clearly visible on routine and oblique radiographs, and CT scans. Arthrography of the facet joints eliciting the typical patient's symptoms and/or the injection of a local anesthetic leading to pain relief may be useful diagnostic tests (18).

Treatment is based on physiotherapy, manipulation and exercises. When pain persists, intra-articular or periarticular injections of steroids may be effective. After initial enthusiasm (46, 52, 64), percutaneous denervation of the facet joints has been almost entirely abandoned. Surgical treatment, consisting of an intertransverse or interbody fusion, may be indicated, although rarely, in the presence of severe degenerative changes at 1 or 2 vertebral levels (16). Arthrodesis of only the posterior joints is contraindicated, due to the difficulty both in achieving a solid fusion and in excluding that low back pain is, at least in part, discogenic in nature.

Pseudarthrosis

Frequency

Pseudarthrosis after an unsuccessful fusion is one of the most frequent causes of failure in low back surgery. In patients with disc herniation, however, this is a rare cause of failure, since fusion is not usually associated with discectomy. This is particularly true of patients with simple disc herniation and of those who have had only one previous failed back operation. In the presence of associated conditions or in patients submitted to multiple spinal operations, fusion is often performed. In these cases, pseudarthrosis is more likely to be a cause of surgical failure, even if pseudarthrosis may not be associated with any clinical symptoms (12, 23, 60). The rate of failures in back surgery attributable to pseudarthrosis ranges from 6% to 16% (5, 20, 37, 45). The studies in the literature, however, do not usually report the initial diagnosis in patients submitted to reoperation due to pseudarthrosis and it is, thus, not possible to determine the role of pseudarthrosis as a cause of failure in patients initially operated on for disc herniation, either isolated or associated with other conditions.

Diagnosis and treatment

Pseudarthrosis can be responsible for low back pain, or even radicular symptoms, in the presence of spinal instability. Low back pain shows no peculiar feature, except in patients with spinal instability, whose symptoms may be those typical of this condition.

Usually pseudarthrosis is clearly evident on plain radiographs and the persistent vertebral motion in the fused area may be demonstrated by flexion-extension radiographs. If the diagnosis is uncertain, biplanar or multiplanar CT may be a useful diagnostic tool (41). The diagnosis of pseudarthrosis cannot generally be made earlier than 6–8 months from surgery. A trial plaster jacket or an external fixator may sometimes be indicated, as in patients with spinal instability.

Several clinical studies indicate that in the presence of symptomatic pseudarthrosis, re-arthrodesis has high chances of significantly improving the clinical symptoms, if a solid fusion is obtained (20, 37, 39). By contrast, Waddell et al. (68) observed unsatisfactory results in most patients with working compensation claims who had undergone a successful or unsuccessful re-arthrodesis. The percentage of solid fusion after re-arthrodesis varies between 55% and 100% (20, 37, 43, 55).

Psychogenic low back pain

Underlying psychologic or psychosocial dysfunctions, such as personality disorders, depression, anxiety, difficulty in interpersonal relationships or work dissatisfaction are often present in patients with postoperative pathologic low back pain. Oppel et al. (51), in a series of 3032 patients treated operatively for lumbar disc herniation, found psychologic disorders in 3.4% of cases; this figure increased to 18.9% in patients with a poor outcome. Waddell et al. (68) found psychologic dysfunctions in 65% of 103 patients with working compensation claims who had undergone one or more previous back operations. However, in the individual patient, it may be extremely difficult to determine whether the psychologic disorders were pre-existent to the operation and the surgical failure is due to the prevalence of the psychologic condition over the organic disease, or whether the psychic disorders depend, to a large extent, on the surgical failure and can be corrected by curing the spinal condition. In both cases, it is important to detect the psychologic disorder and assess its severity, even when a clear-cut organic condition is present, since the therapeutic planning, as well as the results of treatment, may be considerably affected by the patient's psychosocial features.

Diagnosis and treatment

In some cases, the presence of psychologic or psychosocial dysfuntions is clearly demonstrated by the patient's behavior. In other cases, psychogenic pain is difficult to suspect or diagnose. In both situations, it is useful to perform psychometric tests, which may allow the psychologic dysfunction to be detected and/or quantified. Psychologic dysfunctions, in fact, significantly increase the probability of failure of any organic treatment, particularly if surgical. On the other hand, a further failed back surgery entails a high risk of worsening the psychologic disorders and increasing the psychogenic component of pain.

In patients with overt psychologic disorders, the decision to perfom surgery must be taken with extreme caution and only in the presence of a clear-cut, severe organic condition. The same holds when the clinical examination reveals no significant psychologic dysfunction, but the psychometric tests are considerably altered. In the vast majority of these patients, the therapeutic strategy should be aimed at improving the psychologic disorder, returning the patient to a social and productive context, and reducing the organic component of pain with various forms of conservative treatment.

Results of reoperation after failed back surgery

Overall results

The proportion of satisfactory results after reoperation for failed back surgery varies from 28% to 83% (5, 15, 19, 20, 22, 24, 26, 34, 37, 44, 45, 68, 69). In the majority of the series, the percentage ranges from 70% to 80%, neurosurgeons tending to report higher rates of satisfactory results than orthopaedic surgeons. In almost all series, however, recurrent herniations and new herniations are included among the surgical failures and, often, the quality of the results in each condition to which the failure is attributed, is not reported. Hence, for many of the series quoted above, it is not possible to determine the rate of satisfactory outcomes in those conditions that we have considered as causes of surgical failure. The rates vary between 47% and 77% (15, 20, 22, 26, 34, 37) and for the most part between 50% and 65%.

A relevant observation is that a part of the reoperated patients, mainly those submitted to multiple operations, report worsening of their symptoms after repeat surgery. This probably occurs in 5%–10% of cases (15, 34), but much higher figures are also reported (68).

Factors predictive of the result

Various factors may affect the result of repeat surgery. Those with the highest predictive value are: 1) The preoperative and/or intraoperative diagnosis. This is the factor with the greatest influence on the surgical outcome, since epidural fibrosis, arachnoiditis or a negative exploration at primary surgery are very likely to lead to a poor outcome. 2) The time elapsed after the previous spinal operation. A time interval of less than 1 month and more than 1 year between primary surgery and reoperation is more frequently associated with a satisfactory result than a time lapse of 1–12 months (15, 19, 20, 37). In the first case, in fact, the cause of failure is often a technical defect in the surgical treatment, easily correctable by reoperation, whilst in the second case, the pathologic condition is often located at a virgin level and/or is a different condition from that treated initially; in the third case, on the other hand, the pre- or intraoperative diagnosis is often epidural fibrosis. 3) The disappearance or persistence of preoperative symptoms after surgery. A pain-free interval longer than 6 months after primary discectomy significantly increases the chances of a satisfactory result after reoperation (20, 34, 68). 4) The presence of a legal controversy or working compensation claims. These considerably increases the probability of failure (20, 26).

In a few series, the number of previous operations on the lumbar spine was not found to affect the quality of the clinical outcome (5, 6, 37). However, Stringa et al. (67), observed satisfactory results in only 20%–30% of cases submitted to multiple spinal operations. Waddell et al. (68) found that, after the fourth operation, the proportion of patients with satisfactory results (10%–20%) was about half of that observed after the third operation, and the latter was about half of that obtained with the second operation (40%–50%). Similarly, the presence of psychologic disorders was found to be a strong predictor of surgical failure in some studies (20, 68), but not in others (5).

Age, sex, race, type of work and vertebral level involved do not appear to have any influence on the results of repeat surgery. A study (34) showed that patients with nerve-root canal stenosis had significantly better results than those with stenosis of the spinal canal.

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·CHAPTER 23·

RECURRENT AND NEW HERNIATIONS

F. Postacchini, G. Cinotti

Terminology

Some authors (18, 60) use the term recurrence when the herniation occurs in a previously operated disc, on the same side as the primary herniation or on the opposite side; others (10, 11, 16, 44) refer to recurrence even for herniation at a new level with respect to the primary herniated disc. A few authors (12, 37, 80) call "true herniation" the recurrence occurring at the same level and on the same side as the primary herniation, whereas others (13, 68) use this expression for recurrence at a previously operated level, either on the same or the opposite side. The herniation at a new level has also been termed "pseudorecurrence" (66).

We use the term "recurrent" only for disc herniation occurring at the same level and on the same side as the primary herniated disc. Only in this case, in fact, is the herniation a true recurrence, i.e., it has reformed at the same site as the excised herniation. Furthermore, a recurrent herniation of the same disc and on the same side differs from other herniations from a pathologic and surgical point of view, due to the presence of epidural scar tissue. Other types of herniation occurring in patients previously submitted to disc excision may be called "new herniations". This term may not be entirely correct if the herniation was already present at the time of primary discectomy; however, its use is justified by the fact that the herniation caused no clinical symptoms at that time (otherwise the condition should be included in the surgical failures). We call "contralateral herniation at the operated level" the disc herniation at a previously operated interspace and "herniation at a new level" that occurring in a virgin disc.

Incidence

The exact incidence of recurrent and new herniations is unknown. The rate of reoperation has been reported for recurrent or new herniations, but no mention has been made of the rate of patients complaining of recurrent lumboradicular symptoms due to recurrent or new herniations not undergoing reoperation.

The percentage of reoperations for recurrent or new herniations varies, even considerably, in different series. Of 138 patients submitted to standard discectomy (31) who were followed for a mean of 7 years, four (2.8%) were reoperated on for a recurrent or new herniation. Davis (11) retrospectively analysed 984 patients who underwent standard discectomy, 970 (88%) of whom after a mean follow-up of 10.8 years: 6% of the patients were submitted to repeat surgery for a recurrent or new herniation. Of these, 50% had a recurrent herniation, 34% a herniated disc at a new level and 16% a contralateral herniation at the operated level. Of 100 patients followed prospectively for 10 years after standard discectomy, 16% underwent reoperation for a recurrent or new herniation (50). Of these, 68% had a recurrent herniation, 12% a contralateral herniation and 18% a herniated disc at a new level. In numerous studies carried out during the last 35 years, in which patients undergoing standard discectomy were analyzed, the incidence of recurrent herniations, or herniations at new levels, ranged from 5% to 11% (mean 7.4%) (10, 38, 43, 47, 53, 56, 57, 62, 68, 70, 79, 85, 86) (Table 23.1). Intraforaminal and extraforaminal herniations seem to show a lower tendency to recur compared with herniation at other sites (1, 17, 19).

Microdiscectomy appears to decrease the risk of recurrences. In numerous series of patients submitted to microdiscectomy, an incidence of recurrent and new herniations ranging from 3% to 6% (mean 4.6%) has been reported (2, 14, 27, 45, 57, 59, 85) (Table 23.2). Patients submitted to microdiscectomy, however, were followed for a shorter time interval than those who underwent conventional discectomy. Furthermore, comparative studies showed no significant differences in the rate of recurrences between the two procedures (67, 81). One study (67) analyzed the incidence of recurrent herniations after partial or complete discectomy: 21% of the patients submitted to partial discectomy had a recurrent herniation, compared with none of those who had undergone complete discectomy. In keeping with this result, Postacchini et al. (65) reported a recurrence rate of 12% after partial discectomy and no recurrences after complete discectomy. In the majority of the studies, recurrent herniations were more numerous than herniations at new levels.

In a series of 100 patients who underwent reoperation for a recurrent or new herniation (66), the highest incidence of reoperations occurred between the 6th and 24th month after primary discectomy. Thereafter, the incidence of reoperations markedly decreased and remained unchanged over time. In several series, reoperations have been performed, in most cases, within 1 year of primary discectomy (10, 11, 13). The time elapsing between primary and repeat surgery ranged from 1.5 to 4 years (11, 45, 50, 72).

Table 23.1. *Incidence of recurrent or new herniations after conventional discectomy.*

Author	No. of patients	% of recurrent or new herniations
Jackson 1971 (38)	130	5.7
Mattmann 1971 (53)	4120	11.0
Keyl 1974 (43)	857	8.9
Naylor 1974 (56)	204	5.0
LaMont 1976 (47)	273	7.0
Thomalske 1977 (79)	1000	7.1
Schramm 1978 (70)	3238	6.4
Pace 1980 (62)	107	5.6
Wilson 1981 (85)	100	11.0
Nyström 1987 (57)	64	7.8
Ruggieri 1988 (68)	872	5.7
Connolly 1992 (10)	182	8.2

Table 23.2. *Incidence of recurrent or new herniations after microdiscectomy.*

Author	No. of patients	% of recurrent or new herniations
Oldenkott 1980 (59)	67	4.4
Goald 1981 (27)	477	4.0
Wilson 1981 (85)	100	4.0
Ebeling 1986 (14)	485	5.5
Nyström 1987 (57)	56	3.6
Andrews 1990 (2)	112	5.3
Kotilainen 1993 (45)	237	5.4

A third operation for a recurrent or new herniation is probably performed in about 1%–3% of patients submitted to discectomy (50, 63), i.e., in approximately 5%–10% of the patients reoperated on for a recurrent or new herniation (16, 40, 44, 66). Only about 10% of those who have had a third discectomy undergo a fourth disc excision.

The incidence of reoperation at the different vertebral levels is similar to that of primary herniation: L4-L5 is the most frequently involved level, followed by L5-S1 (16, 60, 66).

Reoperations for recurrent or new herniations are two- to six-fold more frequent in males than in females (10, 13, 66, 72). The mean age at reoperation is more advanced compared with that at primary discectomy; in one study, the mean age at reoperation was 5 years higher than that at primary discectomy (66). Compared with adults, teen-agers do not show a higher incidence of recurrent or new herniations. Although it has been reported that, at very long-term evaluation, 20% of patients had undergone reoperation one or more times (15), other long-term or very long-term studies reported a similar incidence of recurrences in teen-agers and adults (41, 58, 69, 82).

Following posterolateral fusion, a recurrent or contralateral herniation may occur only in the presence of pseudarthrosis. In a long-term investigation, disc herniation at L3-L4 level was found in 4% of patients submitted to L4-L5 fusion (25).

Recurrent herniation

Definition of terms

A herniation may be considered as a recurrence if the radicular pain had entirely receded or considerably decreased, for at least a few months after primary discectomy. If this is not the case, the condition should be regarded as a failure of the surgical treatment. The time interval after which a disc herniation may be considered as a recurrence, might arbitrarily be estimated at 3 months. Before this period, in fact, it is unlikely that the newly-formed tissue within the disc is of such entity as to be the source of a disc prolapse causing nerve root compression. A recurrent herniation may be defined as early, when it occurs between the 3rd and the 12th month after surgery or as late, when it occurs thereafter.

Etiopathogenesis

Reparative processes after discectomy

Few experimental studies have analyzed the changes occurring after a disc injury and in only one was the type of discectomy similar to that performed in man. Filippi (20) made a transverse incision along the whole ventral portion of the annulus fibrosus in rabbits. After 40 days, the histologic analysis revealed proliferation of the fibrocartilaginous tissue of the vertebral end-plates and reconstitution of the continuity of the annulus fibrosus. The nucleus pulposus was replaced by lamellae of fibrocartilaginous tissue, the majority of which were orientated in a dorsoventral direction.

Key and Ford (42) produced four types of disc injury in young dogs after hemilaminectomy: 1) fenestration of the annulus fibrosus and removal of the nucleus pulposus with a curette; 2) the same procedure as in 1), plus curettage of the vertebral end-plates; 3) transverse incision of the annulus fibrosus; 4) introduction of a needle in the annulus fibrosus. Two to 5 days after the first procedure, the peripheral portion of the annulus fibrosus was occupied by fibrin; subsequently, a layer of fibrous tissue, which progressively increased in density, was observed. A few discs were prolapsed at the injury site. In the early phase, the inner portion of the disc contained a clot of fibrin and fluid material; thereafter, fibrous tissue or areas of fibrocartilage, separated by fibrous tissue, were present. Similar findings were observed after the third procedure. Following the second procedure, cartilage and bone fragments were present within the initial fibrin clot.

An experimental study in dogs, in whom the ventral annulus fibrosus was injured, confirmed that only the peripheral portion of the annular lesion is filled with fibrous tissue and cartilage areas (32). The inner portion of the annulus, instead, does not heal and the margins of disc injury, at this site, appear to be covered by a layer of mesothelial-like cells.

