H. M. Mayer
Editor

Minimally Invasive Spine Surgery



A Surgical Manual

Second Edition

Springer

H.M. Mayer (Ed.)

Minimally Invasive Spine Surgery

A Surgical Manual

Second Edition

With 492 Figures in 851 Parts and 36 Tables

Springer

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To Frizzi, Lukas and Isabel
for all their love and support

Preface to the Second Edition

Five years have passed since the first edition of this book. Minimally invasive surgical techniques have become a significant part of the daily routine in spine surgery. Some of the techniques which have been described in the first edition have become standard in spine centres all around the world, others have been struggling to stand the test of time.
Three important trends could be observed in the past five years:

1. Microsurgical and endoscopic surgical techniques have been improved. The application spectrum has been enlarged and the results are now more reliable and predictable.
2. So-called "semi-invasive" techniques, mainly for the treatment of low back pain, have become more popular although evidence-based data concerning efficacy and success are still lacking.
3. Spine arthroplasty is the term for a significant change of paradigms in spinal surgery. Minimally invasive partial or total disc replacement in the degenerated cervical and lumbar spine, "dynamic" fixation, or disc-unloading techniques with innovative implants are being tested in various clinical studies all around the world. Autologous percutaneous disc chondrocyte transplantation is the first clinical attempt to achieve a biological regeneration of the degenerated disc.

This new, revised and extended edition of *Minimally Invasive Spine Surgery* contains all current applications of minimally invasive techniques for spine surgery. A total of 70 authors and co-authors have covered all aspects of minimally invasive spine surgery in 51 chapters, which has more than doubled the volume of the first edition.

Again we must point out that the book concentrates on surgical techniques and that it was our aim to provide the reader with the information necessary to perform these types of surgery. However, some of the techniques described are still part of an ongoing process of development and, although we have tried to give the reader a mainly unbiased and neutral description of the techniques, we are aware of the fact that this could not be realized for all chapters.

I thank all my colleagues for again spending their time to produce high-quality chapters, to share their tremendous experience with us and to provide us with the newest information.

I sincerely hope that our efforts will be honoured by a number of readers and that again we can all contribute to the development of minimally invasive techniques in spine surgery.

Munich, Summer 2005 *H. Michael Mayer*

Foreword to the First Edition

This book contains a wealth of information on aspects of minimally invasive spinal surgery. For a surgeon of my vintage, nearing the end of a career spanning the past forty years, I am reassured by the enthusiasm, dedication and seriousness of purpose of this new generation of surgeons and scientists whose work is outlined in the book.

In 1957 Walter Blount delivered his Presidential Address entitled: "Don't Throw Away the Cane" to the American Academy of Orthopaedic Surgeons. The gist of this monumental address was that, as hip surgery was evolving, the lessons of convervatism in management of hip disorders should not be forgotten. While preparing this Foreword I was reminded of its main message because it remains pertinent to present trends in the practice of spinal surgery.

The advanced techniques described in Dr. Mayer's book must not be attempted without intensive study of anatomy and a thorough understanding of spinal pathology. Throughout the text individual authors use the term "learning curve", a term which can spell disaster for the patient who may be on the "curve". Spinal surgery is potentially dangerous. Mastery of it is best gained by personal tuition under the guidance of a busy experienced surgeon. The trend towards learning surgical techniques in workshop settings or in short courses organised by manufacturers of surgical equipment, using plastic models or cadavers is not entirely good for trainees or for surgeons aiming to expand their practices into minimal invasive surgery of the spine, as it may lead to the triumph of technology over reason. By focussing on how to use the wide range of equipment required to perform these operations, biological factors which may adversely affect their use should not be neglected. For example even in the outstanding chapter "Microsurgery of the Cervical Spine" the Statement is made that: "Retracter blades may stick after many hours of surgery: they should be removed under irrigation and individually". One of the most important leasons to have emerged in recent years in spinal surgery has been that retractors should be released at regular intervals throughout an operation to prevent irreversible damage to the blood supply of the muscles at the site of surgery.

At the beginning of this new millennium Dr. Michael Mayer has shown great foresight in assembling such an array of international experts to present a clear picture of what has been achieved in the least decade of the 20th Century and a view of what lies ahead as surgeons strive to harness the rapidly changing technologies in the fields of imaging, optics, endoscopy and instrument design for their wider use in minimal invasive spinal surgery. This book should become the vade mecum for spinal surgeons in this decade. The wide range of information in it covers technical details, logistical facts and many informative and balanced views on aspects of these new techniques. These authors form a worthy cohort of surgeons and scientists from differing backgrounds with common aims. They are voyagers heading into previously uncharted waters.

"But far forward voyagers".
T. S. Elliot, Four Quarters, p40. The Folio Society London, MC MI. XVIII

February 2000

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Preface to the First Edition

"There is no darkness – there is just absence of light."

"Minimally invasive surgery" has been the key phrase dominating clinical and scientific efforts in all surgical specialties over the last decade. There has never been a comparable period in surgery where, within a short span of time, surgical technology has undergone such widespread and fundamental changes. These developments are due to the synergism produced by a parallel "explosion" of knowledge and technological abilities in modern radiological imaging techniques, in advanced surgical instrumentation and implant technology, as well as in intraoperative visualization using modern digital and conventional optical systems. Although there is controversy regarding the semantic correctness of the term "minimally invasive surgery" (because in the majority of the techniques only the surgical approach is "minimally invasive"), it is still synonymous of all surgical techniques which are "less" or, better, "suitably" invasive compared to conventional surgical approaches.

Spinal surgery is probably the subspecialty which has undergone the most revolutionary changes triggered by less invasive procedures. It all started with the inauguration of microsurgical and endoscopic procedures for the treatment of lumbar disc herniations in the mid-1970s. Today we are witnessing a variety of microsurgical and endoscopic techniques, as well as procedures, which require no direct visual control.

Most of these techniques are used in clinical studies but are still lacking basic scientific evidence, some techniques have already replaced standard techniques, while others have been generally accepted at least as alternatives to conventional surgical procedures. The majority of these techniques are highly sophisticated and require special surgical training or even laboratory training, which poses problems in particular for the surgeon not specialized in spine surgery. Scientific meetings are dominated worldwide by the presentation of minimally invasive spine surgery; however, it is difficult for the surgeon to keep abreast of the rapid developments and to be able to decide which technique he should adopt for his daily work.

It was our intention to present an overview of the most important and relevant microsurgical and endoscopic techniques which have been inaugurated over the last two decades. This book is neither a textbook nor a surgical atlas. It was our aim to provide the reader with clear information regarding terminology, history, indications, surgical principles, as well as a critical evaluation of the specific technique. It does not attempt to pass final judgement on the value and necessity of the various procedures; however, it may enable the reader to make her/his own assessment of the value and acceptability of each technique.

The book concentrates on surgical technique and provides the reader with the relevant information necessary to be prepared for the use of the different procedures.

I would like to express my deepest thanks to all colleagues who have contributed to this book and who have provided us with a tremendous amount of new information.

It is my sincere hope that this book will contribute to the further understanding and acceptance of minimally invasive philosophies in the emerging field of spinal surgery.

Munich, February 2000 *H. Michael Mayer*

Contents

General

1 Minimally Invasive Spine Surgery
H.M. Mayer 3

2 Technological Advances of Surgical Microscopes for Spine Surgery
W. Rulffes 8

3 Spinal Microsurgery: A Short Introduction
H.M. Mayer 12

4 Microsurgical Instruments
A. Korge 16

5 Operating Room Setup and Handling of Surgical Microscopes
K. Wiechert 23

6 Computer-assisted Minimally Invasive Spine Surgery – State of the Art
F. Langlotz, L.P. Nolte 26

Cervical Spine

Odontoid

7 Technique of Transoral Odontoidectomy
P.J. Apostolides, A.G. Vishteh, R.M. Galler, V.K.H. Sonntag 35

8 Microsurgical Treatment of Odontoid Fractures
P. Klimo Jr, G. Rao, R.I. Apfelbaum 42

Disc Surgery/Decompression

9 Microsurgery of the Cervical Spine: The Anterior Approach
L. Papavero 54

10 Anterior Cervical Foraminotomy (Microsurgical and Endoscopic)
W.F. Saringer 82

11 Functional Segmental Reconstruction with the Bryan Cervical Disc Prosthesis
J. Goffin 92

12 Microsurgical Total Cervical Disc Replacement
H.M. Mayer 100

13 Microsurgical Posterior Approaches to the Cervical Spine
P.H. Young, J.P. Young, J.C. Young 107

14 Microsurgical C1 – 1 Stabilization
D. Fassett, R.I. Apfelbaum 118

Thoracic/Thoracolumbar Spine

General Techniques

15 Microsurgical Anterior Approach to T5 – 10 (Mini-TTA)
H.M. Mayer 129

16 Microsurgical Anterior Approach to the Thoracolumbar Junction
H.M. Mayer 138

17 Anatomic Principles of Thoracoscopic Spine Surgery
U. Liljenqvist 144

18 Principles of Endoscopic Techniques to the Thoracic and Lumbar Spine 149
G.M. McCullen, A.A. Criscitiello, H.A. Yuan 149

19 Biomechanical Requirements in Minimally Invasive Spinal Fracture Treatment
M. Schultheiss, E. Hartwig, L. Claes, L. Kinzl, H.-J. Wilke 156

Deformities

20 Thoracoscopic Approaches in Spinal Deformities and Trauma
M. Dufoo-Olvera 164

21 Thoracoscopic Techniques in Spinal Deformities
D. Sucato 176

22 Mini-open Endoscopic Excision of Hemivertebrae
R. Stücker 197

Fractures

23 Thoracoscopically Assisted Anterior Approach to Thoracolumbar Fractures
R. Beisse 203

24 A Minimally Invasive Open Approach for Reconstruction of the Anterior Column of the Thoracic and Lumbar Spine
B. Knowles, I. Freedman, G. Malham, T. Kossmann 215

25 Percutaneous Vertebroplasty in Osteoporotic Vertebral Fractures
G.M. Hess, H.M. Mayer 222

26 Microsurgical Open Vertebroplasty and Kyphoplasty
B.M. Boszczyk, M. Bierschneider, B. Robert, H. Jaksche 230

27 Percutaneous Kyphoplasty in Traumatic Fractures
G. Maestretti, P. Otten 239

Lumbar Spine

Low Back Pain

28 Interventional and Semi-invasive Procedures for Low Back Pain and Disc Herniation
M.K. Schäufele 249

Disc

29 Intradiscal Electrothermal Therapy
J. Saal 260

30 Microtherapy in Low Back Pain
A.T. Yeung, C.A. Yeung 267

31 Principles of Microsurgical Discectomy in Lumbar Disc Herniations
H.M. Mayer 278

32 The Microsurgical Interlaminar, Paramedian Approach
H.M. Mayer 283

33 The Translaminar Approach
L. Papavero 297

34 The Lateral, Extraforaminal Approach
L. Papavero 304

35 Transforaminal Endoscopic Discectomy
J. Krugluger 315

36 Microscopically Assisted Percutaneous Technique as a Minimally Invasive Approach to the Posterior Spine
R. Greiner-Perth, H. Boehm, H. El Saghir 322

37 Arthroscopic and Endoscopic Spine Surgery via a Posterolateral Approach
P. Kambin 331

38 The Full-endoscopic Interlaminar Approach for Lumbar Disc Herniations
S. Ruetten 346

39 Outpatient Microsurgical Lumbar Discectomy and Microde-compression Laminoplasty
R.S. Biscup, V. Podichetty 356

Disc Reconstruction

40 Nucleus Reconstruction by Autologous Chondrocyte Transplantation
H.-J. Meisel, T. Ganey 364

41 Autologous Disc Chondrocyte Transplantation
F. Grochulla, H.M. Mayer, A. Korge 374

42 The ALPA Approach for Minimally Invasive Nucleus Pulposus Replacement
R. Bertagnoli 379

43 Mini-open Midline Accesses for Lumbar Total Disc Replacement
H.M. Mayer 385

Spinal Stenosis

44 Microsurgical Decompression of Acquired (Degenerative) Central and Lateral Spinal Canal Stenosis
H.M. Mayer 397

Fusion

45 Microsurgical Anterior Lumbar Interbody Fusion (Mini-ALIF): The Lateral Retroperitoneal Approach to L2/3, L3/4, and L4/5
H.M. Mayer 409

46 Microsurgical Anterior Lumbar Interbody Fusion (Mini-ALIF): The Transperitoneal Approach to L5/S1
H.M. Mayer 423

47 Minimally Invasive 360° Lumbar Fusion
M. Aebi 435

48 The Anterior Extraperitoneal Video-assisted Approach to the Lumbar Spine
M. Onimus, H. Chataigner 450

Dynamic Stabilization

49 Minimally Invasive Dynamic Stabilization of the Lumbar Motion Segment with an Interspinous Implant
J. Sénégas 459

50 Technical and Anatomical Considerations for the Placement of a Posterior Interspinous Stabilizer
J. Taylor, S. Ritland 466

51 Elastic Microsurgical Stabilization with a Posterior Shock Absorber
S. Caserta, G.A. La Maida, B. Misaggi 476

Subject Index 485

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General

Minimally Invasive Spine Surgery

1

H.M. Mayer

Primum non nocere – First do no harm

In the long history of surgery it always has been a basic principle to restrict the iatrogenic trauma done to a patient during surgery to a minimum. Modern surgical technology and techniques have shifted this principle into a new dimension. In spine surgery, the last decade of the twentieth century has been the decade of minimally invasive surgical procedures. The chapters of this book describe in detail the different techniques which are applied to improve symptoms or cure a variety of spinal diseases. They all follow the basic principles of what is more or less a "philosophy" of minimally invasive surgery.

In the following, this philosophy will be described.

1.1 Goals of Minimally Invasive Spine Surgery (MISS)

One of the main goals of MISS is to do an *efficient* "target surgery" with a minimum of iatrogenic trauma. Thus, either the "access surgery" or the "target surgery" itself can be minimally invasive. The majority of minimally invasive techniques in spine surgery refer to the access and not to what is done in the target region. However, the surgical strategy depends on the localization and patho-anatomy of the region or structure which has to be treated (Fig. 1.1). They determine the access, as well as the target strategy.

1.2 Access Principles

The spine as the central "axis" organ can be reached from different directions through different entrances (Fig. 1.2). The surgical entrance (skin incision) must be determined by the topography of the target and the access anatomy. It should be adequately placed and should have an adequate (smallest possible) size. Cosmetic aspects should be considered (e.g., skin incision follows skin lines) (Fig. 1.3).

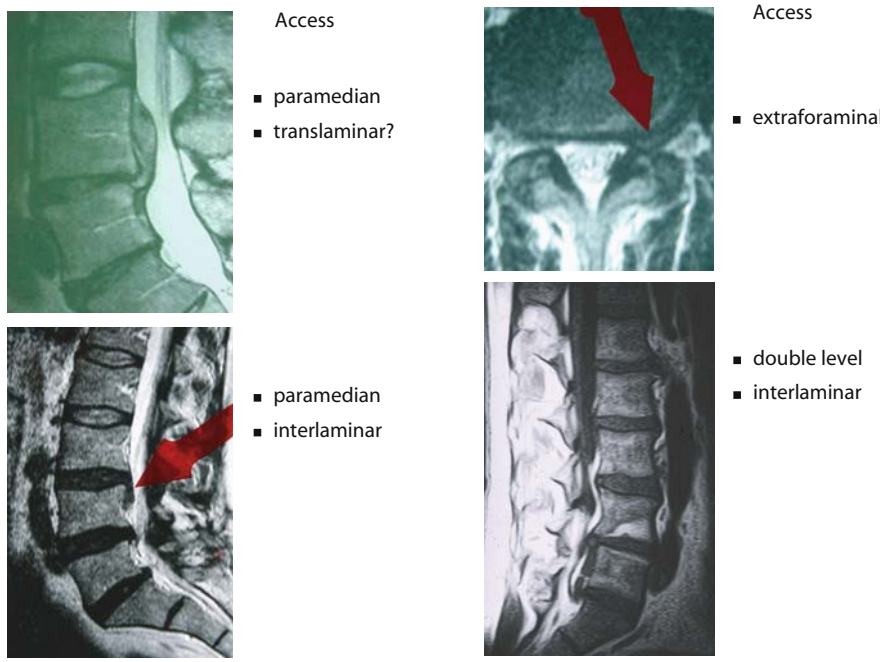


Fig. 1.1. Different localization, size, and configuration of surgical targets (lumbar disc herniations) require different access routes for adequate exposure

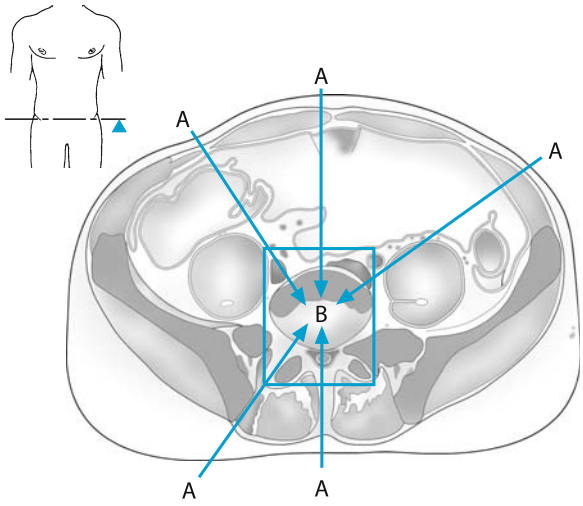


Fig. 1.2. Common access routes to the spine



Fig. 1.3. Transverse (cosmetic) skin incision for anterior approach to the cervical spine



Fig. 1.4. Blunt, muscle-splitting (function-preserving) anterior approach to the lumbar spine

The surgical route to the target area should be the least traumatic, i.e., it should strictly follow anatomical pathways such as preformed spaces or, if this is not possible for the whole skin–target distance, it should be performed with a minimum of collateral damage to surrounding tissues. If collateral damage cannot be avoided, it should be reparable and have a negligible effect on the clinical outcome. If possible, the function of the abdominal and paravertebral muscles should be preserved (Fig. 1.4)

The most important aspect is the adequate exposure of the target area. The target (e.g., disc herniation, disc, spinal nerve, tumor) should be clearly visible and identified. The target treatment (e.g., discectomy, vertebrectomy, neurolysis, tumor removal) should be possible without any restrictions due to the small approach. Spinal manipulation (e.g., reduction maneuvers) should be possible, as well as the insertion of implants for spinal stabilization.

The retreat from the surgical field should leave no or only minor traces (e.g., hematoma, "open" annulus fibrosus following discectomy, scar tissue) and it should not be relevant for the outcome (e.g., muscle damage). In the case of a staged surgical therapy (e.g., dynamic posterior stabilization) or in cases were there is a possibility for a recurrent pathology (e.g., disc herniations) the postoperative traces, such as scar tissue, muscle damage, or intervertebral joint damage, should not negatively influence these further therapeutic options (Table 1.1).

To achieve all these goals, meticulous preoperative planning is necessary. Positioning of the patient on the operation table requires modifications. Localization of entry area under fluoroscopic control is mandatory and surgical preparation techniques must be adapted. Special instruments (see Chapter 4), light and magnification sources (loupe, surgical microscope, headlamp), as well as retractor devices (e.g., frame or ring retractors, tubes, etc.) are necessary (Table 1.2)

Table 1.1. Access principles in minimally invasive spine surgery (MISS)

Skin incision	Adequate placement Adequate size Cosmetic
Route to target	Least traumatic (anatomical pathways!!) Fast
Collateral damage	Negligible Reparable
Target exposure	Adequate
Target treatment	Efficient Without restrictions due to small approach
Postoperative traces	Negligible Not relevant for outcome Options for return (recurrences, etc.)

Table 1.2. Factors which influence MISS strategy

Preoperative planning
Positioning of the patient on OR table
Localization of skin incision
Dissection technique
Instruments and implants

1.3 Preoperative Planning

Topography and volumetry of the target must be clear. This information is usually given by different imaging techniques such as MRI, CT, etc. (Figs. 1.1, 1.5). Especially in anterior approaches to the spine, knowledge of the topography of the prevertebral space can be valuable. Retraction of the prevertebral blood vessels is an important surgical step to expose the anterior circumference of the lumbar spine. Minimally invasive approaches do not allow a wide exposure and mobilization of these vessels. This can increase the risk of indirect damage to branches entering or exiting the arteries and veins. Preoperative vascular topography can be determined with the help of color-coded three-dimensional CT scans which give a clear picture of the individual anatomy (Fig. 1.6; see also Chapter 43). Traces of previous operations in the target of access region also influence the access strategy.

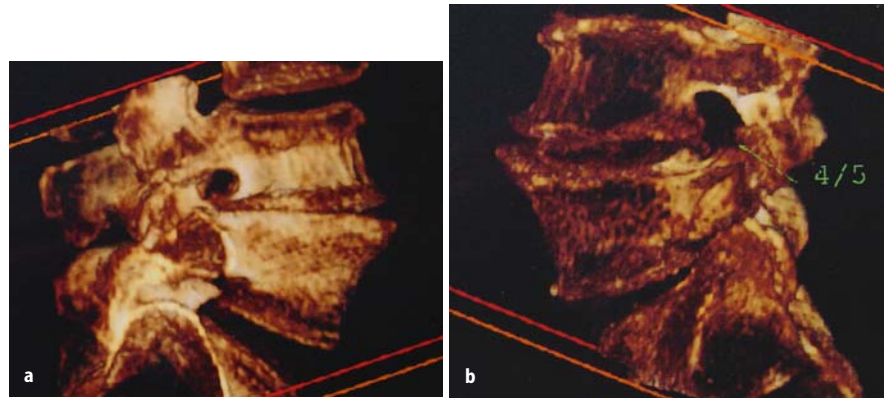


Fig. 1.5. Three-dimensional color-coded CT scan showing the three-dimensional extent of a foraminal stenosis at L4-5.
a Foramen L4-5 right side, marked narrowing. **b** Foramen L4-5 left side, normal size

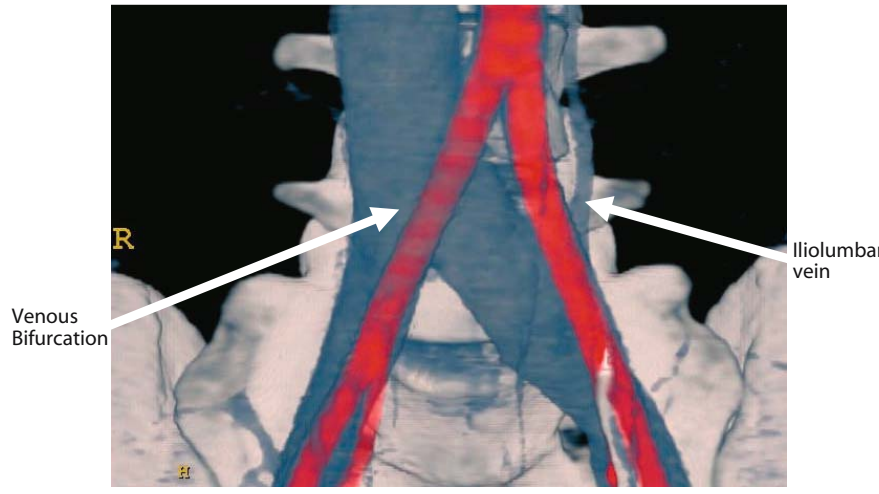


Fig. 1.6. Three-dimensional color-coded CT scan showing angiography of the retroperitoneal, prevertebral blood vessels in front of the lumbar spine

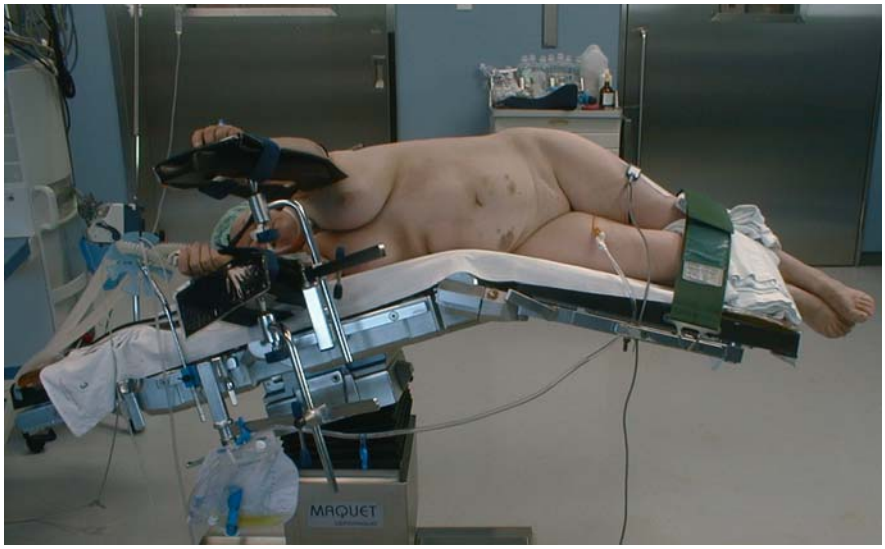


Fig. 1.7. Lateral positioning of patient for anterior lumbar interbody fusion of L2-4. Note: abdominal contents (and abdominal fat) "fall away" from the surgical field by gravity

1.4 Positioning of the Patient

Positioning of the patient can strongly influence the minimally invasive exposure as well as the target surgery. Examples are the lateral positioning and access to the lumbar levels L2-4 for anterior lumbar interbody fusion which eases the access to the spine even in obese patients (Fig. 1.7) or the knee–chest position of patients for lumbar discectomy or decompression procedures which leads to a pressure release in the epidural venous system and thus diminishes the risk of epidural bleeding (see Chapters 32, 44). You will find more examples of "sophisticated" positioning in the following chapters.

1.5 Localization of Skin Incision

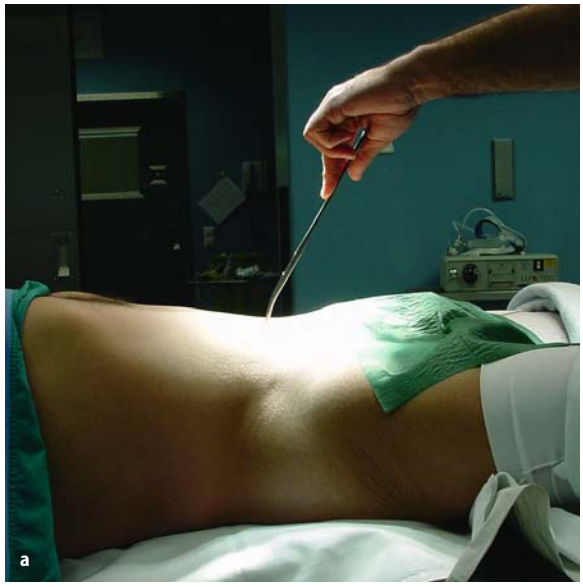
Skin incisions are supposed to be small in MISS. This implies an adequate localization as referred to the target area (Fig. 1.8). In the majority of mini-open techniques, the skin incision is placed directly above the target. In endoscopic techniques, the skin localization of the incision(s) is determined by the intended working direction as well as by the view angles necessary during the operation (see also Chapter 23).

1.6 Surgical Dissection Techniques

The paramount goal of MISS is to minimize tissue trauma. Traditional surgical techniques show striking differences between the surgical dissection and handling of different tissues (e.g., nerve versus bone, muscle versus blood vessel). The increasing knowledge of structure and function of tissues requires a modification of traditional surgical dissection techniques. A muscle or bony structure should basically be treated with the same care as a nerve or a blood vessel. Blunt, muscle-splitting techniques are characteristic for MISS. The use of high-speed burrs instead of large rongeurs can preserve bony structures (see Chapter 44). The individual mobilization of blood vessels can decrease the vascular complication rate (see Chapter 43). The use of hemostatic agents in spinal canal surgery can reduce the risk of epidural hematoma. The microsurgical closure of the annulus fibrosis is supposed to promote the low healing potential of this structure (see Chapter 32).

1.7 Instruments and Implants

Minimally invasive spine surgery is not possible without optical aids. Light and magnification are needed to illuminate and visualize the surgical target in the depth of the human body through small skin incisions. The minimum requirement is provided by headlamps and loupes. The surgical microscope and/or endoscopes are helpful or mandatory for certain techniques (see Chapters 2, 9, 10, 12, 20 – 23). Surgical instruments need to be bayonet-shaped and/or long enough to bridge the distance from the skin to the target. The branches of instruments for electrocoagulation must be isolated to avoid tissue damage in the access region (see Chapter 4). One of the major challenges for the future will be the development and improvement of instruments and implants which allow for intraoperative spinal manipu-



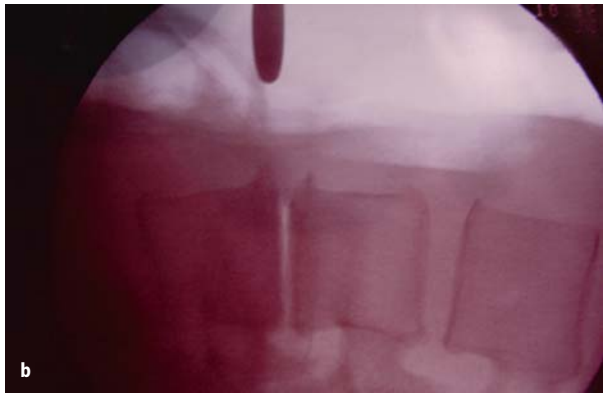


Fig. 1.8a, b. Localization of skin incision for total lumbar disc replacement of anterior interbody fusion

lation (reduction, correction) and fixation. Last but not least, tubes or frame-type retractor systems are mandatory to keep the surgical corridor open (see also Chapters 4, 15, 21, 22, 31, 36, 37).

1.8 Summary

Minimally invasive techniques are currently applied in large variety of spinal surgical procedures (Tables 1.3, 1.4). Surgical invasiveness has been minimized mainly for surgical accesses but not for target surgery. Despite different techniques there are general principles which have to be considered. Only with preoperative planning, the (educational) elaboration of a surgical strategy, the thorough knowledge of the patient's individual-anatomy, the respect of the anatomy, properties, and function of tissues, and the well-trained use of modern surgical high-tech equipment will there be an improvement in peri- and postoperative morbidity and clinical results for our patients.

Table 1.3. Application of minimally invasive techniques in anterior spine surgery

Lumbar spine	**Cervical spine**
Mini-ALIF	Uncoforaminotomies
Nucleus replacement	Discectomy
Total disc replacement	Total disc replacement
Fractures/tumors	SS Decompression
Spinal canal decompression (Instrumentation)	Fractures
	Tumors
Anterior extraforaminal decompression	Vertebral artery decompression
Thoracic spine	
Disc herniations	

Table 1.4. Application of minimally invasive techniques in posterior spine surgery

Lumbar spine	**Thoracic spine**
Disc herniations medial/paramedian/intra/extraforaminal	Costotransversectomy
Spinal stenosis (central/lateral)	**Cervical spine**
Foraminal stenosis	Foraminotomies
Synovial cysts	Craniocervical junction – decompression
PLIF/TLIF preparation	Laminoplasty
Disc excision in severe spondylolisthesis	

2 Technological Advances of Surgical Microscopes for Spine Surgery

W. Rulffes

Minimally invasive spine surgery is not limited to small skin incisions. There should also be as little tissue and structural damage on the way to the target and in the target area as possible. Microsurgical instruments and surgical microscopes provide considerable advantages in accomplishing this feat.

2.1 History of the Surgical Microscope

The first surgical microscope with selectable working distance and coaxial illumination, the OPMI Vario from ZEISS, was introduced for ENT surgery in 1953 (Fig. 2.1). It truly pointed out the way to the future. The triumph of the surgical microscope also aroused the interest of surgeons from other disciplines. By the mid-1960s, the microscope was used in intracranial vascular surgery. Since the middle of the 1970s spine surgery pioneers such as Caspar [1], Yasargil [5], and Williams [4] were the first to perform microsurgical procedures on the lumbar region with the aid of a microscope. Since then, surgical microscopes have become an integral part of spine surgery.



Fig. 2.1. The OPMI Vario surgical microscope

2.2 The Surgical Microscope

Effective spine surgery requires a dedicated microscope which must fulfill a variety of criteria. When deciding on a microscope for spine surgery, most of the following aspects need to be considered to select a system that can be used for most of the minimally invasive procedures.

2.2.1 Optical System

Modern microscopes for spine surgery feature the stepless, motorized adjustment of the focal plane, which enables surgeons and their assistants to work in a comfortable position throughout the entire operation. The compact design of the microscope and good placement of the handgrips reduce the danger of colliding with longer instruments. Apochromatic optics and high-quality zoom systems guarantee excellent resolution.

The necessary standard accessories for microscopes include:

1. A symmetrical stereo bridge to deliver identical images to surgeons and assistants – an absolute must in surgery.
2. Two binocular tiltable tubes in conjunction with rotatable adapters for the surgeon and assistants, which allows observers to adjust the viewing angle to their needs depending on the position of the microscope.
3. The interpupillary distance on the tiltable tubes must be adjustable to the individual surgeon.
4. When necessary, the depth of field can easily be increased by the surgeon using a double iris diaphragm.
5. Eyeglass wearers can set their prescription on the microscope eyepieces.

2.2.2 Illumination System

Homogeneous and coaxial illumination is required when surgeons, particularly in spine surgery, perform procedures in small, narrow and deep channels. Xenon illumination with a color temperature and spectrum resembling daylight conditions is the standard currently in use. It allows recognition of even the finest differences in tissue and color.

2.2.3 Suspension System

The demands placed on a suspension system (Fig. 2.2) in spine surgery are very high. Not every suspension system is designed for spine surgery. Several key points must be addressed:

1. The only free space for a microscope in the operating room is behind the surgeon. The suspension system must therefore have sufficient headroom.
2. Long reach and mobility determine how well a microscope can be used.
3. Contraves or free-floating systems that use weights for counterbalancing can be moved effortlessly.
4. Rotatable handgrips enable microscope operations from the co-observation position.
5. A touchscreen and display facilitate operation. All parameters should be savable in a programmable user menu.
6. A fast autofocus system allows surgeons to concentrate on the procedure and not on operating the microscope.
7. Programmable handgrips enable the surgeon to control the autofocus, digital camera, or video recorder. An additional person is no longer needed.
8. Most functions on a suspension system can also be controlled via the foot control panel.

2.2.4 Video Systems and Documentation

Video systems for presentations and documentation are also very necessary (Fig. 2.3). In general, high-resolution 3CCD cameras are used. They are usually integrated into the microscope system. The entire team can follow the procedure on a video monitor, which generally has a very positive effect on the surgical workflow. Digital video sequences or still shots can be created for presentations or documentation. When photographs



Fig. 2.2. The OPMI Vario/NC 33 system from ZEISS



Fig. 2.3. Digital video recording

are needed, 35 mm or digital SLR cameras can also be connected to the microscope. The cameras are triggered via a programmable handgrip on the microscope. High-resolution pictures from the sterile field can be easily captured.

2.3 Advantages

The advantages of surgical microscopes in spine surgery are obvious (Fig. 2.4) and follow a basic tenet of surgery: "The more you can see, the better you are able to treat." Surgeons have a high degree of safety and control thanks to perfect visualization during the entire procedure. Good illumination and variable magnification enable improved recognition of anatomical structures.

Additional highlights when working with microscopes are:

1. Three-dimensional magnification.
2. Coaxial illumination.
3. Easier differentiation of tissue types.
4. A comfortable working position.
5. A particularly short learning curve. Surgeons become familiar with the microscope after only a few procedures.
6. Almost no interference with other surgical devices in the OR.
7. Particularly suitable for training purposes.
8. No additional microsurgical instruments are needed.
9. Autofocus systems simplify work. Surgeons can concentrate more on the operation.
10. Reduction of the interpupillary distance from 65 mm to 22 – 28 mm enables smaller entrances.

Smaller surgical incisions reduce trauma. Faster operations and shorter rehabilitation times lead to shorter hospital stays. Microscopes contribute to the reduction of overall costs.



Fig. 2.4. Spinal microsurgical approach

2.4 Disadvantages

Experienced surgeons have proved on a daily basis that microscopes have no real disadvantages in minimally invasive spine surgery [3].

Surgeons can quickly learn how to operate a microscope under expert supervision within the framework of fellowship programs, or other special training courses. However, there are a few points to consider:

1. Detailed planning of the surgical procedure is required as the visible field can be reduced to as little as 1 cm^2 depending on the magnification. Good recognition of anatomical landmarks is required [2].
2. At the beginning of using a microscope inexperienced surgeons often have difficulty with hand–eye coordination.
3. As the visual area is limited, the microscope must often be repositioned to eliminate the problem of blind spots and concealed areas.
4. Personnel may have some difficulty with the sterile draping in the beginning, but after only a few procedures this process becomes routine.

On closer examination it becomes clear that most of the disadvantages of a surgical microscope can be directly traced to the experience of the surgeon. As a rule, these disadvantages can be quickly and easily overcome by learning microsurgical techniques in training or hands-on courses headed by experienced instructors.

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3 Spinal Microsurgery

A Short Introduction

H.M. Mayer

3.1 Terminology

Microsurgery means, by definition, to perform surgery with the help of a surgical microscope or other tools (e.g., loupes) which can magnify and illuminate the surgical field. Microsurgery does not mean doing non-microsurgical procedures with the help of small or microsurgical instruments.

3.2 Surgical Principle

Microsurgery not only means working with the help of a surgical microscope. One of the major advantages lies in the possibility to perform operations through small skin incisions ("keyhole surgery"). This needs meticulous preoperative planning, exact positioning of the patient, and reliable localization of the surgical target area in projection to the entry level on the skin surface. All these factors contribute to the "microsurgical philosophy" which realizes one of the major principles in surgery: to perform the most efficient operation with minimum iatrogenic trauma.

3.3 History

The surgical microscope was introduced in the mid-1950s and was first used in specialties such as hand surgery, ENT, and neurosurgery. The pioneers who proposed its use and proved its usefulness in spine surgery were Caspar (1977), Yasargil (1977), and Williams (1978) who were the first surgeons to perform microsurgical approaches for the treatment of lumbar disc herniations [1, 3, 5]. Since the middle of the 1980s, microsurgery has gained more acceptance among spine surgeons. There is now a broad spectrum of possible indications which have been summarized recently by McCulloch and Young [2, 4].

3.4 The Surgical Microscope

A variety of surgical microscopes are currently on the market. For spine surgery, the equipment should fulfill the following criteria

3.4.1 Optical System

- Objective lens with a focal length of 300, 350, or 400 mm. These lenses are available separately, however, the newer microscope models allow for variable adaptation of the focal length (e.g., Zeiss Vario NC 33; Fig. 3.1).



Fig. 3.1. Surgical microscope OPMI Vario NC 33 by Zeiss

- At least two binocular tubes (surgeon, assistant) with adjustable eyepieces.
- One camera tube for documentation.
- Adjustable interpupillary distance.

3.4.2 Illumination System

- Xenon light source. This is the best possible light source with the highest intensity and the longest life span.

3.4.3 Control systems

- For spine surgery, control of the position, focus, magnification, and working distance can be performed via handpieces (Fig. 3.2) or foot switches. With the use of foot switches, the surgeon can continue the operation while simultaneously adjusting the microscope.
- Modern microscope models allow for independent correction of zoom, focus, and magnification by the surgeon as well as by the assistant (Fig. 3.3).



Fig. 3.2. Adjustment of microscope position, focus, magnification, and working distance with the handpiece

3.4.4 Stands

- Electromagnetic coupling of the microscope to its stand is the most advanced principle. It has the advantage of free movement simultaneously in all axes. However, for spinal microsurgery a standard stand can be sufficient (Fig. 3.4).



Fig. 3.3. Vis-à-vis position of surgeon and assistant. Independent control of focus



Fig. 3.4. Standard stand for microsurgical operations on the spine

3.4.5
Video Technology and Documentation (see also Chapter 5)

Documentation for medicolegal as well as for scientific reasons has become easier with the use of microsurgery. It is strongly recommended to couple a video system (chip-camera, video screen, video recorder) to the microscope. This enables the surgeon to document the significant steps of an operation. To achieve the best quality, we propose the use of 3-chip digital cameras as well as a professional video-recording system (e.g., Betacam). For rapid documentation of intraoperative findings, a video color printer can be helpful (see also Chapter 2).

3.5 Advantages

The technical advantages of the surgical microscope are obvious:

- Simultaneous illumination and magnification of the surgical field
- Variable adjustment according to the surgical topography
- Coaxial projection of light
- Three-dimensional-like image
- Sufficient focus depth even with higher magnification

These technical advantages lead to a number of surgical advantages:

- Discipline in surgical planning and positioning.
- Gentle, careful, and less traumatic surgical preparation.
- Surgical training: since the assistant always has the same view of the surgical field, assistance as well as education is more efficient as compared to microsurgical preparation e.g., with loupes.
- Smaller skin incisions and less traumatic approaches decrease peri- and postoperative morbidity and discomfort for the patient.
- In spine surgery this directly results in shorter hospitalization, shorter rehabilitation periods, and thus decreased overall costs.
- Although this is not the strongest argument for microsurgical techniques, the favorable cosmetic result due to smaller skin incisions should not be overlooked.

3.6 Disadvantages

In my opinion there are no true disadvantages of the use of a surgical microscope in spine surgery. However, there are some objections which might depend on the surgical training, the acquired surgical philosophy, as well as the age and experience of the individual surgeon:

- The visual field is limited. This is one of the difficulties which is faced by the surgeon at the beginning of his individual learning curve. The visible area is limited; depending on the magnification

and focus depth this can be an area of less than 1 cm^2. In deep approaches (e.g., transthoracic, retro- or transperitoneal anterior approaches), the "approach track" is not visible after having entered the target area. This requires surgical discipline in order to avoid direct or indirect injury to structures along the way to the target area. It also requires meticulous preoperative planning and detailed knowledge of topography anatomy. For example, in cervical or lumbar disc surgery as well as in anterior approaches to the thoracic and lumbar spine, orientation concerning the right level is not always possible intraoperatively. Since wrong level exploration belongs to the most frequent mistakes in microsurgical approach to the spine it is recommended to routinely use the fluoroscope or computerized navigation techniques (see also Chapters 4, 5).

- Magnification of approach and target area. The surgeon has to be familiar with microanatomic landmarks. This affords a detailed preoperative evaluation of MR images which provide the surgeon wit sufficient information. Spinal microsurgery is not "go-and-see" surgery.
- Visual axis. One of the difficulties beginners are faced with is the adaptation of the visual axis to the axis of the approach as well as to the area of pathology. If the visual axis is not adjusted in parallel to the "approach tunnel," the target area might be obstructed by the surgeons hand or instruments introduced into the surgical field. Especially in approaches which are oblique to the skin surface, the microscope tilt has to be adjusted.
- Hand-eye coordination. This usually is the major problem for surgeons not trained in the use of the microscope. Be patient! It only takes a few hours of practice until correct hand–eye coordination is achieved.
- Adjustment of focus. In non-microsurgical procedures, the eyes of the surgeon adjust to the depth of the surgical field. In surgical approaches deep into the human body, permanent adjustment of focus depth is necessary. This can easily be achieved with the help of the foot switch without interrupting the surgical preparation.

The critical reader might notice that all these "disadvantages" are obviously associated with the "learning curve" of the individual surgeon. However, they can best be avoided by surgical education and discipline which leads to a more sophisticated and safer kind of surgery. In fact there are no "real disadvantages" of the application of microsurgical techniques in spine surgery.

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4 Microsurgical Instruments

A. Korge

As in all surgical fields, an enormous tendency has occurred recently toward minimizing both surgical procedures as well as surgical approaches. The reasons for miniaturized approaches include a reduced infection rate due to shortened skin incisions, less cosmetic alterations, as well as the fact that in the majority of cases, small and localized pathologies only need small and limited approaches. In addition, small incisions need less time for wound closure, thus reducing the overall time of surgery [4].

This tendency is also found in spine surgery with an increasing shift from macrosurgery to microsurgery [1, 2, 3, 5]. Microsurgery has become quite popular, especially in surgical procedures within the spinal canal [3], and has been established within recent decades basically due to the development of efficient optical aids such as powerful and effective surgical microscopes which are being continuously improved. However, the use of microscopes in spine surgery delivered a new intermedium between the surgeon's eye and the operating field, thus influencing simultaneously the individual visual axis between the surgeon's eye and his hands. Therefore, the surgeon's line of vision was restricted and the field of vision became smaller and limited. In addition, the line of vision of a microscope is perpendicular to the surgical area to be operated on. Consequently, the configuration of surgical instruments had to be modified (e.g., bayonet-shaped), as well as their basic dimensions (e.g., smaller and longer), in order to fulfill the specific requirements of microscope-assisted surgery.

Depending on the anatomical area and the number of segments being approached, surgery can be started with either microscopic or macroscopic techniques. Usually, mono- or bisegmental pathologies on the lumbar spine (disc herniation, lumbar spinal stenosis) can be done by a skin-to-skin technique with microscope assistance from beginning to end. In multisegmental decompression surgery, for example due to lumbar spinal stenosis, initial macroscopic preparation down to the interlaminar windows and subsequent use of the microscope might save time.

4.1 Classification of Instruments

Instruments for spinal microsurgery can usually be divided into two major groups:

1. The first group is especially related to the approach from the skin down to the spinal canal, including skin opening, traversing soft tissue subcutaneous, transfascial, and paravertebral to the interlaminar window, and entering the spinal canal.
2. The second group is related to surgical procedures within the spinal canal and within the intervertebral disc space.

Some instruments are effective in both groups (cautery, high-speed drills, suction devices), as is mentioned later on.

4.1.1 Instruments Related to the Approach

4.1.1.1 Instruments for Wound Opening

There is basically no big difference between microscopic and macroscopic instruments for opening the skin even when using the microscope from the beginning. Standardized incision scalpels serve to open the skin and to traverse the subcutaneous tissue. Forceps of standard size and length can be used for skin and tissue retraction, however, delicate forceps such as Adson forceps are more comfortable under microscope assistance.

Self-retaining wound retractors with sharp or blunt teeth keep the wound open. Long lever arms with long branches are troublesome and would not meet the requirements of a minimized approach. They should be replaced by smaller skin retractors such as the most popular rigid Weitlaner self-retaining wound retractor with limited length of the branches (130 mm) and sharp short blades (length up to 20 mm) which can be used for mono- and bisegmental pathologies. Curved and flexible retractors exist. However, they are not essentially required routinely when using small skin incisions. With longer incisions in multisegmental pathologies, longer self-retaining retractors might be useful.

The fascia can be opened in a curved line with standardized curved surgical scissors such as Metzenbaum-type scissors. Subfascially, the paravertebral muscles and ligaments are prepared and detached from the lamina by either sharp dissection using a sharp periosteal elevator or by blunt dissection using a blunt (Langenbeck) retractor with bipolar coagulation and dissection by normal or microscissors. When placed close to the immediate working area, the manually guided retractor also helps to keep the working channel open and facilitates, later on, the insertion of other retractors or specula. The use of a Cobb periosteal elevator is possible; however, when starting surgery immediately with the assisting microscope, the Cobb is usually in the surgeon's line of vision due to its long handle (standard length 290 mm).

When the interlaminar window is reached, the remaining soft tissue debris can be removed by bayonet-shaped rongeurs with blunt ends. Standard soft tissue rongeurs as well as bone rongeurs are less helpful due to their long arms.

4.1.1.2 Retractor Systems

A working channel is created which has to be kept open during most of the remaining surgical procedure. Therefore, effective self-retaining soft tissue retractor systems are required which have to fulfill certain requirements:

- The retractor has to keep away the mobilized soft tissue, such as paravertebral muscles, laterally as well as cranially and caudally while stretching the skin as little as possible.
- The retractor should retract surrounding soft tissue as atraumatically as possible and avoid injuries to the adjacent muscles.
- The retractor has to fit exactly into the wound and should not stand higher than the skin level in order to avoid interference with the surgeon's activities.
- The retractor has to fit the different sizes of patients, especially the distance from skin to the interlaminar window, thus requiring a modular length.
- The retractor should be covered with a black-coated surface in order to reduce reflection of artificial light sources.

Retractors can be articulated or rigid in the form of a frame retractor. Articulated retractors are available for monosegmental up to multisegmental approaches. Self-retaining retractors with ball snap closures with torsion locks consist usually of a single medial hook being placed predominantly between the spinous processus right on top of the interlaminar window being approached. According to the number of levels to be operated on, lateral blades of different length and width are adapted to the assembly (Fig. 4.1).



Fig. 4.1. Articulated retractor for mono-, bi-, and multisegmental pathologies on the entire spine with hook and different blades and key

A versatile frame retractor set for mono- and bisegmental lumbar pathologies is the Caspar Micro Lumbar Discectomy Retractor set (Fig. 4.2). It consists of a speculum retractor with different lengths of the valves (40 – 85 mm) and has a black-coated surface. A non-slip fenestrated configuration of the speculum valves guarantees a secure fit in the muscles. A lateral black-coated blade keeps the paravertebral muscles apart and is adapted to the assembly by a black-coated counter-retractor with a ball snap closure with torsion lock. Lateral blades exist in different lengths from 35 to 85 mm. As no medial hook or blade is necessary, any intraspinal ipsilateral and contralateral "over-the-top" procedures, such as contralateral decompression of a bilateral spinal stenosis from a monolateral approach, can be performed without impairment. Also, with this speculum retractor, special blades with black-coated surfaces (length 40 – 70 mm) are available for extraforaminal



Fig. 4.2. Caspar Micro Lumbar Discectomy Retractor set consisting of a speculum, a counter-retractor, and a lateral blade (all parts black-coated)

pathologies that require paraspinal intermuscular approaches such as a miniaturized Wiltse approach.

When approaching the spinal canal, soft tissue (posterior approaches: ligamentum flavum; anterior approaches: ligamentum longitudinale posterius) always has to be removed. In addition, bony structures, such as cranial and/or caudal hemilaminae adjacent to the corresponding segment, must be taken away quite often.

For perforation of the yellow ligament, blunt dissectors of different sizes, ranging from small to large, are available. Since the yellow ligament consists of two layers, a separate removal of each layer is possible thus giving a safer approach to the neural structures within the spinal canal. Bayonet-shaped handles are helpful.

4.1.1.3 Punches

The removal of the ligamentum flavum from the adjacent hemilamina itself is sometimes done with the use of forceps and a scalpel or with curettes. Both are sharp instruments which can sometimes slip away and, therefore, punches are preferable due to better manual control. Nowadays, the most widely used is the Kerrison punch (Fig. 4.3) and is available in different cup sizes (2 – 6 mm for the lumbar spine, 0.6 – 2 mm for the cervical spine) and different lengths (180 – 230 mm). With punches of different cup sizes at the table, one has to make sure that the shaft length is homogeneous in order to avoid change of the distance between the working hand and the spinal canal. The handle should be small for good ergonomic function. A horn at the handle helps to guide the punch single-handed easily in all directions. Ring handles are no longer popular due to functional impairment. An upward position of the jaw with an angulation of 130° is recommended. Punches with a footplate position of 90° will interfere with the surgeon's line of vision and are, therefore, less favorable when using a microscope. Downward position of the jaw with an angulation of 130° is also available. However, due to the forward working direction that most surgeons are familiar with, upward position of the jaw makes more sense. In cases of pathologies being placed "behind" the punch, it is easy to turn around an upward-directed jaw and work backhandedly, thus avoiding a change of instruments. Kerrison punches occur with standard footplates and special thin footplates, the latter being helpful, for example, in cases of severe narrowing of the spinal canal in order to reduce compression of neural structures during the initial bites. When removing soft tissue such as ligamentum flavum with a punch, grasping the tissue and performing a stripping motion is safer than taking full bites. Only small bites should be done in order to avoid or diminish the risk of large dural tears. Especially within the spinal canal, one has always to be aware that the cup has three sharp biting parts (anterior and bilateral). Therefore, it is helpful to keep the footplate if possible parallel to the neural structures. Working in the spinal canal with the footplate parallel to the posterior vertebral wall has the potential risk of a lateral dura laceration.

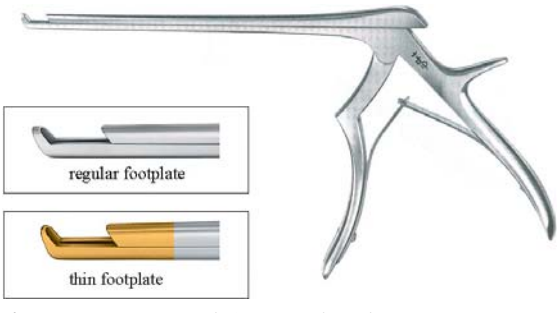


Fig. 4.3. Kerrison punch (200 mm length, 4 mm cup size, 130° jaw position upward) with regular and thin footplate version

4.1.1.4 High-speed Drills and Burrs

Quite often removal of bone becomes necessary. Important tools used to enter the spinal canal and to enlarge the spinal canal are high-speed drills which perform quick and precise dissection of bone structures. High-speed drills guarantee flat smooth surfaces without edges and spurs! In addition, drilling causes some thermal surface treatment with a resulting increase in hemostasis. With the ligamentum flavum being still in place or having only its external layer removed, enlargement of a small interlaminar window can be achieved by modified (usually cranial) hemilaminotomy in a safe manner without the risk of damaging intraspinal structures. However, even if the spinal canal is opened, high-speed drills might serve to remove bone and to smooth bony surfaces. Thus, when performing microscope-assisted over-the-top techniques for bilateral decompressive surgery in spinal stenosis using a monolateral approach, high-speed drills can be used for modified inner laminoplasty and both ipsilateral and contralateral modified partial facetectomy.

A number of different high-speed drill systems for microsurgical procedures are on the market. Differences exist in the infinitely variable speed (revolutions per minute; rpm) ranging from 10,000 rpm up to ultra high speed systems with 90,000 rpm and more. Activation of the motor occurs by hand or by foot. Using foot activation, the surgeon's working hand with the drill is free for any maneuver required, which is advantageous especially to younger and less trained spine surgeons. Control of the motor should always belong to the surgeon, in order to act immediately and properly in unplanned situations. The handpiece can be angulated or



a



b

Fig. 4.4. a Electronic high-speed motor system Micro Speed EC with angular microhandpiece. **b** Different cutting and diamond burrs: from *left* to *right* cylindrical burr, conical burr, Rosen burr, diamond burr

straight; however, angulated versions are more useful when using the microscope.

Besides other factors, pneumatic high-speed systems need a gas supply and generate a high noise level which is often uncomfortable and unsatisfactory. As an alternative, electronic high-speed systems with remarkable speed and electronic control exist, such as the recently released electronic high-speed motor system Micro Speed EC (Fig. 4.4a). Through microprocessor control, high-speed dissection using up to 75,000 rpm and continuous power is possible. Very quiet operation is guaranteed by the vibration-free micromotor for concentrated and precise work, and fatigue-free working due to the low weight of the micromotor. An integrated cooling and irrigation system for controlled irrigation of the operating area is responsible for a clear view and the removal of heat.

Many different burrs exist for both aggressive and subtle removal of bone (Fig. 4.4b). Cutting burrs, whether of conical or cylindrical configuration, or ball-shaped such as Rosen burrs, serve to remove hard cortical as well as cancellous bone. Due to their sharpness, these cutting burrs should not be used in the spinal canal because of the risk of tearing soft tissue which wraps around the burr. Drilling near more delicate anatomical structures, such as nerves, the dura, or vessels, requires less aggressive burrs such as diamond burrs. In the case of contact with soft tissue, diamond burrs affect and harm it only punctately. All types of burrs are available in different sizes.

4.1.1.5 Irrigation and Suction

When using a high-speed motor system, continuous irrigation is mandatory especially in order to avoid or minimize local mechanical hyperthermic reactions such as unplanned thermal coagulation. Continuous irrigation is possible by the assistant using a simple syringe with an adapted blunt irrigation cannula and continuously dropping irrigation solution onto the drill. More elegantly, the drill can be supported with a spray nozzle adapted directly to the handpiece. With an integrated cooling system, continuous electronically controlled permanent irrigation (with variable irrigation flow speed) is performed.

Simultaneously with permanent irrigation, the removal of the injected fluid is mandatory by continuous suction. Suction instruments preferably have a finger cut-off to interrupt suction immediately when for example neural structures become adhered to the suction device. Angulated suction devices again avoid interference with the surgeon's line of vision. Different diameters and lengths of suction devices are available, thus taking the anatomical preconditions (e.g., intervertebral cervical anterior approach, extreme narrow lumbar spinal canal) into consideration. Stylets to clean obstructed suction instruments should be at hand in any required size. Combined suction–irrigation cannulas exist and maybe helpful when high-speed drills without adapted spray nozzles are used. However, since suction is most effective at the bottom of a hole and drilling might require irrigation at a different area, the effect of combined suction–irrigation devices is limited. Suction instruments can be used not only for the removal of any fluid at the operating field, but also for blunt mobilization and dissection of soft tissue as well as for retraction of soft tissue such as the dura or nerve roots. Thus the space for the high-speed drill in the spinal canal is enlarged. Care must be taken as the tip of the suction device may become sharpened, like a knife, by repetitive grinding contacts with the burrs. At this stage, an additional unplanned "cutting instrument" acts in the spinal canal which can easily lacerate neural structures.

4.1.2
Instruments Related to Surgical Procedures Within the Spinal Canal and the Disc Space

A large variety of instruments exist to perform surgical steps in the spinal canal. As mentioned above all different kinds of punches as well as a high-speed drill system with diamond burrs can be used.

4.1.2.1
Dissectors, Hooks, and Manual Retractors

Exploration of the spinal canal and mobilization of fat tissue, nerves, epidural vessels, and others is routinely done with blunt dissectors. Penfield and Freer dissectors are popular; however, due to the long arms, especially when double-ended, this type of dissector might interfere with the surgeon's line of vision. More usable are Caspar microdissectors with a bayonet shape which can be curved downward or upward. The standard length of these dissectors is from 190 to 230 mm. Especially in revision surgery, dissectors might be helpful to mobilize adhesions and to find borderlines in between intact neural structures and scar tissue formations.

Blunt rectangular exploration hooks, with a probe end having different tip lengths, are helpful when exploring the spinal canal and searching dislocated and misplaced structures such as herniated free disc fragments. Curved exploration hooks serve to examine and to reach into the neuroforamina. Exploration hooks can also be used for the mobilization of adhered tissue layers, for example between the posterior longitudinal ligament and the anterior circumference of the dura, if mobilization with dissectors is impossible.

In the majority of cases, intraspinal procedures can be carried out by the surgeon alone with one assisting hand (usually the non-dominant) and one working hand (dominant). Therefore, complete control of all activities within the spinal canal are restricted to the surgeon alone. Sometimes additional help is required, for example if enlargement of the approach is necessary to localize epidural bleeding with one hand using the suction tip and the other one using a high-speed drill. Then, protection and retraction of soft tissue and neural structures is carried out by the assistant using a nerve root retractor. An angulated version of nerve root retractors, as presented in the form of the well-known Love retractors or the Caspar retractors, is mandatory to keep the surgeon's working line of vision free. In accordance with their requirements, all nerve root retractors show a blunt downward-curved intraspinal end. As a comment, we do not use this device routinely due to the fact that its size usually is much larger than the size of a blunt probe. In addition, after being placed a nerve root retractor delivers continuous pressure toward the neural structures, whereas retraction controlled by the surgeon himself can be released occasionally whenever it is possible.

To open the intervertebral space, a bayonet-shaped microknife is helpful. The microknife cutting blade should face downward, but for certain anatomical situations, it can also be mounted in a way that it faces laterally. Thus, one can avoid uncontrolled invisible cutting due to an obstructed view by the scalpel handle. When initially using macroscopic control in a minimally invasive approach with short skin–vertebra distance, as routinely done in anterior cervical spine surgery, a straight knife can also be used. It is obvious that the cutting process should always be carried out away from the neural structures in order to avoid damage.

4.1.2.2
Rongeurs, Osteotomes, and Curettes

With the intervertebral space open, rongeurs for soft tissue disc removal are the instrument of choice. Rongeurs may differ in both the width and the angulation of the jaw (Fig. 4.5). According to the disc level being approached, widths between 2 mm (cervical) and 6 mm (lumbar) are in use. The jaw itself can be smooth or serrated. An up-biting straight forward jaw is the most popular rongeur. Up-biting and down-biting angulated rongeurs are available in various sizes, and the angulation can vary between 130° and 150°. Depending on the surgeon's routine, continuous working with the up-biting angulated jaw in the required direction and if necessary turning the rongeur around is helpful. Otherwise changing the working direction of the angulated jaw would require frequent changes of instruments.

When using rongeurs in the intervertebral space, the jaw always should be kept closed until it has passed the neural structures in order to avoid neural tissue damage. Some rongeurs have a depth guard showing the surgeon the depth reached intervertebrally. Without such a depth guard, as a rule, a rongeur should not be inserted into the lumbar spine deeper than the double distance of the jaw length. Otherwise, damage to pre-

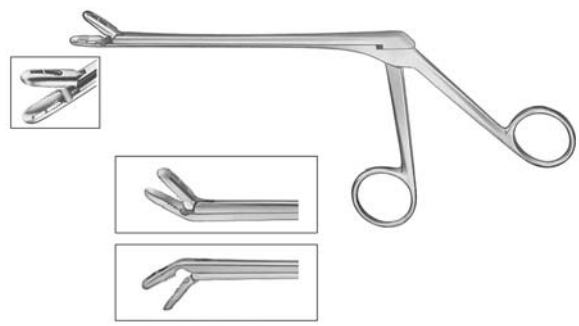


Fig. 4.5. Caspar rongeurs with straight forward up-biting as well as 150° angulated up-biting and down-biting jaws (length 160 mm, jaw size 3 mm)

vertebral structures is possible. When working with an up-biting angulated rongeur, be aware of the potential risk of lacerating the dura from the anterior! The use of rongeurs of different shaft lengths within the same surgical intervention might lead to a disorientation of the depth already gained and therefore should be avoided.

For bony pathologies within the spinal canal, such as calcified intraspinal disc herniation as well as retrospondylar osteophytes, stronger instruments than standard rongeurs are required. Removal can be achieved by either heavy duty rongeurs or bone punches. Sometimes, small osteotomes serve to chisel away these hard tissue formations. In cases of intraspinal bone cement formation, misplaced and unplanned due to posterior leakage into the spinal canal following vertebroplastic procedures when stabilizing vertebral bodies, small osteotomes might be the only effective instruments. Osteotomes are also helpful for thinning the lamina from inside, as in a modified partial inner laminoplasty, when performing a bilateral over-the-top decompression in lumbar spinal stenosis through a monolateral approach. Microscope control of the chiseling procedure is then mandatory to avoid damage to the dura.

Endplate treatment in the intervertebral disc space can be carried out by the use of slightly angulated small curettes which are usually toothed with a square-shaped mouth. Straight or angled scoops in different sizes help to remove the cartilaginous endplates if necessary. Only bimanually guided controlled forward curetting should be performed to avoid any slippage out of the intervertebral space with the potential risk of harming surrounding anatomical structures.

4.1.2.3 Microinstruments

Because of the limited space available in the spinal canal, a miniaturization of spinal canal instruments is required. These microinstruments require long handles and springs thus guaranteeing an optimal hold. Bore holes in the handles allow reliable gripping and holding of the instruments which is important for deep surgery. Bore holes also lead to a reduction of the weight of the instruments. Bayonet-shaped configuration of these instruments is even more important when compared to other microsurgical instruments (Fig. 4.6). The average instrument length is from 190 mm up to 230 mm. Micro needle holders and microforceps with fine or broad tips with or without teeth for grasping tissue are mandatory for intraspinal soft tissue repair such as closure of dural lacerations. A suture pusher replaces the surgeon's finger intraspinally when passing down a knot to the sutured structure as deep as necessary. Microscissors are used to dissect coagulated microstructures (e.g., scar tissue close to the dura, epidural vessels, and others).



Fig. 4.6. Microinstruments: from *left* to *right* micro needle holder, microforceps, microscissors, suture pusher (length 225 mm)

Kept closed, microscissors might be carefully used for local preparation as well. Suture material includes 5 – 0 or 6 – 0 suture size directly adapted to a tiny semicircular needle. Absorbable or non-absorbable material is available. Microstaples represent an elegant alternative for closing dural tears. However, they are much more expensive when compared to conventional suture material.

4.1.2.4 Cautery

Finally spinal microsurgery would not be successful without effective adapted cautery. This is enabled by bayonet-shaped bipolar high frequency microprocessor-controlled coagulation forceps. Bipolar coagulation can be used for immediate control of both extraspinal soft tissue bleeding as well as intraspinal bleeding of epidural vessels. Blunt preparation can be performed and assisted by cautery forceps. Different lengths of the forceps are helpful for comfortable adaptation to the operating site depth. A slim and delicate form of the forceps helps to permit fatigue-free and sensitive working. For reduction of tissue adhesions, forceps tips are preferably rounded with polished surfaces. Insulation is guaranteed by double coating of the shaft. Parallel guidance delivers exact contact of the forceps tips. Coagulation forceps which are curved at the end enable sufficient intraforaminal coagulation.

4.2 Summary

The spectrum of spinal surgery is tremendously enhanced by the option of microsurgery. To be successful, both a high-resolution operating microscope and specially configured and adapted instruments are necessary. To reach a perfect result, however, the surgeon has to train his manual abilities by using these tools continuously and consequently accepting an individual learning curve.

4.3 Comment

All instruments in this paper (including retractors and the Micro Speed EC high-speed motor system), presented with permission by the company, are manufactured and distributed by Braun Aesculap, Am Aesculap-Platz, 78532 Tuttlingen, Germany.

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Operating Room Setup and Handling of Surgical Microscopes

5

K. Wiechert

5.1 Introduction

With use of the surgical microscope, some basic considerations have to be taken into account in order to provide precise and comfortable working conditions. Standardization of the setup and of the operating room conditions is therefore highly recommended. The entire nursing team dealing with the microscope should also be carefully trained in order to ensure trouble-free use of the microscope. Many of the mentioned topics may seem basic to some, but they are essential to make microsurgical spine surgery easier, safer, and more comfortable for the surgeon and the entire team [1, 2].

5.2 Room and Microscope Setup

Since the surgical microscope and the video equipment, as well as the frequently used C-arm, are often bulky, the chosen operating room should be large enough to enable comfortable working conditions without increasing the risk of contaminating sterile areas and equipment. The setup of the entire equipment within the operating room should be standardized to facilitate maximum performance by the surgeon and the entire team (Fig. 5.1). The patient and the operating table are usually placed in the center of the room to create enough space for all the equipment and so the airflow mechanisms can take full effect. The surgical microscope, the instrument table, and the video equipment are the key elements to be taken into account. All the equipment has to be placed in such a position that the surgeon has maximum flexibility and is as comfortable during the procedure as possible. The video equipment must be placed in such a way that the scrub nurse has full view of the screen to follow the procedure.

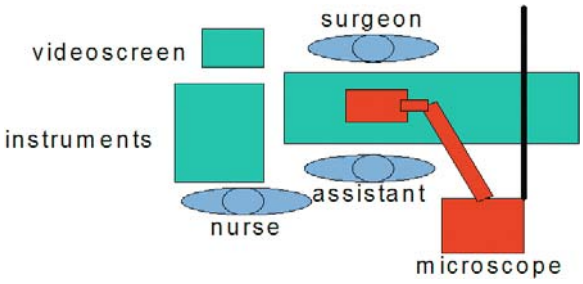


Fig. 5.1. Example of a standard setup in the operating room

Since the surgical microscope plays the key role in performing spinal microsurgery its position in the room depends on the lever-arm construction of the microscope and the joints of the optical unit. If the arms are long enough, positioning the microscope behind the surgeon enables easy handling. Also, if X-ray control becomes necessary during the procedure, the lever arm of the microscope can be tilted upward toward the ceiling or be turned sideways in total to create space for the C-arm without moving the entire stand. If the microscope is ceiling mounted, it should be movable sideways in that particular situation. The joints of the central oculars and handlebars need not be readjusted.

If the arms of the microscope are not long enough to provide comfortable conditions for the surgeon, the entire microscope should be placed on the assistant's side. Since most available microscopes have an asymmetrically constructed optical unit, attention has to be paid to choosing the surgeon's and the assistant's side correctly before draping starts. The surgeon's side is always the one with the closer eye–ocular distance.

The joints of the lever arms should be bent in such a way that the optical unit is midline squared toward the patient, and the surgeon and the assistant have a comfortable working position, especially regarding their head and neck posture.

The height of the table has to be adapted in such a way that the surgeon has his arms at a comfortable 90° flexion position at elbow level.

Immediately before starting the procedure, orientation for the surgeon is facilitated if the final position of the optical unit in regard to the surgical field and the position of the respective motion segment is checked. Any tilt in either plane should be avoided at the beginning, because it may lead to unnecessary dissections in wrong planes and directions, not only but frequently with inexperienced surgeons [2].

5.2.1 Audio-visual Equipment

Standard audio-visual equipment consists of a high-resolution TV monitor and a digital videotape recorder or a DVD recorder. A digital 3-chip camera is mounted onto one of the tubes of the microscope and is connected to the recorder. Documentation of the important surgical steps is facilitated and highly recommended, not only for medicolegal aspects but also to enable the scrub nurse, the anesthesiologist, and the entire surgical team to follow the procedure efficiently and thereby enhance performance. The lighting in the operating room should be dimmed to increase vision in the surgical field by omitting non-focal lighting and reducing diffuse lighting around the oculars, distracting from the surgical field. Dimming also increases contrast of the video monitor [2].

5.3 Microscope Handling

5.3.1 Draping

Usually the draping of the microscope is done by the scrub nurse and the operating room technician. There are several key points which are important during draping for comfortable use of the microscope. Most surgical microscopes have two handlebars on either side of the optical unit. Several buttons allow focusing, zoom, lighting alterations, and movement control in all degrees of freedom. These handlebars should be covered tightly with the drape, allowing proper handling without slipping of the drape or unwanted accidental activation of the controls. The draping starts with the optical lens, which has a tight-fitting ring around it leaving the lens open for maximum optical quality. While the optical unit around the lens remains sterile, the lens itself is uncovered and thereby unsterile. If surgical instruments touch the lens accidentally, they must be immediately removed from the field and sorted out of the sterile environment. The drape, which is usually custom-made for a specific microscope model and available through the microscope manufacturer, is tightened around the joints, allowing full movement of all joints. Attention should be paid to loose folds of the drape over the lever arms that might come in contact with the non-sterile headcover of the surgeon or the assistant. Special attention should also be paid to the oculars. Tight fit of the drape is mandatory in this area. The ends and folds of the drape must not overlap the oculars so the eye contact to the oculars themselves is not obstructed. Minimal microscope drapes that cover only the handlebars and leave the rest unsterile do not fulfill the aseptic requirements of microsurgical spine surgery.

5.3.2 Surgeon's Settings

Since the entire optical unit does not have the lens system in the center of the microscope, it has a surgeon's side and an assistant's side. The surgeon should stand on the side with the shorter eye–lens distance to have a more comfortable working position. The tilt of the oculars and the interocular distance can be adapted as well as the ocular length extensions. Surgeons wearing glasses should choose the shortest ocular length, others should increase it. The tilt of the oculars is frequently readjusted by the surgeon as well as the assistant. Employing an over-the-top technique for microsurgical decompressions with an oblique view and an oblique tilt of the operating table is a classic situation for frequent readjustments of the ocular tilt (Fig. 5.2a, b).