An investigation carried out in rabbits, submitted to transverse division of the anterior annulus fibrosus, demonstrated that the peripheral portion of the annulus is rapidly replaced by fibrous tissue (73). Ossification of the cartilaginous tissue then occurs, leading to the formation of bony bridges between the two adjacent vertebrae. The nucleus pulposus, which to a large extent comes out through the annular incision, is replaced by fibrocartilaginous tissue, a portion of which penetrates into the inner unhealed part of the annulus fibrosus.

Lipson and Muir (51), following the division of the annulus fibrosus in rabbits, observed that the content in proteoglycan aggregates, which was decreased soon after the injury, increased 3 weeks later; then progressively decreased again and reached, after 6 weeks, markedly lower values compared with the normal disc. The water and proteoglycan content decreased after the first day, then increased again until the fourth day, and thereafter progressively decreasing to less than half the normal value. The hyaluronic acid rapidly and progressively decreased after the first week.

Partially in contrast with these experimental studies, a post mortem investigation performed on a subject who had undergone discectomy 2 years before death (61) revealed that the fenestration in the outer annulus fibrosus was healed, but the central portion of the disc was void of tissue. We explored the site of a previous discectomy, 16 and 20 days after surgery, in two patients who had had unsatisfactory results; in both cases, there was no evidence of healing processes at the site of the annular fenestration.

Despite these findings, it may be hypothesized that the reparative processes observed in animals are similar to those occurring in man (Fig. 23.1). The disc space is initially filled with a fibrin clot and, subsequently, with fibrous tissue or fibrocartilage derived from the vertebral end-plates, at the transition zone between the

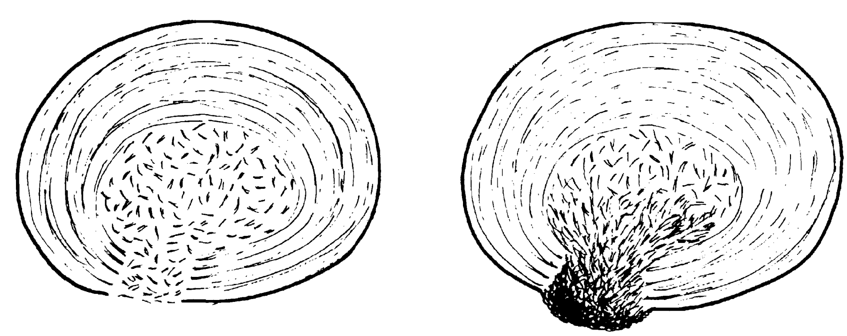

Fig. 23.1. *Reparative processes after discectomy. The disc space is initially filled with a fibrin clot* (A), *which subsequently becomes fibrous tissue or fibrocartilage. The surgical defect in the outer annulus fibrosus* (B) *is filled with dense fibrous tissue, which may bulge slightly beyond the border of the annulus.*

A

B

annulus fibrosus and nucleus pulposus, and from residual nuclear tissue. The annulus fibrosus excised at surgery is replaced, in its peripheral portion, by dense fibrous tissue, which may bulge slightly into the spinal canal (Fig 23.1 B). These processes possibly begin a few days after surgery and continue for several months thereafter.

Predisposing factors

The etiopathogenesis of recurrent herniation is one of the most obscure aspects of this condition and of lumbar disc herniation in general. This is surprising in view of the relatively high frequency of recurrent herniation and the numerous studies concerning this condition. The large majority of the investigations performed so far have focused on the diagnostic and therapeutic aspects of the condition, whereas few and conflicting data have been reported on the factors which may play a role in the etiopathogenesis of the disease. Moreover, much of the available information is based on clinical and surgical findings, rather than on epidemiologic data or the histologic analysis of specimens obtained at surgery.

The height of the disc space before primary discectomy and the involved vertebral level do not appear to be risk factors for recurrence of herniation. It has been suggested that a recurrent herniation is more likely to occur in mild degenerated discs (8, 23, 26, 38), although in none of these studies was the degree of disc degeneration assessed before primary discectomy. In contrast, a prospective study has shown that disc degeneration, as seen on MRI scans performed prior to primary discectomy, was on average more severe in patients who developed a recurrent herniation compared with controls (9). In keeping with this finding, a lower number of recurrences was found in young subjects, who usually present mild degeneration at the herniated disc, than in adults (9).

The amount of disc tissue excised at primary discectomy does not appear to be related to the rate of recurrence. In a retrospective analysis of 323 patients, no correlation was found between the amount of the disc tissue excised and the incidence of recurrent herniation (72). However, it should be borne in mind that the amount of tissue excised at surgery is less than 20% of the total disc weight (58).

Little is known on the effects of physical activities on the rate of recurrences, even if a few data suggest that they do not influence the recurrence rate. Patients wearing a corset after primary discectomy do not show less tendency to develop a recurrent herniation compared with those performing exercise therapy and various physical activities. Similarly, no correlation has been observed between the type of work and the frequency of recurrences. An isolated injury seems to play a role in the etiology of recurrent herniation, since a higher proportion of patients with recurrent herniation, compared to those with primary herniation, related the onset of recurrent symptoms to traumas or precipitating events (9). This finding may be associated with the higher incidence of recurrences in males (66, 72).

Many authors argue that a recurrent herniation is due to incomplete removal of nuclear tissue at primary discectomy (5, 6, 63, 68, 86). Spengler (75), however, did not observe a higher incidence of recurrences in patients submitted to limited discectomy. In contrast with this finding, in two series of patients who underwent microdiscectomy, the recurrence rate after partial disc excision was significantly higher than after complete discectomy (65, 67). Furthermore, in a large series of patients submitted to partial microdiscectomy (84), the rate of recurrences was higher (9%) compared with other microdiscectomy series in which complete disc excision had been carried out. It is thus tempting to suggest that, at least in some cases, the persistence of one or more large fragments of nucleus pulposus, possibly wedged in a radial or circumferential tear of the annulus fibrosus, may be the cause of recurrent herniation.

A large fenestration in the annulus fibrosus might facilitate the occurrence of a recurrent herniation because the posterior annulus is less likely to reform a continuous wall, i.e., a barrier to contain the tissue replacing the disc space after discectomy. However, there are no data to support this hypothesis. Moreover, bilateral discetomy seems to decrease the incidence of recurrences (30).

Pathogenetic mechanism

Early recurrent herniation

Herniation occurring 3 to 5 months after surgery may be due to residual fragments of nucleus pulposus which have not been removed at primary discectomy. This rare cause of recurrence might occur with two mechanisms :

1) A fragment of nucleus pulposus may remain enclosed within the annular lamellae, particularly in the middle portion of the disc. This zone, in fact, is not clearly visible during surgery and is the most difficult to excise. A residual disc fragment located in this zone may not cause any clinical symptoms for several months until, as a result of a physical effort, or spontaneously, a) it penetrates into the outermost lamellae and bulges, or is extruded, into the spinal canal at a different site from the primary herniation, or b) it moves to the site of the previous surgical fenestration where it finds a thinner and less resistent layer of fibrous tissue and may, thus, easily prolapse into the spinal canal

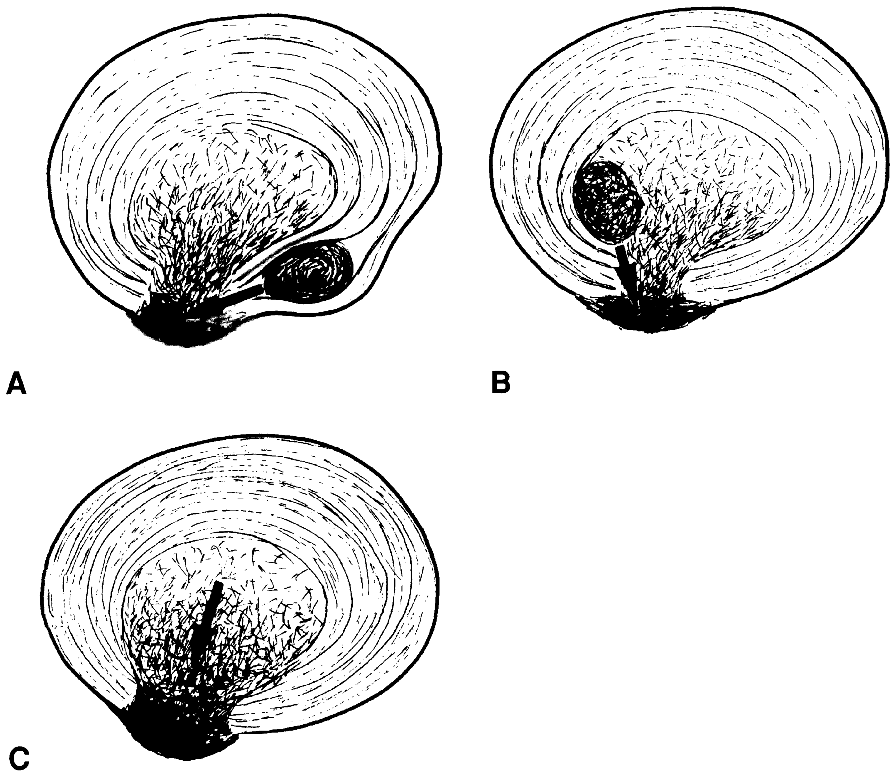

Fig. 23.2. (A) *and* (B) *Pathogenetic mechanism of early recurrent herniation. A fragment of nucleus pulposus, which has remained wedged between the annular lamellae* (A) *may displace to the site of the surgical defect and protrude into the spinal canal. Alternatively, a large free fragment of nucleus pulposus* (B), *which has been left within the disc, reaches the site of the surgical defect, where it may perforate the residual external annulus and penetrate into the spinal canal.* (C) *Pathogenetic mechanism of late recurrent herniation. In the presence of an abnormal reparative process, the protrusion of disc tissue through the surgical defect is facilitated by the large amount of newly-formed tissue.*

(Fig. 23.2 A). In both cases, the fragment may increase in size after primary discectomy due to the regenerative processes occurring at the operated site.

2) A large free fragment of nucleus pulposus may remain within the disc after discectomy and then move to the innermost annulus, i.e., the portion of the annulus fibrosus which likely fails to heal after disc incision. The free fragment may remain for a long period of time, or even forever, at this site without causing clinical symptoms; alternatively, it may exert pressure on the fibrous tissue filling the defect of the outer annulus fibrosus, and thus lead to a contained herniation or, having perforated the outermost annulus, to an extruded fragment (Fig. 23.2 B).

Early recurrent herniations occurring 6 to 8 months after surgery are much more frequent than very early ones. They are probably due to a different mechanism rather than to incomplete removal of the primary herniation. In these cases, the pathogenetic mechanism is likely to be similar to that occurring in the late recurrences.

Late recurrent herniation

These are probably formed by fibrous and/or fibrocartilaginous tissue replacing the nucleus pulposus after primary discectomy. The reason why a minority of patients develop a late recurrent herniation, at different time intervals from primary surgery, remains to be elucidated. Two hypotheses may be advanced:

1) In the majority of patients, the newly formed tissue is mainly fibrous tissue which, in itself, shows little tendency to dislocate and herniate. However, in a few patients, most of, or all, the tissue replacing the nucleus pulposus tends to acquire fibrocartilaginous features. This tendency might be related to the type and magnitude of the mechanical load exerted upon the operated vertebral motion segment in the first few months or years after discectomy. Like the degenerated nuclear tissue, the fibrocartilaginous tissue might have a greater tendency, compared with fibrous tissue, to penetrate into old or newly-formed annular fissures and be extruded at the site of the previous surgical fenestration or at a different site. The variability in the time interval between primary discectomy and recurrence might be related to a different rate with which subjects form fibrocartilaginous tissue after the primary operation.

2) In a few patients, exuberant reparative processes, leading to the formation of abundant regenerated tissue after discectomy, might occur. Due to the abnormal amount of newly-formed tissue, this may likely herniate into the weakest zone of the annulus fibrosus, i.e., at the site of the previous surgical fenestration (Fig. 23.2 C). This pathogenetic mechanism could explain why, in many cases, the recurrences are larger than the primary herniations.

However, even for recurrent herniation, alternative pathogenetic mechanisms to that of herniation of the nucleus pulposus through the annulus fibrosus cannot be excluded (page 163). As with primary herniation, it may be hypothesized that, in specific circumstances, a portion of the annulus fibrosus, or the fibrous tissue filling the site of the surgical fenestration, might be extruded from the annulus.

Pathology

Three types of recurrent herniation may be identified: small protrusion, medium or large herniation located at the level of the disc, and migrated herniation.

The terms "contained" or "extruded" are improperly used in patients with recurrent herniation, at least when the latter occurs at the same site as the primary disc prolapse, since they refer to that portion of the annulus fibrosus which has been excised at primary discectomy. However, use of these terms may be justified by the analogy between the surgical findings observed in primary and recurrent herniations. In some patients, in fact, the herniation appears like a protrusion of the posterior annulus, which resembles a contained primary herniation; very often, in these cases, the posterior annulus is of relatively hard consistency and its incision does not cause a spontaneous extrusion of tissue from the disc space. In other patients, the herniated tissue is located within the spinal canal, but is still connected to

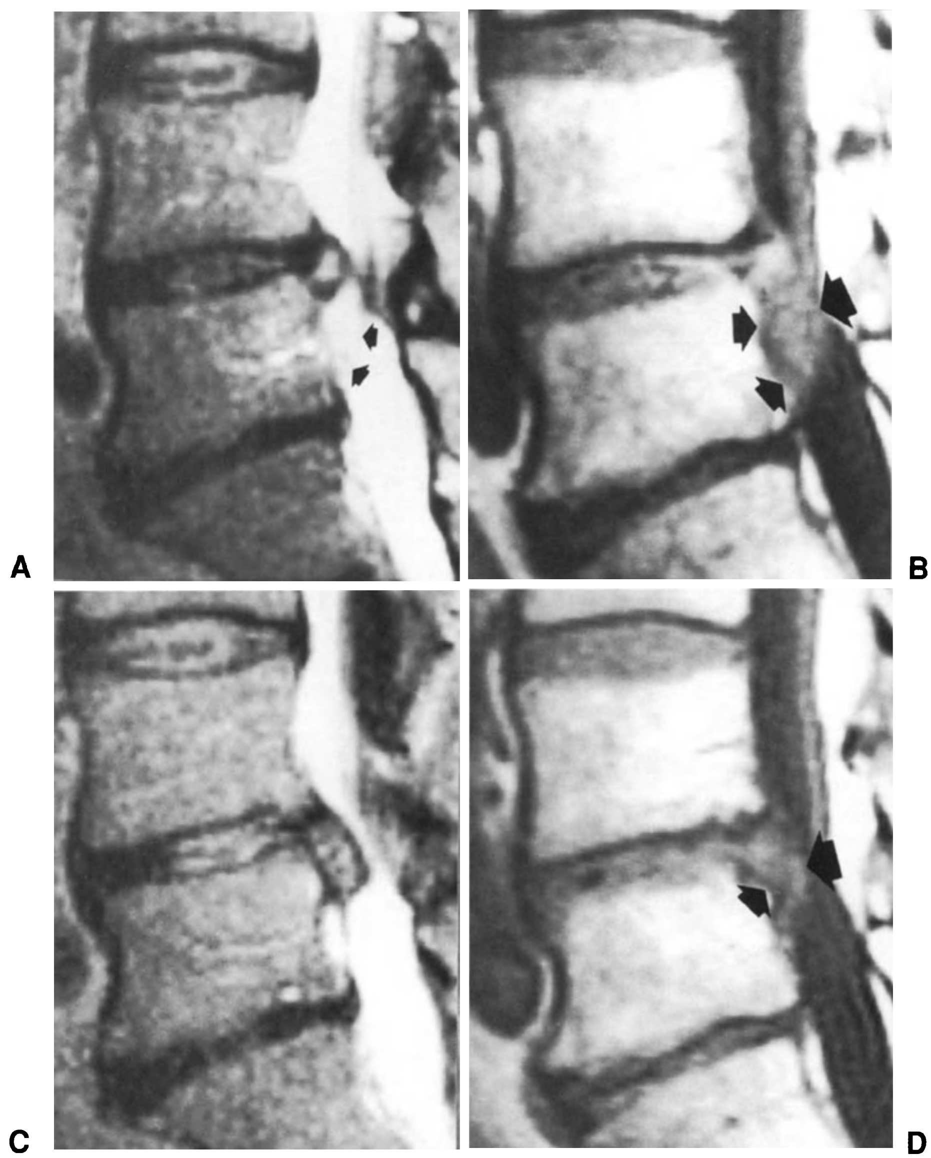

Fig. 23.3. *MRI scans of patients with large recurrent herniation at L4-L5 level.* (A) *and* (B) *Preoperative turbo spin-echo T2-weighted and T1-weighted sagittal images, respectively, showing, caudally to the L4-L5 level, a large disc fragment (arrows) with an increased signal intensity in the T2 sequence.* (C) *and* (D) *Turbo spin-echo T2-weighted and T1-weighted sagittal images, respectively, carried out 11 months after surgery, showing, at L4-L5 level, a large recurrent herniation which is almost completely extruded into the spinal canal (arrows).*