Some microscopes have the option for settings of focus and zoom speed, light intensity, and magnification range. The author proposes a medium zoom speed, quick focus speed, maximum light intensity, and full magnification range. The xenon or halogen light source

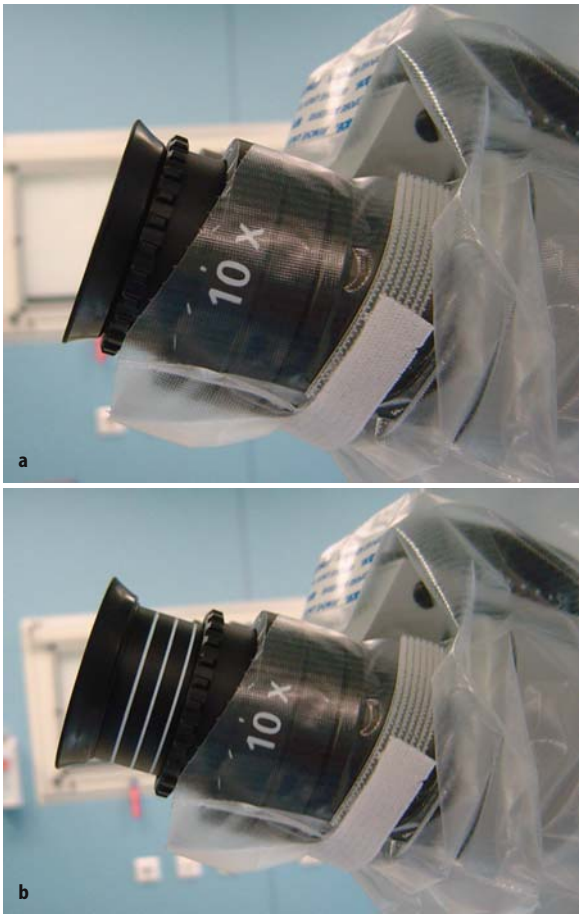


Fig. 5.2. a Short length of the oculars. **b** Long length of the oculars

can provide sufficient lighting within the surgical field only when the alignment of the microscope toward the surgical field is precise and potentially light- and view-obstructing soft tissue is retracted or removed. The lighting blind should be opened to its maximum at the beginning of the procedure and limited to the retractor size as soon as they are placed. The lighting intensity is thereby increased and illumination, especially in deep anatomical structures, is improved.

The handlebars allow for monomanual adjustment of all important settings, especially zoom and focus and the movable degrees of freedom. However, this can only be reached if the entire microscope is balanced correctly. After release of the lock, the microscope must not drop in any direction if it is balanced properly. On microscopes that provide lateral movement of the handlebars, the handle for the surgeon's dominant hand should be tilted upward about 45°. More space for handling of the instruments is obtained.

5.3.3 Magnification

The extent of magnification in a specific situation depends, of course, on personal preference. Generally, the more meticulous the anatomical structures dissected, the higher should be the magnification.

5.3.4 Assistant's Settings

On most models, the surgeon's settings regarding magnification, lighting, and zoom are displayed through the assistant's side as well. However, on some models the assistant has the option of obtaining his own settings of these parameters. A certain degree of magnification below that of the surgeon has proved useful to keep the overview. The individual settings for the oculars and their tilt have to fit individual considerations.

5.4 Transporting the Microscope

Before moving the microscope to another room, all the lever arms have to be bent inward to ensure that the space taken up by the device is minimal. The joints and the footbrakes must be locked as soon as the microscope is in its final position. Often the manufacturer provides an extra cover for the optical unit to prevent dust accumulating, and this should always be used when the microscope is not in the operating room.

The cables connecting to the monitor and the recorder as well as the electrical power cables should be sorted out and kept attached to the microscope to speed up the setup process next time it is used.

The entire microscope should be cleaned daily, and the maintenance of the optical unit and the lenses should be carried out according to manufacturer's guidelines.

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6 Computer-assisted Minimally Invasive Spine Surgery

State of the Art

F. Langlotz, L.P. Nolte

6.1 Introduction

With the advent of precise pre- and intraoperative imaging means, the development of sophisticated image data visualization, and the accessibility of submillimetric, real-time tracking of objects in space, surgical navigation systems have been created that aim at enhanced surgical accuracy and ultimately improved clinical outcome [3, 6, 9, 13, 17, 20]. Numerous studies have shown the superiority of computer-assisted versus conventional instrumentation at different levels of the spine regarding accuracy and thus potential safety [4, 14, 24, 25]. However, this technique has been less successful in contributing to the reduction of intraoperative invasiveness, although this aim has been anticipated by most of the pioneering authors [13, 17, 20]. It is the aim of this article to outline the basic principles of computer assistance for spine surgery, which will help the reader to understand why navigated interventions must be invasive in the first place. In addition, efforts towards less and minimally invasive procedures of the past and current research will be presented and discussed.

6.2 Computer-assisted Orthopaedic Surgery

The idea of computer-assisted orthopaedic surgery is to replay surgical action on a computer monitor in real-time providing a valuable visual feedback to the operating surgeon. This concept is, therefore, comparable to a GPS satellite navigation system installed in a car, which constantly displays the car's location on a street map. In order to generate such feedback during spine surgery three tasks have to be fulfilled by a spinal navigation system: (a) an image or a set of images of the spine has to be provided serving as the "map" of the patient, (b) the spatial location of all important instruments has to be measured constantly in three dimensions and in relation to the operated bone, and (c) the relative instrument position has to be transferred into image space to enable visualization at the correct location.

6.2.1 Image of the Spine

Theoretically, any two- or three-dimensional image of the spinal anatomy may be used as the "patient map". However, the need to display the bony structures clearly and to process the image data digitally by computer software made preoperative CT scans and intraoperative fluoroscopic images the modalities of choice in current navigation systems. Preoperative imaging allows for careful inspection of the clinical problem to be treated as well as for precise planning of the intended intervention. On the other hand, relying upon preoperative CT scans for navigational feedback may be non-optimal when the corresponding shape of the operated vertebra is about to be altered considerably during the operation, for example, in cases of tumour removal or fracture reduction. Moreover, a suitable digital dataset in the form of a preoperative CT scan may not be available, and the irradiation that goes along with a new CT acquisition may not be justifiable for a particular case. Intraoperative fluoroscopy may be used as alternative imaging in these situations. This technique allows to capture conventional fluoroscopic images with the help of the navigation system and uses them to provide navigational feedback to the surgeon. Since the images can be reacquired intraoperatively, this technique may also be applied in cases when preoperative CT scans no longer reflect an altered intraoperative situation. This advantage, together with the obsoleteness of manual registration (see below), often outweighs the disadvantage that the absence of a preoperative dataset does not allow detailed computer-aided planning prior to the intervention. Another disadvantage of fluoroscopy-based navigation (the missing third dimension in conventional two-dimensional projective fluoroscopic images) has been overcome recently by the introduction of a new three-dimensional fluoroscope (see below).

MRI datasets have so far failed to become frequently used as navigational images in computer-aided spine surgery. The inherent geometric distortions together with the difficulty to create three-dimensional representations of the bony anatomy in an easy fashion have

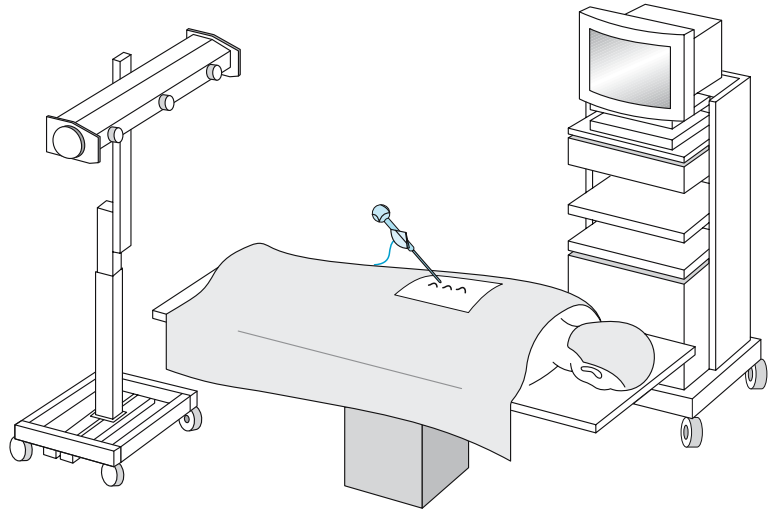


Fig. 6.1. Intraoperatively, a spinal navigation system observes surgical instruments and the operated vertebra with the help of an optoelectronic camera. The resultant position data are displayed on a computer monitor in real-time

prevented MRI becoming regularly used in spinal navigation. Research groups have looked into the fusion of preoperative CT and MRI scans [22] to enable the use of information from both modalities simultaneously during computer-assisted surgical (CAS) application. Again, remaining questions and difficulties have so far hindered the widespread use of these approaches.

6.2.2 Measuring Instrument Position

To exactly determine the current position and orientation of instruments in the hand of a surgeon in relation to the treated vertebra requires the precise and contactless tracking of both bone and tool. Surgical navigation systems follow the principle of rigid bodies, i.e. each observed object is regarded as undeformable and of known shape. The tracking of such an object can then be simplified to the tracking of at least three non-collinear points that are rigidly attached to it. This theoretical principle is realized by means of infrared light-emitting diodes (IREDs) or infrared light-reflecting markers that are observed by a camera system. IREDs need external power to actively emit light and, therefore, most active navigation systems require instruments to be connected via cables. In contrast, passive markers reflect light that originates from an infrared light source integrated in the tracking camera and that illuminates the camera's entire field of view. In both cases, direct line-of-sight between the camera system and the observed IREDs/markers is mandatory.

Alternative measurement technologies, such as electromagnetic tracking, have not been successful in the past due to large inaccuracies [3].

6.2.3 Displaying Instrument Position

To display a tracked instrument at its correct location with respect to the treated spinal section, it is necessary to also track the operated vertebra. For this purpose, a so-called dynamic reference frame or dynamic reference base (DRB) [20] is attached to the spinous process (Fig. 6.1). Technically, this DRB establishes a local coordinate system (COS) that is affixed to the rigid structure of the vertebra, and instruments are tracked with respect to it. Real-time navigational feedback is then provided by transferring the measured three-dimensional instrument coordinates from the DRB-COS into image space (Fig. 6.2). The mathematical matrix that allows this transformation is determined by a registration step. For preoperative CT scans this task is completed intraoperatively and involves the surgeon acquiring relevant structures on the bony surface of the operated vertebra [19]. In contrast, fluoroscopic navigation does not rely on interactive digitization. Instead, the imaging device is calibrated preoperatively, which enables the intraoperative registration to be an inherent and automatic procedure [11].

6.3 Minimizing Invasiveness

Orthopaedic surgery is treating structures that are usually located deep inside the human body. As a consequence, three reasons can be identified why it has to be invasive in the first place [15]:

1. The surgeon needs to have visual access to the operation field. Such access is usually gained by exposure of the operated structures.

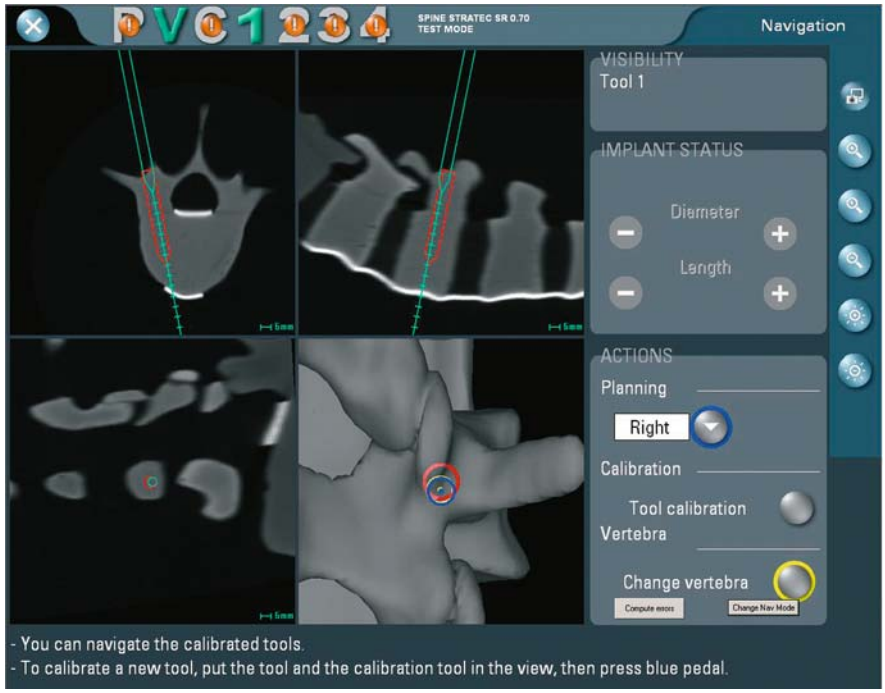


Fig. 6.2. During CT-based navigation, the current instrument position is presented in relation to a preoperative CT scan. The optimal position of this L4 pedicle screw (*red contour*) has been planned preoperatively and serves as the target to be reached by the navigated pedicle awl

2. Surgical instruments need to act on the bone. Tools such as awls, drills or probes require direct physical contact with the bone as well as a certain working volume.
3. Many orthopaedic interventions include the placement of implants such as screws or rods. The delivery of these devices can only be accomplished in an invasive manner.

It is obvious that invasiveness due to reasons 2 and 3 can only be reduced by improving instruments and implants, and today manufacturers of medical technology have advanced and optimized their products to a very high level.

Computer assistance could be seen as a means to target reason 1 of invasiveness. The real-time feedback provided on the monitor of a navigation system represents considerable and valuable details about surgical action and might thus allow for smaller incisions. This potential has been foreseen by many of the pioneers in computer-assisted surgery [13, 17, 20]. However, the enthusiasm and optimism of these early users did not turn out to become common reality. Consideration of the additional elements, described above, that are required for the application of surgical navigation explains this apparent discrepancy. Referencing of the operated vertebra is a must [8] and up to now requires the stable attachment of a DRB to the spinous process. When using preoperative CT scans as the navigation basis, intraoperative registration necessitates access to a considerable area of the bone surface in order to digitize anatomical landmarks or characteristic bony structures.

Up to now, research efforts have been focused on alterative registration methods, and the development of fluoroscopy-based spinal navigation (Fig. 6.3) was surely catalysed by the vision to implement registration as a preoperative calibration step rather than requiring interactive and error-prone data acquisition as an intraoperative procedure. With the help of such a fluoroscopy-based CAS system, Foley et al. [5] could demonstrate that even two-level fusions could be carried out through stab incisions when a dedicated minimally invasive rod placement device was used. Besides cosmetic advantages of the resulting smaller scars, the authors point out that the muscular apparatus in the operated region can be left almost completely intact, which should eventually result in better recovery times.

For CT-based navigation, several alternative registration methods have been proposed to improve registration accuracy, ease the intraoperative registration procedure, or allow for registration in a less invasive manner. Placing fiducial markers to the patient as "artificial anatomical landmarks" prior to image acquisition is a common technique for navigated cranial surgery [1]. Such markers [27] make very strong signals in the acquired CT scan and may be identified easily. Moreover, digitizing them intraoperatively on the patient with high precision is a trivial task that can be performed reliably and fast. To further optimize this concept, Lund et al. evaluated a combined marker and DRB placement approach [16]. Before the CT scan, a small

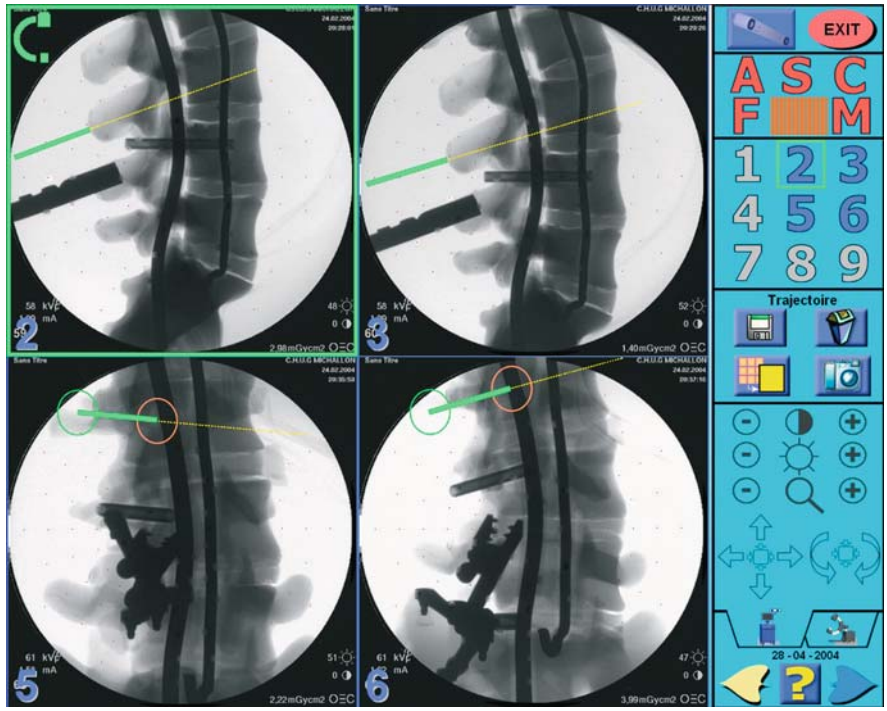


Fig. 6.3. During fluoroscopy-based navigation, instrument position is projected into several two-dimensional fluoroscopic images at the same time. The two circles at the tip (*orange*) and end (*green*) of the instrument indicate the orientation of the tool relative to the image plane

clip was affixed to the spinous process (Fig. 6.4) under local anaesthesia and the wound closed again. The clip housed three spherical titanium markers at positions that were exactly known to one another. In addition, it featured a highly precise connection into which the DRB could be placed in a well-defined orientation. After CT scanning, the marker spheres were identified in the image data and the operation was started. The placed clip was exposed again and the DRB attached (Fig. 6.5). Thanks to the previously measured marker location the spatial relationship between reference base and image data could be calculated automatically without any additional interactive and invasive landmark digitization on the patient. The authors used their method during two cases of pedicle screw placement in the lumbar region and report sufficiently accurate feedback by their navigation system. However, the additionally required surgical procedure to place the clip to the spinous process was found to expose the patient to unacceptable discomfort. Moreover, the logistical and financial efforts caused by this preceding operation were estimated to be too exhaustive.

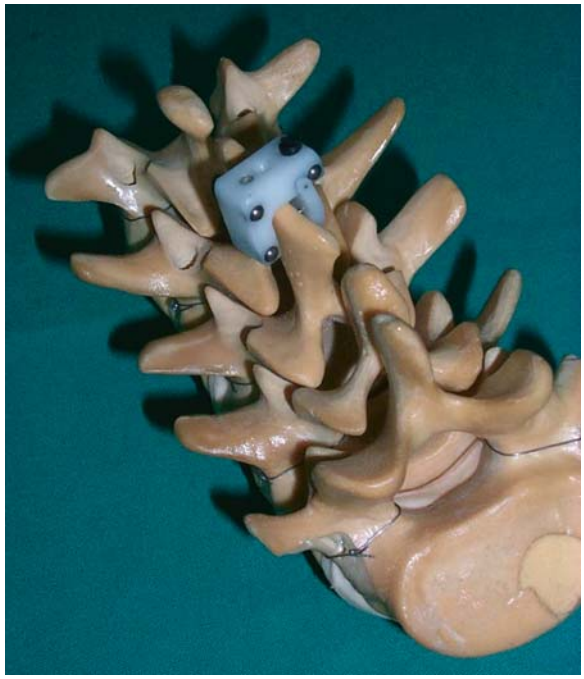


Fig. 6.4. This base part of a prototype dynamic reference base is mounted to the spinous process prior to CT data acquisition. The three high-precision titanium spheres help registering the device with the image data in an automatic way

Recently, research has focused on non-invasive registration methods based on intraoperative ultrasound [18]. From a technical point of view, both A-mode (amplitude mode) and B-mode (brightness mode) ultrasonography using calibrated and tracked ultrasound probes are methods that can yield the three-dimensional locations of bony surface points assessed through layers of soft tissue. In practical applications, however, this non-invasive digitization is not trivial. For A-mode ultrasound a single sound pulse is sent and received along one acoustic axis, comparable to the sonar depth measurement of a ship. For the reflected sound signal to be detectable by the probe, the explored



Fig. 6.5. Intraoperatively, the upper part of the dynamic reference based is mounted. Thanks to its precise fitting to the base, it facilitates automatic registration of the preoperative CT scan with the intraoperative setup

bone surface must be oriented horizontally. This limits the applicability of A-mode ultrasound at the spine to the transverse processes and small areas of the facet joints and the spinous processes. B-mode ultrasound (Fig. 6.6) in contrast is easier to use intraoperatively because it scans a fan-shaped area rather than a single axis. However, the resulting two-dimensional images are noisy, and the automated detection of bone contours is a challenging image-processing task. As a consequence, only experimental results are available [2] for the application of this technique to anatomical areas other than the spine.

6.4 Further Clinical Applications

The technical challenges outlined above indicate why CAS techniques have so far failed to make minimally invasive procedures state-of-the-art in spine surgery. Nevertheless, a number of authors have succeeded in avoiding large surgical approaches thanks to image-guided methods. Some have already been mentioned in the previous section. In addition, there are several reports of the use of navigation technology applied during procedures that are carried out in a minimally invasive manner even when no navigational support is applied. The CAS system in these cases is used to increase safety and precision and to decrease radiation exposure to the patient and surgical staff. An example is intradiscal electrothermal therapy with the help of fluoroscopy-based navigation [21]. Using C-arm images for nav-

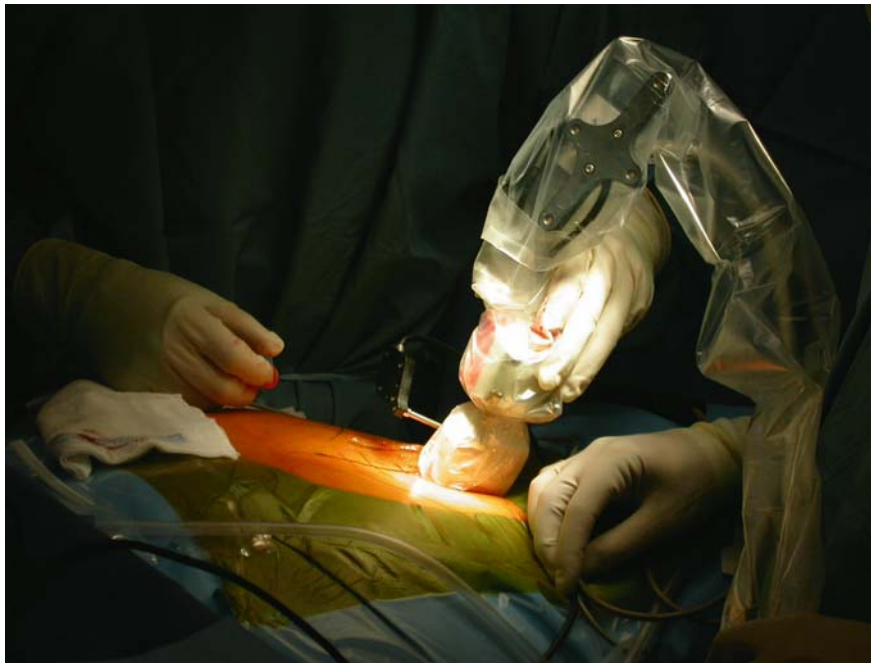


Fig. 6.6. In this experimental setup the use of a tracked B-mode ultrasound probe for registration data acquisition is evaluated

igation appears to be a generally accepted multipurpose method that authors try to apply to a variety of surgical approaches to the spine, including ventral fracture stabilization [28] or disc replacement [23].

Recently, an isocentric motorized fluoroscope was introduced [10]. It performs an automated 190° rotation during which it acquires a series of 100 two-dimensional images. From these data, a three-dimensional dataset is reconstructed intraoperatively that is similar to a CT scan. Since the data are generated with a calibrated and tracked imaging device, there is no need for manual registration, and navigation within the images is possible immediately after image generation and transfer to the navigation system. Although the use of this fluoroscope is not limited to the spinal area, several authors have already presented very promising results with it in applications such as pedicle screw placement [7], kyphoplasty [26] and other types of spinal instrumentation [12].

6.5 Discussion and Conclusion

The first decade of spinal navigation systems tried to improve the precision of implant placement and the reliability with which surgical interventions can be carried out while at the same time often reducing intraoperative radiation exposure. Very often, however, these advantages had to be paid for with the prohibition of minimally invasive procedures or even led to increased invasiveness when compared to the corresponding conventional techniques. Recent research efforts now try to enable spinal navigation in a less invasive manner. CAS systems have been utilized to provide additional visual feedback during existing minimally invasive procedures. Intraoperative image acquisition using both two- and three-dimensional modalities, require only a DRB to be attached to the bone eliminating the need for large-scale bone access that is a prerequisite for the manual registration of preoperative image data. Last but not least, alternative imaging methods are in the focus of current research to evaluate their potential in non-invasive bone-contour detection. In any case, establishing procedures with minimized invasiveness will require combined research and development efforts by navigation system producers, implant manufacturers and surgeons in order to optimize each aspect of the process.

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Cervical Spine

Odontoid (Ch. 7, 8) 35
Disc Surgery/Decompression (Ch. 9 – 14) 54

Technique of Transoral Odontoidectomy

7

P.J. Apostolides, A.G. Vishteh, R.M. Galler, V.K.H. Sonntag

Modified from Operative Techniques in Neurosurgery, 1:58 – 62, Apostolides, Vishteh, and Sonntag, "Technique of transoral odontoidectomy," copyright 1998, with permission from Elsevier.

7.1 Terminology

The transoral approach to the craniovertebral junction is an excellent surgical technique for treating ventral midline extradural compressive pathology. The target region is reached by an approach crossing the oral cavity through the open mouth ("transoral").

7.2 Surgical Principle

The transoral operation provides direct midline access to the ventral craniovertebral junction to facilitate decompression of the lower brain stem and upper cervical spinal cord. The surgical exposure typically extends from the inferior third of the clivus to the top of the C3 vertebra (Fig. 7.1) and is limited primarily by the pa-

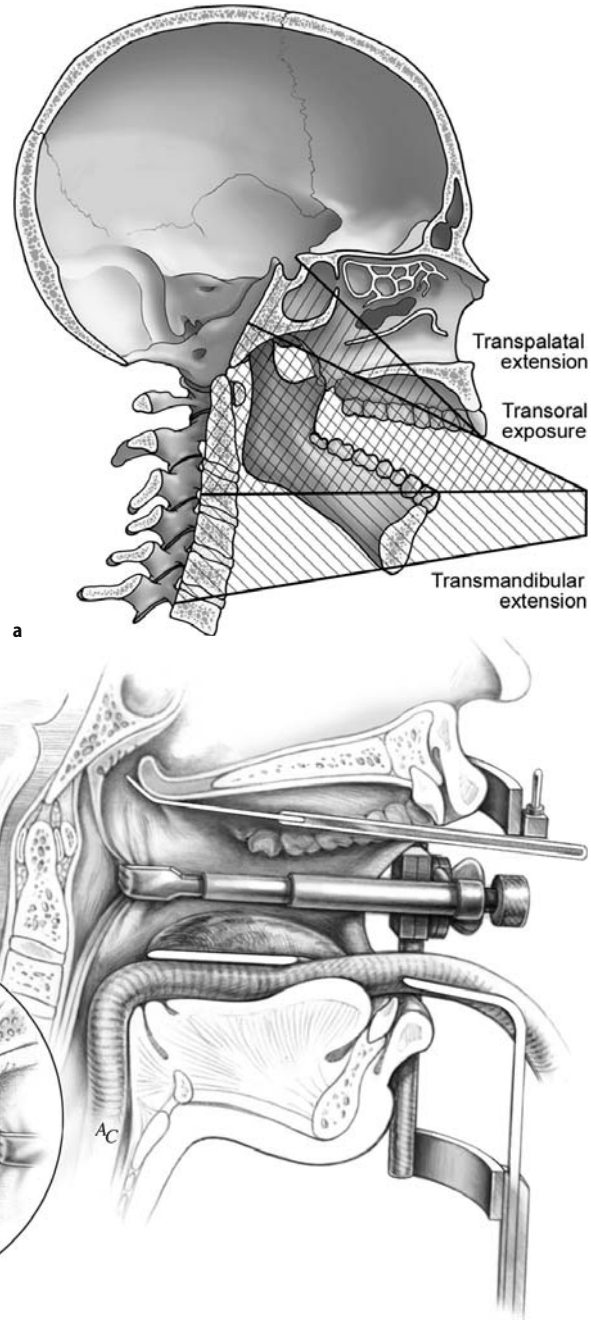


Fig. 7.1. a Routine transoral exposure. This exposure may be increased superiorly with a transpalatal extension or inferiorly with a transmandibular extension. **b** Sagittal view showing routine transoral exposure with normal and pathological anatomy (*inset*). *With permission from Barrow Neurological Institute*

tient's ability to open his or her mouth. The standard transoral exposure can be extended superiorly with a transpalatal or transmaxillary approach [3–5, 16–23], or inferiorly with a mandibulotomy and median glossotomy (Fig. 7.1a, b) [3, 8, 14, 16–20].

7.3 History

The approach was described first by Kanavel in 1917 [15]. Since then and especially since the application of the surgical microscope, the approach has been described by many authors mainly for the extirpation and treatment of extradural lesions [3, 7, 8, 11, 13, 18, 22].

7.4 Advantages

This approach is the direct and unobstructed way to the anterior part of the craniocervical junction. The anterior bony structures (inferior third of the clivus, anterior arch of C1, and anterior part of C2 and C3) can be exposed by dissection of the posterior wall of the pharynx. The apex of the odontoid process as well as the anterior part of the foramen magnum can be exposed after resection of the anterior arch of C1.

7.5 Disadvantages

The approach is limited by the surgical corridor provided through the open mouth. There is a considerable risk of severe complications such as infection with or without involvement of the meninges, disturbances of wound healing, cerebrospinal fluid (CSF) leakage as well as complications arising from trauma to the uvula and soft palate. In patients with rheumatoid arthritis involving the mandibular joints, the approach is occasionally limited by the inability to open the mouth sufficiently (> 2.5 cm).

7.6 Indications and Contraindications

The primary indication for a transoral procedure is an irreducible midline extradural lesion that compresses the cervicomedullary junction. A transoral procedure occasionally may be required to obtain a tissue diagnosis or to debride an infection.

Transoral surgery is contraindicated if the patient has an active nasopharyngeal infection or reducible ventral lesion, or if the vertebral or basilar arteries are located within or ventral to the lesion. The transoral approach is usually inappropriate for intradural pathology because of the significant risks of CSF leakage and meningitis associated with the frequent inability to achieve a watertight dural closure [7, 10–12, 21].

7.7 Patient's Informed Consent

Informed consent of the patients should include explanations of the potential complications such as lesions to the tongue, postoperative hematoma, irritation, and sensory deficits in the oral cavity. It should also include the risk of disturbed senses of taste and smell or swallowing due to postoperative swelling of the intraoral structures. The risk of postoperative infection and the necessity for antibiotic medication should be emphasized.

7.8 Surgical Technique

7.8.1 Preoperative Preparation

All transoral surgeries are performed under general anesthesia administered via a fiber-optically placed orotracheal tube that can be retracted from the surgical field to provide optimal exposure of the posterior oropharynx. Routine tracheostomy is rarely necessary unless severe preoperative bulbar or respiratory disturbances are present [1, 2, 9, 13, 23]. All patients receive routine perioperative antibiotics (cefuroxime, 1.5 g). Unlike some authors, [6, 18, 23] we do not obtain routine preoperative nasal and oropharyngeal cultures unless an active infection is suspected based on the patient's history or clinical examination.

Continuous intraoperative somatosensory evoked-potential monitoring and brain stem auditory evoked-potential monitoring are used to assess the physiologic status of the spinal cord and brain stem during the procedure.

7.8.2 Positioning

The patient's head is secured with a Mayfield clamp and the patient is placed in the supine position. The head is placed in a neutral position and the neck is slightly extended.

7.8.3 Surgical Steps

A low-profile self-retaining transoral retractor system (Spetzler-Sonntag, Aesculap, San Francisco, CA) is

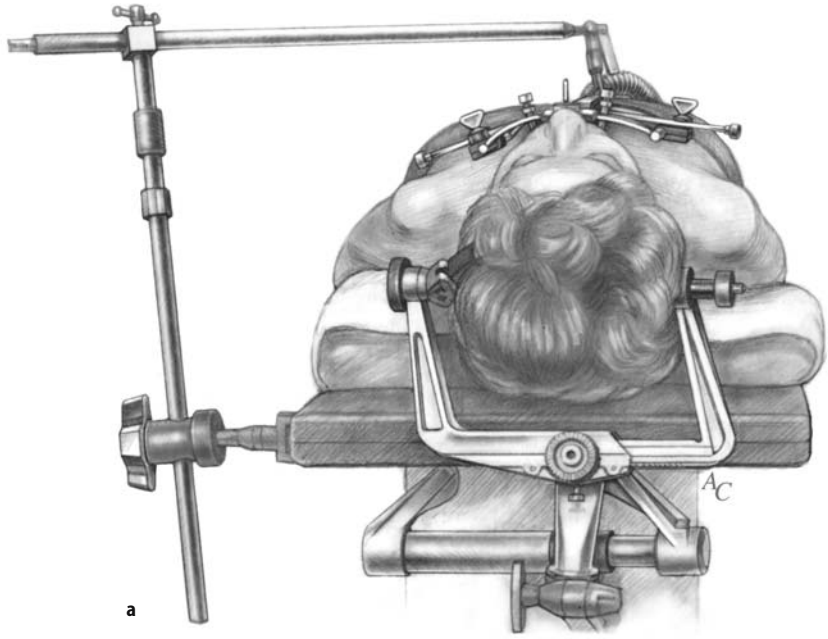
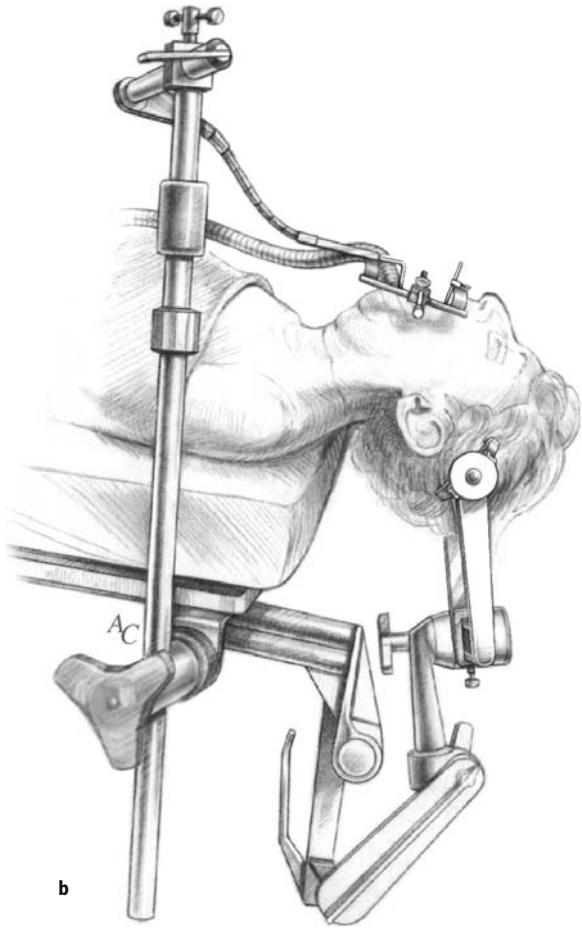


Fig. 7.2. Superior (**a**) and lateral (**b**) views of patient positioning and the retractor system used in the transoral approach. The patient's head is secured with a Mayfield clamp. The patient is placed in the supine position with the head in the neutral position and the neck slightly extended. The rectangular retractor frame is placed over the patient's mouth and attached to the operating room table via crossbars. *With permission from Barrow Neurological Institute*



used to achieve wide exposure of the posterior oropharynx. The rectangular retractor frame is placed over the patient's mouth and attached to the operating room table via crossbars to stabilize the instrumentation and to allow the table to be rotated during the procedure (Fig. 7.2a, b). The tongue and endotracheal tube are retracted caudally with a rigid wide-blade retractor. To avoid severe swelling or necrosis, the tongue should be inspected carefully to ensure that it is not pinched between the retractor blade and the patient's teeth. The soft palate and uvula are retracted superiorly with a malleable-blade retractor. Adjustable, telescoping tooth-bladed retractors are attached to the retractor frame and inserted into the oropharynx to retract the pharyngeal flaps laterally to widen the exposure.

The oropharynx and the retractors are sterilized with Betadine solution. An intraoperative radiograph often is obtained to judge spinal alignment after positioning and to confirm the extent of the rostral and caudal exposure provided by the retractor system. The table is often placed in the Trendelenburg position to provide the best perspective of the craniovertebral junction. The surgical microscope is used immediately to improve lighting, to provide variable magnification, and to allow the co-surgeon to observe and assist during the procedure. The surgeon sits above the patient's head and has a direct view of the patient's mouth and oropharynx (Fig. 7.3a).

The C1 tubercle is palpated to verify the position of the midline (Fig. 7.3b). The midline posterior oropharyngeal mucosa is infiltrated with 0.5% or 1% lidocaine with 1/200,000 epinephrine. A vertical midline

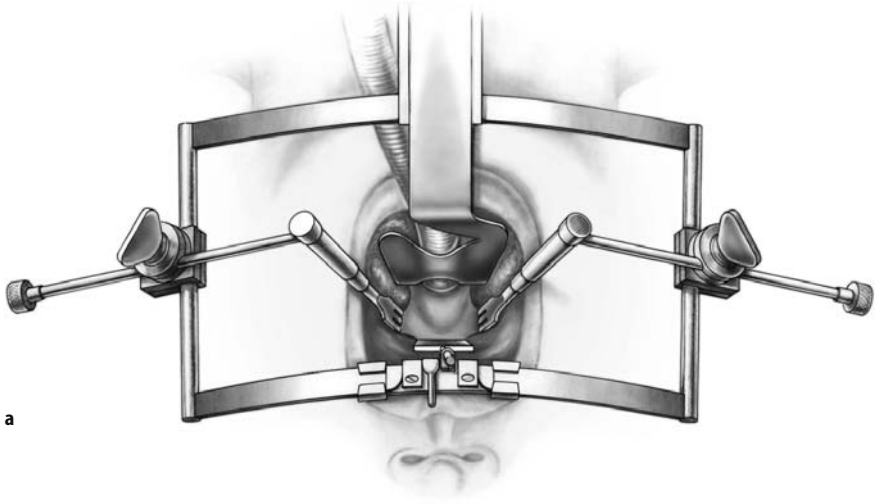
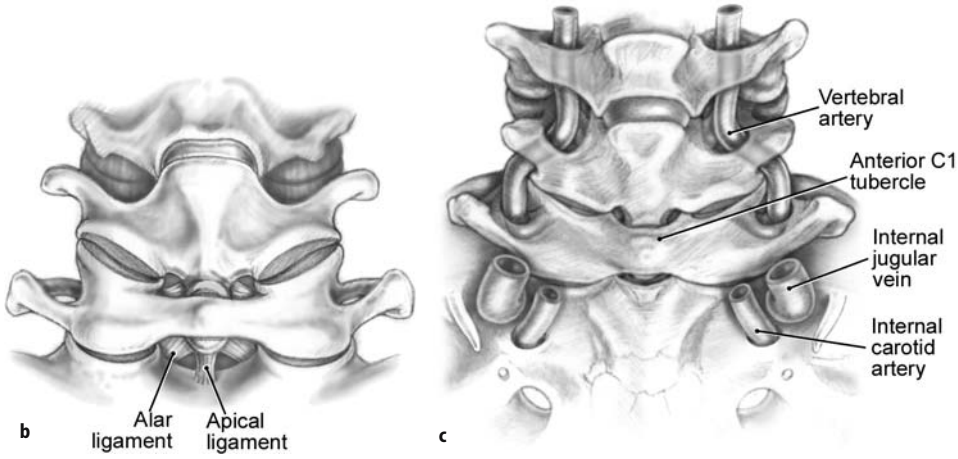


Fig. 7.3. a Surgeon's view of patient's mouth and oropharynx after placement of the low-profile, self-retaining retractor system. **b** Anatomical relationships of the anterior aspects of the clivus, C1-C2, and the adjacent vascular structures underlying the posterior oropharynx mucosa and muscles. The C1 tubercle is a key landmark that verifies the position of the midline. **c** Anatomical relationships of the alar and apical ligaments fixating the dens to the occiput. *With permission from Barrow Neurological Institute*



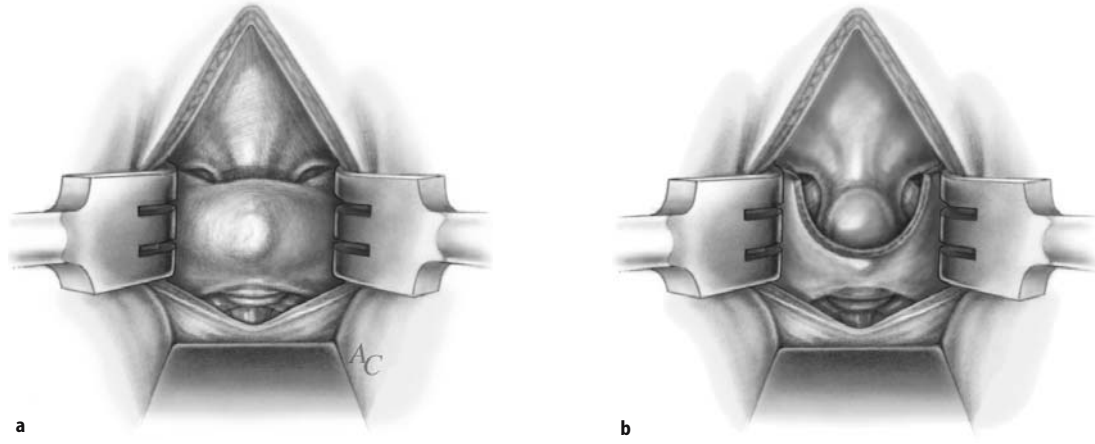


Fig. 7.4. Transoral odontoidectomy. **a** A vertical midline incision is made in the median raphé of the posterior oropharynx to expose the anterior arch of C1 and the body of C2. **b** The inferior portion of the anterior C1 arch is resected to expose the base of the odontoid process.

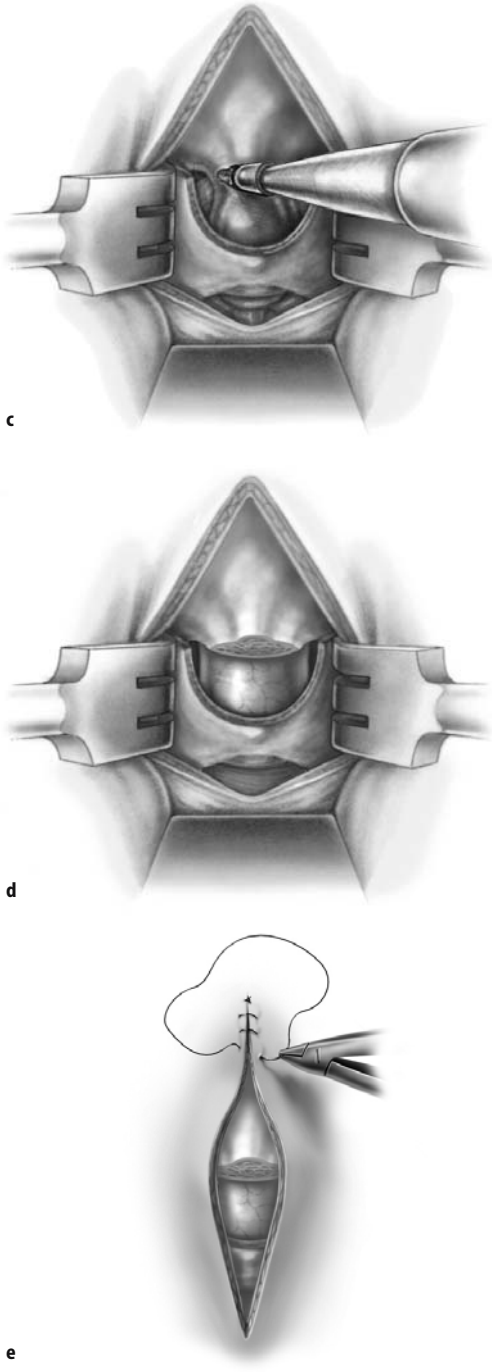


Fig. 7.4. (cont.) c The dens is transected at its base. **d** The dens is removed to complete the decompression. **e** The incision is closed in a single layer with a running 2 – 0 vicryl suture. *With permission from Barrow Neurological Institute*

incision is made in the median raphé of the posterior pharyngeal wall mucosa, pharyngeal muscles, and the anterior longitudinal ligament using either monopolar cauterization or a Shaw scalpel (Fig. 7.4a). If possible, a palatal incision is avoided because it can cause nasal regurgitation, dysphagia, and a nasal tone of voice. The layers of the posterior oropharynx are maintained as a single thick layer to facilitate a strong tissue closure. Periosteal elevators are used to dissect the anterior longitudinal ligament subperiosteally and to separate the tissue flap from the anterior surfaces of the C1 arch, the C2 vertebral body, and the inferior clivus.

Curettes and periosteal elevators are used to define the boundaries of the clivus, the anterior arch of C1, the base of the odontoid process, and the C2 vertebral body. The inferior one-third to two-thirds of the anterior C1 arch is resected to expose the base of the odontoid process using a high-speed air drill and Kerrison rongeurs (Fig. 7.4b). We try to limit the resection of the anterior C1 arch to preserve the structural integrity of the C1 ring. However, enough bone must be removed to expose the dens adequately. If necessary, the anterior C1 arch should be resected completely.

After the base of the dens has been exposed satisfactorily, the lateral margins of the odontoid are defined. The alar and apical ligaments are detached sharply with curved curettes. The base of the dens is partially transected with a cutting burr (Fig. 7.4c); the osteotomy is completed by removing the posterior cortex with a small Kerrison rongeur or diamond burr. The dens is grasped with a toothed odontoid rongeur and removed en bloc (Fig. 7.4d). The dens can be removed in a piecemeal fashion, but it is often more difficult to access its apex.

Soft tissue pathology often must be resected to decompress the neural elements adequately. The transverse ligament and tectorial membrane also may need to be removed to adequately visualize the dura and normal pulsation of the thecal sac. However, the surgeon must beware of attenuated dura and ligaments that adhere to the dura. Meticulous microsurgical techniques are necessary to avoid a CSF leak from inadvertent dural entry, which is associated with a high risk of postoperative morbidity and mortality. If an intraoperative CSF leak occurs, a fascial patch is placed directly over the dura and secured with fibrin glue. A lumbar drain is inserted postoperatively, and antibiotic coverage and the lumbar drain are maintained for at least 5 – 7 days.

The boundaries of the decompression can be assessed intraoperatively by placing iodinated contrast material into the decompression site and obtaining a lateral cervical radiograph or by employing stereotactic navigation. Adequate decompression is confirmed when the dura bows into the wound and assumes its usual anatomic contour. Once the brain stem and spinal cord have been decompressed, the wound is irrigated with antibiotic solution and hemostasis is achieved. The wound is closed with interrupted or running 2 – 0 vicryl suture in a single layer that includes the mucosa, pharyngeal muscles, and ligaments (Fig. 7.4e). Multilayer closures are more difficult to perform and can at-

tenuate the tissue layers and weaken the incision line. A nasogastric feeding tube is inserted while directly visualizing the oropharyngeal incision to avoid inadvertent malpositioning of the tube.

7.9 Postoperative Care

Moderate tongue and pharyngeal swelling can be expected for the first 24 – 72 hours after surgery. The endotracheal tube should be maintained until the swelling subsides because premature extubation can lead to respiratory distress, respiratory arrest, and death. In our experience, topical steroids provide little if any benefit in minimizing soft tissue swelling and therefore are not used routinely.

Enteral nutrition via the indwelling feeding tube is started on postoperative day 1 and continued 3 – 5 days. The patient's diet is slowly advanced from liquids to soft regular foods and then to regular foods usually within 14 days. If the feeding tube is inadvertently removed before oral feedings have been started, appropriate parenteral nutrition should be provided. Replacing the feeding tube risks penetration of the healing mucosal incision and inadvertent malpositioning of the tube.

Postoperative spinal instability should be expected after transoral odontoidectomy. Patients should therefore remain in an external orthosis until spinal stability can be restored. Although some authors advocate immediate posterior fixation of the spine after transoral decompression, we prefer to wait several days to reduce the risk of infection in the posterior cervical wound.

7.10 Hazards and Complications

Medical complications, including pneumonia, urinary tract infections, deep venous thrombosis, pulmonary emboli, and myocardial infarctions, are common after transoral surgery, particularly in patients with severe preoperative neurological deficits or debilitating medical illnesses. Therefore, it is important to optimize the patient's general medical condition before surgery and to use prophylaxis for deep venous thrombosis during and after surgery. Postoperatively, pulmonary toilet should be aggressive, and the patient should be mobilized early after stabilization to limit the development of these potential complications.

Wound infections should be treated with broad-spectrum antibiotics until culture sensitivities are available. Wound dehiscence at any time requires reoperation and reclosure. Wound dehiscence occurring after the first week should raise the suspicion of a possible underlying retropharyngeal infection or abscess.

CSF leakage represents a significant risk to the patient and should be addressed promptly. Appropriate treatment includes dural patching, meticulous pharyngeal wound closure, and placement of a lumbar drain. If a CSF leak stops with lumbar drainage but recurs after the drain has been closed or discontinued, the patient requires a lumboperitoneal shunt. If CSF leakage persists despite lumboperitoneal drainage, reoperation and dural patching are required. Postoperative meningitis should raise the suspicion of a CSF leak. Proper treatment includes intravenous antibiotics and placement of a lumbar drain.

Neurological deterioration after transoral surgery is rare. Patients with new neurological deficits should be evaluated for loss of spinal alignment, persistent cervicomedullary compression, epidural hematoma, epidural abscess, meningitis, or vertebrobasilar occlusion.

7.11 Conclusions

The transoral approach is an effective surgical method for the direct decompression of irreducible ventral midline extradural compressive pathology of the craniovertebral junction. Specialized low-profile retractor systems, the surgical microscope, contemporary microsurgical dissection and dural closure techniques, and meticulous postoperative radiographic assessment of spinal stability minimize perioperative complications and facilitate good long-term outcomes.

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8 Microsurgical Treatment of Odontoid Fractures

P. Klimo Jr, G. Rao, R.I. Apfelbaum

8.1 Terminology

The first two cervical vertebrae, *C1* and *C2*, are also known as the *atlas* and *axis*, respectively.

The *odontoid process of C2*, also known as the *dens*, is the superiorly projecting bony prominence from the body of C2 that sits within the anterior portion of the ring of C2. C1 rotates around this.

Anterior odontoid screw fixation involves the reduction and stabilization of an odontoid fracture using a screw that extends from the inferior anterior aspect of the C2 body, across the fracture line, and through the tip of the odontoid process.

8.1.1 Classification of odontoid fractures [5, 9, 35]

A *type I* fracture is a rarely occurring fracture of the apical portion of the odontoid process. A *type II* fracture is a fracture through the base or waist of the dens. These are the most common and may be either anterolisthesed or retrolisthesed. Type II and "shallow" type III fractures have been further classified, based on the anterior–posterior direction of the fracture line, as anterior oblique, posterior oblique, or horizontal fractures (Fig. 8.1). Anterior oblique fractures slope inferiorly from posterior to anterior, whereas posterior oblique fractures slope inferiorly from anterior to posterior and horizontal fractures slope minimally or not at all. *Type IIa* fractures are type II fractures with a comminuted base and *type III* fractures extend into the body of C2.

8.2 Surgical Principle

The C1-2 articulation is one of the most complex joints in the spine. It allows a significant amount of motion while still protecting the spinal cord. Approximately 50 % of cervical rotation occurs at this joint. The rotation that occurs around the odontoid process is facilitated by the unique anatomy of this region [63]. Both articular surfaces of the C1 and C2 lateral masses have a convex orientation in the sagittal plane and are sloped upward from lateral to medial. Capsular ligaments are weak, strong posterior ligaments are absent (the strong ligamentum flavum is replaced by the thin atlantoaxial and atlanto-occipital membranes), and an intervertebral disc and its restricting annulus fibrosis are also absent. As C1 rotates on C2, the sloping joint surfaces allow C2 to rise upward. This allows greater excursion before the alar ligaments connecting the dens to the occiput tighten and restrict this motion than would be allowed if the surfaces had a horizontal orientation. Other important adaptations are that the space available for the cord is generous, the instantaneous axis of rotation (IAR) is close to the spinal cord, and the vertebral arteries loop laterally. These features allow rotation without jeopardizing the neural and vascular elements.

Translation anteriorly and posteriorly must of course be avoided to protect the spinal cord. This is achieved by having the odontoid process or dens, the superior osseous protrusion of the body of C2, contained within the anterior portion of the ring of C1 by the transverse ligament (transverse portion of the cruciate ligament). The transverse ligament is one of the

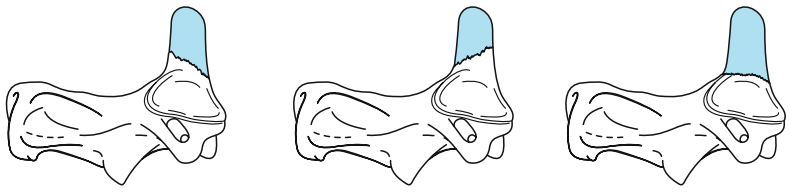


Fig. 8.1. Schematic illustrations of the anterior oblique (**a**), posterior oblique (**b**), and horizontal (**c**) fracture classification. This classification scheme is based on the inferior direction of the slope of the fracture, as demonstrated on lateral radiographs. In our series [9], horizontal fractures occurred in 49 %, posterior oblique in 34 %, and anterior oblique in 16 % of the cases

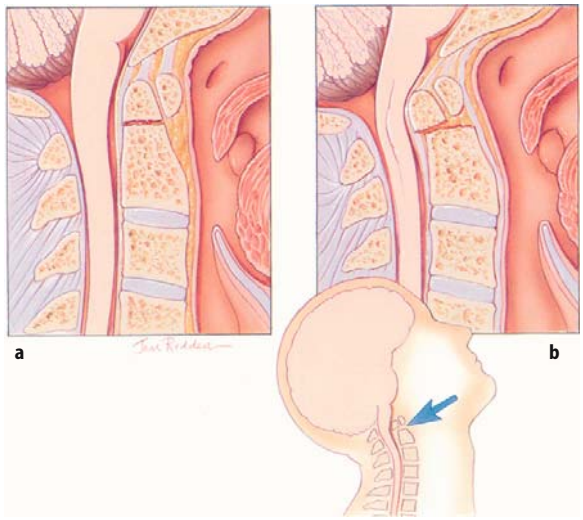


Fig. 8.2. Type II odontoid fracture in a neutral position (**a**) and extension (**b**). Note the retrolisthesis with extension causing spinal cord compression (*inset* in **b**)

strongest ligaments in the human body. Disruption of either the transverse ligament or odontoid process will result in instability, with the patient no longer protected from potential neurologic damage under physiologic loads (Fig. 8.2). This is true even if no motion is seen on flexion and extension radiographs because the other supporting structures may prevent motion under relatively mild stresses. The supporting structures are not capable, however, of resisting larger forces that may be experienced in minor traumas such as falls or low-impact motor vehicle accidents. If the instability is due solely to failure of the bony elements, healing is possible with external immobilization. If the transverse ligament is disrupted, however, surgery is required to achieve bony fusion.

Odontoid fractures are common cervical spine injuries and account for 10 – 20 % of all cervical spine fractures [9, 15, 24, 30, 39, 53, 57]. Most of these odontoid fractures involve the odontoid process at the base or extend into the body of C2 (59 %). Odontoid fractures are usually precipitated by a blow to the vertex or upper portion of the skull [51]. Because of the mechanics of the C1-2 articulation as described above, odontoid process fractures usually cause atlantoaxial instability, placing the patient at significant risk for immediate or delayed catastrophic spinal cord compromise [20]. Thus, accurate diagnosis and spinal stabilization, when needed, is imperative. The treatment strategies for odontoid process fractures vary from external stabilization to various internal fixation techniques.

8.3 History

Surgical options for treating type II and shallow type III odontoid process fractures include posterior atlantoaxial fusion and direct anterior dens screw fixation. Historically, posterior cervical fusion was the primary operative treatment when external immobilization failed or was considered unsuitable. Various wiring techniques combined with bone grafting, including those described by Brooks, Gallie, and later Dickman and Sonntag, have been used to achieve posterior cervical fusion [16, 23, 31, 49]. Successful fusion when these are combined with a rigid orthosis is in the 80 – 90 % range.

In 1992, Jeanneret and Magerl reported their experience treating odontoid fractures with C1-2 transarticular screw fixation, which is used for internal fixation and combined with a posterior bony fusion [40]. A number of authors have reported successful fusion rates approaching 100 % using transarticular screws [22, 33, 47, 60]. However, certain conditions can make C1-2 transarticular screw placement difficult. These conditions include insufficient space for screw placement in the isthmus of C2 or an anomalous course of the vertebral artery.

Fusion of the C1-2 joint eliminates 50 % of the rotation of the head, a significant loss of motion. Consequently, an alternative technique for treating odontoid fractures has been developed that attempts to preserve the normal motion of the C1-2 joint. This technique is the anterior odontoid screw fixation.

Several authors have described surgical techniques for anterior odontoid screw fixation [13, 15, 28, 32, 44]. Nakanishi first described the technique in 1980 in the Japanese literature [52]. In 1982, Bohler independently reported on the development of the technique in Vienna [13]. Although the initial techniques of anterior screw fixation were complex, the procedure has gained increased acceptance as improved instrumentation has allowed a minimally invasive approach [61] and improvements in fluoroscopic guidance have been made [1, 8]. Direct anterior screw fixation is an osteosynthetic technique that provides immediate spinal stabilization.

8.4 Advantages

Anterior odontoid fixation has several advantages over posterior C1-2 fusion. The dissection is less invasive and takes advantage of natural tissue planes. It poses less risk of damage to the neural structures and the anatomy of the vertebral artery is such that it is not at risk. As stated previously, this procedure does not re-

quire atlantoaxial arthrodesis; therefore, cervical mobility, especially rotation, is maintained. Reported perioperative morbidity appears to be less with the anterior fixation technique than with the posterior fusion. The technique may also be used in patients who have a concomitant C1 ring fracture but an intact transverse ligament. It is also applicable in those patients, especially elderly patients, who refuse or are unable to tolerate a halo.

8.5 Disadvantages

Anterior odontoid screw fixation has two main disadvantages. If the transverse portion of the cruciate ligament is disrupted in addition to the odontoid fracture, stabilizing the fracture will not result in atlantoaxial stability. As discussed in the "Surgical Principle" section, atlantoaxial stability is dependent on an intact dens *and* transverse ligament. Disruption of the transverse ligament is most often caused by a C1 ring fracture (Jefferson fracture).

Patients with chronic fractures (greater than 6 months old) or with os odontoideum should not usually be treated with an odontoid screw. Long-term stability of the odontoid is dependent on the ingrowth of new bone across the fracture line. The purpose of any hardware is to achieve immediate stabilization so that such fusion may occur, but the hardware is not expected to provide the long-term stability by itself. Because the mating surfaces of the odontoid fragment and body of C2 are usually corticated and widely separated in patients with chronic fractures or os odontoideum, fusion is less likely to occur.

8.6 Indications

The initial evaluation of odontoid fractures should begin with careful clinical evaluation and examination of cervical spine plain radiographs. Any evidence suggesting an odontoid fracture should prompt the clinician to perform serial thin-slice CT scanning from the skull base through to the top of C3. Reconstructed CT images allow the surgeon to identify the injury and assess the fracture type, the orientation, and the degree of dens displacement. As discussed previously, concerns about the integrity of the transverse ligament can be addressed by MRI studies. In patients with combined C1 and C2 fractures involving the ring of C1 (Jefferson fracture), a combined left and right overhang of the C1 lateral masses on C2 of greater than 7 mm on an open-mouth view (Rule of Spence) suggests disruption of the transverse ligament [59]. On a lateral cervical spine X-ray, the atlanto-dental interval (ADI) is the distance between the anterior margin of the dens and the closest point of the anterior arch of C1. Fielding et al. [29] demonstrated that an ADI of 4 mm or more suggests a disrupted transverse ligament. Finally, separation of the tubercle on the interior surface of the ring of C1, where the transverse ligament attaches, is also usually indicative of transverse ligament incompetence.

Non-operative management will be mentioned briefly because it directly pertains to the selection of patients who require surgery. Multiple studies have reported rates of successful fusion using a halo vest immobilization with the success rates ranging from 7% to 100% [4, 6, 10, 12, 17–19, 24–26, 30, 34, 35, 38, 43, 45, 46, 54, 55, 57, 58, 62]. When these rates were combined in a review article, the overall fusion rate with halo immobilization was about 65% [42]. Attempts to define factors that predispose to a non-union with external immobilization have suggested the following contradictory indications: (1) anterior fracture displacement greater than 4 mm [10]; (2) displacement in any direction of greater than 5 mm [18] or 6 mm [34]; (3) fracture angulation greater than 10° [18]; (4) fracture comminution (type IIa) [35]; (5) patient age greater than 40 years [10], greater than 50 years [43], or greater than 65 years [6, 25]; and (6) posterior fracture displacement [25, 34]. The variation in these studies may be due to the fact that plain films are used for many of the criteria. A plain film is a "snapshot in time" and does not indicate the full extent of displacement possible or whether additional angulation or displacement in a different direction will occur. Thus, one patient with 3 mm of anterolisthesis may not move further and would likely heal with immobilization, whereas another patient with the same 3 mm of anterolisthesis on a plain film might be capable of 10 mm of antero- *and* retrolisthesis. Such a patient has a low likelihood of healing with immobilization. Because of the uncertain rate of fusion with halo immobilization alone, as well as the burden of halo fixation and significant loss of cervical motion seen with posterior fusion techniques, we believe that all recent (less than 6-month-old) type II or shallow type III odontoid fractures with an intact transverse ligament should be offered treatment with direct anterior screw fixation.

8.7 Contraindications

Contraindications to anterior odontoid screw fixation include patients with concomitant C2 body fractures, a disrupted transverse ligament, or chronic non-unions. Relative contraindications are anterior oblique fracture orientation and severe osteopenia. Advanced age has not proved to be a contraindication.

8.8 Patient's Informed Consent

All patients should be counseled regarding the usual potential complications associated with any invasive spinal procedure, such as bleeding, infection, malpositioned hardware, and failure to achieve fusion. Neurologic injury is very rare because even if the screw extends past the apical cortex of the dens, the screw trajectory and regional anatomy is such that vital neural structures are still some distance away. Patients should also be informed that failure to achieve adequate reduction of their fracture or premature failure of their hardware could result in the need for a posterior C1-2 fusion. Dysphagia, usually temporary, is a frequent occurrence. Persistent dysphagia requiring placement of a feeding tube is a fairly infrequent complication but is more commonly encountered in the elderly [21]. We generally do not put patients in external orthosis postoperatively. However, in situations where a suboptimal reduction and fixation was achieved or when the patient has poor bone quality, external orthosis, usually in the form of a rigid cervical collar, may be needed.

8.9 Surgical Technique

Our technique for direct anterior screw fixation of odontoid fractures has been described and illustrated in several publications [7, 8]. It is a straightforward procedure that uses the familiar standard anterior approach to the midcervical spine. The procedure, which we will describe in detail below, can be summarized as follows. After accessing the midcervical spine, a working tunnel is created superiorly, anterior to the longus colli muscles, to the C1-2 region and secured with a special retractor. A pilot hole is drilled and tapped through specially designed concentric guide tubes, and then a screw is placed, all under biplanar fluoroscopic control. The outer guide tube is unique in that it has small spikes that anchor it to C3. This allows translation of C3 and the body of C2 either anteriorly or posteriorly relative to the odontoid process and C1 to realign them in the proper anatomic relationship. Thus, optional alignment can be obtained and a retrolisthesed odontoid is not a contraindication to the procedure.

The treatment goals for odontoid fractures are to restore normal alignment, achieve bony fusion, and prevent future neurologic compromise. The first step in the acute management of these fractures is to stabilize the neck to prevent additional subluxation and restore normal alignment. This generally can be accomplished preoperatively with Gardner-Wells traction using a light weight, initially 5 pounds or less, or intraoperatively when positioning the patient.

Preoperative positioning of the patient and the C-arm fluoroscopes is the key to success with this procedure. The patient is placed supine on a standard operating table. To achieve a satisfactory trajectory to the odontoid, the patient's neck must usually be extended. However, this can be dangerous if the patient has a retrolisthesed odontoid. As mentioned above, the guide tube system can be used to correct misalignment and this will allow extension of the neck prior to drilling and screw placement. To allow for such extension, a folded sheet or blanket, about 2–4 inches thick, is placed on the table to support the patient's shoulders. The head is initially supported on padding to keep the neck in a neutral position until the lateral fluoroscope is in place.

General endotracheal anesthesia is then induced. If the patient reduces in extension, intubation with a laryngoscope is safe and usually employed. Alternatively, fiberoptic techniques can be used, and are usually preferable, if the fracture is retrolisthesed or if extension results in such retrolisthesis.

Holter traction with 5 pounds of weight is placed, and, under fluoroscopic monitoring, the patient's head is gently allowed to extend and the padding under the head removed if doing so does not result in additional retrolisthesis of the odontoid. If such motion does occur, the padding under the head is left in place until after the guide tube is placed later in the procedure. For the AP fluoroscopic view (transoral), a second fluoroscope is placed. We rotate the lateral fluoroscope C-arm arc to a position that places it about 30° above the horizontal. This allows the anesthesiologist good access to the patient and allows the AP fluoroscope, if the two fluoroscopes have the same size arc, to be positioned at about a 45° diagonal to the head with the generator and image intensifier above and below the patient, respectively. The use of two C-arms allows the surgeon to check lateral and AP views by merely selecting the proper foot pedal. The patient's mouth is held open with a radiolucent mouth gag. A wine bottle cork, notched for the teeth or alveolar ridges, is excellent for this. Although less preferable, if only a single fluoroscope is available, it can be positioned to allow frequent swinging from the lateral to AP position and back. Making a tunnel by strategically placing IV poles and drapes helps, as then only one side of the C-arm needs to be redraped with each change of orientation. Using one C-arm can give satisfactory results although it is more demanding of time and patience.

The patient's neck is prepared and draped, and a unilateral horizontal incision is made at approximately C5 (Fig. 8.3). The platysma is then elevated and divided, and the fascia of the sternocleidomastoid is sharply incised along its medial border. Blunt dissection is used to expose the anterior surface of the vertebral column at the midcervical level by opening the natural tissue

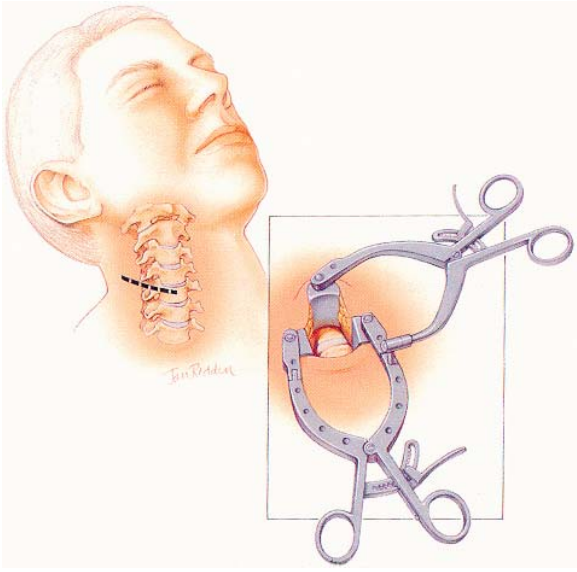


Fig. 8.3. Illustration showing location of neck incision. *Inset* Illustration of retractor in place

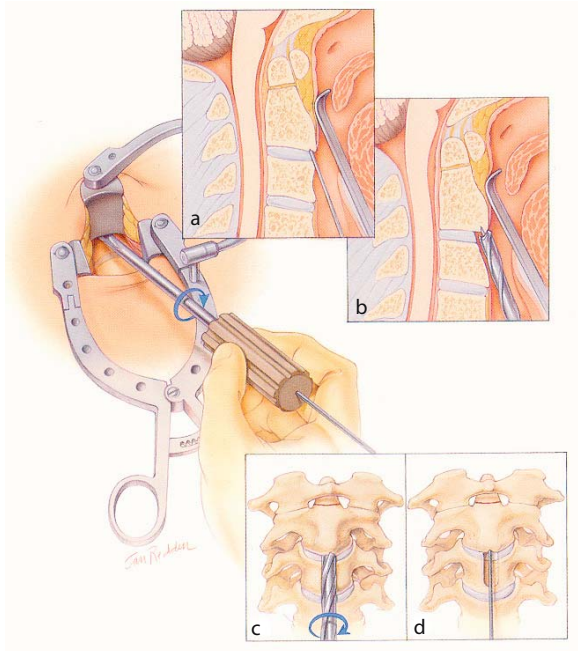


Fig. 8.4. A hollow hand drill is placed over the K-wire to create a trough in the face of C3 and the C2-3 disc. The position of the K-wire with respect to the superior retractor blade is shown in *inset* **a**, and then with the drill placed over the wire (*inset* **b**). *Inset* **c** depicts the creation of the trough, which is seen in *inset* **d**

planes medial to the carotid artery sheath and lateral to the trachea and esophagus. The fascia of the muscular longus colli is then incised in the midline, and the muscle is elevated cleanly from the vertebral bodies at the C5-6 level.

Sharp, large-toothed Caspar retractor blades are then inserted beneath the musculus longus colli bellies bilaterally and secured with a special lateral self-retaining retractor. This forms a stable base, anchoring the retractor and countering the rostral retraction forces from the cranial retractor that will attach to this base. Blunt dissection in the retropharyngeal space anterior to the longus colli muscle using a Kitner or peanut dissector is then used to open a path in front of the vertebral bodies to the C1-2 level. An angled retractor of the appropriate size is then inserted into this space and coupled to the lateral retractors to create a working tunnel up to C2 (Fig. 8.3). The trajectory needed to access the anterior inferior edge of C2 and continuing upward to the odontoid apex is a very shallow one. This retractor system has been designed to help achieve this trajectory by eliminating any inferior components.

A K-wire is then inserted through the incision, up to the inferior edge of C2 and impacted a few millimeters into the body of C2. If a single screw is to be placed, a midline entry site is chosen (Fig. 8.4). A paramedian position, approximately 2 – 3 mm off midline, is used if two screws are to be placed.