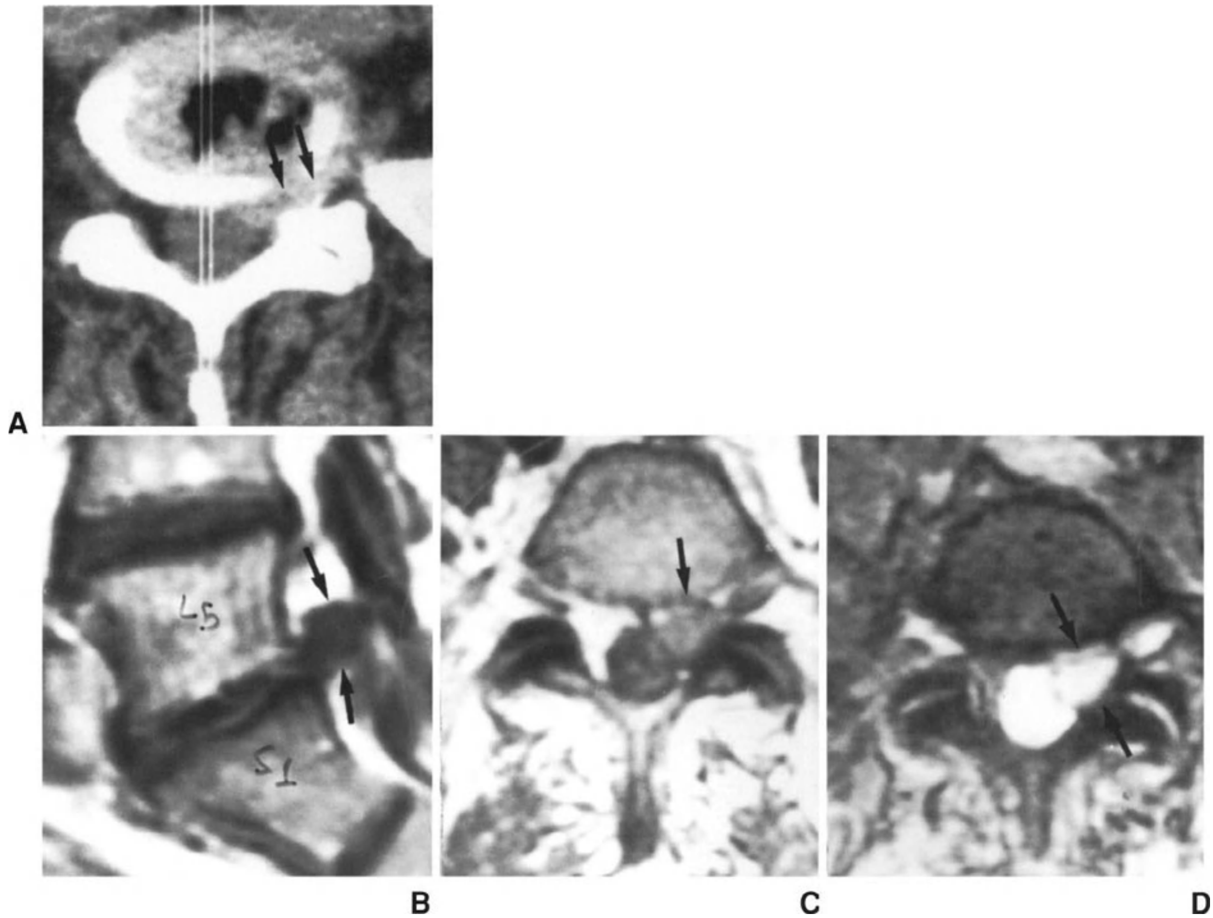

Fig. 23.4. *CT and MRI scans of a patient with recurrent herniation.* (A) *Preoperative axial CT scan at L5-S1 level revealing a left disc herniation located, in part, posterolaterally and, in part, within the neuroforamen (arrows).* (B) *Sagittal MR image obtained 20 months after primary discectomy, showing a large recurrent herniation (arrows) at L5-S1 level.* (C) *and* (D) *Axial MR images showing the disc fragment extruded cranially (arrows); the recurrence appears to be larger than primary herniation.*

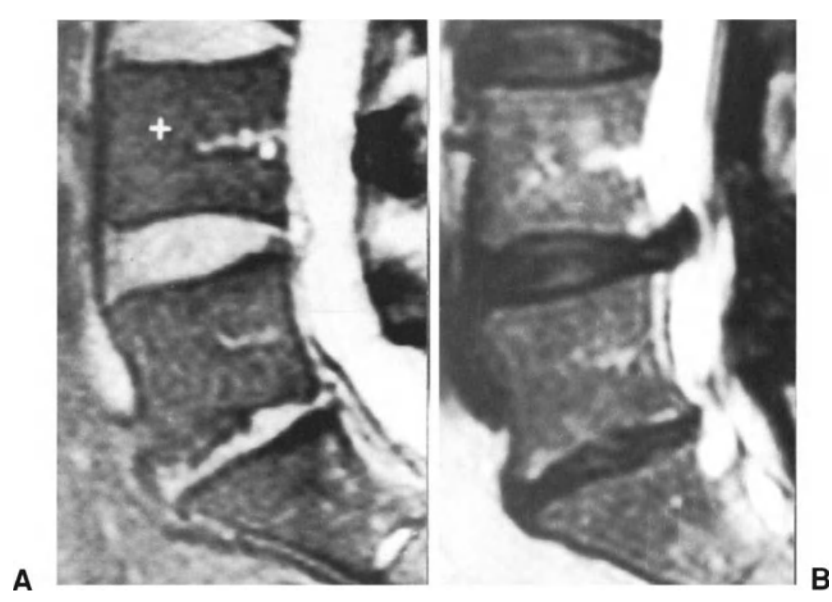

Fig. 23.5. *MR images of a patient with recurrent herniation.* (A) *Preoperative sagittal image revealing a small extruded herniation at L4-L5 level.* (B) *Sagittal image obtained 15 months after primary discectomy, showing a recurrent herniation which is larger than primary herniation.*

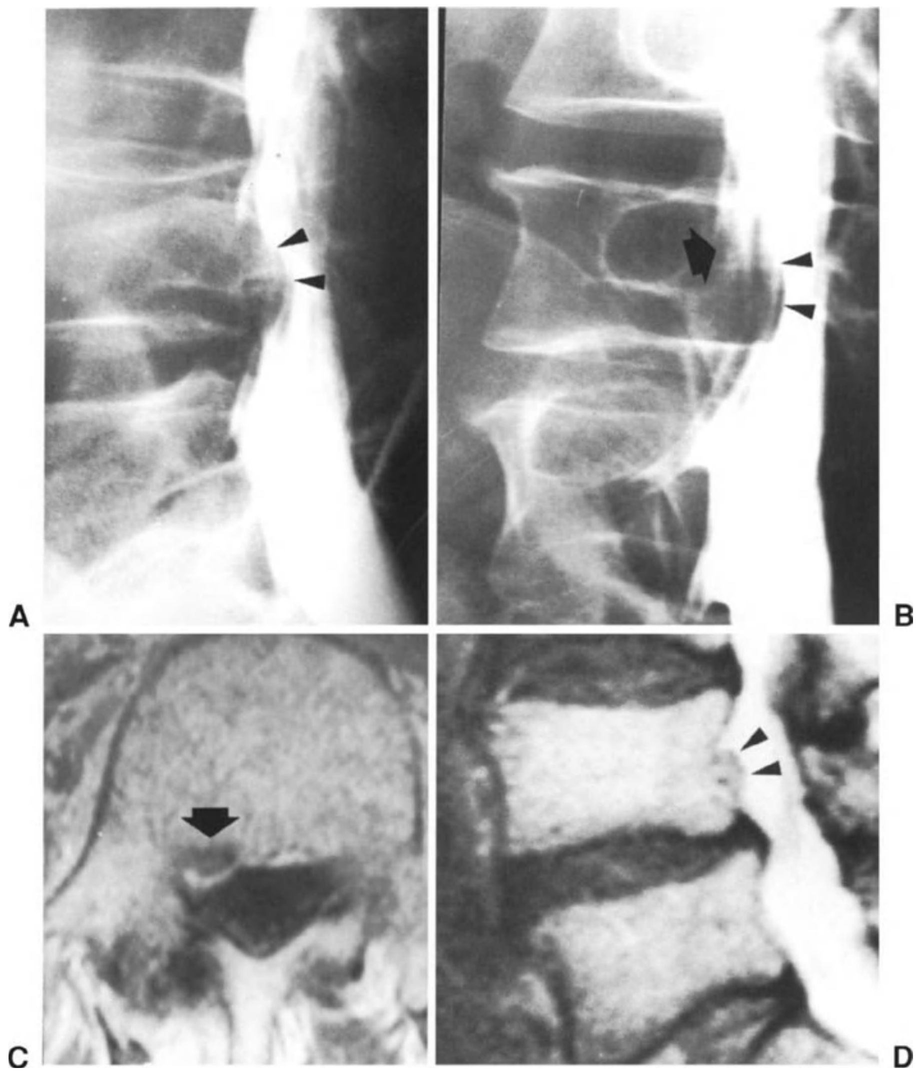

Fig. 23.6. *Myelograms and MRI scans of a patient with recurrent herniation at L4-L5 level. The myelograms obtained before primary discectomy show, on the lateral view* (A), *a large disc fragment migrated behind the L4 vertebral body (arrowheads) and, on the oblique view* (B), *amputation and trumpet-like dilation of the L4 nerve-root sleeve (arrow) and a filling defect of the thecal sac (arrowheads). MRI performed 4 years after primary discectomy shows, on axial scan* (C), *a recurrent herniation migrated cranially in the right nerve-root canal and, on sagittal scan* (D), *a small fragment migrated cranially to the L4-L5 disc (arrowheads).*

the disc (Fig. 23.3). In some of these cases, the herniated tissue may be excised without violating the disc space, which frequently contains little, if any tissue.

Usually, small herniations are contained and large herniations are extruded. Disc prolapse is usually located posterolaterally or centrolaterally. A frequent feature of recurrent herniations, particularly of the extruded type, is that their dimensions are clearly larger than primary herniations (Figs. 23.4 and 23.5).

Migrated herniations rarely occur. They are usually formed by a small fragment of fibrocartilaginous tissue or by fragments consisting entirely, or to a large extent, of cartilaginous or osteocartilaginous tissue. Like in primary herniation, the fragment may migrate cranially or caudally (Fig. 23.6); rarely is a migrated fragment found intraforaminally. Since recurrent herniations are often of large size, and due to the presence of epidural scar, penetration of the herniated tissue within the dural sac can occur more frequently than in primary herniations.

Like the tissue contained within the disc, the extruded fragment is usually of fibrous or fibrocartilaginous consistency. Sometimes, it may have intermediate characteristics between the latter and the fibrogelatinous tissue typical of primary herniation. This tends to occur more easily in early recurrent herniation, even if there is no strict correlation between the macroscopic features of the herniated tissue and the time interval from primary discectomy.

The scar tissue may adhere to the disc, the thecal sac and the emerging nerve root. The residual ligamentum flavum is often a fibrous laminar structure surrounded by scar tissue. There is no epidural fat in the spinal canal and the dura mater is covered by a thin layer of fibrous tissue and may, thus, be difficult to identify. The nervous structures can be retracted only when the thin adhesions connecting the disc, and often the posterior aspect of the vertebral bodies, to the dural sheath, have been divided. The amount of scar tissue varies, particularly in the zone located posterolaterally to the neural structures, i.e., at the site of the previous laminotomy. Instead, the amount of scar tissue located ventrally to the nervous structures does not appear to vary between subjects.

In patients submitted to microdiscectomy, the epidural scar tissue may be less abundant than in those undergoing standard discectomy, although the difference is slight and not consistent. When autogenous fat graft has been placed over the laminar defect, a thin layer of fibroadipose tissue may be observed, separating the scar tissue of the muscular layer from that covering the neural structures.

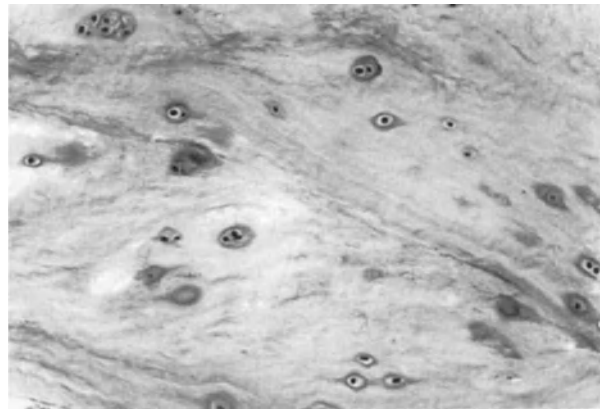

Fig. 23.7. *Histologic appearance of recurrent disc herniation. The tissue consists of few chondrocyte-like cells and intercellular matrix formed, to a large extent, by fibrous tissue (hematoxylin-eosin).*

Microscopic features

A recurrent herniation consists of few chondrocytes and rare cells with intermediate features between chondrocytes and fibrocytes, scattered in an abundant fibrous intercellular matrix (Fig. 23.7). Chondrocytes, either isolated or in clones, exhibit similar histologic and ultrastructural features to those observed in primary herniation. They are surrounded by a pericellular

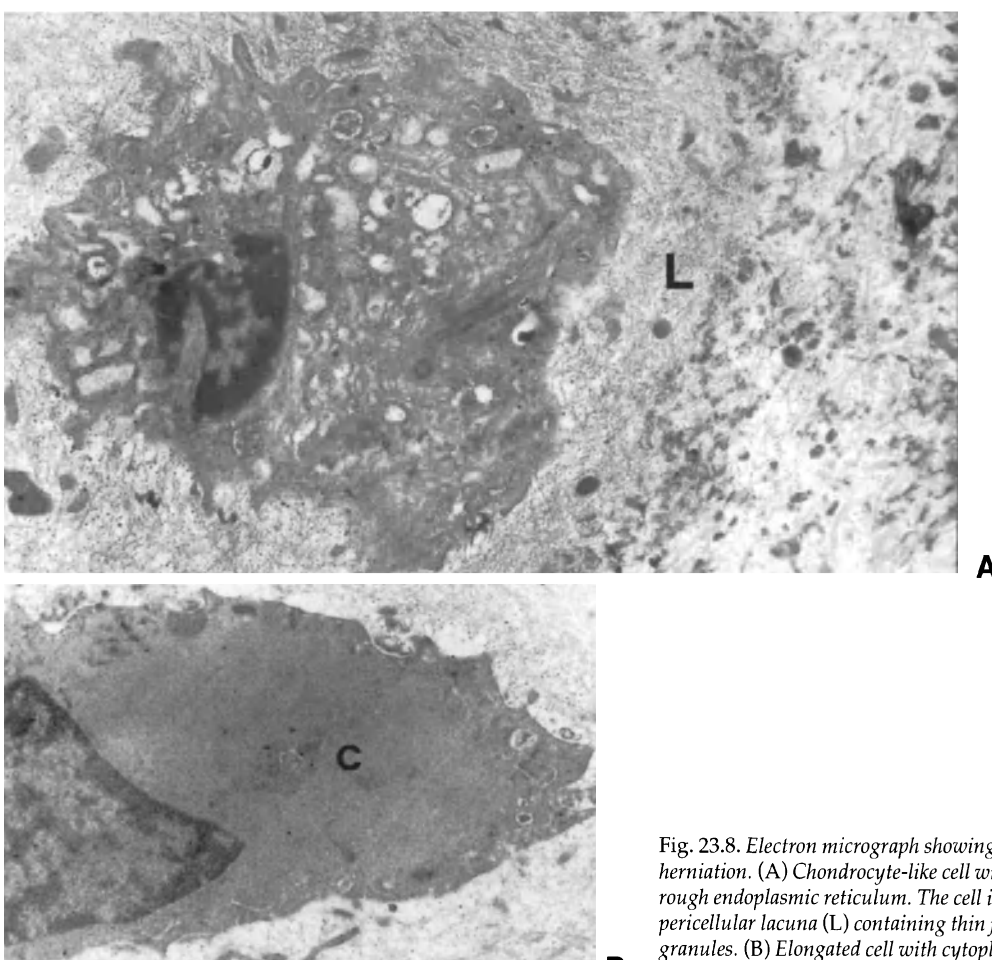

Fig. 23.8. *Electron micrograph showing two cells of recurrent disc herniation.* (A) *Chondrocyte-like cell with a moderately developed rough endoplasmic reticulum. The cell is surrounded by a large pericellular lacuna* (L) *containing thin fibrils and proteoglycan granules.* (B) *Elongated cell with cytoplasm* (C) *entirely filled with filaments. No well-defined pericellular lacuna is visible.*