A hollow 8-mm drill is placed over the K-wire and rotated by hand to create a shallow groove in the face of C3 and the C2-3 disc and annulus to the inferior border of C2 without removing any of C2 (Fig. 8.4). This groove will accommodate the drill guide to allow for insertion of the tools and screw at the anterior inferior edge of C2. The drill guide system consisting of outer and inner guide tubes that mate together (Fig. 8.5) is then placed over the K-wire. The outer drill guide has forward-projecting spikes. By locking the handle of the guide tube, these spikes are walked up the face of the vertebral column with small rotating movements of the guide tube until they are over C3. A plastic impactor cover is placed over the drill guide system after shortening the K-wire as necessary, and the spikes of the outer drill guide tube are firmly set into C3 under fluoroscopic guidance by tapping on the impactor with a mallet (Fig. 8.6). The inner drill guide is then extended in the previously created groove to contact the inferior edge of C2 (Fig. 8.7). As has been emphasized, the alignment of the C2 and C3 vertebrae, relative to the odontoid and C1, is controlled by the drill guide, which is kept firmly fixed to C3 by maintaining forward pressure on its handle (unlock handle and place it in the most comfortable position). Alignment can now be optimized in either direction by lifting or depressing C3 and the body of C2 relative to the odontoid. In the case of a retrolisthesed odontoid, further extension of the neck is achieved by removing the padding under the head after translating C2 and C3 posteriorly, realigning the odontoid to the body of C2. Using fluoroscopy, correction of the alignment can be perfected and maintained in this manner.



Fig. 8.5. Drill guide system. Inner and outer guide tubes mate together and are placed over the K-wire

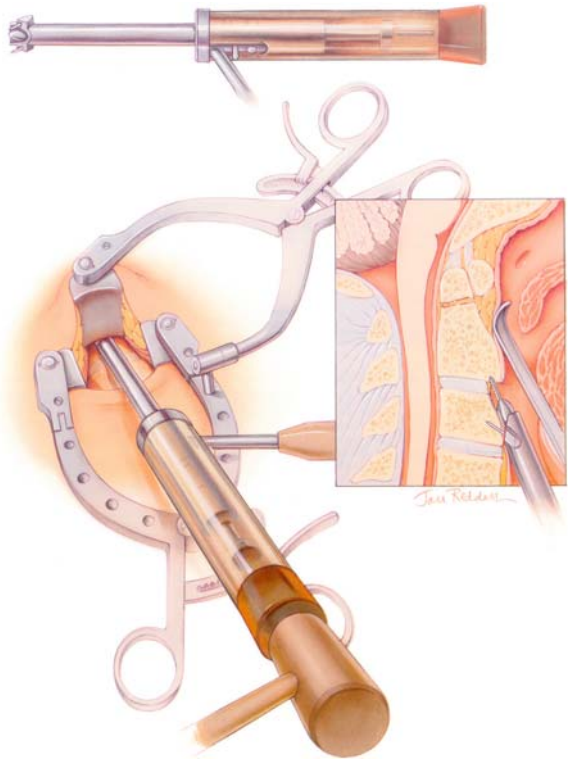


Fig. 8.6. After the drill guide system is walked up the front of the vertebral column to the C3 level, the K-wire is shortened and the plastic impactor sleeve is used to set the spikes of the outer drill guide into C3

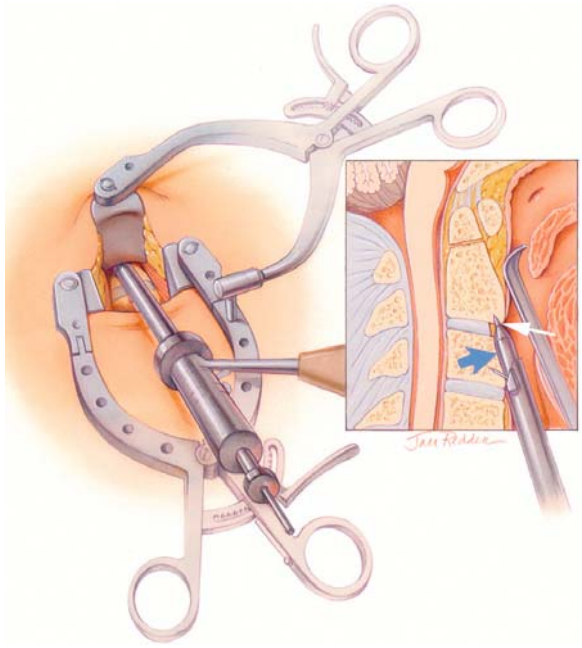


Fig. 8.7. The drill guide system is in place with the inner guide tube (*blue arrow*) advanced to the inferior end of C2 (*white arrow*) in the previously created groove

Once the guide tubes are secured and alignment is achieved, the K-wire is removed and replaced with a drill bit, which engages the starter hole made by the K-wire (Fig. 8.8). A right-angle drive is available to clear the thoracic region if needed. A hole is drilled under careful biplanar fluoroscopic control from the inferior anterior edge of C2, through the body of C2, and into the odontoid to its apex. It is important to drill fully through the odontoid tip. Because the trajectory to do this is very tangential to the spinal canal, the thecal sac is not in jeopardy. It is usually possible to extend more than a centimeter from the odontoid tip before encountering the dura in most patients, so penetrating the apex of the odontoid by a few millimeters is not risky. The drill is calibrated to allow accurate depth measurement from the end of the inner drill guide. After noting this measurement and saving the fluoroscopic picture on the adjacent storage screen of the fluoroscope, the pilot hole is then tapped (threaded) by removing the drill and the inner drill guide and replacing them with the tap, which is manipulated by hand while its progress is monitored fluoroscopically. It too has a depth calibration to verify the proper screw length (Fig. 8.9).

The screw is selected based on the measured depth. If the inner drill guide does not touch the bottom of C2 and/or a gap is present between the odontoid and body of C2, the measured screw length should be reduced by a few millimeters. The screw is placed through the outer guide tube and into the C2 body through the drilled and tapped hole (Fig. 8.10a). Lag screws are used with a non-threaded proximal shaft to allow the distal fragment to be pulled down to the body of C2 (Fig. 8.10b). As the screw is being placed, its progress is monitored fluoroscopically. It is very easy to match the alignment precisely when tapping and placing the screws by comparing the live fluoroscopic image with the image of the drilling saved on the fluoroscope. The head of the screw should be recessed into the C2-3 annulus/disc edge or slightly into the inferior edge of C2, and the screw tip should be fully engaged into the apex of the odontoid when it is tight (Fig. 8.10b). Traction can be removed as

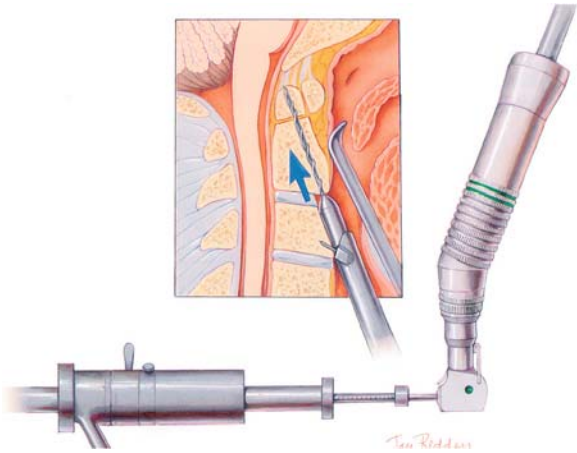


Fig. 8.8. The K-wire is removed and replaced with the drill, which is guided fluoroscopically to the apex of the odontoid after reducing the odontoid dislocation. Calibration marks on the shaft indicate the depth of penetration beyond the inner drill guide

the screw is fully tightened. Extension by several millimeters beyond the tip is safe, as this will result in the screw tip being within the apical ligaments. The angle of placement is such that the neural elements are not jeopardized. Screws that fail to engage the apical cortex fully have backed out in some cases, so this should be avoided.

The issue of whether to place one or two odontoid screws is controversial. Some patients do not have an odontoid process large enough to accommodate two screws [56]. Two-screw constructs have been advocated to prevent rotation of the dens around a single screw. We generally advocate placement of two screws if an odontoid fracture will accept two screws. However, clinical success appears to be similar with the one- and two-screw constructs [9, 41, 48].

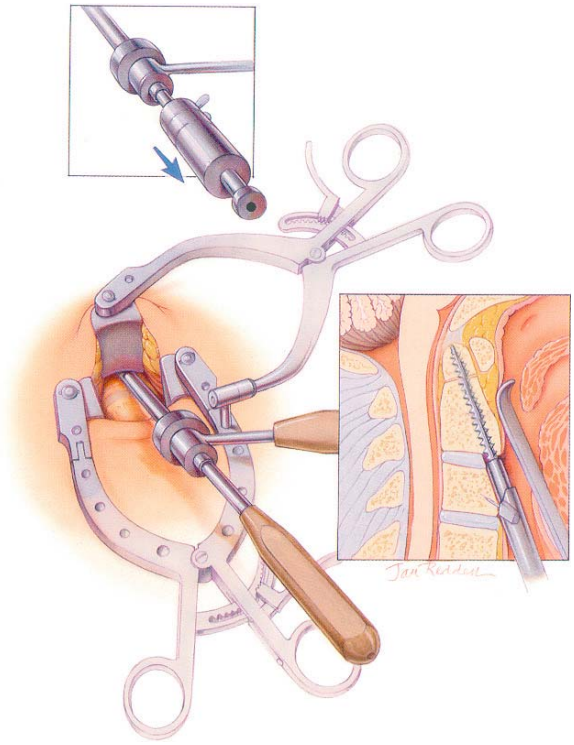


Fig. 8.9. Inner guide is removed (*inset*) and the tap is used to cut threads into pilot hole to the apex of the odontoid

Placement of a second screw, if desired, is accomplished in a similar manner using an entry site a few millimeters from the first screw. The K-wire is used for initial guidance, and an 8-mm drill is used to cut a groove in the anterior surface of C3 and the C2-3 disc. As in cases in which a single screw is used, the surgeon places the drill guide, drills the hole, taps the hole, and places the screw. The second screw can be either a lag screw or a fully threaded one (Fig. 8.11).

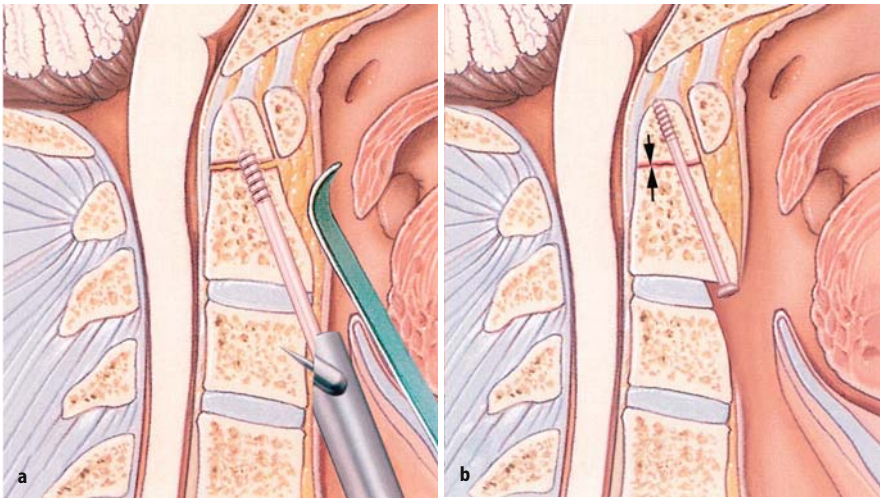


Fig. 8.10. The screw is inserted through the guide tube system and advanced through the threaded pilot hole (**a**). The final position of the screw should be just past the apical cortex of the odontoid (**b**). By using a lag screw (partially threaded with smaller proximal shaft), the odontoid fragment may be reapproximated to the body of C2 (*arrows*)

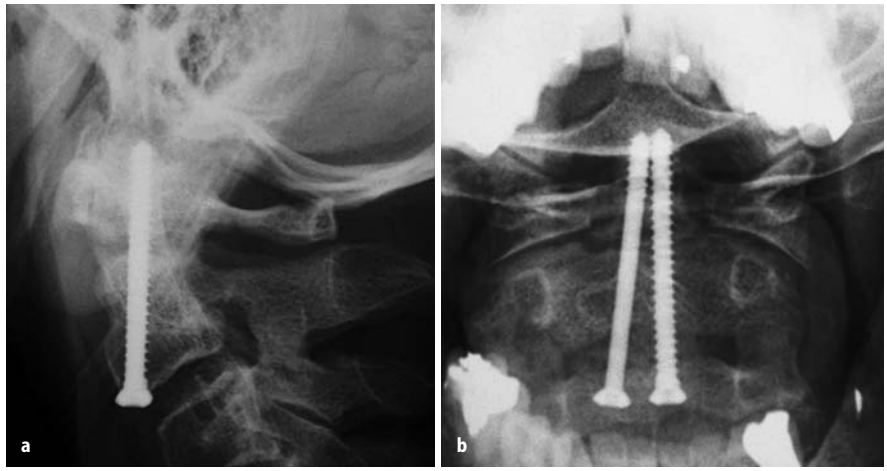


Fig. 8.11. Plain lateral (**a**) and anteroposterior (**b**) radiographs showing good placement of two odontoid screws, one a fully threaded and the other a lag screw

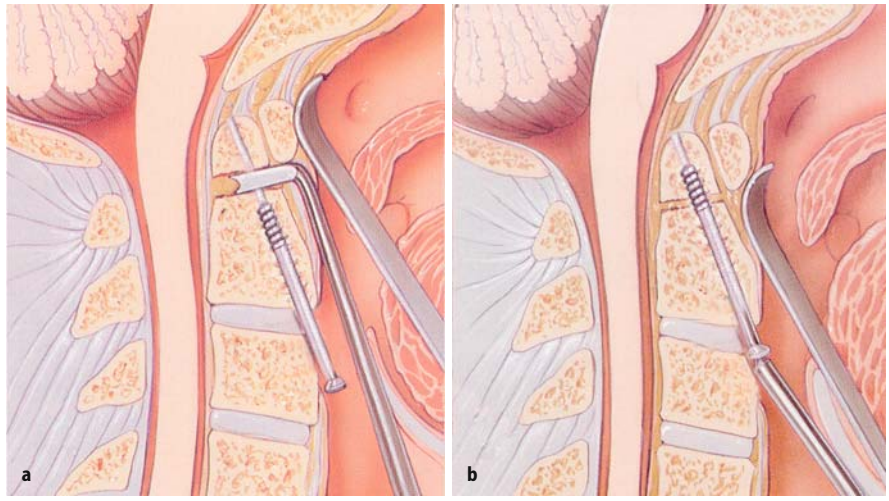


Fig. 8.12. For chronic fractures, the first screw is placed just below the fracture line initially and then the guide tube is removed. Special bifaced curettes are used to freshen the fractures site (**a**). The screw is then advanced to its final position using the ball driver (**b**)

If attempting screw placement in a chronically non-united fracture, the screw can be inserted into the body of C2 until just below the fracture site. The drill guide is then removed and special bisurfaced, angled curettes are used to freshen the fracture site and remove fibrous tissue (Fig. 8.12a). This is performed by forcing the tip of the smaller curette through the weak anterior longitudinal ligament at the fracture site (as monitored fluoroscopically) and rotating the handle. It is then replaced with the second small curette angled in the opposite direction, which is manipulated similarly. Two larger curettes are then sequentially introduced and manipulated in the same manner. The screw head is then reengaged by the ball driver (Fig. 8.12b), which can be inserted at an angle of ±15° to the long axis of the screw and fully tightened. Because success with chronic non-union has been low, we do not recommend this except in special circumstances.

After screw placement, flexion-extension of the patient's neck under fluoroscopy is used to confirm spinal stability. The retractors are removed and the wound is checked for hemostasis. Most bone bleeding from the drilling is stopped when the screw is placed, but occasionally bone wax is needed. Bipolar cautery can be helpful in controlling bleeding from the longus colli muscle edges. Closure is then completed in layers. We use interrupted absorbable sutures in the sternocleidomastoid muscle fascia, platysma muscles, and subcutaneous tissues and use sterile adhesive strips on the skin.

8.10 Postoperative Care and Complications

Odontoid screw fixation is a well-tolerated procedure, even in the elderly population that makes up a large proportion of our patients. We routinely keep patients in the ICU for the first night, primarily to monitor their airway closely. On postoperative day one, plain X-rays are performed. Dysphagia is not an uncommon complication, especially in the elderly. It is often transient,

but in some cases, temporary feeding tubes must be placed to provide nutrition. Patients usually are not required to wear cervical collars unless we are concerned about their bone density or they have an anterior oblique fracture. Patients frequently can be discharged from the hospital within 24–48 hours after their surgery. Patients typically return for a clinic visit and imaging studies at 1, 3, 6, and 12 months postoperatively, or sooner if necessary. Late complications will be discussed in the next section.

8.11 Results

We recently reviewed a two-center experience with direct anterior screw fixation for recent (fractures less than 6 months old) and remote (fractures greater than 18 months old) type II and shallow type III fractures [9]. Patients that underwent direct anterior screw fixation for recent type II and shallow type III fractures had successful stabilization in 91% of the cases (88% bony union) compared with 69% (25% bony union) in the remote group (Table 8.1). The only factor associated with statistically significantly higher rates of non-union, fibrous union, or non-anatomic union in recent fractures was an anterior oblique fracture orientation. Other factors such as age, sex, number of screws (one versus two), and direction and degree of fracture displacement did not have a significant effect on fusion in this patient population (Table 8.2). Although we would not have anticipated it, patients who underwent a trial of immobilization and failed did as well with surgery performed 3–6 months after their injury as did those operated on closer to their date of injury. The cases of non-anatomic union in our series occurred when the guide tube system was not used. In most cases, the fused position was within 1–3 mm of normal alignment. These were without neurologic sequelae and the patients did not require further treatment.

Despite having a lower rate of anatomic bony union, anterior oblique-oriented fractures still had a bone stabilization rate of 75% (50% anatomic bone union and 25% non-anatomic union), which compares favorably with results obtained using most external immobilization modalities. We therefore continue to employ anterior screw fixation in this patient subpopulation. To avoid non-anatomic union with this fracture orientation type, we consider placing these patients in a hard cervical collar postoperatively until evidence of fibrous or bony union occurs. In addition, fixation of the anterior oblique fractures in a 1- to 2-mm posteriorly displaced position may compensate for anterior movement of the odontoid during the healing process and reduce non-anatomic outcome.

Attempts to apply odontoid screw fixation in 18 patients with chronically non-united odontoid fractures (more than 18 months after the injury) did not result in satisfactory outcomes. These patients had a significantly higher rate of failure to achieve bony union (75%) and more complications (Table 8.2). The complications in this remote fracture group were primarily hardware related as no hardware can be expected to succeed if bony fusion is not achieved. The most common hardware complications were screw fracture (19%) and screw pull-out of the odontoid (6%). We therefore recommend treating these lesions with posterior C1-2 fixation and fusion. A select subgroup of patients who have relatively large odontoid processes, which are not ankylosed to either the arch of C1 or the clivus, and who have a small gap (less than 2 mm) between the odontoid and the body of C2 may remain potential candidates for direct screw fixation if they wish to try to retain C1-2 mobility. They are cautioned that successful fusion is achieved less often and that, if a fusion is not achieved, they will subsequently require posterior stabilization. Because we did not have any patient present with an odontoid fracture between 6 and 18 months after their injury, we are not able to draw any conclusions about the expected fusion rates for patients operated on during this period.

The complication rate for this method of fixation in recent fractures is similar to that seen with posterior fixation techniques (Table 8.2). The most common complications were hardware related and included screw cut-out anteriorly through the body of C2 (4%), screw back-out (3%), and C2 subluxation (1%). Screw cut-out usually occurred in patients with concomitant C2 body fractures, which were recognized but were thought to be located laterally and thus unlikely to af-

Table 8.1. Postoperative fusion status in patients with recent and remote fractures [9]

Fusion status	Number of patients (%)	
	Recent group (< 6 months)	Remote group (> 18 months)
Anatomic bony union	99 (85)	4 (25)
Non-anatomic bony union	4 (3)	0 (0)
Fibrous union	4 (3)	7 (44)
Non-union	10 (9)	5 (31)
Total	117 (100)	16 (100)

Table 8.2. Complications after direct anterior screw fixation in recent and remote groups [9]

Complication	Number of complications (%)		
	Both groups (n = 133)	Recent group (n = 117)	Remote group (n = 16)
Hardware	14 (11)	10 (9)	4 (25)
Medical morbidity	3 (3)	2 (2)	1 (6)
Mortality	1 (1)	1 (1)	0 (0)
Total	18 (14)	13 (12)	5 (31)

fect odontoid screw performance. Often, however, the scans underestimate the extent of such fracturing so we now believe that concomitant fractures in the C2 body should be seriously considered as a possible contraindication to anterior odontoid screw fixation. Patients with hardware failure were subsequently fused successfully by screw revision, halo orthosis, or posterior C1-2 fusion. Medical complications were rare and included only two (2%) cases of superficial wound infection that were treated successfully with oral antibiotics. There was one (1%) death in this series. A patient became quadriplegic and had a respiratory arrest after the distal fragment (odontoid) became dislocated subsequent to screw back-out 3 weeks after surgery.

8.12 Critical Evaluations

Numerous recent case series in the literature have evaluated anterior screw fixation of odontoid fractures with healing rates generally ranging from 80% to 100% [2, 3, 6, 11, 14, 27, 37, 41, 50, 61]. Morandi et al. treated 17 cases in which adequate reduction and fixation was obtained in all cases except one [50]. They placed a single screw in all of their patients. The average surgical time was only 40 minutes, and much of the actual intraoperative time was spent positioning the patient and the fluoroscopes. ElSaghir and Böhm [27] used two screws in 30 patients with type II odontoid fractures. Reduction and stabilization was achieved in all patients. The authors did remove the screws in 8 patients to avoid mechanical insult to the C2-3 disc by the head of the screw. Within this group of 8 patients, 1 patient did develop circumferential fusion at C2-3 even after the screws were removed. Subach et al. [61] treated 26 patients with a single screw. Unlike most other surgeons, they placed all of their patients in external orthoses postoperatively. Fusion, as defined by the presence of bridging bone, was present in 25 of 26 patients. The authors had 1 patient with a suboptimal screw placement who was placed in a halo with subsequent fusion and another patient that required a posterior fusion because of an inability to reduce the fracture adequately.

Jenkins et al. [41] provided clinical evidence that one- and two-screw fixations were equivalent in terms of union rates. They had 20 patients treated with a single screw and 22 treated with two. The union rate, as defined as the absence of dens movement independent of the C2 vertebral body with or without evidence of trabecular bone spanning the previous fracture line, in the single and double screw groups was 81% and 85%, respectively.

Some authors have investigated whether age is a factor in determining outcome following anterior screw fixation. Harrop et al. found stable union in 8 patients and concluded that odontoid screw fixation can be performed safely in patients [36]. Börm et al. [14] found similar fusion rates for patients aged 70 years or older (group 1) compared with patients less than 70 (group 2). However, medical complications not related to surgical technique occurred more frequently in the group 1 patients (20% vs 8%). Conversely, Andersson et al. [6] found an unacceptably high rate of problems in their 11 patients aged 65 or older and recommended posterior C1-2 fusion as the treatment of choice for the elderly. An analysis of 40 patients over the age of 70 treated in our institution over a 10-year interval showed fusion rates equal to the overall series (88%), but the elderly patients did have a higher incidence of dysphagia, which often was more protracted [21].

In conclusion, odontoid fractures are common cervical spine injuries. They render the spine unstable and put the patient at significant risk for potentially catastrophic spinal cord injury. Rapid and precise diagnosis is essential and leads to one of several options to stabilize the spine. Though some odontoid fractures, notably type I and III fractures, can be treated with external immobilization, growing evidence suggests that treatment of recent type II and shallow type III fractures by direct anterior screw fixation may be preferable. This easily learned and relatively straightforward minimally invasive method of treatment has a high rate of fusion and confers immediate stability, usually obviating the need for external halo vest immobilization. It provides an optimal milieu for bone fusion by eliminating motion at the fracture site and by keeping the odontoid tightly opposed to the body of C2 in its normal anatomic position. If successful, it preserves normal C1-2 motion, which accounts for one-half of the rotatory excursion of the head.

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9 Microsurgery of the Cervical Spine: The Anterior Approach

L. Papavero

Dedicated to Wolfhard Caspar, M.D., Ph.D., on the occasion of his 65th birthday

Numerous valuable reviews on anterior cervical discectomy, interbody fusion, vertebrectomy, and anterior plating are available. Since 1990 approximately 210 papers dealing with these topics have been published. Nevertheless, clear-cut answers to some questions are still lacking:

- Which traumatic lesions of the C-spine would be treated better by an anterior than by a posterior approach?
- Is plain discectomy a sufficient treatment of single-level degenerative disc disease? In which cases should disc prosthesis be preferred to interbody fusion? Should autologous bone graft be used routinely in anterior cervical fusion?
- Does corpectomy offer advantages over multiple interbody fusion in the case of multilevel spondylotic cervical myelopathy?
- Can internal fixation be recommended in the surgical treatment of cervical spondylodiscitis?
- Is the use of a bone strut indicated for reconstruction of the C-spine in tumor disease?
- When does the indication for anterior plating become controversial?

Unfortunately, this paper cannot offer enough evidence to proclaim a specific procedure the "gold standard." The author had the privilege to work 11 years with Wolfhard Caspar and after 22 years still enjoys his clinical cooperation. The maxim "good judgement comes from experience and experience comes from bad judgement" has been substantiated by quite a large personal series of anterior cervical procedures. The following pages should be understood as a subjective frame of recommendations.

The final decision on the surgical approach should be well founded on the patient's clinical pattern, the surgeon's experience, and cost consciousness.

9.1 Terminology

ACD: Anterior cervical discectomy
ACF: Anterior cervical (interbody) fusion
Corpectomy: Resection of the vertebral body corresponding to the interuncinate distance (usually 16–18 mm)
Vertebrectomy: Removal of all elements of the vertebra
"Long-distance" plating: More than three-level ACF or more than two-level corpectomy

9.2 Surgical Principle

Traumatic lesions, degenerative disease, tumors, and infectious or inflammatory pathologies determine a functional damage of the C-spine and its contents by a variable combination of the following mechanisms:

1. Compression of neurostructures [11, 13, 26]
2. Disturbance of spine alignment [1]
3. Instability

Therefore, the goals of any (also surgical) treatment should be:

1. Decompression
2. Restoration of the cervical lordosis
3. Stabilization

The anterior approach with the currently available technology fulfills these requirements [5, 6, 28, 34, 36, 39, 48].

In anterior cervical surgery perhaps more than in other procedures, a painstaking attention to detail is the key factor of therapeutic success. This is demonstrated by the broad range of incidence of complications in the different series of procedures (in contrast to the quite homogeneous incidence of recurrence in lumbar disc surgery). The learning curve of each surgeon also has a profound impact on outcome and complication rates: this holds particularly true for hardware failure.

At this point two considerations should be made:

1. For the sake of safety, the decompression of the neurostructures should be performed at least with head loupes, and better still with the aid of a microscope [32].

2. Removal of dorsal osteophytes, corpectomy, impacting of the graft, and plating should be controlled by intraoperative fluoroscopy.

Both measures improve the surgeon's view: firstly, in the interspace or on the epidural surface and, secondly, "around the corner" of the vertebral endplate and "through" the vertebra. The completeness of decompression and the accuracy of both fusion and instrumentation are critical for the overall outcome.

Modular components of anterior cervical surgery are:

1. Perioperative measures
2. Soft tissue approach
3. Plain discectomy
4. Resection of the osteophytes or corpectomy
5. Interbody fusion (single/multilevel) or vertebral body replacement
6. Graft harvesting (surgeon's choice)
7. Anterior plating

The single steps can be standardized in order to lower morbidity. The patient's clinical presentation and pathological condition require a specific combination of the surgical modules in order to provide an individually tailored operation.

9.3 History

The first ACFs were performed for degenerative disease in the 1950s [20, 23, 49]. In 1960, Bailey reported ACF as a treatment for C-spine trauma [3]. The pioneering work of Cloward was published in 1961, however not without resistance from the reviewers [21].

Orozco introduced anterior plating in 1970 as an adjunctive treatment option in cervical fractures and designed a plate specifically for this procedure [45]. In 1981, Caspar developed the first "comprehensive" set for anterior cervical surgery, consisting of instruments for the operative exposure, for the decompression and fusion, and for the osteosynthesis [14–17]. The distractor resting on pins screwed in the vertebral bodies allowed for the first time a parallel distraction and an unhindered exposure of the interspace. The trapezial plate (nowadays available with both bi- and monocortical screws) is still one of the most popular non-constrained fixation systems [16].

Recently, due to the fascination of minimally invasive spine surgery, percutaneous [37, 62] and laser-assisted [48, 50] discectomy for contained disc herniations without accompanying osteophytes has been reported. A limited anterior uncoforaminectomy has been advocated [35, 36] whenever a lateral disc herniation or a bony spur arising from the uncinate process compresses the root. Chapter 10 deals with the details of this technique. Long-term follow-up studies have shown the development of degenerative changes in segments adjacent to fusion. Also plain ACD is followed by a spontaneous fusion in 70 % of cases [7, 25, 60]. The incidence of so-called adjacent segment disease is up to 25 % over a ten-year time span after first surgery [30, 34]. The implantation of a disc prosthesis protecting the adjacent levels from the abnormal stresses associated with fusion could be advantageous. Although the role of artificial discs in preventing adjacent segment disease remains to be seen in the long term, results of the two-year follow-up seem promising. More about this innovative treatment option is given in Chapters 11 and 12.

9.4 Advantages

1. Minimally traumatizing exposure of the C-spine through natural tissue planes along with preservation of the posterior elements of stability (i.e., muscles, ligaments, and facet joints).
2. The approach makes it possible to address the majority of traumatic, degenerative, neoplastic, and inflammatory lesions affecting the weight-bearing anterior column.
3. Optimal visualization of the anterior epidural space over 18 mm transverse width.
4. The approach allows for fusion and stabilization along with correction of any kyphotic deformity.
5. A second-stage posterior approach can be performed when necessary (e.g., tumors requiring vertebrectomy) as soon as anterior stabilization has been obtained.
6. Low morbidity and supine positioning which make the procedure reasonably well tolerated also by elderly patients.

9.5 Disadvantages

1. Traumatic lesions presenting transpedicular fractures cannot be treated because of the impossibility of reducing the slipped facet(s).
2. Lesions as high as C1/C2 and as low as C7/T1 are not easily approached.
3. Loss of single or multiple motion segments through fusion.
4. Concern for secondary degenerative changes of the segments adjacent to the fusion site.

9.6 Indications

9.6.1 Trauma

1. Subluxations or luxations without transpedicular fractures (Fig. 9.1)
2. Vertebral body fractures, especially with displaced bone fragments
3. Correction of surgically induced "swan neck deformity" following extensive laminectomy

Spinal Cord Injury without Radiographic Evidence of Trauma (SCIWORET, Fig. 9.2)

9.6.2 Degenerative disease

1. Single/multiple level median and paramedian soft disc herniation
2. Single/multiple level median and paramedian spondylosis (Fig. 9.3)
3. Ossification of the posterior longitudinal ligament (OPPL)
4. Spondylolisthesis



Fig. 9.2. A quite uncommon indication for the anterior approach. A 25-year-old male referred after a biking accident. The patient presented a severe quadriparesis, (contin. see p. 57)

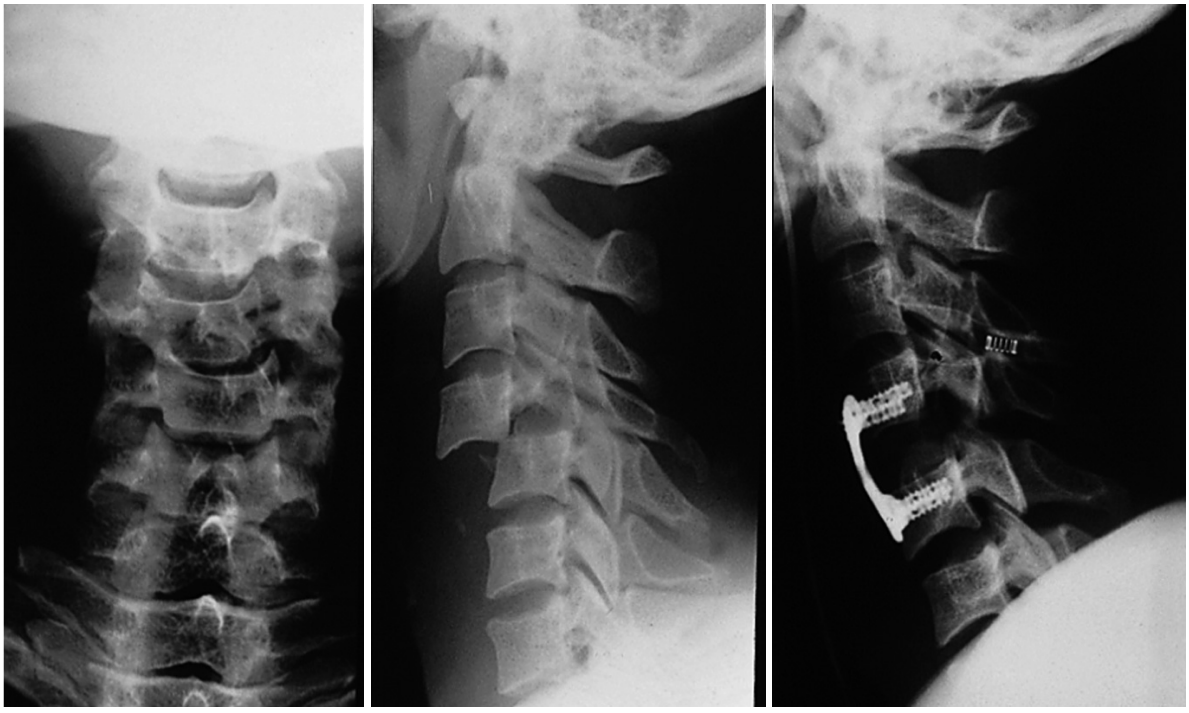
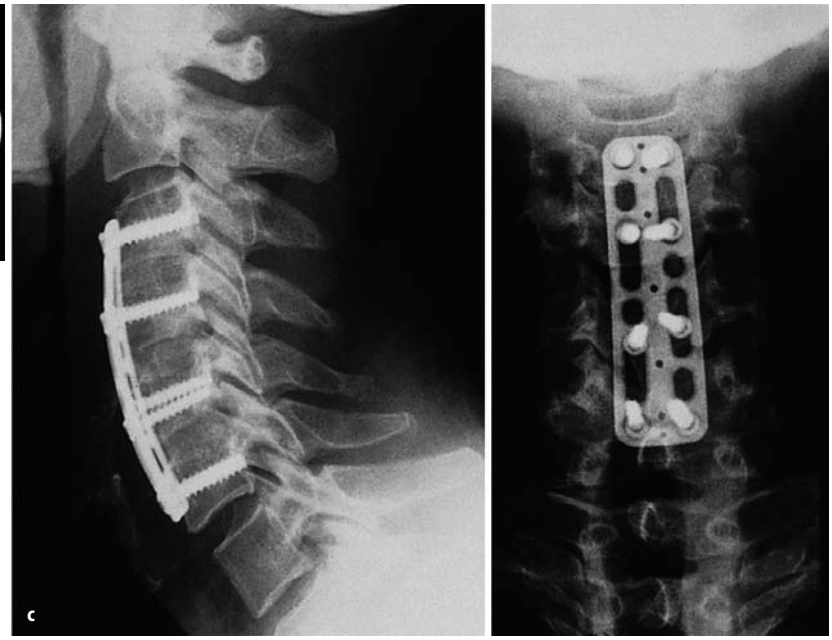
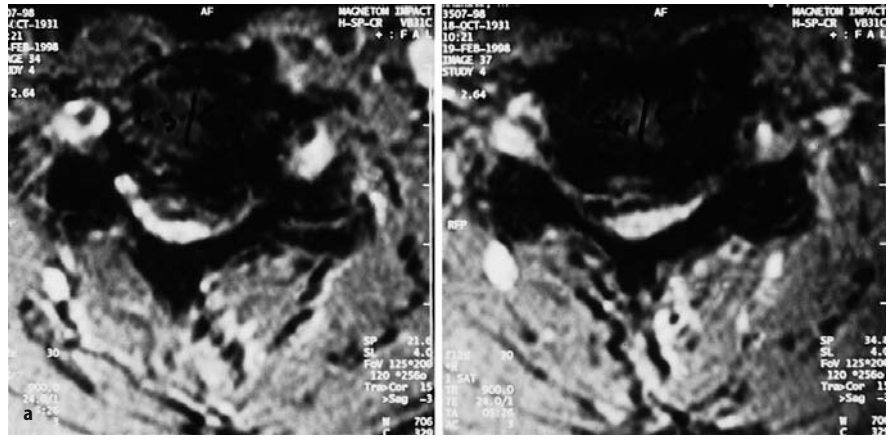


Fig. 9.1. A classic indication for the anterior approach. Luxation-fracture C4/C5 which is barely detectable in the AP view (*left*). Fusion with autologous tricortical iliac crest graft and instrumentation with a cervical spine locking plate (CSLP; *right*)





(Fig. 9.2 cont.) with marked weakness of the hands, but only minor sensory changes. **a**, **b** Although the plain X-ray films showed only moderate dorsal osteophytes at C3/C4 (short neck!), the MRI depicts the full extent of the spinal cord contusion from C3 to C7. **c** Three-level decompression, fusion, and plating was performed. Note the restoration of the cervical lordosis



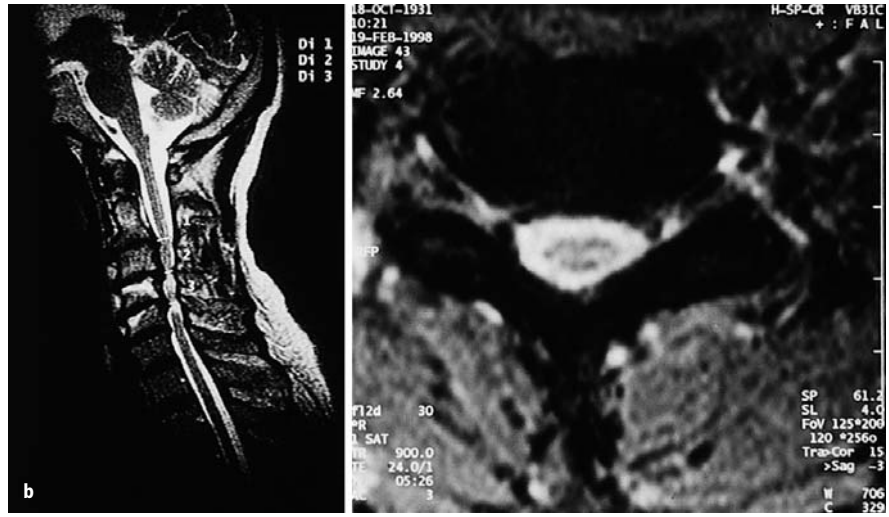


Fig. 9.3. A case of cervical myelopathy treated by the anterior approach. **a** Spondylotic spurs C5/C6 (*right*) and C4/C5 (*left*). **b** In comparison the normal level C7/D1

9.6.3 Tumor

1. Vertebral body benign tumors or metastases
2. First-stage corpectomy when vertebrectomy is indicated

9.6.4 Infectious disease

1. Spondylitis (Fig. 9.4)
2. Spondylodiscitis
3. Epidural abscess (Fig. 9.4).

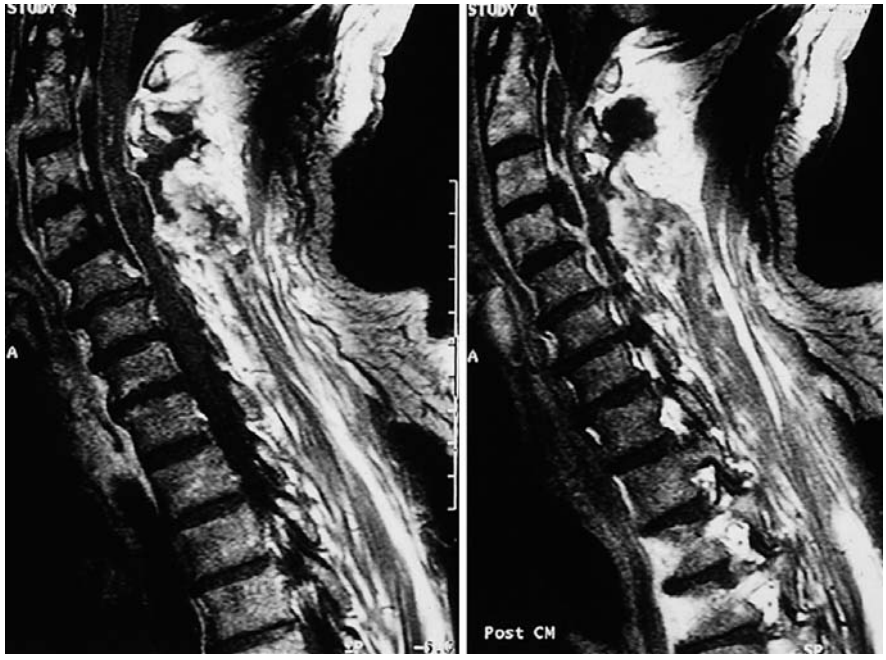
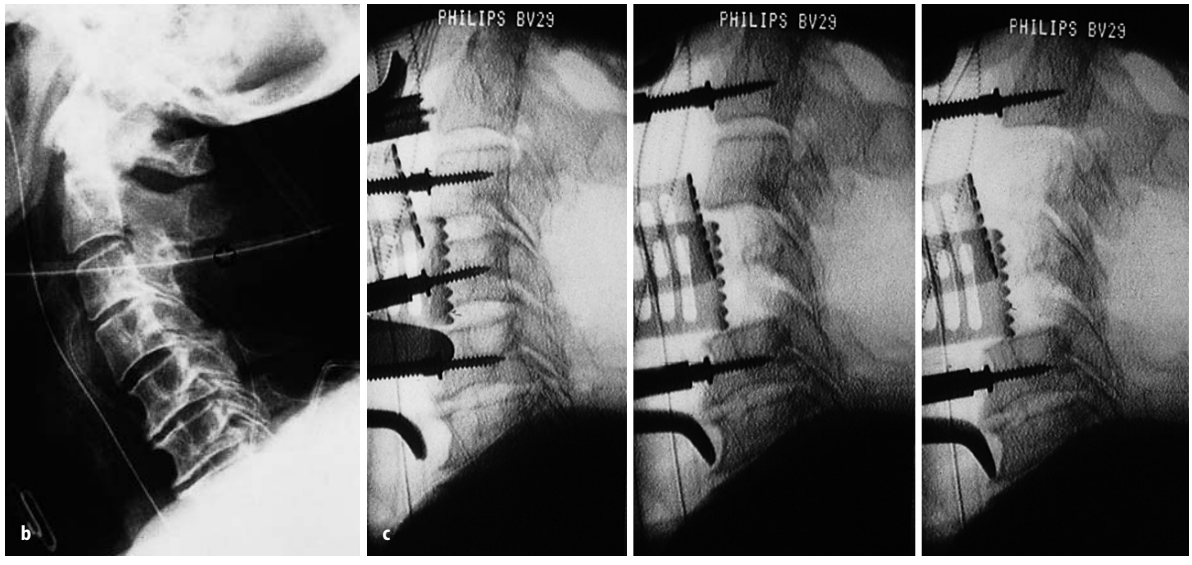


Fig. 9.4. A salvage indication for the anterior approach. **a** Spondylitis C3 and C4 with epidural abscess from C2 to C4



b Laminectomy C3 and C4 has been performed in the (unsuccessful) attempt to drain the fluid collection.
c Fluoroscopic control of the corpectomy C4 (*center*) and C3 (*right*)

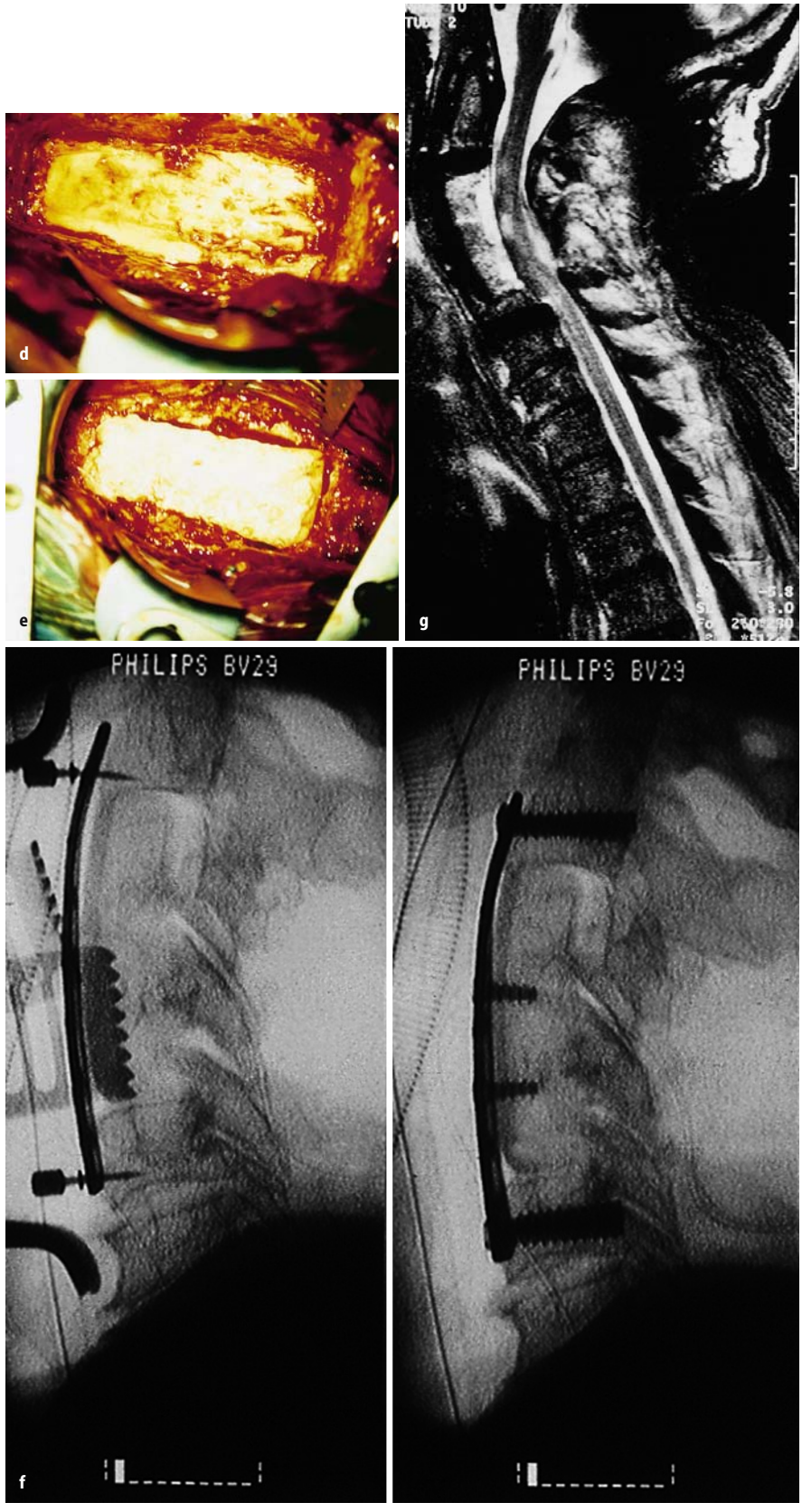


Fig. 9.4. (contin.) d Epidural space. **e** Iliac crest graft becoming wider in the caudal part. **f** Fixation of the Caspar plate with temporary spikes and insertion of bicortical screws. **g** Postoperative MRI confirming the decompression of the spinal cord

9.7 Contraindications

9.7.1 Absolute

1. Isolated traumatic disruption of the posterior elements
2. Predominant dorsal compression of the neural structures (Fig. 9.5)

9.7.2 Relative

1. Thyromegaly

9.8 Patient's Informed Consent

The numerous, among them several quite unusual, complications and causes of postoperative discomfort following anterior cervical surgery are well known. In our view, the following aspects should in particular be discussed with the patient during preoperative counseling.

1. The most feared complication by the patient is spinal cord injury resulting in para- or quadriplegia. Although a direct laceration of the spinal cord is an infrequent occurrence, especially when the microscope is routinely used, the possibility of a neurological worsening should be clearly pointed out. In the case of an intraspinal space-occupying lesion (e.g., displaced bone fragments, huge disc herniation, spondylotic bars, or tumor and, to a greater extent, if associated with a narrow canal), we should always bear in mind that intubation, positioning, and an intraoperative drop in blood pressure can dramatically endanger an already impaired cord function.
2. Postoperative hoarseness and impaired swallowing may result as a consequence of excessive blade retraction (erroneously inserted in the tracheoesophageal groove) or, even worse, due to transection of the recurrent laryngeal nerve. Because of the particularly disabling (although usually reversible) effect of this occurrence, the patient should be made aware of it.
3. Postoperative interscapular pain is a frequent, occasionally long-lasting, consequence of plain ACD (Fig. 9.6). On the other hand, transient neck and shoulder pain is experienced by patients following ACF, probably caused by a graft overstretching the facet capsules. An autologous bone graft subsides roughly 2 mm during the first 2 weeks after insertion, whereas Smith-Robinson type interbody cages take a couple of months to settle in the adjacent vertebral endplates.



Fig. 9.5. A case of cervical myelopathy (wheelchair!) treated by posterior approach. **a** Thoracic kyphosis with compensatory cervical hyperlordosis. **b** MRI shows buckling of the yellow ligament causing dorsal compression of the spinal cord. **c** Hampered deambulation was possible 1 year after laminectomy C3-6

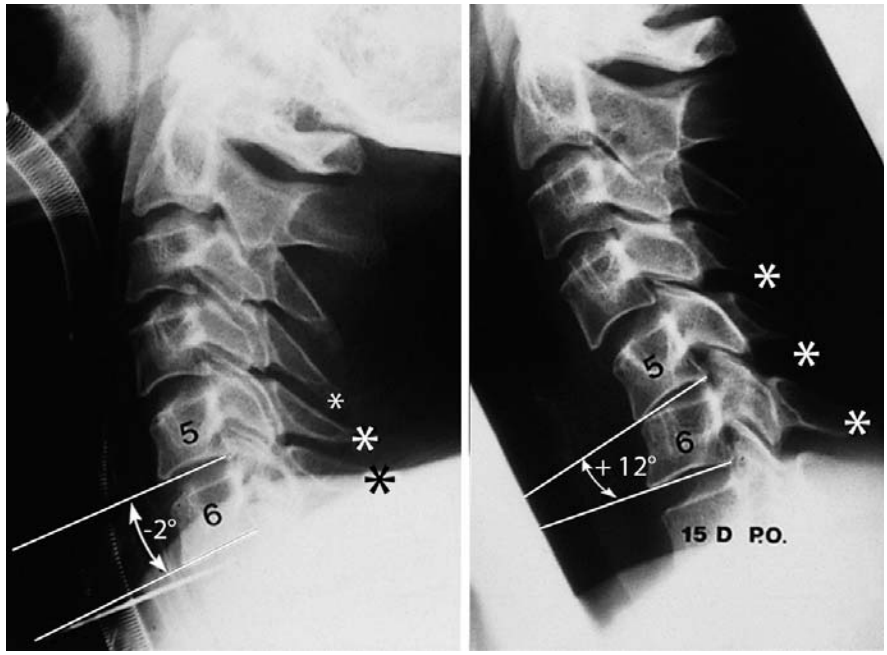


Fig. 9.6. *Left* Before discectomy C5/C6: segmental lordotic angle –2°. Normal interspinous distance. *Right* After discectomy: segmental kyphotic angle +12°. Painful muscular sprain due to the increased interspinous distance (*asterisks*)

4. Graft-related complications such as non-union, moderate dislocation, or collapse do not necessarily mean an unsatisfactory outcome. However, patients may be made unsure by the radiologist at postoperative X-ray control. Therefore, preoperative information regarding this eventuality can be recommended.



Fig. 9.7. (Asymptomatic!) hematoma after harvesting a graft for two-level corpectomy

5. The description of donor site morbidity, usually pain at the iliac crest, should be realistic. This holds particularly true when the harvesting of multiple or long grafts is necessary (Fig. 9.7).
6. During recent years, the use of metallic (titanium) or non-metallic (polyetheretherketone, PEEK, or carbon composite polymers) cages for ACF became popular. It has been shown in prospective clinical studies that cages perform better than autogenous iliac bone in terms of reduced incidence of graft complications and avoidance of donor site morbidity [18, 46]. Therefore, the patient should be informed about these options.

9.9 Surgical Technique

The numerous variations of surgical technique cannot all be described in this chapter, which inevitably reflects personal surgical maneuvers. Although these techniques have proven to contribute to a patient's **satisfactory** outcome, they should and will be further refined. A comprehensive and brilliant presentation of microsurgical cervical techniques is given in the book "Essentials of Spinal Microsurgery" written by McCulloch and Young [40].

In the following sections, the basics (valid from C2 to **T1**) of each single step will be summarized. Where appropriate, some comments referring to trauma, degenerative disease, tumors, or infectious disease will be added.

9.9.1 Perioperative Measures

Fiberoptic intubation is indicated in:

- Unstable traumatic lesion with/without neurological deficits (*cave* reluxation, disc perforation, or displacement of bone fragments!)
- Cervical myelopathy due to huge soft disc herniation or spondylosis (*cave* narrow spinal canal!), especially if the preoperative assessment has shown that the degree of cervical extension tolerated by the patient (Lhermitte's sign) is small
- Cord encroachment caused by conspicuous intraspinal tumor extension (*cave* sudden ischemic/compressive injury!)

9.9.2 Drugs

- One gram of cephazoline is administered intravenously 30 minutes prior to the skin incision.
- A methylprednisolone loading dose of 30 mg/kg is followed by a 23-hour intravenous drip of 5.4 mg/kg according to the NASCI II recommendation in spinal cord injury [12].

Likewise, in patients with a severe preoperative myelopathy this protocol is employed on the assumption of a "spinal cord-protective" effect during operation. However, to our knowledge there is no controlled study supporting this policy.

9.9.3 Microscope

Although we are aware of the fact that many intraspinal procedures are performed without any magnification device at all or with loupes and headlights, we cannot accept these methods as alternatives to the microscope unless in emergency situations or in poorly equipped operating rooms. Table 9.1 summarizes the advantages of the microscope over loupes (Fig. 9.8).

In our experience, the repair of a lacerated dura (trauma), the removal of spondylotic spurs sticking to a hypertrophied posterior ligament (degenerative disease), the resection of an infiltrated posterior ligament (tumor), as well as meticulous hemostasis are made safer by the use of the microscope. As a result, the patients benefit from reduced postoperative morbidity. Therefore, we strongly recommend to invest time in the learning curve and money in the microscope as a surgical aid (Fig. 9.9). Probably you will never hear that a spine surgeon practicing microsurgery has abandoned the microscope due to disappointment after initial enthusiasm!

9.9.4 Intraoperative Fluoroscopy

A draped C-arm in lateral projection (Fig. 9.10) is helpful (and surgically time-saving) in:

- Centering the skin incision exactly on the target vertebra
- Marking narrowed interspaces, despite huge ventral osteophytes
- "Guiding" the burring of collapsed or pseudoarthrotic interspaces parallel to the endplates
- Optimally inserting the distraction screws and controlling the extent of distraction
- Checking the complete resection of dorsal spondylotic bars
- Ensuring a "gapless" fitting of the bone graft or interbody cage to the adjacent vertebral endplates
- Confirming the restoration of cervical lordosis during positioning, grafting, and plating

Table 9.1. Advantages of the microscope over loupes

	Loupes	Microscope
Magnification	Limited in degree, and fixed during a procedure	Relatively unlimited and variable
Motion	Long surgery causes neck fatigue and motion of the loupes	No motion of the microscope
Focus	Each time the surgeon looks up, refocusing is necessary	Microscope in constant focus, regardless of the surgeon's attention
Illumination	Not parallel to line of vision	Parallel to line of vision, and stronger
Deep three-dimensional vision	Limited when the skin incision is less than 65 mm	Maintained with even a 25-mm skin incision
Patient size	The larger the patient, the larger the wound	Neutralized (the optics adjust to patient size)
Teaching	Assistants excluded	Assistants included
Surgeon's neck	Fixed in flexion and requiring repositioning. Fatigue during long surgery	Spared, can be adjusted through inclinable binoculars
Documentation	Not possible	Photographs and video possible

Modified from: McCulloch and Young (1998) Essentials of Spinal Microsurgery. Lippincott-Raven, Philadelphia, p 4

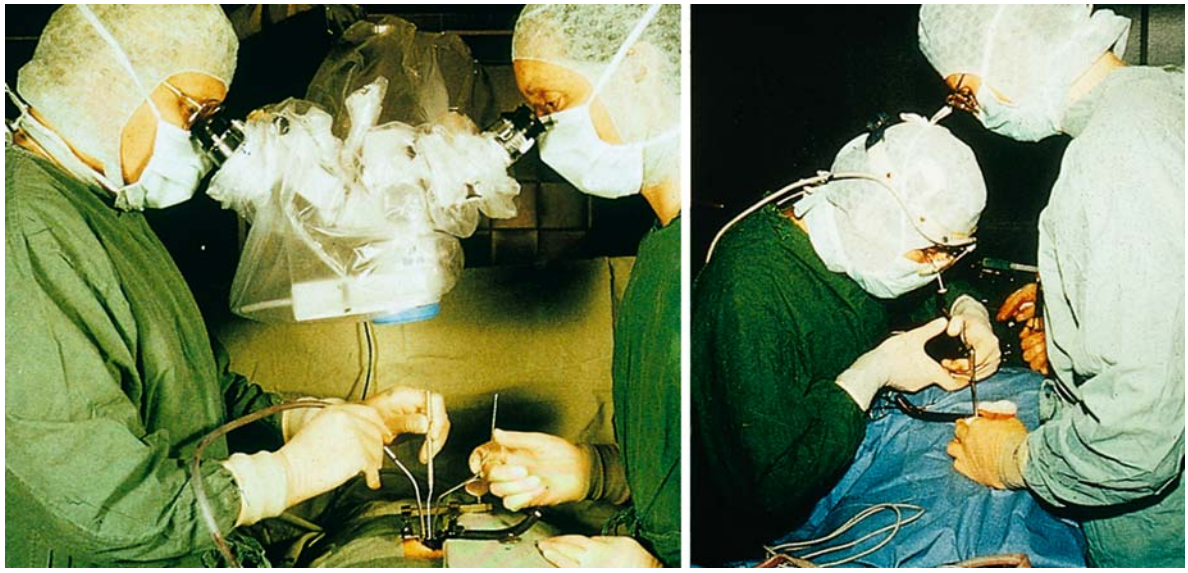


Fig. 9.8. For the advantages of the microscope over loupes see Table 9.1

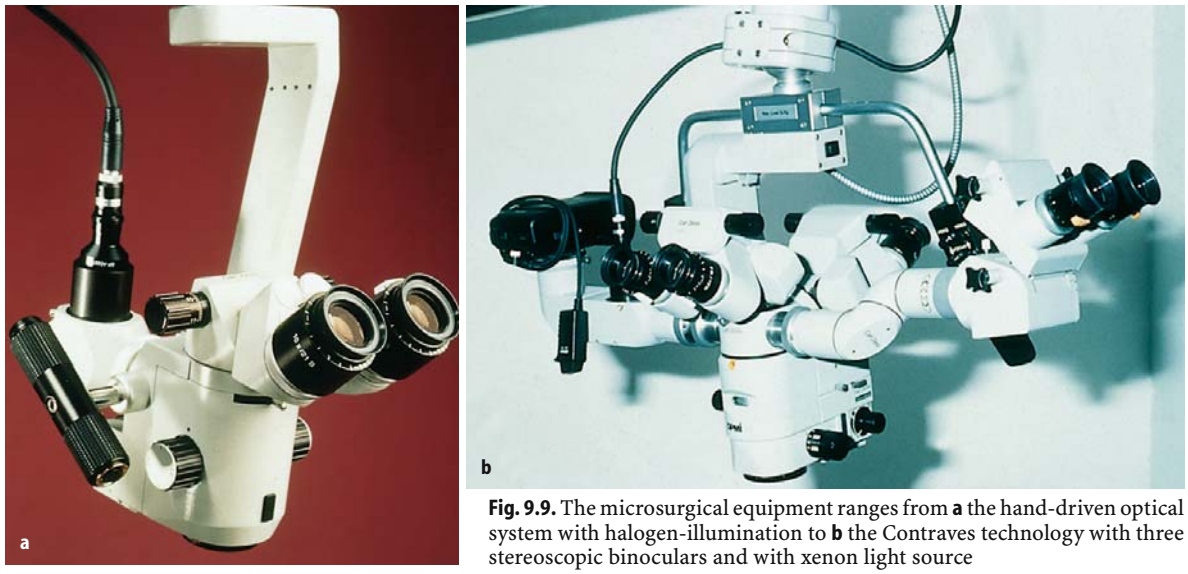


Fig. 9.9. The microsurgical equipment ranges from **a** the hand-driven optical system with halogen-illumination to **b** the Contraves technology with three stereoscopic binoculars and with xenon light source

- Choosing the plate length and its extent of bending as well as optimizing the screw (also monocortical!) placement

AP fluoroscopy may become helpful in centering long plates (three- or four-level procedures) on the midline, especially in the case of small vertebral bodies.

The time of image intensifying can be greatly shortened by using modern equipment (e.g., Siretom 2000, Siemens or BV 29, Philips) with an electronically controlled on/off device and double monitors (the right one usually for the frozen image). Semilucent or completely radiolucent retractor blades additionally reduce the X-ray load.

9.9.5 Intraoperative Evoked-potential Monitoring

We consider this tool very helpful in surgery of intramedullary tumors. Regarding intraspinal, but extramedullary, procedures we feel that the combined use of the microscope and intraoperative fluoroscopy reduces the surgical trauma to a minimal extent which could hardly be diminished even further.

9.9.6 Preoperative Angiography

If surgical intervention for tumor is planned, angiography is helpful in showing the arterial supply to the spi-

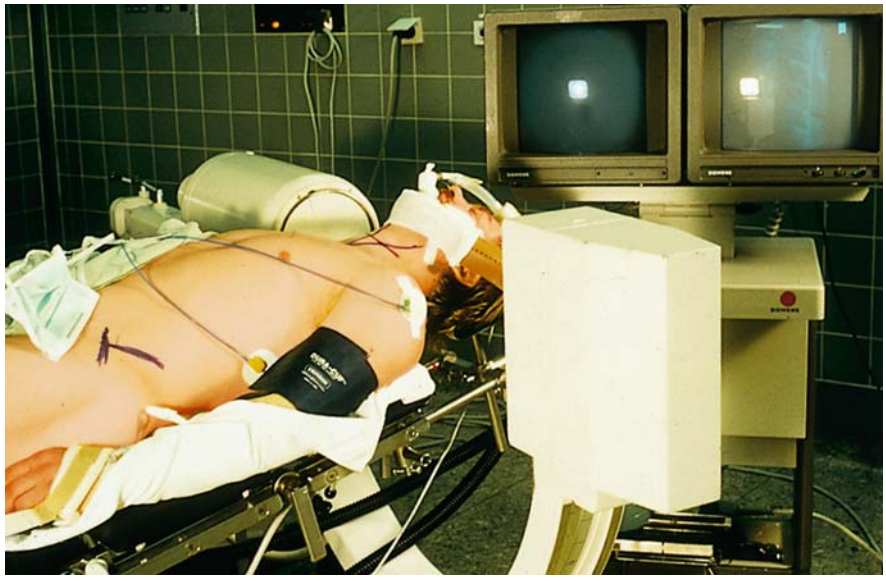


Fig. 9.10. Patient positioned for a procedure at a lower cervical level (table upwards). Note the wrist-cuff and the chin rubber-band. Image intensifier is placed in lateral position

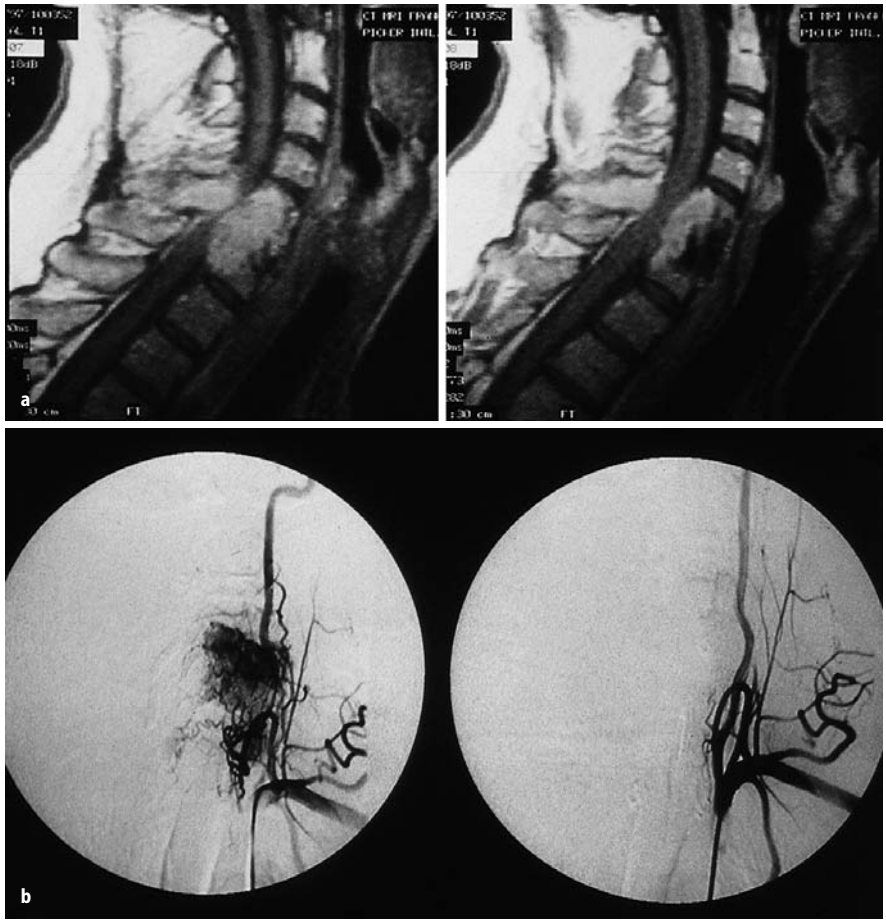


Fig. 9.11. a Postoperative magnetic resonance imaging of a 40-year-old male operated on (without previous angiography) for corpectomy C5 and C6. Surgery had to be stopped after a blood loss of 8 l over 50 minutes. A fibular graft (hypointense) was inserted to temporarily stabilize the situs. The patient spent 4 months on ICU and became wheelchair-bound. **b** Occlusion of the right-sided vertebral artery and selective embolization of the left-sided tumor feeding vessels

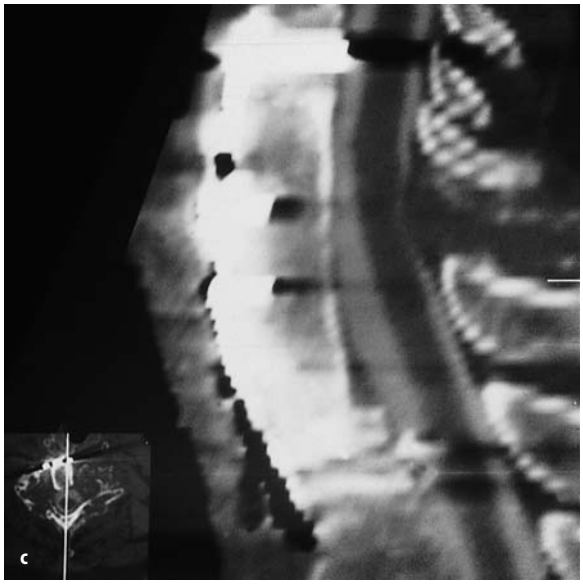


Fig. 9.11. (contin.) c Postoperative computed tomography: corpectomy C5/C7, fusion with iliac crest graft, and plating had been performed (3 l blood loss). Histological diagnosis: thyroid cell carcinoma. I^{125} therapy followed. After 4 years of normal deambulation, paraparesis developed again due to a compression of the spinal cord by the residual dorsal tumor. Angiography was repeated, but embolization could not be performed. On the occasion of the third surgery the patient died *in tabula* due to uncontrollable bleeding

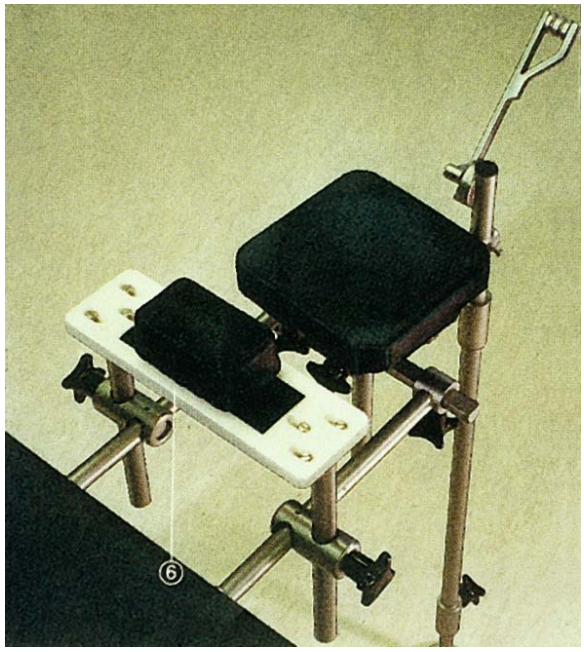


Fig. 9.12. The combined head–neck rest allows separate adjustment of the head (including skull traction) and of the C-spine: in difficult anatomical conditions the positioning can be optimized by fluoroscopy. The neck support is radiolucent also in AP projection

nal cord and the dislocation of the carotid/vertebral arteries. Furthermore, embolization should be considered as a significant adjunct prior to surgical resection of highly vascularized vertebral metastases (e.g., renal cell carcinoma; Fig. 9.11) [16, 45].

9.9.7 Positioning

If anterior cervical procedures are scheduled quite regularly, an adjustable head and neck holder (Aesculap, Tuttlingen, Germany) can definitely be recommended, although the device is quite expensive (Fig. 9.12). Traction and extension of the C-spine can be adjusted very precisely (further optimized by fluoroscopic control!). Weights (range 0.5–1.5 kg) can be applied to wrist-cuffs if required to pull down the shoulders in patients with short necks. A permanent fixation of the shoulders with wide adhesive tapes (brachial plexus stretching!) is no longer necessary (Fig. 9.10).

In order to get a line of vision coaxial to the direction of the interspaces, the head of the table may be elevated roughly 10° for surgery from C5 to T1, horizontal for procedures C4/C5, and slightly tilted downwards for approaching the uppermost levels (ensuring that the patient's chin is out of the way).

It must always be remembered to release the head traction device (up to 10% of the body weight) before starting plating!

9.9.8 Which Side Approach?

- According to the surgeon's preference from C2 to C6.
- Left side from C6 to T1 since less likely to injure the recurrent laryngeal nerve [51, 52]. Contralateral to the side of previous surgery, with the twofold advantage of a virgin tissue approach and of scars retracting trachea and esophagus away from the dissection site.
- Contralateral to a foraminal pathology: the oblique view allows for easier decompression.

9.9.9 Soft Tissue Approach

A transverse skin incision (3 cm for single-level up to 8 cm for four-level exposure) along Langer's line provides a cosmetically favorable result. If instrumentation is planned, the incision should be 1 cm across the midline, in order to center the plate on the midline better. Generous dissection underneath the platysma (cut perpendicular to its fibers) allows for extensive caudal and rostral exposure. Blunt finger dissection along the anteromedial border of the sternocleidomastoid mus-

cle leads eventually into the prevertebral space. The midline orientation is usually given by the medial borders of the longus colli muscles, but can be difficult if ventral osteophytes deform the anterior vertebral surface and push the muscles aside. In extreme anatomical conditions, marking the midline at this point of the procedure with temporary spikes may be helpful for orientation of the plate.