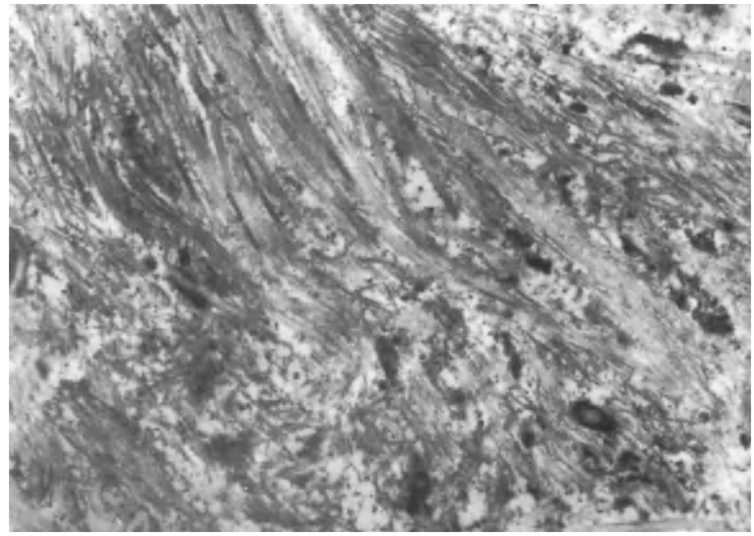

Fig. 23.9. *Electron micrograph showing extraterritorial matrix of a recurrent herniation occurred 2 years after primary discectomy. The tissue is formed by bundles of collagen fibers of medium and large size, separated by little amorphous ground substance.*

lacuna containing a dense network of thin fibrils and proteoglycan granules (Fig. 23.8 A). The fibrochondrocytes are elongated cells with no definite pericellular lacuna, showing a scallopped cell membrane and short cytoplasmic projections similar to those of chondrocytes. In some cells the cytoplasm is entirely replaced by filaments (Fig. 23.8 B). Many cells are necrotic or disintegrating.

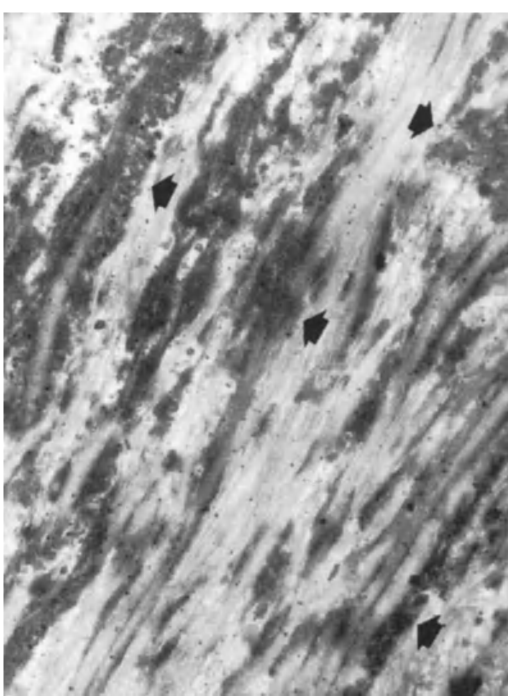

Fig. 23.10. *Extraterritorial matrix of a recurrent herniation occurred 3.5 years after discectomy in a 62-year-old patient. The tissue is formed by thick collagen fibers and numerous aggregates of electron-dense granular material (arrows).*

The intercellular matrix is formed by bundles of collagen fibers orientated in various directions and little amount of amorphous ground substance, in which proteoglycan granules are scattered (Fig. 23.9). Aggregates of electron-dense granular material may be found, at times in large amount (Fig. 23.10). The collagen fibers vary considerably in thickness, but many have large diameters. Collagen fibers are intermingled with thin fibrils, which often appear to be more numerous in proximity to the cells and where the ground substance is more abundant. Granulation tissue may be observed in some areas (48).

The main difference between primary and recurrent herniation is that, in the latter, the intercellular matrix contains a larger number of collagen fibers and a smallest amount of amorphous ground substance (48, 64). Hence, recurrent herniation consists of a more fibrous tissue compared with primary herniation. The morphologic features of early and late recurrent herniations are similar, even if, in the latter, the intercellular matrix tends to be more fibrous, the proteoglycan granules are less numerous and the electron-dense granular material less is abundant.

Clinical findings and diagnosis

In patients with recurrent herniation, radicular pain often involves the entire lower limb and is predominant with respect to low back pain. These clinical features may be of prognostic value, since in the operated patient in whom low back pain is the prevalent symptom and radicular pain is confined to the upper part of the lower limb, spontaneous resolution of symptoms is likely to occur after a few days or weeks. The pain usually presents a precise radicular distribution in the dermatome involved at the time of primary herniation. In patients with severe nerve-root compression, radicular pain increases during walking but, unlike in primary herniation, is rarely increased by coughing or sitting. Sensory disturbances are rarely reported.

Nerve-root tension tests are usually positive, even if seldom markedly. The size of the herniation and severity of nerve-root compression being equal, nerve root tension tests are usually less positive in patients with recurrent herniation compared to those with primary herniation. Likewise, a recurrent herniation often causes mild motor deficits, generally less severe than those induced by a primary herniation. Changes in reflex activity, instead, are more likely to be found in patients with recurrent herniation; usually, however, the changes (depression or absence) are not due to the recurrent herniation, but were already present before primary discectomy or were enhanced, or caused, by primary discectomy and did not recover subsequently. The most common event, which, however, is not frequent, is that a decreased reflex after primary discectomy disappears completely due to the recurrent herniation.

The fact that, in the majority of patients, the motor deficits are of mild entity and that reflex changes are of little diagnostic value, often makes the clinical diagnosis of recurrent herniation difficult. The difficulty is increased in those patients in whom the clinical presentation prior to the recurrence of symptoms is unknown. In fact, whilst in a non-operated patient the absence of an osteotendinous reflex has a definite diagnostic significance, in the operated patient this finding is of little value, particularly if it is unknown whether the reflex was normal or decreased before the recurrence of pain. This holds also for a motor deficit, such as a decreased strength of the extensor hallucis longus, which may be due either to the recurrent herniation or incomplete recovery of the motor loss caused by the primary herniation. Similarly, the clinical diagnosis of the involved vertebral level may be difficult, since it is often based only on the site of radiation of radicular pain.

Imaging studies

In the presence of recurrent lumboradicular pain, the first step in decision-making is to establish whether to perform a neuroradiologic investigation or to wait for the results of conservative treatments. In patients with moderate radicular pain of few weeks' duration and mild clinical signs of nerve-root compression, it is generally preferable to postpone the neuroradiologic studies, since in many cases a gradual regression of symptoms occurs spontaneously. In contrast, in the presence of severe radicular pain lasting 1 month or longer and/or marked motor deficits attributable to a recent disc herniation, imaging studies should be carried out.

The second step in decision-making concerns which neuroradiologic investigation is to be preferred. This decision is particularly important when the need to distinguish a recurrent herniation from epidural fibrosis is foreseen. Myelography may show a filling defect of the thecal sac and emerging nerve root, but is of little value in distinguishing a recurrent herniation from epidural scar tissue (36, 54). Numerous studies indicate that CT without intravenous contrast medium has little chance of differentiating epidural scar tissue from recurrent herniation (35, 46, 71, 77). Hence, in the operated patient, CT should be performed after administration of contrast medium. In this case, the diagnostic accuracy is high in the presence of a recurrent herniation, but decreases when only epidural scar tissue is present: in two studies (74, 78), the diagnostic accuracy was found to be 71% and 87%, respectively. In comparison, the accuracy of MRI ranged between 79% and 100% (22, 24, 34, 74). In one study, the combination of enhanced MRI and CT led to a diagnostic accuracy of 80%. The role played by gadolinium in increasing the accuracy of MRI remains to be elucidated (4). After gadolinium injection, epidural scar tissue usually shows a higher signal intensity compared with disc tissue and, hence, the posterior profile of the annulus fibrosus and emerging nerve root may be more clearly identified. In operated patients, therefore, MRI should preferably be carried out after gadolinium injection (Figs. 23.11 and 23.12). In several investigations, the diagnostic accuracy of disco-CT ranged from 80% to 94% (3, 29, 39); however, in one series, the diagnostic accuracy and specificity were 66% and 60%, respectively. Thus, the data available suggest that when a recurrent disc herniation is suspected, MRI is the diagnostic tool of choice, possibly performed with gadolinium. If the diagnosis remains uncertain after MRI, disco-CT or enhanced CT should be carried out.

Conservative treatment

The natural history of recurrent disc herniation is entirely unknown. Likewise, very little is known regarding the effectiveness of conservative management. Hakelius (31) and Naylor (56) reported that 5% and 8%, respectively, of their operated patients had complained of recurrent radicular pain which had resolved with conservative treatments. However, in both series, the diagnosis was based exclusively on the clinical evaluation.

In our experience, patients with a small recurrent herniation tend to have a spontaneous resolution of

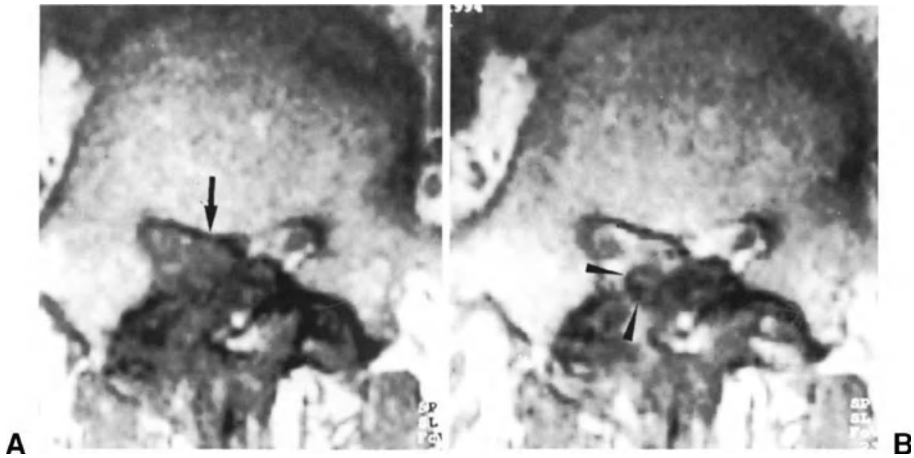

Fig. 23.11. *MRI scans of a patient with recurrent herniation at L4-L5 level, which developed 13 months after the removal of a herniation migrated caudally to the L4-L5 disc on the right.* (A) *Spin-echo T1-weighted axial image before gadolinium injection, showing tissue of uncertain origin in the epidural space (arrow) at the site of primary discectomy.* (B) *Spin-echo T1-weighted axial image after gadolinium, in which the abnormal tissue in the epidural space shows an increased signal intensity compared with pre-contrast image, except for a small fragment of tissue displacing the thecal sac posteriorly, (arrowheads). These images suggest the presence of an extruded disc fragment surrounded by abundant epidural scar tissue. This diagnosis was confirmed at surgery.*

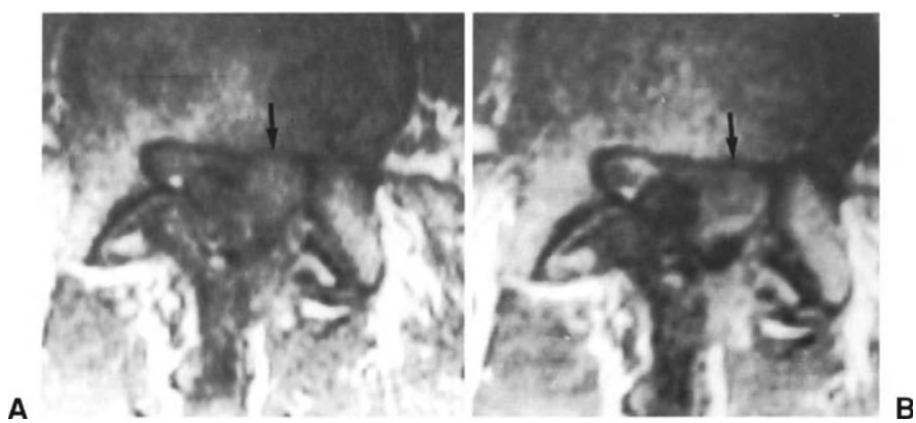

Fig. 23.12. *MR images of a patient with recurrent disc herniation at L4-L5 level 16 months after primary discectomy.* (A) *Spin-echo T1-weighted axial image before gadolinium injection. The left nerve-root canal is occupied by tissue of uncertain origin (arrow).* (B) *After administration of gadolinium, the tissue does not exhibit an increased signal intensity, but appears to be surrounded by a band of hyperintense signal (arrow). The latter indicates a fragment of disc tissue surrounded by epidural scar.*

lumboradicular symptoms, which may be hastened by conservative treatments. Hence, conservative management should be carried out for 3–6 months before operative treatment is taken into account, also because in these patients the result of surgery is unpredictable. In contrast, in patients with a medium or large recurrent herniation causing severe nerve-root compression, a complete resolution of the radicular pain is less likely to occur compared to patients with primary herniation. This is due to the intrinsic characteristics of the herniated tissue, which shows little tendency to decrease in size as a result of dehydration processes, and to the presence of epidural fibrosis, which reduces the mobility of the affected nerve root and, thus, the possibility that the root can escape compression by the herniation. In these patients, if lumboradicular symptoms remain unchanged after 1–2 months, conservative treatment should be discontinued. This holds particularly for those patients who have obtained a satisfactory result after primary discectomy and this has been followed by a long painless period, since these factors considerably increase the chances of a satisfactory outcome after reoperation.

The modalities of conservative treatment are samilar to those carried out in patients with primary herniation.

Surgical treatment

Conventional surgery

Exposure of interlaminar space

A slightly longer skin incision than that performed for a primary discectomy is carried out, in order to expose a larger portion of the proximal and distal laminae;

this usually entails an incision 8–10 cm long. The thoracolumbar fascia is divided close to the spinous processes using the diathermy blade. This may be accomplished with no risks until a depth of 3 cm is reached. The paravertebral muscles are then detached with a periosteal elevator from the residual portion of the proximal and distal laminae. If any difficulty is encountered in identifying the laminae, the dissection should be extended at a greater distance from the interlaminar space; sometimes, it may be necessary to begin the dissection from one of the adjacent interlaminar spaces and then proceed towards that exposed at the primary discectomy by following the laminar surface. Exposure of the residual laminae is essential, because they represent an anatomic structure of reference by which to identify the interlaminar space corresponding to the herniated disc and to determine the depth at which the division of the paravertebral muscles can be safely performed using the diathermy blade or the periosteal elevator. We prefer the use of the periosteal elevator in the deep portion of the muscle layer to reduce the risk of injury to the nervous structures.

While exposing the interlaminar space, the muscle layer is detached from the lamina opposite that already exposed (proximal lamina, if the distal lamina has been exposed); alternatively, the lamina is identified, and exposure of the interlaminar space is then started. Detachment of the muscle layer, which may be more or less fibrotic, should be extended to the articular processes.

Once the laminae and articular processes have been identified and partially exposed, a self-retaining retractor is positioned. We use a large Taylor retractor. Exposure of the laminae and articular processes is completed with a periosteal elevator and / or a large curette, by scraping off as much scar tissue as possible from the bone surface. Close to the previoulsy excised laminar edge, the fibrous tissue is detached with a small curette, which is then inserted ventrally to the laminar border to excise the scar tissue from the anterior aspect of the lamina.