The correct interspace is marked by fluoroscopy and correspondingly the medial border of the longus colli muscles is cauterized and dissected. Attention should be paid that the retractor blades grip underneath the muscle belly. Stay sutures through the muscle bellies may be helpful. Semilucent titanium (Aesculap) or aluminum (Sofamor Danek, Memphis, TN, USA) blades or radiolucent blades (Medicon, Tuttlingen, Germany) can be inserted (Fig. 9.13).

9.9.10 Discectomy, Resection of Osteophytes, and Corpectomy

Following the incision of the anterior annulus, the disc space is cleared with curettes in its superficial half. The insertion pins of the Caspar interbody distractor system are screwed into the middle third of two or more adjacent vertebrae parallel to the endplates (Fig. 9.14a). If a vertebral body is destroyed by trauma or tumor, it can be skipped over and the second screw is placed in the next healthy vertebra (Fig. 9.13d). The advantages of this system are the unhindered exposure of the interspace and the option of parallel distraction or compression (e.g., of the graft/strut; Fig. 9.14b). Furthermore, in trauma patients the combination with a conventional interbody spreader allows for reduction of slipped facets, thus avoiding the necessity of an additional dorsal approach.

At this point the microscope is centered on the interspace and the deeper portion of the disc is removed in between the medial borders of the uncinate processes. If indicated, the posterior longitudinal ligament is resected with 1- to 2-mm Kerrison rongeurs (thin footplate). It must be remembered that the ligament is a bilayered structure (the posterior layer can be mistaken for the dura) and that its thickness decreases from the midline to the foramina (Fig. 9.14).

Before dorsal spurs are resected, parallel preparation of the endplates with cylindrical or conical burrs is

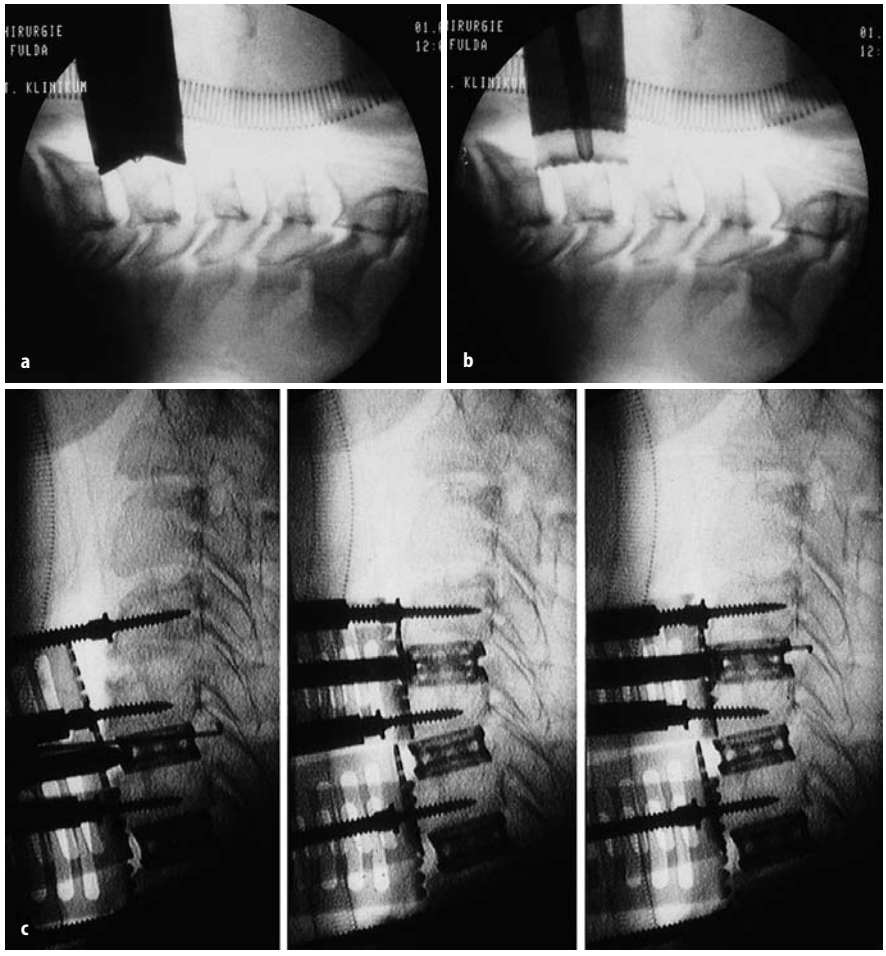


Fig. 9.13. a Conventional stainless-steel retractor blades: the rongeur can be barely seen. **b** Same situs with titanium blades. **c** Three-level fusion with interbody cages. The soft tissue is held by a couple of retractors with slotted titanium blades

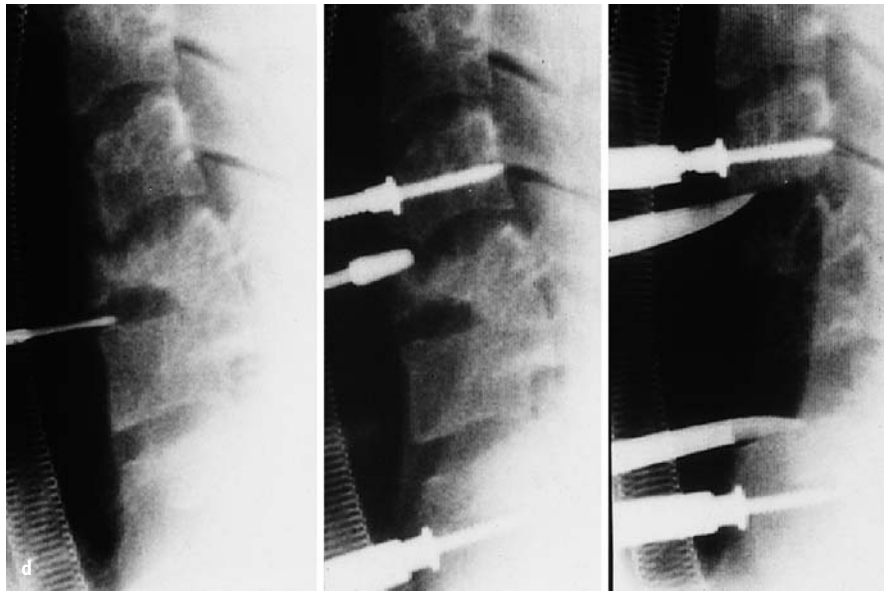


Fig. 9.13. (cont.) d Measuring of the graft site (*right*) after two-level corpectomy. The blades allow for excellent control of the instruments

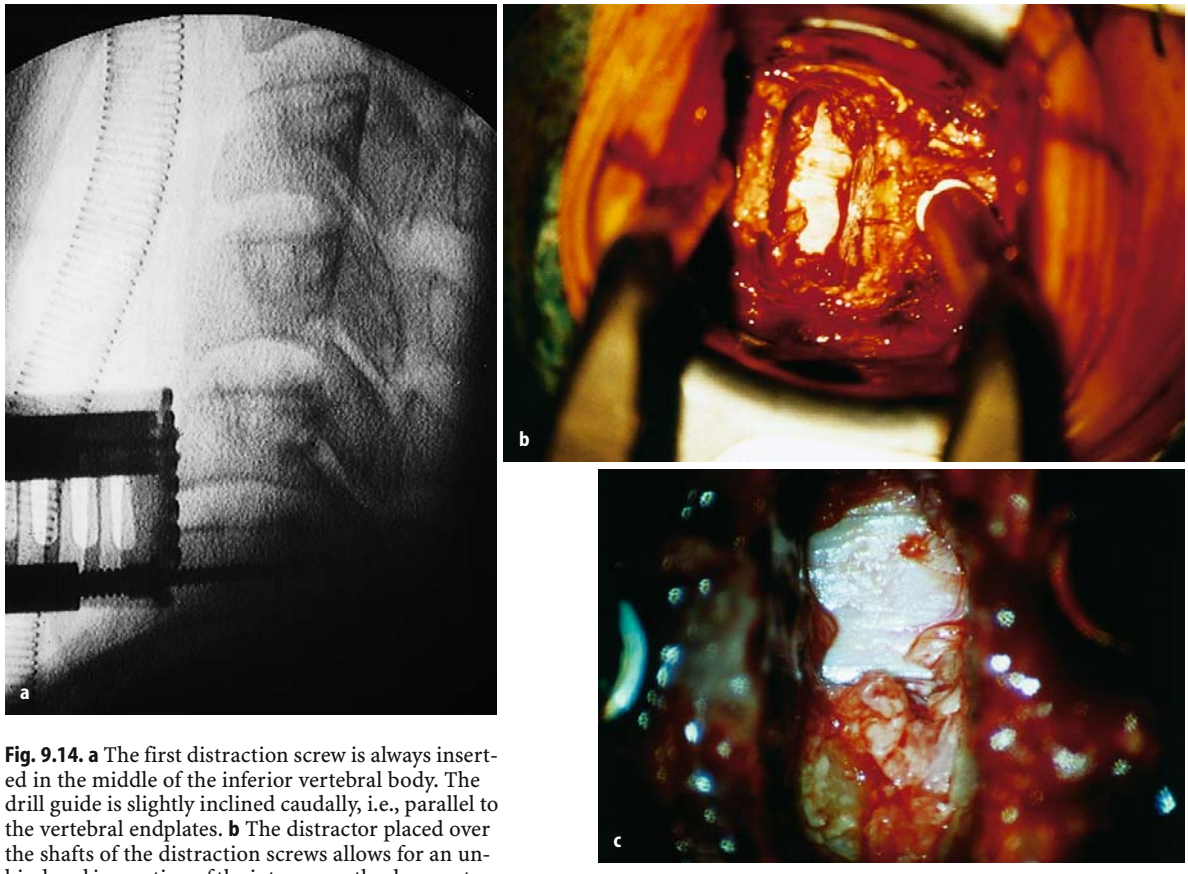


Fig. 9.14. a The first distraction screw is always inserted in the middle of the inferior vertebral body. The drill guide is slightly inclined caudally, i.e., parallel to the vertebral endplates. **b** The distractor placed over the shafts of the distraction screws allows for an unhindered inspection of the interspace: the dura mater is visible in the depth. **c** Greater magnification. On the one half of the epidural space spondylotic spurs and a hypertrophied ligament still encroach on the dura, which has been decompressed on the other half

recommended. The re-created interspace height facilitates the oblique insertion of small cutting instruments (drill, curette, or rongeur) in order to resect the spondylotic bars. The simultaneous removal of osteophytes and of the thickened posterior ligament provides a clear dissection plane between the posterior ligament itself and

the dura. The complete resection of spurs is checked by image intensifier, with a blunt hook "hooking" the posterior vertebral cortex on the midline and paracentrally on both sides. In the case of broad-based osteophytes only this control assures a radical decompression, leading in severe cases to a partial corpectomy!

Single/multiple corpectomy can also be planned if trauma, tumor, or degenerative changes have compromised the vertebral body. In order to reduce the blood loss, harvesting the autologous strut or preparing the allo- or xenostrut (measuring abundant size!) should be done following the burring of the most cranial and the most caudal endplate, but prior to starting the corpectomy. On the anterior surface of the vertebral body to be resected, two longitudinal lines joining the medial borders of the uncinate processes exposed into the interspace above and below are drawn with bipolar forceps or a small cutting drill. The width ranges usually from 16 to 18 mm. Bone removal is accomplished by means of a heavy-duty rongeur or by drilling, while taking care to keep decompression to the interuncinate dimension. As the posterior cortex is revealed, decision has to be taken about resection of the posterior ligament. Whenever possible this should be spared, keeping in mind its function as a tension band, although excision is clearly indicated if ligament pathology is still compressing the cord. Hemostasis of the lateral bone shells is performed with a diamond-dust-coated burr. Vessels of the posterior longitudinal ligament can be coagulated (bipolar!). Epidural bleeding usually stops after inserting Gelfoam strips underneath the residual lateral vertebral bone.

9.9.11 Interbody Fusion (Single/Multilevel) or Vertebral Body Replacement

It is still controversial as to whether anterior cervical discectomy should be routinely followed by interbody fusion [41, 43]. The respective advantages and disadvantages of each option along with the comparable long-term results have in the past led to, in some cases dogmatic, pro-fusion or anti-fusion attitudes. To be on the safe side the decision should be tailored to the patient's specific pathology. In the author's view, ACF is indicated in the following conditions:

1. Traumatic disc disease [44, 57]
2. Spondylotic myelopathy
3. Whenever the decompression of cord and roots requires an extensive resection of dorsal osteophytes and/or of the thickened posterior ligament
4. Loss of segmental cervical lordosis
5. Surgery following previous laminectomy or previous ACF of an adjacent level
6. Multiple-level procedure
7. Unusually high disc space

The goal of ACF consists in restoration of the interspace height and of the transverse diameter of the neuroforamina, unbuckling of the posterior ligament, and maintenance or restoration of the segmental cervical lordosis. Good results can be obtained with different grafting techniques. The Smith-Robinson procedure performed with the Caspar instrumentation is presented here.

9.9.12 Graft Site Preparation

The best way to use the intrinsic load-bearing capacity of the tricortical iliac crest graft (TICG) is to create parallel vertebral endplates at the graft site (Fig. 9.15a). This task is best performed by sweeping the cortical bone with a cylindrical or conical burr until punctate hemorrhages occur. Frequent fluoroscopic control of this step enables the surgeon to overcome the misleading anatomy of the vertebral endplates, which requires a burring of the caudal endplate different from that of the cranial endplate (*cave* the "ramp" effect!; Fig. 9.15b). Likewise, the anterior and the posterior third of the endplate should be burred in a different manner from the central area (*cave* the "central gap" effect!; Fig. 9.15c).

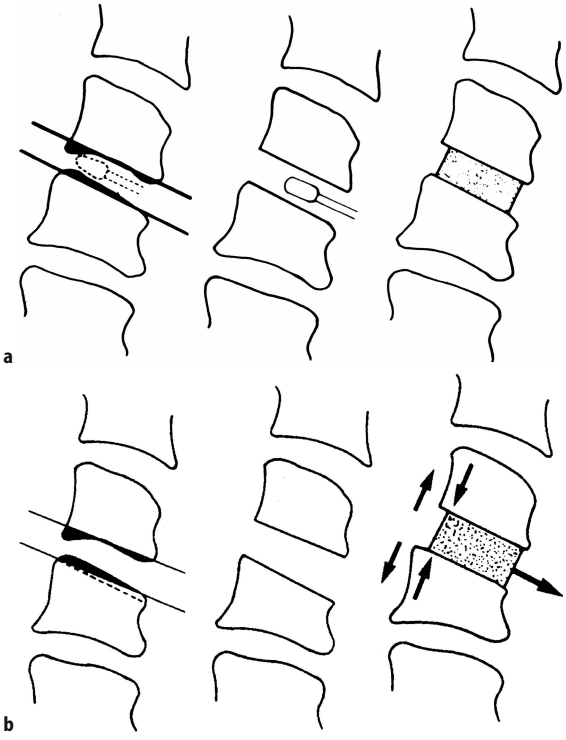


Fig. 9.15. a The anterior and the posterior third of the cranial vertebral endplate, but only the posterior third of the caudal endplate, should be burred with a conical (*a*) or cylindrical (*b*) burr in order to create parallelism for a gapless insertion of the graft. **b** Trimming down also the anterior third of the caudal endplate increases the risk of a ventral extrusion of the graft, the so-called "ramp effect" (contin. see p. 70)

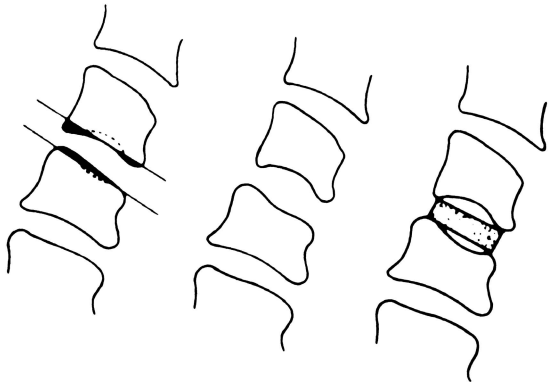


Fig. 9.15 (cont.) c An insufficient burring of the naturally biconcave shape of the interspace reduces considerably the contact surface between graft and endplates ("central gap" effect). Non-union and graft crushing many follow

9.9.13
Graft Measurements (Fig. 9.16)

1. Height (H)
   - (a1) In single-level ACF: H of the interspace without distraction (e.g., 5 mm) + 2 mm (= graft 7 mm), or
   - (a2) H of the interspace with (maximum) distraction (e.g., 9 mm) – H of the interspace without distraction (e.g., 5 mm): 2 (= graft 7 mm).
   - (b) In multiple-level ACF: H of the interspace without distraction + 1 mm
   - (c) *Cave*: a graft height of less than 6 mm bears an increased risk of spontaneous fracture!
   - (d) Corpectomy: as (a2)

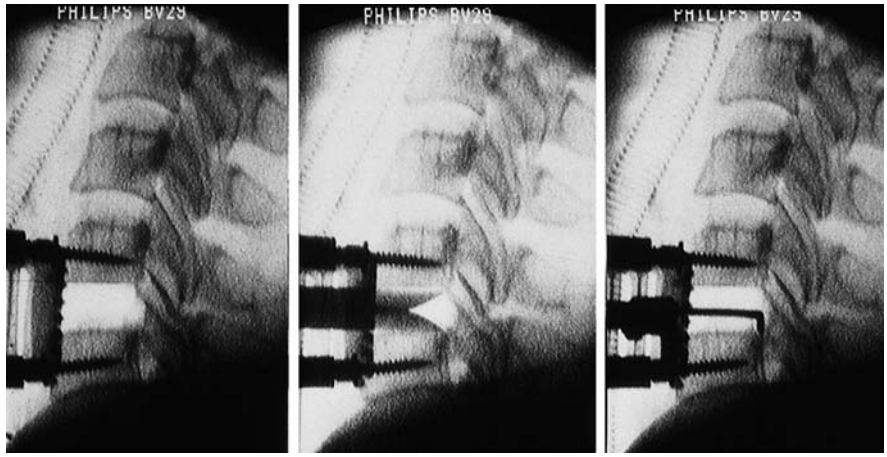


Fig. 9.16. Parallel vertebral endplates under moderate distraction (*left*); measurement of the height (*center*) and of the depth (*right*) with the caliper

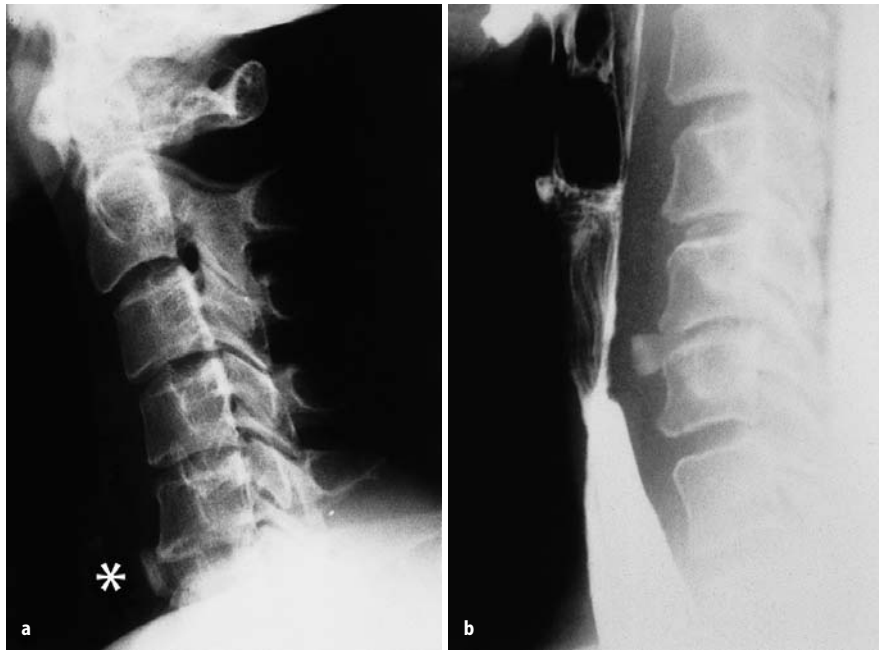


Fig. 9.17. a Asymptomatic pinching of the anterior graft cortex (*asterisk*). **b** Graft pinching as a cause of difficulty in swallowing

2. Depth
   (a) With plating: AP diameter of the interspace – 3 mm (epidural safety margin): the graft is flush with the anterior cortex
   (b) Without plating: AP diameter of the interspace – 5 mm (epidural safety margin) + 2 mm countersunk underneath the anterior cortex, in order to prevent graft "pinching" (Fig. 9.17)
   (c) Corpectomy: 15 mm is usually a suitable depth
3. Width
   (a) 14 – 17 mm depending on the morphology of the iliac crest. In the case of a very thin crest (e.g., less than 7 mm), two grafts should be inserted in a parallel manner.
   (b) If a cage is inserted, the maximal interuncinate width should be chosen, in order to maximize the graft–endplate contact surface.

9.9.14 Graft Insertion

A graft holder with fixation screw in the bone block facilitates round-shaping of the edges of the (auto/allo)-graft with a cylindrical burr. A safe insertion technique requires:

1. A reliable graft holder (screw fixation for bone; thread/locking device fixation for cage) which is better with an adjustable depth safety stop
2. A graft site under distraction
3. Fluoroscopic control while gently tapping the graft into position, for exploring the epidural safety margin with a blunt hook
4. Reversal of the vertebral distractor into a compression device to improve graft settling
5. Release of the skull traction (if any)
6. Filling of chips of spongiosa into the residual spaces lateral to the graft on one side, while the other side allows for free drainage of the epidural blood

9.9.15 Graft Choice

An extensive analysis of the pros and cons of the various graft options exceeds the intent of this chapter. The following list reflects our policy, but is certainly open to discussion:

1. Single/multiple-level ACF (virgin case): The time has come to question if autologous TICG (aTICG) is the gold standard. In our department a composite implant consisting of a titanium cage containing a hydroxyapatite cylindrical core impregnated with vertebral bone marrow (Tibon, Biomet, Berlin, Germany) has been used over five years in 183 patients (Fig. 9.18) without any cage-related complications [46, 55]. Nowadays, a PEEK cage (Solis, Stryker, NJ, USA, or Neocif, Biomet) filled with calcium phosphate granules (Calcibon, Biomet Merck BioMaterials, Darmstadt, Germany) offers the advantage of radiolucency and a resorbable scaffold.

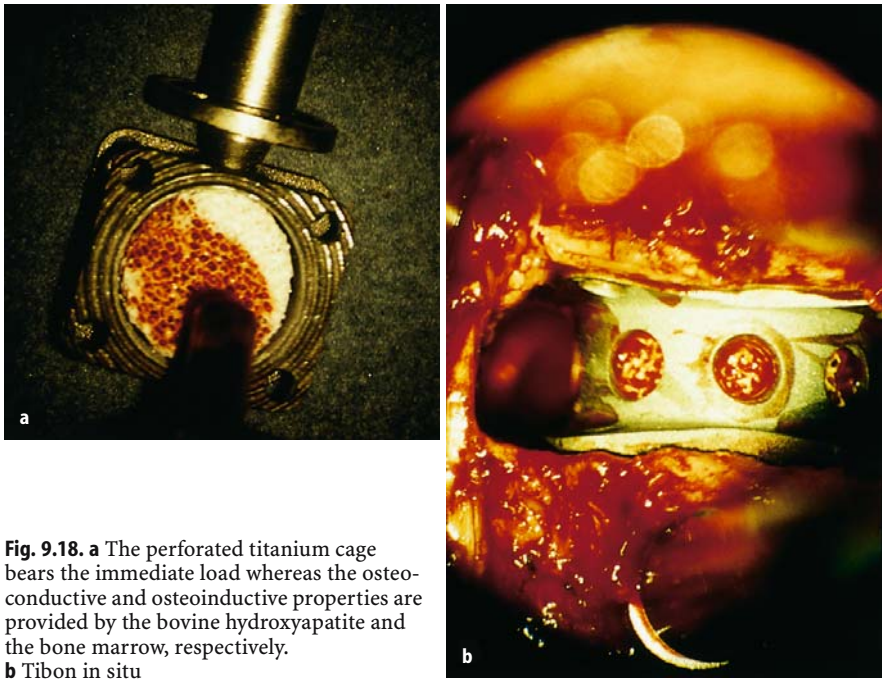


Fig. 9.18. a The perforated titanium cage bears the immediate load whereas the osteoconductive and osteoinductive properties are provided by the bovine hydroxyapatite and the bone marrow, respectively.
b Tibon in situ

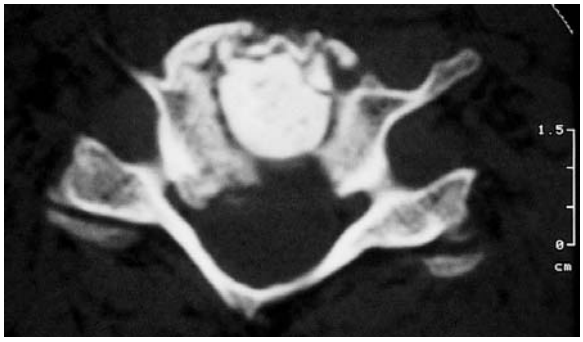


Fig. 9.19. The polymethylmethacrylate spacer is embedded in fibrous tissue corresponding to a stiff pseudoarthrosis

The use of neither polymethylmethacrylate (PMMA; Fig. 9.19) [2, 10, 24] nor bioconductive osteoconductive polymer (BOP) as bone substitute is advocated. Although conceding that they are effective interbody spacers and compare quite favorably with the results of autologous grafts, the lack of bony integration fails to meet the basic requirement of ACF.

The use of cadaveric allograft seems to be an acceptable alternative to autologous bone; however, at our institution we experienced a marked reluctance of the patients to accept this option, which has been boosted by the risk of HIV transmission.

2. Revision surgery for failed ACF: aTICG only (+ plating).
3. Corpectomy: aTICG is used for replacement of up to three vertebral bodies (Fig. 9.20). A titanium mesh cylinder (Harms basket) filled with chips of spongiosa is implanted for replacement of four vertebral bodies or (filled with methylmethacrylate) in tumor patients with a life expectancy of less than 6 months. In patients with a better prognosis, aTICG is the first choice even if postsurgical radiation therapy is planned: contrary to the current opinion, this does not interfere with solid bony fusion of the strut [31].

9.9.16 Graft Harvesting

The anterior iliac crest has most commonly been used to harvest tricortical grafts for ACF. Some side effects of this approach are too well known to need to be dealt with here. A particularly careful, i.e., minimally traumatizing, subperiosteal dissection of both the gluteus medius and iliacus muscles exposes the donor bone. The combined use of the oscillating double-blade saw, available in heights from 6 to 12 mm at 1-mm increments, and of the graft cutter (Aesculap) assures an exactly rectangular bone block.

When taking multiple grafts with the double-blade saw, a bone ridge should be left in between the single cuts: this provides a stronger iliac crest and a better cosmetic result. As an option, a porous hydroxyapatite block (Endobon, Biomet Merck BioMaterials) can be inserted to fill the defects.

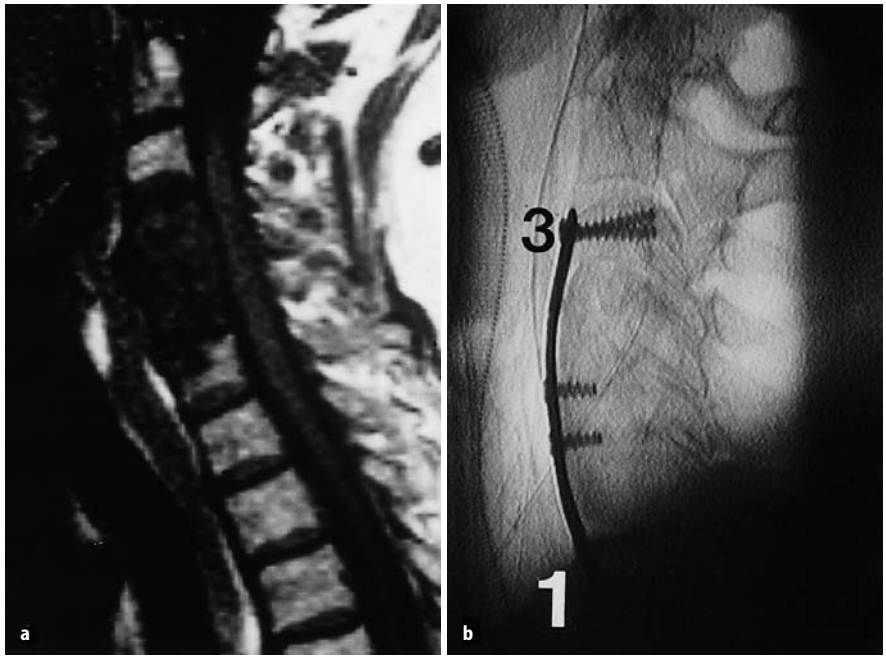


Fig. 9.20. a Metastasis of breast cancer destroying vertebral bodies C4-6 and infiltrating C7. **b** If care is taken in the choice of an appropriate iliac crest segment, the tricortical graft may also replace four vertebral bodies

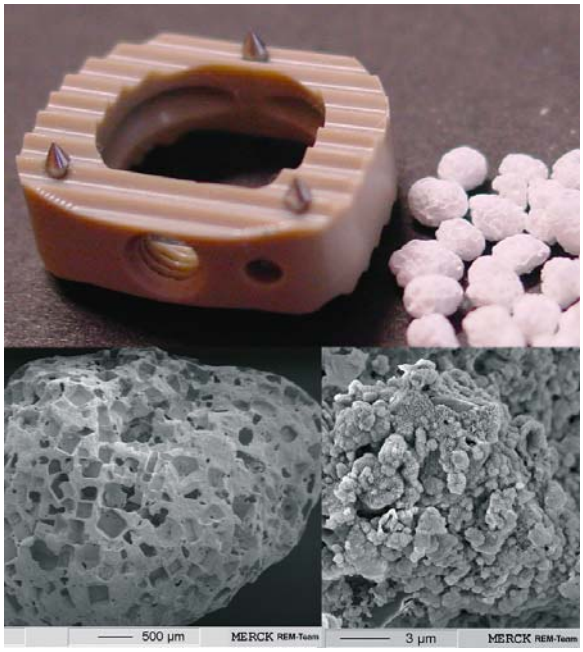


Fig. 9.21. *Top* PEEK cage (Neocif, Biomet, Berlin, Germany) and calcium phosphate granules (Calcibon, Biomet Merck Biomaterials, Darmstadt, Germany). *Bottom* The macro- and microporous structure enhances the augmentation with autologous blood or bone marrow aspirated from a vertebral body adjacent to the fusion site

Table 9.2. Properties of materials used in interbody cages

Property	PEEK	Titanium
Radiolucency	+	–
Material elasticity (Young's modulus)	17 GPa	110 GPa
Long-term biocompatibility	Good	Good
Years of follow-up in the literature	7	13
Bone-bonding property of the surface	+	++
Cage: graft volume ratio	Acceptable	Excellent

9.9.17 Cages and Bone Graft Substitutes

"...these data suggest that neither ACD (anterior cervical discectomy) nor ACF (anterior cervical fusion) is the ideal procedure. The ideal procedure for cervical radiculopathy and myelopathy would be ACF without autograft. If an economical biomaterial could be developed with a good potential to promote arthrodesis, then ACF could be performed with this material. The result would be a rapid diminution in pain for the patient with a simultaneous reduction in the cost of the procedure by decreasing the amount of surgery involved, shortening the hospital stay, and eliminating the complications associated with graft harvesting." [59]

This conclusion explains well the need to search for an alternative. A brief overview of current options will be given. Basically, we distinguish between the following:

1. Cage: Interbody cages should provide the immediate load-bearing capacity while allowing fusion to occur in their core. They can be manufactured as an equivalent of tricortical grafts (Cornerstone-SR, Medtronic, NJ, USA; I/F Cage, AcroMed, Rotterdam, The Netherlands; Osta-Pek, Co-Ligne, Zurich, Switzerland) or as cylinders for the dowel technique (BAK, Spine-Tech, Minneapolis, MN, USA) (Fig. 9.21). The material used is a carbon-fiber-reinforced forced polymer, PEEK, or titanium alloy. The structural characteristics are listed in Table 9.2.
   Some cages feature a wedge profile design, i.e., a taper of –7° or a height loss of 1.5 mm from anterior to posterior (Solis, I/F Cage). This "built-in" lordosis should be consistent with the physiological sagittal plane alignment. Other devices maintain a "parallel plates" design (Tibon): the removal of dorsal osteophytes requires slightly more resection of the dorsal part of the endplates. After releasing the distraction device, the vertebrae settle on the implant and the lordotic angle is restored to a large extent. Furthermore, the remaining posterolateral annular fibers are still kept under tension.
   In recent years, novel resorbable poly(L-lactic acid) (PLLA) cages have been evaluated in animal models [56, 61]. The first clinical application in instrumented posterior lumbar interbody fusion (PLIF) has been reported with a 6-month follow-up. Despite the regular radiographic finding it is too early to draw any clinical conclusion [53].
2. Graft material: A small amount of cancellous bone can be harvested percutaneously from the iliac crest. Non-resorbable porous hydroxyapatites (Pro Osteon, Interpore, Irvine, USA; Unilab Surgibone, NJ, USA; Endobon, Biomet Merck BioMaterials) or resorbable calcium phosphates (Cerasorb, Curasan, Kleinostheim, Germany; Calcibon, Biomet Merck Biomaterials) are used to fill the cage. The implanted bioceramics should be augmented at least with autologous blood. The impregnation with bone marrow aspirated from a vertebral body adjacent to the fusion site is based on experimental data supporting this method [4, 38]. The value of adding platelet-rich plasma or bone morphogenic proteins (BMP) is still under investigation at the time of writing.

Table 9.3. Distinctive features of uni- and bicortical anterior cervical plating systems

Features	Unicortical	Bicortical
Quick screw insertion	+	–
Fluoroscopy shortened	+	–
Variable screw-plate angle	±	+
Screw purchase in osteoporotic bone	±	+
Rigid plate-screw construct[a]	+	-

[a] Screw loosening is followed by anterior dislocation of the whole construct

9.9.18 Plating

Indications for the use of anterior cervical plates are still the subject of controversial discussion. Again, as stated for interbody fusion, the following policy of our institution should be regarded only as a suggestion:

1. In single-level ACF following trauma, degenerative subluxation, revision surgery for failed ACF, restoration of segmental lordosis (i.e., in the case of "swan neck deformity" following laminectomy), and poor bone quality of autologous graft.
2. In multiple-level ACF, routinely if aTICG is used and optionally if cages are inserted, for example, if restoration of the lordotic curve is necessary.
3. In single/multiple corpectomy it is used routinely.
4. Plating is not contraindicated in the treatment of spondylitis or epidural abscess, but the indication should be weighed carefully.

9.9.19 Comments on Surgical Technique

At the time of writing, there are 14 anterior cervical plating systems available in Germany. They can be classified into uni- and bicortical screw systems as in fixed and dynamic plates. Some of the respective advantages and disadvantages are compared in Table 9.3.

The Caspar trapezial osteosynthetic plate (Aesculap) is a quite popular bicortical system, and the Morscher cervical spine locking plate (Synthes, Switzerland) is the best known unicortical system (Fig. 9.1). The decision whether to buy a bicortical or unicortical system is often largely influenced by sponsored workshops and courses. Today, the various systems are becoming more and more alike. Therefore, the most frequent indication for plating [i.e., single-level plating following trauma (Fig. 9.1) as opposed to "long-distance" instrumentation as required by multisegmental degenerative or tumoral pathology (Figs. 9.11c, 9.20b)], the experience of the surgeons, as well as the quality of the ancillary surgical equipment (i.e., positioning devices, image intensifier, etc.) are more consistent factors for decision-making.