The more abundant and dense the fibrous tissue filling the interlaminar defect after primary discectomy, the more demanding the exposure of the interlaminar space. The longitudinal extent of the previous exposure is important in this regard, since a wide exposure implies that scar tissue is present also in the interlaminar spaces adjacent to that exposed at primary discectomy. This makes more difficult the identification of the laminae delimiting the interlaminar space to be explored and increases the risk of operating at a wrong level. The level where the scar tissue is more abundant and adherent to the bone is likely to be the previously explored level. However, if any doubt persists, a fluoroscopic control should be carried out.

When, at the previous operation, a total laminectomy (cranial or caudal) or a central laminectomy has been carried out, detachment of the muscle layer has to be deepened until the posterior border of the articular processes can be palpated. The latter need to be clearly exposed, since they represent the only bony structure of reference to determine the depth at which the spinal canal is located.

Laminoarthrectomy

It is usually advisable to widen the previous laminotomy proximally and distally before starting arthrectomy. However, in some cases, it may be preferable to start with the arthrectomy and then proceed with the laminotomy. This holds particularly when the lamina is thick or shows an abnormally ventral direction, or when it is difficult to detach the scar tissue from the anterior border of the lamina. Usually, laminotomy and, particularly, arthrectomy, are initiated with a small Kerrison rounger and then continued with a medium or large rongeur, until an adequate space has been created between the bony surface and the scar tissue filling the interlaminar defect. Arthrectomy should be performed very carefully, since, having already excised the medial portion of the facet joint at primary discectomy, total arthrectomy is more likely to occur inadvertently. On the other hand, disc excision cannot usually be performed without removing at least one fourth or one third of the residual facets. Only in this case, in fact, can the vertebral canal be entered laterally to the nervous structures and at a zone where the scar tissue is less abundant and, thus, the disc more easily identifiable.

One of the most common errors in this phase is to start the arthrectomy too far laterally and superficially; this may occur due to the fear of injuring the thecal sac or when the superior articular process has been mistaken for the proximal lamina. Such a mistake may considerably prolong surgery and lead to a too wide, or even total, arthrectomy. The error may be avoided by wider exposure of the laminae and articular processes, reaching, if necessary, their outer border. Conversely, this mistake is likely to occur when laminoarthrectomy is started before adequate exposure and identification of the bony structures.

Discectomy

Once the laminoarthrectomy has been widened, the soft tissues present in the interlaminar space are retracted medially. Usually, the nervous structures are not recognizable, since they are covered by scar tissue and the residues of the ligamentum flavum. In this phase, it is not essential to identify the emerging nerve root or the thecal sac, but it is sufficient to medially retract the tissue until the intervertebral disc has been exposed. As at primary discectomy, retraction of the neural structures has to be made at the proximal portion of the interlaminar space, since the disc is usually located at this site. Retraction should be rather vigorous to dissect the scar tissue from the ventral aspect of the vertebral canal. On the other hand, there is no great risk of damaging the nervous structures since these are protected by the scar tissue.

Identification of the intervertebral disc is more demanding compared with primary discectomy due to the presence of adhesions covering the disc and the adjacent vertebrae. Dissection should be gentle and careful to avoid injuries to the dural sac or the dural sleeve of the radicular nerve, which frequently occur at this phase. The intervertebral disc may be identified by its soft consistency with respect to the adjacent vertebrae. To confirm this, a ventral pressure may be exerted with a thin dissector, until the disc space is entered.

Subsequently, an adequate portion of the disc is exposed until the posterior annulus fibrosus can be incised with a scalpel or a tenotome. Usually, it is advisable to penetrate into the disc with a small pituitary rounger to widen the annular fenestration, thus allowing use of a medium-sized pituitary rounger later. Once the disc tissue has been removed, a Frazier probe is introduced between the thecal sac and the posterior aspect of the annulus fibrosus in order to weaken, and then remove, disc fragments located in the midline. After complete discectomy has been carried out, migrated fragments are sought if they had not already been removed before disc excision.

Microdiscectomy

Use of the operating microscope is more demanding for reoperations than for primary surgery due to the greater difficulties in identifying the anatomic structures. Thus, reoperation with the microscope should be carried out only by a surgeon who is well trained in microdiscectomy. When the surgeon is accustomed to operating with the microscope, discectomy is more easily accomplished than with the naked eye and there are fewer risks of damaging the nervous structures and missing, or removing only partly, migrated disc fragments. Furthermore, the microscope usually allows a smaller portion of the facets to be excised than with the naked eye, thus reducing the risks of postoperative spinal instability. It may be preferable to use the microscope only when the entire, or a large part, of the laminoarticular layer has been exposed through a slightly longer skin incision (3–4 cm) than that made for a primary microdiscectomy. The operation is carried out with the same modalities as repeat surgery with the naked eye.

Arthrodesis

Some surgeons often perform spinal fusion in patients operated on for recurrent herniation and almost invariably in those with a second recurrent herniation. Other surgeons never carry out fusion. The rationale of spinal fusion is to eliminate the risk of another recurrence and relieve low back pain, which tends to be more severe after a reoperation than following primary discectomy.

We rarely perform a fusion, since the incidence of a second or third recurrence is extremely low. On the other hand, fusion may facilitate or accelerate degenerative changes, and thus even a new herniation, in the discs adjacent to the fused area. Moreover, after reoperation, the majority of patients complain of mild low back pain, which usually does not require any specific treament. The lower morbidity and the more rapid functional recovery after discectomy alone versus discectomy plus fusion should also be taken into consideration in this decision-making.

Spinal arthrodesis may be indicated in patients complaining of severe low back pain before primary discectomy and / or reoperation. In these cases, MRI should be carried out before repeat surgery. If the disc above and / or below the recurrent herniation show no degenerative changes, there are no contraindications to perform a fusion; however, if this is not the case, the usefulness of extending the fused area to an adjacent degenerated level should be carefully evaluated. When MRI shows degenerative changes of more than one of the adjacent discs, fusion is usually contraindicated.

Complications

Dural tears are the most frequent complication and have been found to occur in 8% (44) to 17.4% (76) of patients submitted to reoperation for recurrent herniations or other spinal conditions. The higher frequency of this complication during repeat surgery compared with primary discectomy is due to the adhesions between the thecal sac and the posterior annulus or between the former and the scar tissue present in the epidural space. The injury usually occurs in the attempts at exposing the posterior aspect of the annulus fibrosus or while retracting the thecal sac and the emerging nerve root during disc excision. Hence, the dural injury is often located in the anterolateral or anterior portion of the thecal sac. In this event, direct repair of the lesion may be highly demanding or even impossible.

Table 23.3. Satisfactory results in patients treated operatively for recurrent or new herniation.

Author	No. of patients	Satisfactory results (%)
Greenwood 1952 (28)	17	100 (1)[a]
Fontanesi 1966 (23)	15	73 (1)
Epstein 1967 (16)	47	80 (3)
Finnegan 1979 (21)	13	92 (3?)
Martin 1980 (52)	18	78 (2)
Zerbi 1980 (86)	14	71 (2)
Hardy 1982 (33)	27	77 (3?)
Ebeling 1989 (13)	42	82 (2)
O'Sullivan 1990 (60)	34	64 (2)
Connolly 1992 (10)	19	80 (3)
Kim 1992 (44)	9	77 (2)
Jönsson 1993 (40)	19	80 (3?)

[a] 1: Series including only recurrent herniation. 2: Series including recurrent and contralateral herniation. 3 : Series including recurrent and contralateral herniation and herniation at a new level. ?: Site of herniation not clearly reported.

The incidence of other complications seems to be similar to that found after primary discectomy. However, two permanent motor deficits of the L5 nerve root occurred in a series of 76 reoperations for recurrent or new herniations (60).

Results

The proportion of satisfactory results after repeat discectomy is not well established, since in the vast majority of studies, patients with recurrent herniation have been evaluated together with those presenting contralateral herniation or herniation at a new level (Table 23.3). In numerous series the proportion of satisfactory outcomes ranged between 77% and 82% (10, 13, 16, 33, 40, 44, 52). Finnegan et al. (21) reported 92% of satisfactory results in patients with recurrent or new herniation. In contrast, in one study (60), only 64% of patients reoperated on at the same level (recurrent or contralateral herniation) achieved satisfactory results. Greenwood (28) noted that none of the 17 patients submitted to reoperation for recurrent herniation reported an unsatisfactory outcome.

Two factors seem to play a role in predicting the surgical outcome: the quality of the result obtained after primary discectomy, and the preoperative diagnosis and/or the intraoperative findings. The patients who report satisfactory results after primary discectomy (or previous discectomy) have high chances of obtaining good results after reoperation (13, 60), However, the quality of the result tends to be slightly worse after reoperation, i.e., the proportion of excellent and good outcomes compares unfavorably with that achieved after primary discectomy. This may be due to persistence of low back pain and/or radicular symptoms (pain, paresthesias, cramps) in a higher proportion of patients than after primary discectomy. The frequency of residual motor deficits, or their severity, does not seem to be higher than after primary discectomy. A preoperative diagnosis, and/or an intraoperative finding, of small recurrent herniation and epidural fibrosis are more frequently associated with unsatisfactory results than the finding of medium-sized or large herniation. An unsatisfactory result is more likely to occur when the time interval between primary discectomy and reoperation is less than 1 year; however, this correlation is probably less evident in patients with recurrent herniation than in those with a surgical failure. As in patients undergoing primary discectomy, the presence of pending litigations or working compensation claims decreases the chance of a satisfactory outcome (21, 83).

In patients submitted to three or more discectomies, the chances of obtaining a satisfactory result appear to be inversely related to the number of previous operations.

Contralateral herniation at the operated level

Compared with recurrent and new herniations, this is the most rare condition. Contralateral herniation often occurs a few years after primary discectomy. Usually, at the time of the previous disc excision, the involved disc showed no protrusion on the opposite side. In other cases, a contralateral herniation develops within 2 years of primary discectomy, in discs showing, at the time of previous surgery, a slight protrusion or, occasionally, a midline disc herniation on the opposite side. Often the spinal canal or nerve-root canal are constitutionally narrow. Usually, the contralateral herniation is contained or extruded; a migrated disc fragment is seldom present (Figs. 23.13 and 23.14). In the majority of cases, the herniation is posterolateral or paramedian, whereas an extraforaminal herniation is extremely rare (55).

The clinical presentation does not differ from that of primary herniation. The patient usually complains of unilateral radicular symptoms. In the presence of a midline or paramedian herniation, there may be radicular signs and symptoms on the opposite side.

Two issues may arise when planning the surgical treatment: whether the disc has to be explored on the side of primary discectomy and whether spinal fusion should be associated to disc excision. There are no reasons for exploring the disc on the side of primary discectomy, unless radicular symptoms or severe, but asymptomatic, compression of the nerve structures are present, which may not be eliminated by disc excision on the virgin side. Exposure of the site of the primary

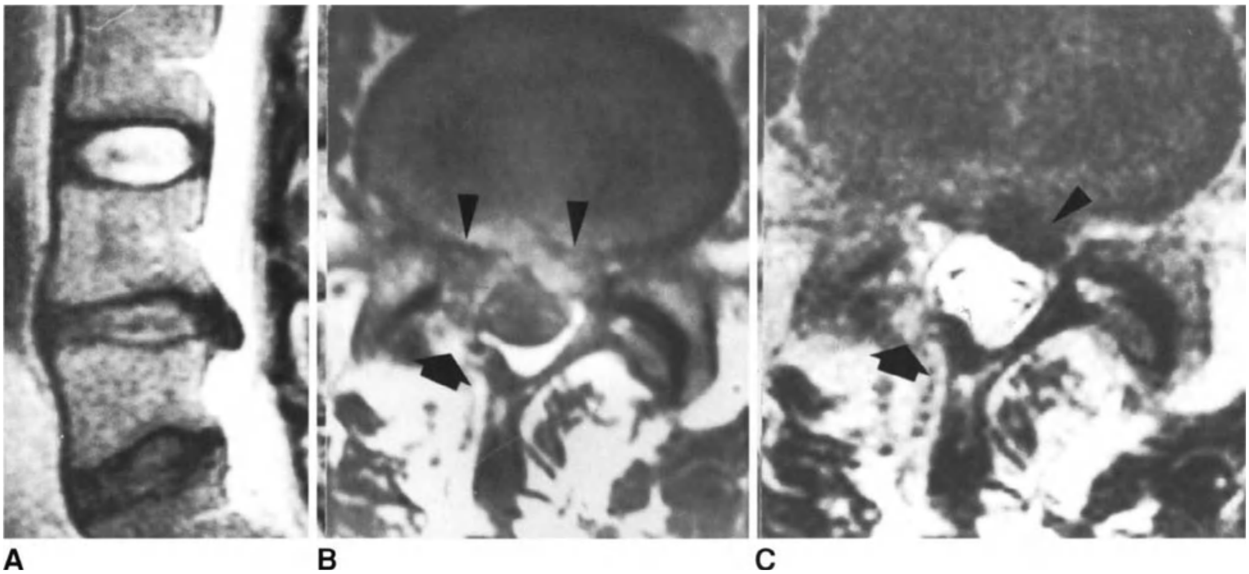

Fig. 23.13. *Contralateral herniation at the operated level. MRI sequences obtained 4 years after primary discectomy.* (A) *Spin-echo T2-weighted sagittal image showing an extruded herniation at L4-L5 level.* (B) *Spin-echo T1-weighted axial image, which reveals the previous laminotomy on the right side (arrow) and tissue occupying the radicular canal on both sides (arrowheads).* (C) *Spin-echo T2-weighted axial image showing, in the left radicular canal, abnormal tissue (arrowhead), with a signal intensity similar to that of the disc. The arrow indicates the previous laminotomy.*

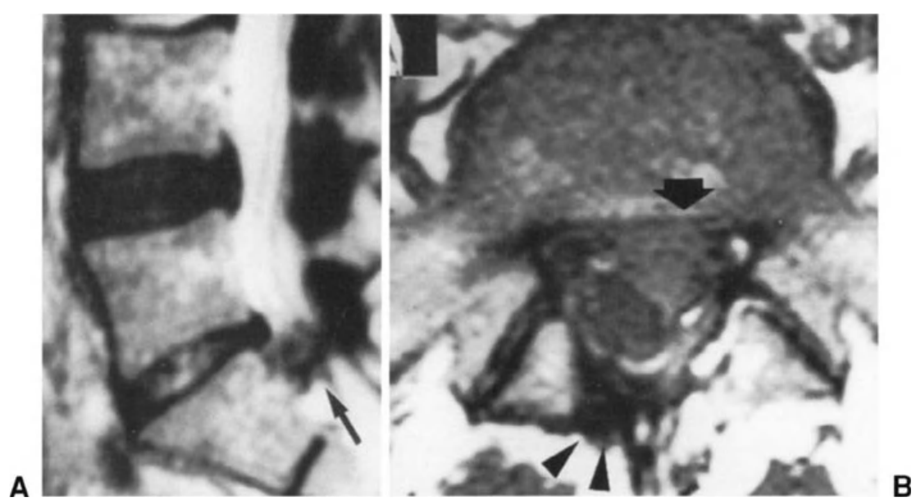

Fig. 23.14. *Contralateral herniation at the operated level. MRI sequences obtained 8 years after primary discectomy.* (A) *Spin-echo T2-weighted sagittal image depicting a disc herniation migrated caudally to the L5-S1 disc (arrow).* (B) *Spin-echo T1-weighted axial image revealing the previous laminotomy on the right (arrowheads) and a large disc herniation on the left (arrow).*

discectomy should be avoided, unless strictly necessary, in order to limit the risk of increasing postoperative instability, since a reoperation on the operated side implies widening of the previous arthrectomy. The indication for fusion may be absolute or relative. The indication is absolute in the presence of segmental hypermobility on flexion-extension radiographs. Relative indications are: a wide arthrectomy on the side of previous disc excision; a potential instability (spondylolysis, spondylolisthesis, scoliosis) of the affected vertebral motion segment; and severe low back pain. In these cases, the decision should be based on the evaluation of various factors, such as the patients's age, the presence of degenerative changes at the adjacent vertebral levels, and the affected vertebral level (chapter 20). If, as usually occurs, fusion is not planned, care should be taken to avoid an extensive arthrectomy on the side of new herniation.

Some authors (16, 23) found satisfactory outcomes in all patients submitted to discectomy for contralateral herniation, whilst others obtained unsatisfactory results in patients undergoing bilateral disc excision (49). In the authors' experience, the surgical results are comparable to those achieved by patients undergoing primary discectomy, provided no postoperative instability has been produced.

Herniation at a new level

Herniation tends to occur at the level above the previously operated disc (13, 53), particularly when the latter is the L5-S1 disc (60). This may be due to the increased mechanical stresses occurring at the level above as a result of the decreased mobility of the operated disc, caused by reduction in height and / or loss of normal anatomic structure produced by discectomy.

At the time of primary disc excision, the disc where the new herniation has developed, might show no prolapse or it might already exhibit herniation. With the advent of CT and MRI, it has been shown that many patients have a herniated disc at two or more levels. Usually, only one of the herniations causes symptomatic nerve-root compression and disc excision is performed only at this level. However, very little is known on the evolution of the non-excised herniation and the frequency with which it increases in size and / or changes its pattern (e.g., from contained to extruded), becoming symptomatic. On the other hand, no study has so far established whether, at the time of primary discectomy, the disc where the new herniation develops was normal, degenerated or herniated. In the series of Ebeling et al. (13), seven of the 14 patients with herniations at a new level underwent surgery within 1 year of primary discectomy, but the authors provide no information on the features of the disc where the new herniation had occurred or on the size of the spinal canal (normal, narrow or stenotic) at the time of primary discectomy.

Between 1988 and 1995, we operated on 12 patients with disc herniation at a new level. The previous discectomy had been performed 2 to 19 years earlier (mean 10.6 years). In 10 cases, we were able to analyze the neuroradiologic investigations performed prior to primary discectomy. Only two patients, who underwent repeat surgery 2 and 4 years, respectively, after primary disc excision, showed, at the time of primary discectomy, a disc prolapse at the level at which the new herniation had occurred. Moreover, none of the patients submitted to primary discectomy between 1990 and 1995, in whom CT or MRI studies showed a second herniated disc in addition to the symptomatic herniation, was treated operatively for herniation at a new level. These findings indicate that herniation of a different disc from that responsible for radicular symptoms may already be present at the time of primary discectomy; however, in the vast majority of cases, the herniation at a new level occurs in a subsequent period with respect to primary discectomy, in discs which were normal or only degenerated at the time of primary surgery (Fig. 23.15).

Clinical presentation and diagnosis

The clinical picture does not differ from that of a primary herniation. However, the diagnosis of level may be difficult when the new herniation is on the same side as the primary herniation, particularly if at the level above. In these cases, in fact, radicular symptoms may mimic those of a recurrent herniation. Furthermore, at the previously operated level, a small disc prolapse may be present, which makes it difficult to establish whether the symptoms are due to a recurrent herniation in the presence of a concomitant asymptomatic herniation at the level above, or to a symptomatic herniation at a new level. On the other hand, the clinical diagnosis may be demanding, due to the presence of residual neurologic deficits after the primary operation.

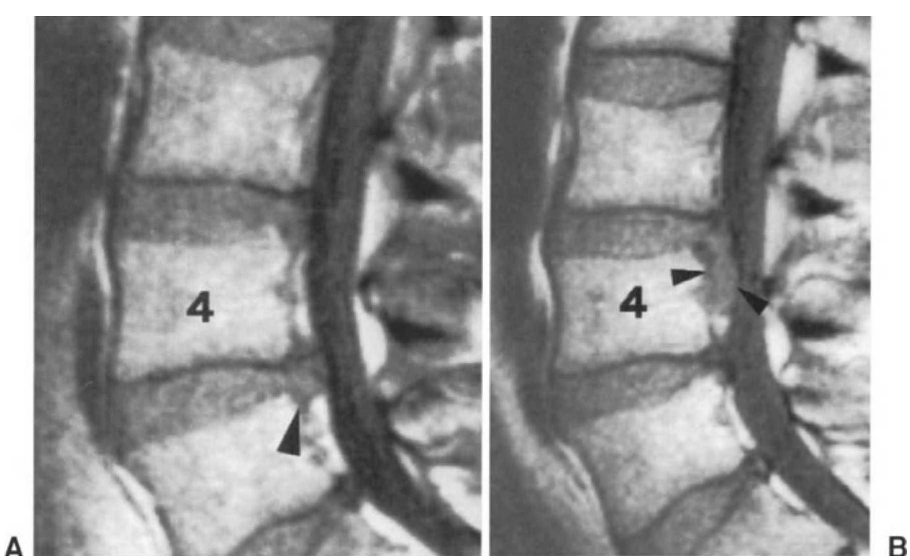

Fig. 23.15. *MRI scans of a patient with disc herniation at a new level.* (A) *Spin-echo T1-weighted sagittal image obtained before primary discectomy, showing disc herniation at L4-L5 level (arrowhead).* (B) *Spin-echo T1-weighted sagittal image 3 years after discectomy, revealing a disc fragment migrated caudally to the L3-L4 disc (arrowheads).*

When diagnostic doubts persist after CT and MRI studies, it may be useful to perform discography at the site of the new herniation or even of the previously operated disc, with the aim of provoking the patient's lumboradicular symptoms. If the doubt is not resolved by discography and surgical treatment is planned, both discs should be excised to be certain that the herniation responsible for the patient's symptoms is removed.

Surgical treatment

Surgical treatment is not different from that performed for a primary herniation when the new herniation is at a non-adjacent level to the previously operated disc. When the new herniation is at a level adjacent to the primary herniation and on the same side, and previous discectomy was carried out using a conventional technique, with partial exposure of the adjacent interlaminar spaces, the laminae and ligamentum flavum, at the new level, are usually covered by scar tissue. This may not be the case if primary discectomy was performed by microsurgical technique and only the involved level was exposed. The scar tissue needs to be carefully detached with a periosteal elevator from the laminae at the new intervertebral level. There are no risks in performing this procedure if less than half of the proximal lamina was excised at primary discectomy (caudal lamina, at second discectomy). This may be determined preoperatively on the anteroposterior radiograph of the lumbar spine. Excision of the scar tissue adhering to the ligamentum flavum may be completed with a medium-sized curette. However, in many cases, it may be difficult to expose the ligamentous tissue. At this phase, the operating microscope may be used. Then, the ligamentum flavum and scar tissue covering the proximal and distal lamina are detached, as in primary surgery.

If subtotal removal of the proximal lamina was carried out at primary discectomy, detachment of the scar tissue covering the lamina is more difficult and care should be taken not to fracture the residual portion of the lamina or enter the interlaminar space above. When the proximal lamina was entirely excised, the articular processes should be carefully exposed and bone excision started from the proximal lamina and the medial border of the articular processes.

In a few series (13, 49, 60), the results of surgery for disc herniation at a new level compare unfavorably with those achieved after primary discectomy and with those reported for recurrent herniations (including recurrent herniations and contralateral herniations at the same level in our classification). In our experience, the proportion of satisfactory results is similar to that obtained after primary discectomy. The results of two recent investigations (18, 44) are in keeping with our findings. Nevertheless, it should be pointed out that excellent results are less likely to occur after discectomy at a new level than following primary discectomy. This is generally due to the greater severity of postoperative low back pain.

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·CHAPTER 24·

PROFESSIONAL LIABILITY IN TREATMENT

F. Postacchini, G. Martini

Principles of legal medicine

The physician's liability for damages in conservative or surgical treatment may be postulated when the result of his/her activity is the persistence or aggravation of a pre-existing disease, or the onset of new symptoms. Two aspects need to be distinguished: lack of result and incorrect behavior. The lack of result consists in an incomplete resolution, persistence or reappearance with time, of the pathologic condition and/or the clinical impairment present prior to treatment. The lack may be due not only to the physician's intervention, but also to numerous factors of a biological nature, which may cause complications for which the physician cannot be considered responsible. The error may be caused by an inadequate approach to the therapeutic problem due to failure to diagnose or improper diagnosis, incomplete execution of treatment, or inducement of lesions responsible for new clinical symptomatology.

A causal relationship must be identified, from a medicolegal viewpoint, in the presence of treatment failure or complications during treatment. This relationship is the factor that binds the observed effect to the suspected cause, which must be pertinent for quality, quantity, duration and mode. Furthermore, other principles of legal medicine, which play a key role in the evaluation of the physician's behavior and the results of his conduct, must be borne in mind.

The physician has a duty to provide proper care and not just to obtain a result. He/she may be accused of omission or improper action, concerning diagnosis or treatment, but in the presence of a professionally correct behavior he/she cannot be held responsible for the outcome of these actions. The quality of the result, in fact, depends on numerous biological factors, which are not directly dependent on the professional ability of the physician (1, 2).

A behavioral defect is not liable to punishment when direct damage deriving from this behavior cannot be demonstrated.

Damage suffered by a patient may be of a biological or financial nature. Damage to a person caused by insufficient or erroneous treatment must be considered an increased damage; its medicolegal evaluation must be carried out separately from the damage produced by the initial disease, for which, the physician is obviously not responsible. Financial damage which is often at the center of legal contention, is of three kinds: damage related to the prolongation of transitory physical disability caused by the initial disease, which was not treated by the physician as effectively as expected; damage due to the financial burden sustained by the patient for an ineffective blameworthy treatment; and damage caused by further treatment expenses, which the persistence or aggravation of the clinical condition have made necessary. Further damage, even more difficult to determine, is correlated to the pain suffered by the patient during ineffective treatment ("pretium doloris"); this damage is very theoretical and difficult to evaluate, since it is strictly related to the sensitivity and affectivity of each individual (10).

The degree of professional liability is related to the difficulty of the clinical case and the cultural and technical ability of the physician. It is the physician's duty to diligently maintain an adequate level of scientific updating, to prudently evaluate new scientific acquisitions and to skilfully express them as effective diagnostic and therapeutic actions (20, 21).

Omissions or underestimations made in an attempt to conceal responsibilities may constitute fraudulent behavior. This is the worst offence that a physician may commit in his profession (16).

Clinical documentation

Layout of a medical document which reports all phases of the diagnostic evaluation and treatment is compulsory for all physicians involved in patient management.

The attending physician or the physician on duty is responsible for accurately filling out the hospital chart, which is of considerable importance from a medicolegal point of view, since it represents a document under the seal of a public officer and thus legally probative. The chart represents a document which contains all clinical information pertaining to the disease and evidence both of physicians' actions and biological reactions of the patient to treatment (1).

The hospital chart is characterized by a few formal and substantial elements; in the event of lack or alteration of these components, the physician may be charged with default of official deeds or corruption of evidence, which constitute a criminal offence (15). A hospital chart should possess the following characteristics: completeness, contemporaneity, conclusiveness and consistency. Diagnostic and therapeutic procedures must be documented clearly and exhaustively to avoid errors in interpretation; this refers, in particular, to the physical examination, the description of the possible surgical procedure and the characteristics of the postoperative course. The clinical event should be reported at the same time as it occurs; subsequent annotations and corrections may be interpreted as fraud to an official document. Each single diagnostic and therapeutic event should be reported in a definite manner, without taking into consideration subsequent elements occurring with time; annotations should be clinically coherent and with no omissions or inconsistencies, in order to illustrate progress of the disease in a continuous and sequential manner.

Information and consent

The doctrine of informed consent holds that the patient must be reasonably informed on the nature and possible results of therapy in order to give total consent to treatment (2, 8, 10, 20). Information and consent, therefore, represent a prerequisite to treatment. This is particularly appropriate for patients, such as those with disc herniation or associated diseases, in whom invasive treatments are generally not carried out in an emergency.

The first level of information concerns quality and entity of the diagnosed or suspected disease and the possibilities of spontaneous regression, persistence or aggravation of symptomatology.

The second level of information concerns the therapeutic ability of the various treatments available and, when surgery is indicated, the relative techniques, common complications, likelihood of resolving symptoms and possible co-operation of the patient in the postoperative period.

The patient is generally not able to understand technical details of invasive treatments. However, he/she is certainly able to comprehend the general modalities of surgical treatment, and the differences between the various techniques, such as microdiscectomy and traditional surgery, chemonucleolysis and percutaneous nucleotomy.

It is not strictly necessary to tell the patient the generic risks of invasive treatment such as those of routine anesthesia. Information must, instead, concern specific risks involved in a specific surgical procedure, such as, for instance, the possibility of allergic reactions in chemonucleolysis. Furthermore, the patient must be fully informed of the use of non-consolidated techniques or means, in order to evaluate possible advantages.

Possible complications may be the subject of generic information, particularly in the case of atypical and extraordinary events, and as such, not foreseeable. The ability of the proposed treatment to cure the disease or resolve the symptoms should be clearly outlined, at least as far as concerns treatments with a relatively high probability of failure; this applies, for example, to percutaneous techniques or to spinal fusion carried out to relieve chronic low back pain. It is necessary for the patient to clearly understand the difficulty and the likelihood of complications and failures involved in the treatment. This is necessary to avoid disappointment caused by unforeseen poor results which, as such, may be more easily attributed to inadequate or incorrect treatment.

Consent to treatment is a voluntary act, which requires evaluation of opportunity by subjects with legal and mental capabilities, based on a precise knowledge on the matter on which the subject is called to express a choice and on events to which the subject accepts to be submitted. Consent (or lack of consent) should be given by the patient preferably in writing. This consent is formal as well as substantial, and must be free and spontaneous, devoid of any imposition, contemporary (i.e., exclusively referred to the moment of treatment), revocable and informed.

Diagnostic evaluation

Clinical data

Clinical evaluation of patients with a lumboradicular syndrome is based on the analysis of the site, severity and duration of symptoms and of neurologic deficits. The inductive procedure which, by means of these elements, allows identification of the pathologic changes is definitely an essential factor in the cultural preparation of a specialist. The most frequent cause of diagnostic errors is a defect in the inductive procedure or failure to detect the alterations which lead to a pathologic condition different from that suspected. While collecting the clinical history, skill and caution should be employed not to underestimate apparently insignificant details and to search for their significance with clinical examination and diagnostic investigations, which may require consulting other specialists. Various conditions, in fact, may simulate or aggravate a lumboradicular syndrome and lead to errors entailing negligence, which is in proportion to the severity of clinical consequences. Request for expert advise is a useful complement to avoid diagnostic errors in the presence of clinical syndromes of uncertain interpretation.

Diagnostic tests

These provide necessary confirmation to diagnosis based on the clinical features or confirm the diagnostic suspicion emerging from the clinical data. The number of diagnostic tests which should be carried out is a frequent subject of discussion in legal medicine, since their role is often emphasized with respect to the clinical data. In actual fact, clinical features should determine the indication for diagnostic tests, which should have a precise aim and a clinically logical sequence. All tests may be theoretically useful or indispensable in patients with suspected disc herniation. However, a few examinations have precedence over others due to their diagnostic abilities, simplicity of execution or availability of equipment.

Plain radiographs are of limited diagnostic value, but may be useful in the choice of subsequent investigations. A radiographic examination should be carried out when CT and MRI are not completely in keeping with the clinical features. Furthermore, it should precede other imaging studies in patients who have already undergone surgery for lumbar conditions, since the correct interpretation of these studies may be influenced by the radiographic findings.

CT has become a currently used test in patients with suspected disc herniation on account of its high diagnostic value, simple execution and low cost. MRI is often more diagnostic than CT, but it also has limitations, which may provide it with a lower diagnostic ability than CT or myelography. CT and MRI are currently the examinations of choice in the diagnosis of lumbar conditions, and at least one of the two should be carried out in patients with a herniated disc requiring surgical treatment.

Myelography, being an invasive procedure, should be carried out when CT and/or MRI provide ambiguous findings. This investigation, however, is of high diagnostic value and, with the hydrosoluble contrast media currently used, does not expose the patient to a significant risk of complications. From a medicolegal viewpoint, therefore, its use is completely justified, even as a substitute to CT or MRI, if the clinician considers the test necessary and the patient is informed of the possible side effects caused by the contrast media.

Electromyography may document functional impairment of the nerve roots compressed by disc herniation or related pathologic conditions. However, this test may be of little value in the diagnosis of a herniated disc, because either an accurate clinical examination frequently provides adequate information on nerve-root function or the test does not allow diagnosis of the nature, and often the anatomic site, of the condition responsible for radiculopathy. Electromyography is particularly useful to differentiate radiculopathy from peripheral neuropathy. Furthermore, it may be useful, in the presence of severe radicular impairment, to document what has been found on clinical examination.

Blood tests are usually of little or no usefulness in the diagnostic evaluation of patients with a suspect herniated disc. These tests may be useful or necessary in the differential diagnosis with inflammatory, neoplastic or infectious conditions, which may simulate a herniated disc syndrome.

Numerous other tests may be considered useful or necessary by the surgeon or his consultants in order to reach an accurate diagnosis. However, all examinations, in particular invasive procedures must be carried out on the basis of a well-founded clinical suspicion.

In consideration of the increasing number of diagnostic tests provided by medical science to the clinician, a legitimate question arises: which examinations should be considered necessary and sufficient from a medicolegal viewpoint? There is no answer to this question, since the multitude of clinical situations does not allow us to establish a basic protocol, which may exempt the physician from the accusation of failure to diagnose or incorrect diagnosis. In the identification of the causes of clinical signs and symptoms, it is the physician's duty to reach a level of reasonable certainty, which is closely related to the diagnostic difficulties in each single case.

Failed or incorrect diagnosis

These generally stem from defective or erroneous interpretation of the clinical findings and/or diagnostic tests.

A clinician may make an incorrect or incomplete diagnosis due to inadequate cultural or technical preparation, lack of updating, negligence in patient evaluation or an incorrect interpretation of clinical and laboratory findings. Both the patient and the specialist who carries out the laboratory tests may have a responsibility in the diagnostic error. The former may report an incorrect, incomplete or confusing medical history. The latter may draw up an incorrect or inadequate report, due to omissions or partial information, which may lead astray or be insufficient to answer the question raised. In this case, the error must also be attributed to the specialist who carried out the diagnostic tests. However, the clinician is required to have the necessary cultural preparation to interpret and evaluate himself currently used tests such as plain radiographs, CT, MRI or myelography. The clinician, therefore, may not be excused, or may be only partially excused, when his/her mistake derives from an incorrect interpretation, by the specialist, of currently used investigations.

Professional liability

In the event of a diagnostic error, various important situations may occur as far as professional liability is concerned:

1. Prior to surgery, examinations currently considered sufficient for diagnostic purposes, have been carried out; diagnosis was orientated towards a pathologic condition, which justified signs and symptoms, but subsequently was seen not to be responsible for the clinical picture. The clinician is not liable for damage if the clinical picture did not generate any definite suspicion that diagnosis was erroneous. Likewise, if the pathologic condition presented a particular and atypical diagnostic difficulty, the error may be due to the limitations of current scientific knowledge, rather than the actions of the physician.

2. Diagnosis is made intraoperatively and treatment led to a significant, but not total, improvement to the patient. In this case, there is no professional error, since the patient did not experience any damage.

3. Erroneous or incomplete diagnosis is due to the fact that the necessary diagnostic tests were not carried out. The physician is liable, due to negligence, if he/she did not use the available diagnostic procedures or ignored or underestimated the indication to carry out further tests. The non-availability of adequate diagnostic equipment where the patient is hospitalized may not be used as an excuse in the presence of a sound clinical suspicion, since, in this case, the physician must transfer the patient to another hospital where the necessary examinations can be carried out.

4. The physician does not detect a pathologic condition (such as spondylolisthesis) associated to disc herniation and treatment leads to worsening of the associated pathology. The clinician is liable for damage if the concomitant disease, even if of mild severity, was apparent from diagnostic examinations carried out prior to surgery. On the other hand, the physician is not liable if the associated condition was detected, but not treated concomitantly with the herniation; in this case, however, the physician must have previously informed the patient on the reasons, albeit questionable, which led to the decision of partial abstention from treatment.

5. The diagnostic error is derived from an incorrect or inadequate interpretation of diagnostic tests by the specialist (radiologist or other specialists) and the clinician did not detect the incorrect interpretation. The specialist is liable for damage to the patient on account of inexpertness and negligence. However, the clinician is also liable if examinations were those currently used, since he/she should be able to interpret them correctly.

A diagnostic error may have considerable medicolegal consequences if it leads to biological and/or financial damage to the patient. This error is due to inexpertness; very often, however, it may be attributed to negligence and the medicolegal relevance is proportionate to the severity of the consequences to the patient.

Case reports

Case 1. *A 38-year-old male with thoracic spine pain, recurrent low back pain and completely negative radiographic findings, presented improvement of his pain after medical and physical therapies carried out during a period of hospitalization. A few days after discharge, sudden monolateral lumboradicular pain appeared, for which an L4-L5 hemilaminectomy was performed. Surgery revealed a bulging degenerated disc, and discectomy was carried out. The day after surgery, paraplegia occurred on account of a giant cell tumor of the posterior arch of T11. Decompressive surgery at this level led to no improvement in the clinical picture.*

The surgeon who had carried out the discectomy was held liable for failing to diagnose the tumor at T11 level, despite the fact that thoracic symptomatology was occasional, vague and much less severe than the lumboradicular symptoms, and radiographic examinations repeatedly carried out (before the advent of CT and MRI) had revealed no suspect findings in the thoracic spine.

Case 2. *A 24-year-old male with unilateral low back and anterior thigh pain on the right side underwent surgery at L4-L5 level, which revealed mild disc bulging. Symptoms remained unchanged following discectomy. A more accurate evaluation of the preoperative radiographs led to the detection of an osteosclerotic area in the ipsilateral iliac bone, in proximity to the sacroiliac joint. CT revealed a suspect osteoid osteoma, which was excised with complete resolution of symptoms. Both the radiologist, who did not detect the osteosclerotic image in the iliac bone, and the surgeon, who did not correctly interpret the clinical picture and did not pay sufficient attention to the radiographic findings, were held professionally liable and the case ended in a decision for the defense.*

Case 3. *A 26-year-old male had severe radicular pain and showed marked motor and sensory deficits of the left S1 root. The report by the radiologist who had carried out CT examination only mentioned an L5-S1 disc protrusion on the left. At operation, a small contained L5-S1 disc herniation was found and excised; based on the radiologist's report, the surgeon did not search for migrated disc fragments. Following surgery, radicular pain persisted and motor loss was found to be increased. On a subsequent examination of the preoperative CT scans, another physician unequivocally detected a large fragment of disc, migrated at a distance from the L5-S1 intervertebral space. A second operation led to resolution of pain and partial improvement of motor deficit. Both the radiologist and the physician who had carried out the first operation were held liable for inexperience and negligence; the former for failure to detect the migrated fragment on CT scans, and the latter for not having searched for migrated fragments or other causes of nerve-root compression in the presence of a clinical picture not justified only by the mild L5-S1 disc protrusion.*

Conservative treatment

In the presence of a lumboradicular syndrome due to a herniated disc, the physician may decide to carry out conservative treatment for various reasons: mildness of nerve-root signs and symptoms or distinct prevalence of low back pain compared with radicular symptoms, short duration of the disease, small size of the herniated disc or poor psychologic stability of the patient. Not only is the decision to continue conservative treatment usually justified, but, in some cases, execution of surgery may imply an excess of indication. Surgery should be carried out rapidly, and often in an emergency, only in the presence of progressive worsening of neurologic deficits or a cauda equina syndrome. Also in these cases, poor general conditions or concomitant diseases exposing the patient to the risk of severe intraoperative or postoperative complications may justify the decision to abstain.

Professional liability

A physician who decides to carry out conservative treatment might be accused of favoring deterioration of the clinical conditions or prolonging the period of inability, but he can usually easily defend himself / herself maintaining his right to decide the method of treatment. The physician may be liable if he/she unjustifiably delays surgery, for days or weeks, in the presence of a cauda equina syndrome or a demonstrated progressive increase in radicular deficit.

Case report

A 42-year-old female with chronic lumboradicular symptoms presented a relapse of severe pain in the right leg and slight motor deficit of the right triceps surae. An orthopaedic surgeon, following careful evaluation of the pathologic condition, represented by a small L5-S1 disc herniation, and adequate information to the patient, opted for medical and physical therapy and application of a corset. A few weeks later, immediate excision of disc herniation was proposed by a neurosurgeon, who threw serious doubt on the correctness of the therapeutic decision of his colleague. Surgery was carried out with a good result. The first physician was not held liable for advising conservative treatment. The second physician cannot be censured from a professional point of view, however definitely from an ethical and deontological point of view for damaging the professional reputation of his colleague.

Surgical treatment

Defective approach

Surgery for disc herniation and associated conditions should satisfy two opposite requisites: to carry out a sufficiently wide opening of the vertebral canal in order to allow adequate disc excision and removal of possible migrated disc fragments without risk of damaging the neural structures; and to preserve, as far as possible, the osteoligamentous structures responsible for vertebral stability in order to avoid postoperative instability of the motion segment. Either insufficient opening of the spinal canal, which may make surgery ineffective, or decrease in vertebral stability may represent a defective approach.

Interlaminar flavectomy alone, which entirely preserves vertebral stability, may make excision of extruded or migrated fragments difficult or impossible and may expose the neural structures to the risk of traumas during removal of the herniation. Laminotomy (or interlaminar fenestration or hemilaminoarthrectomy), more or less enlarged in a longitudinal direction, generally allows excision also of fragments migrated into the intervertebral foramen, after removal of at least the medial one third of the articular processes.

Hemilaminoarthrectomy with total resection of the facet joint permits a wide access also to extraforaminal herniated disks, but decreases vertebral stability. This reduction in stability may be of little clinical importance when the spine is preoperatively stable, whilst it may increase, to a critical extent, a pre-existing real or potential instability.

Central laminectomy can be necessary in the presence of marked stenosis of the spinal canal, however it is not generally indicated in patients with a herniated disc alone. It does not, in fact, facilitate access to the intervertebral disc or migrated disc fragments and may reduce vertebral stability, although usually not significantly, if at least the outer half of the articular processes are preserved.

The need to reach a compromise between preservation of the anatomic structures and decompression of the caudal nerve roots justifies the need for an accurate preoperative analysis of the pathologic characteristics of the herniation and the degree of stability of the motion segment involved.

In percutaneous procedures, a defective approach may consist in failure to penetrate in the disc space (or more specifically in the nucleus pulposus) or to invade the vertebral canal with surgical instruments (7, 22, 26). This is usually due to technical errors, occasionally favored by congenital or acquired vertebral anomalies.

Professional liability

The choice of surgical access is part of the therapeutic strategy that the physician has the right to choose, based on the clinical evaluation of the patient, results of preoperative investigations and personal surgical experience. However, it is the physician's duty to inform the patient on the modes of the surgical approach and the reasons for making a certain choice, at least when the access chosen is different from that usually carried out for the specific pathologic condition of the patient.

A clear-cut postoperative instability caused by an excessively wide decompression, especially if not required by a specific clinical need, often outlines a professional offense in surgical conduct. This holds particularly when instability is entirely produced or considerably increased by the operation. On the other hand, if postoperative instability may be foreseen prior to surgery, it is the surgeon's duty to plan a possible spinal fusion to be carried out concomitantly with decompression or to inform the patient on the reasons for not performing an arthrodesis.

Percutaneous access may not be indicated, as in the case of migrated herniation, or may be carried out erroneously from a technical point of view due to lack of experience of the surgeon or inadequacy of the fluoroscopic equipment. The fault may be attributed, in the former case, to inexpertness or imprudence in the interpretation of clinical data or preoperative investigations and, in the latter, to inexpertness or negligence.

Professional liability for a defective surgical approach should be considered more severe if the physician is particularly expert and qualified in spinal surgery. Another element which may aggravate the offence is the underestimation, for negligence, of the possibility of causing an injury when it is well known that awareness of this possibility must be part of the common cultural patrimony of the physician carrying out the surgical procedure.

Case reports

Case 1. *A 39-year-old female with recurrence of L4-L5 disc herniation, following open discectomy performed at the same level and on the same side two years before, underwent automated percutaneous nucleotomy with no relief of symptoms. The surgeon who had carried out nucleotomy was not held liable due to lack of damage to the patient, even if the indication for percutaneous nucleotomy in the case of a recurrent herniation, is debatable.*

Case 2. *A 58-year-old male with severe, often bilateral, sciatic pain, diagnosed as having a large paramedian L5-S1 herniated disc, was submitted to bilateral laminoarthrectomy. After about 1 year, the patient began to complain of severe low back pain radiating to the posterior aspect of the thighs. Radiographs showed spondylolisthesis of L5 not present prior to surgery.*

The surgeon was found guilty of causing vertebral instability and not having carried out spinal fusion following a highly demolitive surgical procedure, which however was required by the preoperative pathologic condition. Furthermore, information provided to the patient on the possibility of postoperative vertebral slipping and possible need for subsequent spinal arthrodesis, which was later carried out by another surgeon, had been lacking.

Failure to decompress or defective decompression

The most frequent defect in decompression of the neural structures consists in no or incomplete excision of a disc fragment extruded in the midline, or incomplete disc excision leaving behind a marked annular bulging or a disc protrusion, albeit small in size. The latter incident may occur more easily when partial discectomy is carried out, or in young subjects in whom complete discectomy may be difficult on account of mild degenerative changes of disc tissue. In these cases, if the annulus fibrosus bulges markedly, it may still compress the neural structures even after removal of the nucleus pulposus.

Another fairly frequent cause of defective decompression (4, 6) is the lack of detection and removal of a migrated disc fragment. This may occur especially in migrated intraforaminal herniations, in which the migrated fragment may not be sought, or inadequately searched for, if its existence and location are not clearly demonstrated by preoperative imaging studies. In these cases, it may be necessary to carry out a wide laminoarthrectomy to expose the compressed nerve root and/or the migrated fragment. If the surgeon is only slightly in doubt concerning the presence of a migrated fragment, he/she may decide not to enlarge the laminoarthrectomy in order not to compromize vertebral stability, particularly when the presence of a disc protrusion apparently justifies the clinical picture and exploration of the vertebral canal failed to reveal migrated disc fragments.

Concomitant stenosis of the spinal canal may be the cause of persistent radicular symptoms. This may occur when stenosis is at the same level as, or even at a different level from, the herniation.

The persistence of radicular symptoms due to isthmic spondylolisthesis at an adjacent level to that of discectomy or at the same level, is a rare occurrence. In the latter case, disc excision may lead to an increase in olisthesis, or to vertebral instability responsible for persistence of nerve-root compression on the same side as discectomy or for onset of radicular symptoms on the opposite side.

Patients undergoing chemonucleolysis or percutaneous nucleotomy often experience persistence of, or even an increase in, radicular symptoms. In these cases, however, the defect is often in the indication for the procedure rather than in the execution.

Professional liability

Incomplete excision of disc tissue, responsible for persistent compression of neural structures, leads to a defective result for which it may be difficult to determine whether professional liability exists. This occurs only when preoperative signs and symptoms remain unchanged following surgery and insufficient decompression of the neural structures is related to serious omissions during surgery. There is no responsibility, therefore, when new disc herniation occurs at a variably long time interval after surgery, at the same level as the primary herniation or in different discs from that operated on.

A poor surgical outcome is, at times, related to a behavioral defect of the physician, as occurs when a large extruded or migrated disc fragment is not detected and removed at surgery due to negligence and/or lack of expertise. In other cases, however, the defective decompression may be only partially foreseen and avoided. For instance, persistence of annular bulging in a young patient with mild disc degeneration may sometimes be avoided only by performing bilateral discectomy, which, however, may also lead to a decrease in vertebral stability, or by means of concomitant spinal fusion, which is generally not recommended in young subjects. Likewise, in a patient with severe stenosis, partial compression of the neural structures may sometimes persist on account of the difficulty or impossibility of completely eliminating the osteoligamentous cause of compression, due to the risk of causing, or accentuating the pre-existing, neurologic deficits.

In the medicolegal evaluation, the simple detection "a posteriori" of a defective decompression may not allow formulation of an impartial judgement or may even give rise to an erroneous evaluation and, thus, an incorrect motivation in a possible verdict for the plaintiff. On the other hand, it must be underlined that CT and MRI findings may be partially misleading in the first few months following discectomy, since they may reveal a persistent disc protrusion even in patients with an excellent surgical outcome.

The expert called to ascertain a possible professional liability of the surgeon should retrace the same inductive and deductive path followed by the surgeon, bearing in mind the difficulties involved in vertebral surgery.

Case report

A 67-year-old female with a lumboradicular syndrome caused by a right intraforaminal L3-L4 disc herniation, diagnosed by CT, underwent surgery with no relief of low back and radicular pain. CT carried out 8 months later revealed the presence, in the intervertebral foramen, of a free fragment of disc showing the same shape and size, as well as the same location, as that present preoperatively. The surgeon was considered negligent and the case was settled.

Error in identifying the pathologic level

This is one of the most common mistakes in surgery for a herniated disc (13, 14, 27). It may be responsible for a defective decompression and/or approach. The more cranial the affected disc and the more decreased the interlaminar and interspinous spaces, the greater the frequency of this error; furthermore, it is more frequent when the skin incision is limited to the interlaminar space involved, as in the case of microdiscectomy (18, 24).

Three situations may be identified: a) the surgeon initially operates on a wrong level, but detects the error before or after discectomy and, upon identification of the correct level, performs the planned operation; b) the surgeon does not detect the error and carries out laminotomy and discectomy only at the wrong level; c) the error in identification of the affected level is not detected during surgery, but the posterior arch is partially or entirely resected also at the involved intervertebral level, where, however, discectomy is not carried out. In the former case, the early postoperative backache may be more severe than expected, but the probability of relieving radicular symptoms is no different from that in cases with no error in level identification. In the second case, preoperative symptoms remain unchanged or occasionally increase in severity. In the latter case, preoperative symptomatology may improve or disappear on account of the partial decompression of the neural structures resulting from bone resection.

Professional liability

In general, the surgeon's liability decreases parallel with the objective increase in the difficulty of preoperative and intraoperative detection of the pathologic level. Responsibility, therefore, may be very slight, or even non-existent, when error in level identification is very easy due to the site of the herniation or the objectively considerable difficulty in identifying the pathologic level during surgery. This holds particularly if numerous fluoroscopic or radiographic cheks have been carried out preoperatively or intraoperatively to identify the pathologic level.

In the first of the three aforementioned situations, the surgeon is generally not liable, since laminotomy (with or without discectomy) at an unaffected level does not usually produce significant damage to the patient. In the second situation, the surgeon is liable due to a defective approach and failure to decompress the neural structures; professional liability, however, may be slight, or even absent, when identification of the pathologic level was, objectively, extremely difficult. This holds also for the third situation, particularly if surgery led to considerable improvement in clinical symptoms and neurologic impairment.

Intraoperative injuries

These may be accidentally produced or favored by the surgeon during laminoarthrectomy, retraction or decompression of the neural structures, or excision of disc herniation. The main discriminating elements from a medicolegal point of view are the severity of the damage that they involve and the possibility, or not, of making intraoperative diagnosis and carrying out immediate treatment.

Nerve-root injuries. Contusion, or partial or total tear, of a nerve root may generally be attributed to errors in surgical maneuvers, occasionally facilitated by particular anatomic conditions, such as nerve-root anomalies, periradicular fibrosis, adhesion of the root to the herniated disc or the walls of the spinal canal, or lumbar stenosis (25). Profuse intraoperative bleeding due to epidural varicosities or coagulation disorders may favor nerve-root injury on account of the difficulties in adequately visualizing the anatomic structures.

Dural tear. This is the most frequent injury during surgery for lumbar disc herniation. The injury assumes a medicolegal relevance when it remains undetected during operation or it is inadequately treated, thus leading to development of a CSF fistula or a pseudomenigocele. In both cases, the surgeon may be accused of failed diagnosis, inexpertness, or negligence for not performing effective treatment.

Cauda equina syndrome. This is one of the most dreaded complications in lumbar surgery due to the severity and often irreversibility of the neurologic damage. The latter may be caused by surgical trauma to the neural structures or postoperative epidural hematoma (11, 17, 19). Surgical trauma may be favored by a defective approach (e.g., posterior rather than lateral approach for L1-L2 herniation), or specific anatomic and/or clinical conditions (intradural herniation, large herniated disc in a patient with marked stenosis and/or severe pluriradicular preoperative deficits). In both cases, often the surgeon does not realize, during surgery, that he has produced severe nerve-root impairment. A postoperative hematoma may be favored by having maintained intraoperative controlled hypotension until the complete closure of the thoracolumbar fascia. This may hinder the surgeon from detecting profuse epidural bleeding and thus realizing the need for carrying out accurate hemostasis and/or applying a drain.

Injuries to abdominal structures. Vascular injuries causing hemoperitoneum are potentially the most severe complications in lumbar disc surgery, since they involve a high mortality rate (3, 5, 29). These lesions may more easily occur in the presence of marked disc degeneration, responsible for a decrease in the mechanical resistance of the anterior portion of the annulus fibrosus (28). The diagnostic suspicion should arise in the anesthetist when marked hypovolemic shock occurs during, or immediately after, surgery, and in the surgeon in the presence of profuse hemorrhage from the disc space. Diagnosis of an arteriovenous fistula is more difficult and generally delayed, however this complication requires less urgent treatment.

Injuries to abdominal organs, which are exceedingly rare, are favored by the same predisposing conditions involved in vascular lesions.

Peripheral nerve injuries. These may involve the upper or lower limb. The former are caused by incorrect positioning of the limb when the patient is placed in the prone position. The latter are usually caused by incorrect positioning of the patient on the operating table by the surgeon.

Professional liability

The medicolegal relevance of these injuries should be evaluated taking into account that the damage to the patient represents, compared with the primary disease, a new impairment, which is not derived from a complication of routine treatment, and thus unforeseen or unavoidable, but from a specific surgical risk, which, having been described and therefore known, must be foreseen and avoided or, in the event that it occurs, must be treated rapidly and correctly.

An intraoperative injury usually involves professional liability; in a series of 109 cases of lumbar surgery for which surgeons in the United States were prosecuted for professional liability, complications were represented by a dural injury in 20 cases, cauda equina syndrome in 20 and nerve-root injury in 14 (12). However, this is not always the case: liability is strictly related to the behavior of the surgeon rather than to injury outcome, even if this is considerably poor. It is very important, therefore, to establish whether the damaging action by the surgeon was favored by pre-existing pathologic conditions and whether diagnosis, treatment or information concerning the injury were defective.

Favoring conditions. Pathologic changes related to the quality, severity and duration of the disease are often the main, if not the only, causes responsible for intraoperative injury. The surgical act which actually produces the injury may imply no liability of the surgeon if he/she was prudent and skilful; the surgeon's action, in this case, may only be a precipitating factor, or a concause, in a pathologic condition which intrinsically possesses a high potential of risk. For example, a mild surgical trauma related to the normal execution of surgery, in a patient with a severe radicular deficit, may lead to an increase in nerve-root impairment: the surgeon is not specifically liable, if his/her conduct did not deviate from the rules of vertebral surgery.

At times, the risk of intraoperative injuries is very high, or causing a lesion is almost inevitable on account of the nature of the disease. In these cases, it is of paramount importance to evaluate the benefits to be derived from surgery with respect to the severity of the consequences of a possible surgical injury. The decision of running a high risk may be justified if this is done in the interest of the patient, who must give his consent after having received exhaustive information.

Diagnosis. Diagnosis may be intraoperative or postoperative, and direct or indirect.

Diagnosis is immediate and direct when abnormal situations occur with respect to the normal course of the operation, such as leakage of CSF from the thecal sac or massive hemorrhage from inside the disc, which are clear signs of injury to the thecal sac or abdominal vessels, respectively. In these cases, the lesion should be treated immediately due to its intrinsic severity and, if necessary, treatment of the primary disease should be interrupted or witheld. Failure to diagnose the injury, in contrast with clear-cut surgical findings, or their underestimation, implies lack of expertise and negligence of the surgeon and his collaborators.

At times, the liability for damage deriving from an injury should not be attributed to the surgeon, but to other specialists if they omitted to inform or delayed providing the surgeon with details of clinical findings suggesting the injury. For instance, an injury to abdominal vessels may not be apparent to the surgeon during the operation, but the anesthetist may be able to suspect it on account of the occurrence of hypovolemic shock. In this case, the anesthesist is responsible for the consequences which may derive from a delayed or omitted diagnosis. It is his/her responsibility, in fact, to diagnose hypovolemic shock during anesthesia or the early postoperative period and to immediately inform the surgeon of the abnormal clinical findings.

A nerve-root or cord injury is clinically evident only after surgery, since it is asymptomatic under anesthesia. Diligence of the surgeon always requires immediate postoperative monitoring of neurologic functions to establish the presence, site and severity of an injury as soon as possible; delayed detection may, in fact, represent a negligent omission of action.

Treatment. Treatment concerns all physicians involved in the surgical procedure. The anesthetist is responsible for the general conditions of the patient. The surgeon and his team must do all they can to reduce or remedy the consequences of damage. This may require immediate intervention of other specialists, such as an abdominal or vascular surgeon, as well as the use of an intensive care unit.

The possibility of immediate and effective treatment entails timely availability of adequate diagnostic and therapeutic equipment, and qualified medical personnel. A lack of these may entail the liability of those who did not prudently and diligently foresee all the necessary means for carrying out surgery or treating possible complications. This does not mean, for instance, that, on account of the possible occurrence of abdominal vascular injuries, a vascular surgeon should be present in the hospital during surgery for lumbar disc herniation. However, in the event of suspect or ascertained vascular injury which puts the patient in immediate danger, the surgical team is obliged to require the intervention of the specialist as rapidly as possible.

Information concerning the injury. Members of staff involved in treatment should report in detail the nature and severity of the injury and its causes on the hospital chart. They must also inform the patient of these aspects and of the consequences of the injury. This information is not only an ethical and legal obligation, but also assures the patient of the straightforward behavior of the treating physicians. Lack of information or reticent information is probably the most frequent cause of claims from patients who are usually willing to understand a difficulty or an error, but not to be cheated.

Case reports

Case 1. *A 47-year-old female underwent excision of an L3-L4 herniated disc. Eight days after surgery, the patient noted a soft subcutaneous swelling in the area of the surgical wound. Over the next few days, swelling reached the size of a chicken's egg. Ten days after surgery, the surgeon applied a compressive bandage and advised the patient to stay in bed. The swelling remained unchanged, but headache and fever appeared. Nineteen days after surgery, another physician prescribed MRI, which revealed a pseudomeningocele caused by intraoperative dural injury, and successfully repaired the lesion. A verdict against the first physician was passed, since he had not adequately diagnosed and treated the patient when pseudomeningocele had become clinically evident.*

Case 2. *A 68-year-old male underwent surgery for left L4-L5 disc herniation. During surgery, a tear of the left iliac artery occurred, with consequent retroperitoneal hemorrhage. Diagnosis of hemorrhage was made intraoperatively. Surgery was interrupted and the intervention was requested of a vascular surgeon, who attempted to repair the vascular lesion without success on account of the large size of the tear. The patient died during surgery. A verdict in favor of the surgeon who carried out the spinal operation was passed, since it was considered that the vascular injury had been favored by the severe degeneration of the annulus fibrosus and anterior longitudinal ligament, and that behavior, as far as concerns diagnosis and treatment of the complication, had been entirely correct.*

Case 3. *A 38-year-old female, while undergoing excision of a right L4-L5 herniated disc, sustained a tear of the right iliac artery, of which the surgeon was not aware. Hemorrhagic shock was initially attributed to cardiac causes. Three hours after surgery, the hypovolemic nature of the shock was recognized and the patient was transferred to another hospital where she died. The behavior both of the surgeons and the anesthetist was considered negligent and inexperienced, since they had not diagnosed the complication and immediately performed adequate therapy.*

Case 4. *A 39-year-old man, submitted to surgery for recurrent lumbar disc herniation, sustained laceration of an iliac artery, which was diagnosed by the orthopedic surgeon intraoperatively. After a relatively long interval (90 minutes), the patient was transferred to a hospital in another town, in which there was a department of vascular surgery. Repair of the vascular tear was carried out 5 hours after spinal surgery, however the patient died a few days later also on account of incomplete closure of the tear, as revealed by autopsy.*

A verdict for the plaintiff was rendered due to the delay in diagnosis and treatment of the vascular injury.

In the appellate lawsuit, a verdict for the defense occurred on account of the impossibility of determining the "time required" to diagnose an abdominal vascular lesion and of the lack of evidence concerning the actual efficacy of a more timely vascular operation.

A Supreme Court trial lawsuit ended with a verdict for the plaintiff because "... there is always a causal link between inexpert, negligent or imprudent behavior of the physician who did not endeavor to carry out extremely urgent surgical intervention and the subsequent fatal event, when such an *intervention, even though its use in saving the patient's life was not certain, might have had considerable probabilities of reaching that aim".*

Infections

Infections occurring during surgery are usually caused by bacteria from the external environment. Sources and vehicles are numerous and often unknown and not avoidable: patient's skin, non-sterile surgical instruments, structural discontinuities or tears in surgical gloves, fine dust from the environment or from surgeons (hat, glasses, forehead) during accidental reciprocal contact, and surgeon's breath. General and immunological conditions of the patient are also important, since they may favor the development of infection and affect its resistance to treatment.

Professional liability

The development of an infection cannot generally be attributed to the surgeon, unless one of the following situations is demonstrated: failed recognition of a preexisting infection due to insufficient preoperative evaluation of the patient's general conditions; execution of surgery in an insufficiently sterile operating room (it is the surgeon's responsibility to ascertain the nature of surgeries previously carried out in the operating theatre); postoperative hospitalization of the patient in close proximity to other patients with infectious diseases involving external emission of infected material; or omission of antibiotic treatment when detection of symptoms due to infection makes it necessary.

In the past, it has been maintained that antibiotic treatment is not necessary in patients with spondylodiscitis, since evolution of the disc infection would not be affected by antibiotics. This view can no longer be accepted on account of the multitude, and efficacy, of modern antibiotics. Furthermore, it has been shown that their efficacy is higher when they are administered immediately before surgery (9, 23). The physician may, therefore, be considered negligent if antibiotic prophylaxis has not been carried out in patients who will later develop spondylodiscitis.

Biopsy of the infected disc or vertebral body, and culture of the material obtained, can help to identify the germ involved and to administering the most appropriate antibiotic. However, in postoperative spondylodiscitis, the proportion of negative cultures is rather high, especially when the patient is, or has recently been, under antibiotic treatment. Therefore, spinal biopsy in the presence of postoperative spondylodiscitis is not mandatory, also considering that the procedure is invasive.

Case report

A 27-year-old male underwent removal of L4-L5 disc herniation with immediate resolution of the symptoms. Ten days after surgery, severe low back pain associated with fever appeared. Spondylodiscitis was suspected and then demonstrated, and adequate antibiotic therapy was carried out. The patient had been hospitalized, before and after surgery, in the same room as a patient with a severe open infection. The verdict for the plaintiff was based on the assumption that the surgeon had been imprudent and negligent in underestimating the possibility of transmission of the infection from one patient to the other.

Professional liability of the consultant physician

The duty of correct behavior concerns not only the treating physicians, but also the consultant summoned to evaluate the methods and results of surgical treatment. During layout of the expert report, the physician must carry out an accurate analysis based on the following:

1. Reconstruction of the clinical state prior to surgery. This is indispensable in order to determine previous clinical conditions and evaluate the possible increased damage provoked by improper surgery.
2. Analysis of the methods and course of surgery. This includes the possible therapeutic alternatives, the level of aware consent from the patient, the technique chosen and the role of surgical risk as a cause of failure. Surgical risk should be considered as the possibility of injuries or complications occurring during or after intervention, which are responsible for lesions, that, at times, may be detected at variably long time intervals after surgery, due to changes in the patient's biological condition.
3. Evaluation of the therapeutic results at different time intervals. With time, the result of treatment may improve, but negative evolutions of the biological condition may also occur, which may represent a damage, directly or indirectly related to the initial treatment.
4. Evaluation of current biological conditions and physical disability of the patient by clinical examination and non-invasive diagnostic tests. Obviously, all alterations demonstrated prior to treatment should be subtracted from the disability resulting from management.

Also the consultant must demonstrate expertness, prudence and diligence in his/her work. He/She should be acquainted with clinical and pathologic features, and methods of surgical treatment of diseases of the lumbar spine, possibly through direct experience, in order to correctly analyze and interpret the risk factors and complications of treatment, and their etiologic role in the possible damage experienced by the patient. Prudence in the medicolegal evaluation implies the acquisition of all elements of judgement allowing valid conclusions to be made; this may require the advice of specialists particularly expert in the specific field when the case is difficult to evaluate.

Professional liability may also exists for the consultant, when he/she expresses opinions which can erroneously influence the verdict, because they are based on incomplete or incorrect knowledge, leading to serious mistakes in the analysis of the damage sustained by the patient.

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