Recently, the Caspar plate can also be fixed with a self-cutting monocortical screw (green colored). The diameter is 4 mm and the length ranges from 14 to 19 mm at 1-mm increments (Fig. 9.22). In this way, the advantage of a free screw trajectory is combined with the easier handling. Uni- and bicortical screws (Fig. 9.23) can also be combined as needed, for example, bicortical screws in C6 and unicortical in C7, taking the case of a short-necked patient (Fig. 9.22). The author's preference goes to the Caspar plate, but not as a "foregone conclusion." Quite extensive experience also with the CSLP and the ORION system (Fig. 9.24) has led to an appreciation of their advantages.

Increased graft compression and decreased stress shielding are the postulated advantages of dynamic plates (ABC, Aesculap; DOC, de Puy Acromed, USA), features which are expected to improve the results of "long-distance" plating. In a study comparing multilevel anterior cervical corpectomy stabilized with fixed ($n = 38$) or with dynamic ($n = 28$) plates, the rate of surgery secondary to hardware failure was 13 % in the first group versus 3.9 % in the second group [27]. However, when the same author analyzed the outcome of 60 patients who underwent single-level corpectomy fixed with the same dynamic plate, 17 % of plate-related complications were reported, half of the patients requiring revision surgery [28].

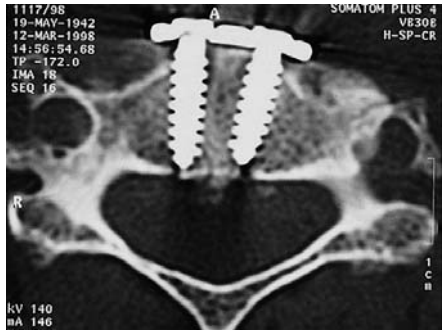


Fig. 9.22. These almost "bicortically" inserted monocortical screws demonstrate the author's surgical habit! A penetration depth of 14 mm is sufficient to achieve adequate torque

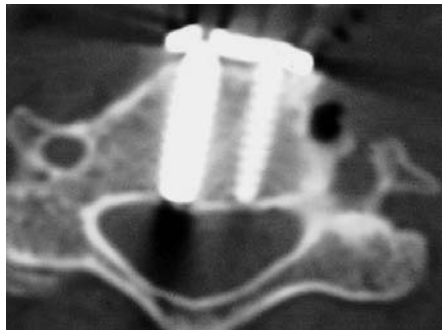


Fig. 9.23. Conventional bicortical screws: the oversized rescue screw (*left*) and the standard screw (*right*)

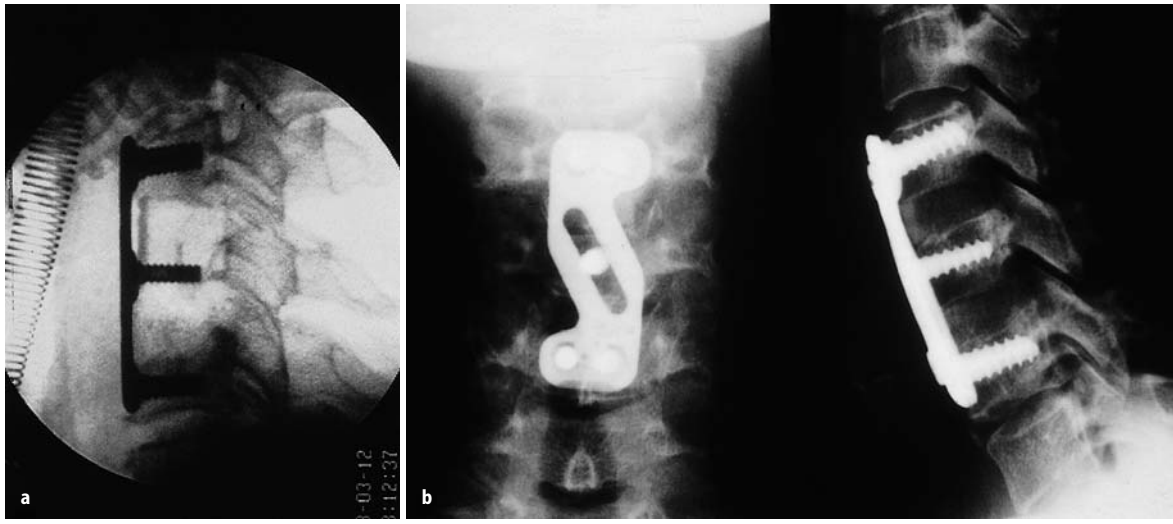


Fig. 9.24. a CSLP plating following C5 corpectomy: note the typical 12° upward inclination of the upper screws. **b** Orion plate

Recent advances in material technology focus on the development of resorbable plates. The prospect of avoiding MRI artifacts and metallic hardware-related complications is fascinating. Furthermore, the gradual degradation of the implant is expected to transfer the axial load initially shared by the plate progressively to the bone and, therefore, to increase the fusion rate [58]. Clinical studies are underway to assess the biomechanical and resorptive characteristics of bioabsorbable plates.

Independently of the plates used, the hardware-related complication rate seems to correlate strongly with the learning curve (of both surgeon and operating room nurse!). Therefore, once familiar with a particular system, the surgeon will rarely improve on results by switching too frequently from one product to the next.

A detailed description of the operative technique with a particular system is generally provided by the manufacturer.

In the following some considerations are given resulting from a "sufficient number" of personal errors:

1. Osteophytes of the anterior C-spine surface should be carefully eliminated (allowing sufficient time!) with the diamond burr. Fluoroscopy shows how much of ventral spurs bridging an adjacent interspace can be removed for optimal placement of the plate without touching the disc.
2. The length of the plate is determined with the aid of the image intensifier. A "direct vision" appreciation only may be erroneous.
3. Additional lordotic plate bending may be necessary, although most plates are prebent. It must be remembered to check whether any plate bending is necessary also in the transverse direction (more difficult!) in order to achieve a flush plate fitting.
4. Centering the plate (especially a long one) on the midline may be difficult for several reasons (Fig. 9.25). This may be eased by:
   (a) Performing the skin incision 1 cm across the midline to facilitate a symmetrical dissection of the soft tissue and retraction of the longus colli muscles.
   (b) Labeling the midline (e.g., with temporary spikes or with drill holes) *before* the dissection of the longus colli muscles, which may be asymmetrical.
   (c) Suturing the arms of the retractor to the skin in order to avoid "rotation" (usually from medially, where more soft tissue pushes, to laterally) over time.
   (d) On direct vision, the lower end of the plate should look a little too contralaterally placed.
   (e) Lateral fluoroscopy: the highest point marked with a tip, going from one longus colli muscle to the contralateral one, corresponds to the true midline.
   (f) AP fluoroscopy is the ultimate proof of correct plate placement.
5. If screw torque is critical, the screws should be placed in the subchondral area instead of in the middle third of the vertebral body. Oversized rescue screws (Fig. 9.23a), bone cement, or cancellous bone tapped into the screw hole may be helpful to increase the grip.
6. If the plate secures a multiple corpectomy strut, three or four screws should be inserted in the vertebra above and below the graft.
7. If the posterior cortex cannot be shown by fluoroscopy but a bicortical screw purchase is required, "knock at the door" with the tip of the drill (absolute silence is required in the operating room!), alternating 1-mm drilling and knocking with the tip,

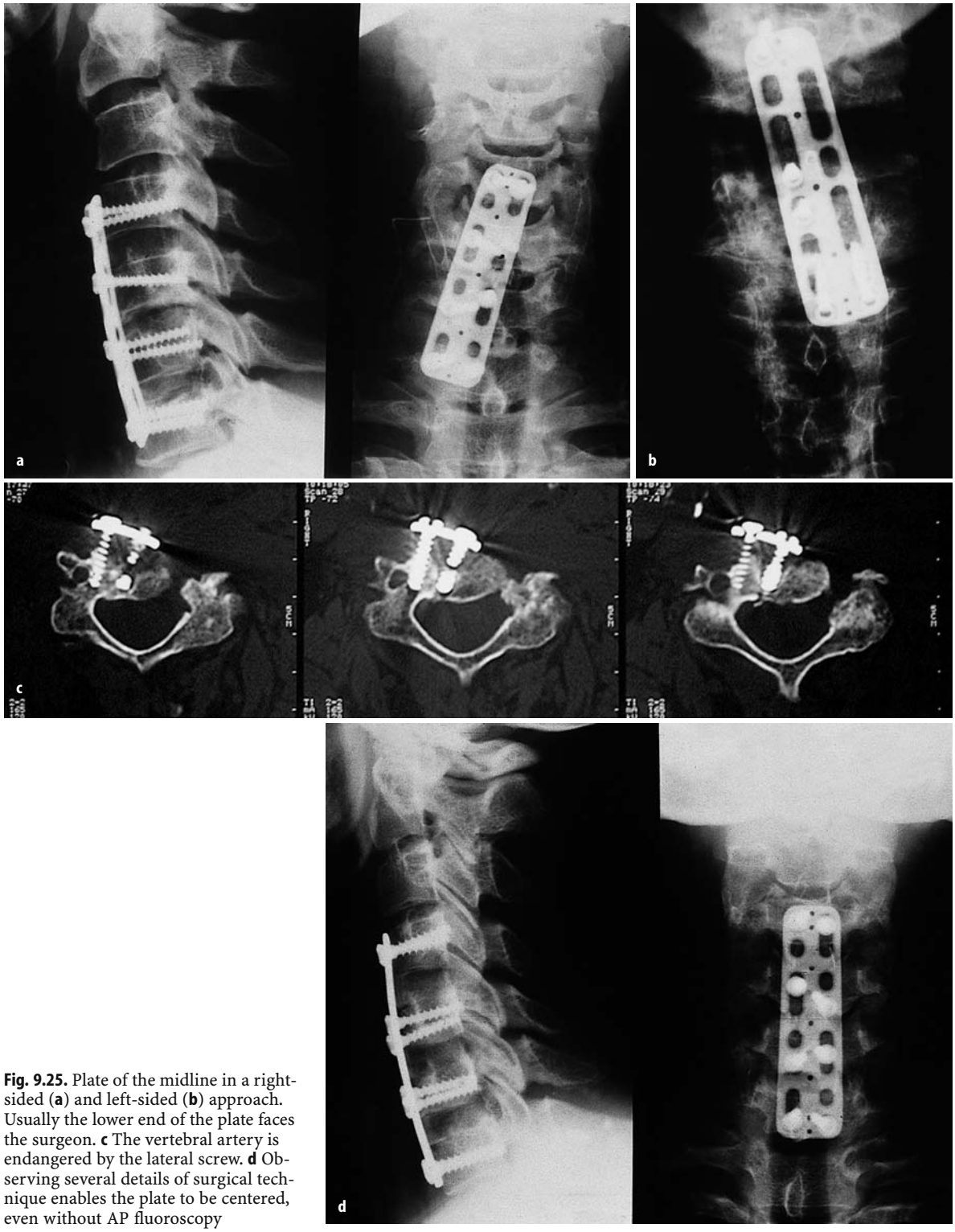


Fig. 9.25. Plate of the midline in a right-sided (**a**) and left-sided (**b**) approach. Usually the lower end of the plate faces the surgeon. **c** The vertebral artery is endangered by the lateral screw. **d** Observing several details of surgical technique enables the plate to be centered, even without AP fluoroscopy

until the transition zone between cancellous bone and posterior cortex (which is perforated 1 mm in depth) is appreciated.

8. Last but not least, plating does not substitute a good fusion technique!

9.9.20 Wound Closure

Fenestrated retractor blades may stick after many hours of surgery: they should be removed under irrigation and singularly. A drain is routinely inserted, more in order to achieve a reapproximation of the visceral structures than to prevent the formation of a prevertebral hematoma. The importance of careful hemostasis cannot be overstated. Reconstruction of the omohyoid muscle (if necessary) and of the platysma is performed with 3 – 0 absorbable sutures. The closing of superficial planes is according to the surgeon's preference.

9.10 Postoperative Care

Patients can be mobilized on the same day. A soft collar is applied for 4 weeks postoperatively if a TICG has been inserted and not at all if cages have been implanted.

9.10.1 Complications

Traditionally, complications of anterior cervical surgery are divided into [22]:

1. Injuries of the spinal cord and cervical roots
2. Injuries of the visceral or vascular structures
3. Graft failures
4. Hardware failure

Some observations derived from daily practice are reported.

9.10.2 Injuries of the Spinal Cord and Cervical Roots

Although the surgeon performing this procedure should always be aware of the danger and be prepared to manage a potential catastrophic occurrence, the use of the microscope has fortunately reduced an already quite rare occurrence (0.1 – 3.3 %) [8, 29]. However, the author remembers cases in which the neurological injury happened independently of the use of a magnification device:

1. Preoperative closed reduction of a fracture-luxation in an already anesthetized patient.
2. Penetration of the needle into the spinal canal during fluoroscopic confirmation of the correct interspace.
3. Excessive hammering during the graft placement with "slipping through" of the bone block in the epidural space.
4. Beware of brachial plexus injury due to prolonged traction (tape fixation of shoulders!): if required, movable weights can be hung on wrist slings.

Dural tears may be caused by accidental drilling or resecting a tumor-infiltrated posterior ligament. Usually a muscle (i.e., omohyoid) patch with fibrin glue is placed immediately before the insertion of the graft or strut in order to tamp the leakage. The postoperative lumbar drainage should be kept along with antibiotic prophylaxis for 2 or 3 days.

9.10.3 Injury of the Visceral or Vascular Structures

Correct positioning of the sharp-toothed retractor blades underneath the bellies of the longus colli prevents slippage toward the visceral or vascular structures. Furthermore, the retraction force is transmitted mostly to the muscle tissue.

The tendency to keep the skin incision as short as possible for cosmetic reasons may hamper an adequate dissection of the fascial and muscular planes. The prolonged retraction of anatomical structures which are not sufficiently mobile is probably the most common cause of postoperative dysphagia and hoarseness. The reduction of cuff pressure to 20 mm Hg is helpful to decrease the incidence of postoperative sore throat and hoarseness [47]. During graft-harvesting surgery, the cervical retractor(s) should also be released.

9.10.4 Graft Failures

Even in experienced hands, graft extrusion, collapse, and non-union cannot be avoided. Although optimal graft site preparation and graft shaping reduces this specific complication rate to roughly 5 – 8 % per segment, additional systemic risk factors such as smoking, diabetes mellitus, rheumatoid arthritis, and osteoporosis may worsen the outcome in an unpredictable way.

Conversely, the 38-month results of 184 patients treated with 235 Tibon implants do not (up to now) show any difference in clinical and radiographic follow-up between risk (smoking, diabetes mellitus, and age > 70 years) and non-risk patients. Although some degree (range 1 – 3 mm) of subsidence of the bone substitute in the vertebral endplates has been observed, it seems that the mechanical properties of the implant still provide adequate neuroforaminal widening, unbuckling of the posterior ligament, and lordotic alignment of the spine (Fig. 9.26).

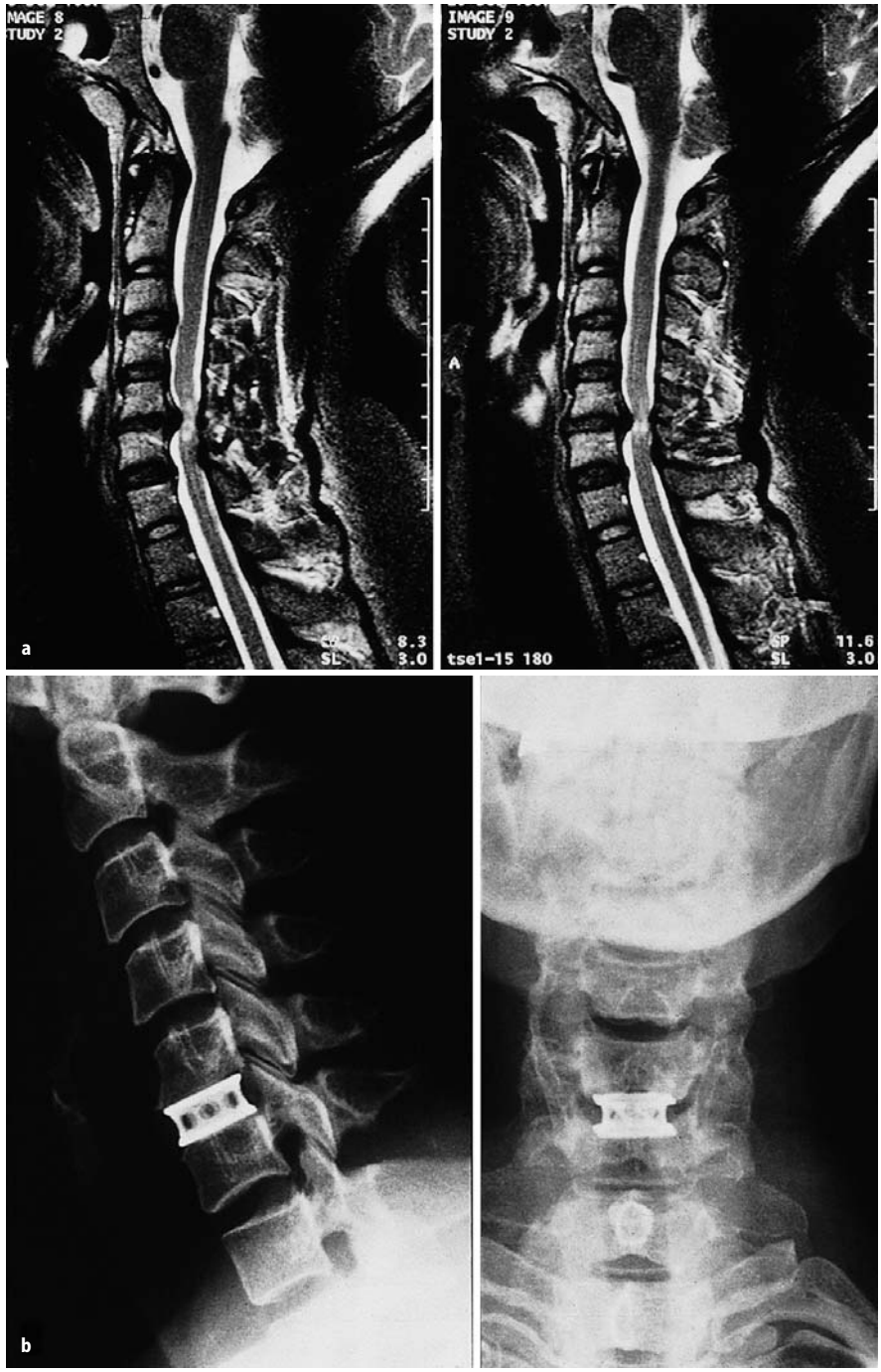


Fig. 9.26. A 47-year-old female presenting cervical spondylotic myelopathy due to hard disc pathology C5/C6. **a** Preoperative magnetic resonance imaging showing the intramedullary hyperintense focus **b** Two weeks after surgery, the patient suffered from a severe whiplash injury. The control X-ray shows the straightened spine and the still correct location of the implant

9.10.5 Hardware Failure

In the decade since 1995 there has been considerable concern about the risks involved with internal instrumentation (e.g., overpenetration of the posterior cortex with bicortical screws) or when plating fails (screw or plate fracturing and loosening). A large series of 696 consecutive anterior plating procedures was evaluated retrospectively [39]: 371 non-constrained systems were compared with 325 constrained implants. Radiographic hardware failure, defined as any broken or loosened screw or plate regardless of clinical significance, occurred in 23 % of cases. However, the incidence of a clinically significant hardware failure, if revision surgery was performed only because the hard-



Fig. 9.27. The collapse of the cranial graft has caused the uppermost screw to slide along the slot of the Caspar plate. Revision surgery was not needed

ware posed a potential threat to tracheoesophageal or neurovascular structures, dropped to 0.7%. In the five patients concerned, re-exploration of loosened hardware revealed extensive soft tissue envelopment of the implant. A radiographic failure was evident in 19% (43/224) of cases treated with the stainless steel Caspar plates but in 35% (20/57) of patients treated with the more recently introduced Caspar titanium plates. The explanation could be the steep learning curve. The author's personal series consists of approximately 230 Caspar titanium plate procedures. In four patients (two-level ACF with iliac crest graft, smokers) revision surgery was performed during the first postoperative year because of severe neck pain. In all cases the upper graft was collapsed and the upper screws wobbled in the cranial slots of the plate (so-called pistoning) (Fig. 9.27). The current design features holes at the ends of the plate.

9.11 Results

It may be of interest to report some data of a prospective non-randomized single-center trial to assess the efficacy of titanium cages filled with hydroxyapatite (implant A) and of PEEK cages filled with calcium phosphate granules (implant B) as bone graft substitutes in ACF.

Between 1996 and 2002, 246 patients underwent ACF. They were affected by spondylotic myelopathy ($n = 153$) and/or radiculopathy ($n = 93$); 184 patients were treated with 235 implants type A and, more recently, 62 patients with 86 implants type B. Both graft substitutes were loaded with bone marrow aspirated from an adjacent vertebra. Single-level (192), two-level (43), and three-level (11) procedures were performed. Anterior plating was added in 17, 23, and 7 cases, respectively. Independent observers assessed the follow-up (minimum 12 months, mean 39 months) with the European Myelopathy Score [33] and with Odom's criteria [42]. Clinical results comparable with those obtained in a historical control ($n = 100$) group treated with autologous bone graft were reported. Interestingly, the analysis of complications showed that:

- The four revision surgeries were performed for esophageal perforation (2) and wrong level fusion (2).
- The implants ($n = 321$) did not require any surgical revision. The degree of subsidence (2 mm/34, 3 mm/12) of some of them in the adjacent vertebrae correlated with the height of the graft substitutes ($P < 0.05$). At the beginning of the learning curve the frequently used 7-mm-tall implants caused overdistraction of the level along with interscapular pain. The currently inserted 5- or 6-mm implants are well tolerated. A significant correlation of subsidence with risk factors such as smoking, diabetes mellitus, and age (osteoporosis), although expected from the experience with autologous bone, was not apparent. Nor was there any difference in subsidence between titanium and PEEK ($P = 0.2$).
- Postoperative sore throat decreased through maintaining the endotracheal tube cuff pressure at 20 mm Hg during surgery.
- Two severely myelopathic patients worsened following three-level ACF. Although neither implant dislocation nor spinal cord encroachment could be shown on MRI, a marked medullary edema was highly suspicious of surgically induced (micro)-trauma. Since then, surgery on risky myelopathic patients is performed with combined MEP and SSEP monitoring.

Serial investigations of the implants with quantitative computed tomography (qCT) 3 days and 6 and 12 months after surgery have shown a progressive bone ingrowth from the vertebral endplates through the ceramic core. The non-resorbable hydroxyapatite scaffold is covered by an autologous bone layer (Fig. 9.28). The granular structure of the calcium phosphate particles becomes trabecular with increased density (Fig. 9.29). The qCT data of 64 patients show that the

bony integration of the ceramic core is still ongoing at 1 year after surgery. This phenomenon seems to be much slower than bone remodeling.

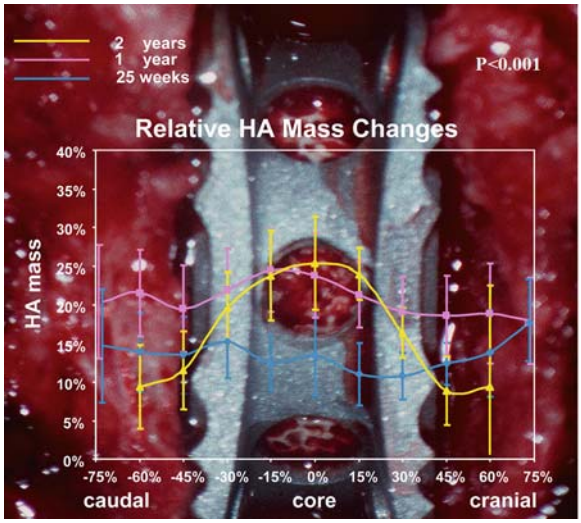


Fig. 9.28. Measurements up to 24 months after surgery of the relative change in hydroxyapatite (*HA*) mass content (*y*-axis) in Tibon and in the adjacent vertebral bodies. The *x*-axis corresponds to the baseline measurement 3 days after surgery. –75%, Caudal vertebra facing the implant; –15% to +15%, core of the implant corresponding to the bovine HA; +30%, cranial plate of the implant; +75%, cranial vertebra

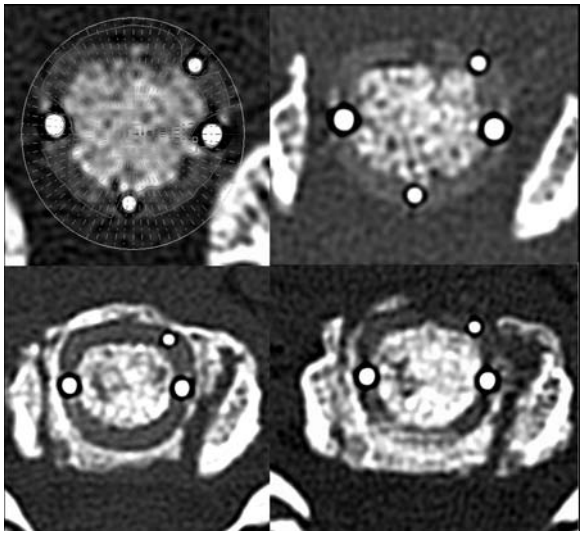


Fig. 9.29. *Top left* In quantitative computed tomography the volume of a PEEK cage filled with calcium phosphate granules is divided in many small partial volumes whose density is measured voxel by voxel. CT scans 3 days (*top right*), 6 months (*bottom left*), and 12 months (*bottom right*) after surgery. Note the scattered increasing density. Courtesy of Ralph Zwönitzer, CAMmed, Berlin, Germany

9.12 Critical Evaluation

9.12.1 Diagnostics

MRI has undoubtedly improved the quality of intraspinal (particularly intramedullary) imaging. Nevertheless, analysis of the bone structures (fractures, abnormalities due to degenerative or tumoral disease) for surgical planning is still better based on CT scans (bone window). In selected cases, flexion-extension MRI provides valuable information not given by static investigations or by functional plain films. A spinal angiography facility is not available in all institutions where spinal metastases are surgically treated. However, preoperative embolization of hypervascular spinal metastases (e.g., renal cell carcinoma and thyroid carcinoma) has been shown to significantly decrease blood loss and surgical morbidity [19, 54].

9.12.2 Treatment

In a prospective study, cervical MRI has shown significant disc and osteophyte pathology in 28% of asymptomatic individuals aged above 40 years [9]. This fact underscores the need for correlating abnormal MR images with adequate symptoms and clinical signs, in order to restrict the indication for surgical treatment. In other words, attention should be paid not to make the "first line" investigation MRI the "only line" diagnostic tool in decision-making for surgery.

In four decades of application, anterior cervical surgery has been refined to an extent that serious complications can be reduced to a minimum. Similarly, cervical instrumentation and, more recently, bone graft substitutes have provided implants whose benefits by far outweigh the risks.

Regardless of traumatic, degenerative, or tumoral compression of the spinal cord or of the cervical roots, the most important prognostic factors are the duration of symptoms, the severity of clinical findings, and the patient's age [7]. However, cervical microsurgery and appropriate hardware can definitely influence the natural history of these diseases.

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10 Anterior Cervical Foraminotomy (Microsurgical and Endoscopic)

W.F. Saringer

10.1 Terminology

Anterior cervical foraminotomy performed microsurgically or endoscopically is defined as a mono- or multisegmental unilateral direct resection of an offending lesion, either a posterolateral spondylotic spur or a disc fragment compressing the nerve root, from anterior between its origin in the spinal cord and its passing behind the vertebral artery (VA) while maintaining the form and function of the intervertebral disc of the affected level.

10.2 Surgical Principle

- The approach to the anterior vertebral column is performed using a microsurgical technique at the side of the radiculopathy in an almost similar fashion to conventional anterior cervical discectomy (ACD).
- Caudal and cranial to the intervertebral disc space the medial portion of the longus colli muscle is incised transversally. The incised portion is kept lateral, and the lateral border of the uncinate process (UP) is exposed.
- Anterior foraminotomy is performed by resection of the UP – in the case of foraminal stenosis caused by spondylotic disease, the operation is accomplished at this stage by the osseous decompression of the nerve root.
- In the case of foraminal stenosis caused by posterolateral disc herniation, the operation is continued by the removal of the herniated disc fragment.

10.3 History

The following table outlines approaches for anterior cervical foraminotomy and nerve root decompression in chronological order.

Author (year)	Procedure
Verbiest (1968) [13]	Anterolateral approach with displacement of the VA laterally and ACD, performed with and without fusion
Hakuba (1976) [3]	Transuncodiscal approach without displacement of the VA and ACD, performed with and without fusion
Lesoin et al. (1987) [6]	ACD and anterolateral foraminotomy, with fusion
Snyder and Bernhardt (1989) [11]	Anterior cervical fractional interspace decompression: 6-mm-wide cylindrical burr hole in the lateral third of the intervertebral disc and fragmentectomy
Jho(1996) [4]	Anterior cervical foraminotomy with resection of the "uncovertebral joint" (the UP, the lateral portion of the cephalic endplate and lateral portion of the intervertebral disc), technical note
Johnson et al. (2000) [5]	Anterior cervical foraminotomy: technique as described by Jho, clinical results, 21 cases
Tascioglu et al. (2001) [12]	Anterior cervical foraminotomy: slightly modified technique as described by Jho, 3 cases
Saringer et al. (2002) [7]	Microsurgical anterior cervical foraminotomy: resection of the UP and fragmentectomy leaving the intervertebral disc untouched, clinical results
Saringer et al. (2003) [8]	Endoscopic anterior cervical foraminotomy: same surgical procedure as microsurgical, minimally invasive
Hacker and Miller (2003) [2]	"Failed anterior cervical foraminotomy": technique as described by Jho but poor clinical results

10.4 Advantages

The technical advantages are:

- Direct resection of an offending lesion compared to posterior foraminotomy
- Complete decompression of the nerve root and the spinal cord under visual control reducing the risk of injury to those structures
- Preservation of the motion segment by maintaining the form and function of the intervertebral disc of the affected level
- Avoiding the application of an implant
- Avoiding fusion-related complications including graft-related complications, graft site complications and adjacent-level disease
- Short operative time compared to ACD and fusion due to the avoidance of the fusion procedure
- Additionally, the use of an endoscope provides an improvement of the visualisation and a more intense light.

The clinical advantages are:

- Reduced operative trauma compared to ACD and fusion and even posterior foraminotomy, which allows patients a shorter hospital stay and to resume full activity sooner

10.5 Disadvantages

- Decompression of the contralateral side is impossible via the ipsilateral approach.
- It is a technically demanding procedure that requires practice in order to become familiar with the instruments and in particular with the endoscope.

10.6 Indications

This procedure is indicated in patients with unilateral mono- or multilevel radicular symptoms caused by unilateral mono- or multilevel cervical foraminal stenosis due to:

- Posterolateral spondylotic appositions
- A posterolateral disc fragment

The patients have to have the offending lesion in a lateral or foraminal location, compressing the nerve root from ventral between its origin in the spinal cord and its passing behind the VA.

10.7 Contraindications

This procedure is contraindicated in patients with:

- Bilateral syndromes
- Significant spinal canal stenosis (median soft or hard disc) and myelopathy
- Alignment abnormalities
- Foraminal stenosis caused by arthrosis of the facet joint (dorsal stenosis)

These patients should be referred for ACD and fusion or laminectomy.

10.8 Patient's Informed Consent

Patients should be informed about the risks inherent to mono- or multilevel anterior approaches to the cervical spine, to the neural foramen and to the spinal cervical canal:

- Nerve root and/or spinal cord lesions with postoperative neurological deficits including radicular symptoms and para- or tetraparesis, and bladder and bowel dysfunction
- Dural leaks with cerebrospinal fluid (CSF) fistulas and/or cysts
- Vertebral artery lesions with major intraoperative bleeding and possible postoperative development of a spurious aneurysm and possible postoperative neurological deficits due to brainstem and cerebellar infarction
- Meningitis
- Spondylodiscitis with epidural abscess
- Segmental instability with chronic cervical pain requiring an ACD and fusion
- Postoperative hoarseness due to excessive retraction (transient) or transection of the recurrent laryngeal nerve

10.9 Surgical Technique

10.9.1 Diagnostic Evaluation

Anterior-posterior, lateral and oblique standard radiographs of the cervical spine and magnetic resonance imaging (MRI) evaluation of the cervical spine was performed in all patients. In case of insufficient visualisation of the foraminal anatomy, which may occur when MRI is utilised in spondylotic disease, a thin-slice computed tomography (CT) and high-resolution computed tomography (hrCT) were obtained for a definite accurate diagnosis.

As all patients in this series presented with radiculopathy and distinct motor weakness, electroneurographic studies were not performed routinely.

10.9.2 Anaesthesiological Aspects

The operation is performed under endotracheal general anaesthesia. The introduction of a central venous line is not necessary. Arterial blood pressure monitoring as well as the introduction of a urinary catheter are recommended irrespective of the expected time for the operation. The average blood loss during these operations was 110 ml, therefore blood transfusions are not routinely necessary and own blood donations are not required. Elderly patients and patients with accompanying diseases which pose higher anaesthesiological risks require reliable intraoperative monitoring.

10.9.3 Positioning

The patient is positioned supine with the head slightly turned to the contralateral side. The cervical spine is gently extended in the lordotic position by placing a gel cushion under the neck. A cervical traction device or caudal fixation of the arms are not used. The approach is made at the side of the radiculopathy.

10.9.4 Localisation

The vertebral level and site of the skin incision is confirmed preoperatively by fluoroscopy. Localisation is performed by positioning a spinal needle lateral to the neck. The anterior neck is then prepared and draped using an aseptic technique. The transverse skin incision is made exactly over the segment of interest. If two adjacent levels have to be approached the projected skin incisions for the cranial and the caudal level are marked under lateral fluoroscopic guidance. Then a transverse skin incision is made slightly inferior to the midline between the two marked sites. If two non-neighbouring levels have to be approached, two separate approaches with separate skin incisions are recommended.

10.9.5 Operative Procedure

10.9.5.1 Microsurgical Technique

10.9.5.1.1 Skin to Prevertebral Space

The surgical approach was made in an almost similar fashion to conventional ACD [1, 9, 10]. A transverse skin incision of 3 cm is made at the intended site, two thirds medial and one third lateral to the medial border of the sternocleidomastoid muscle. The platysma is incised along the line of the skin incision. Access to the cervical column is prepared by sharp and blunt dissection opening the superficial fascia at the medial border of the sternocleidomastoid muscle, keeping the visceral structures medial and the neurovascular bundle lateral. The prevertebral fascia is opened and the anterior aspect of the vertebral bodies, the intervertebral disc and the medial portion of the longus colli muscle (LCM) of the target level are exposed. The correct level is reconfirmed by lateral fluoroscopy.

Approximately 5 mm caudal and cranial to the margin of the intervertebral disc space the medial portion of the ipsilateral LCM is incised transversally for a length of about 10 – 14 mm. The incised portion is kept lateral, and the lateral border of the UP is deliberately exposed. At C7 care must be taken not to imperil the VA, where it runs between the transverse process and the LCM. The VA is not exposed intentionally.

10.9.5.1.2 Microsurgical Anterior Foraminotomy

At this stage the use of the operating microscope starts. The operative field is limited cranially, caudally and laterally by the LCM. The laterally reflected portion of the LCM serves as an additional protective layer to the VA. The exposed field includes the lateral third of the intervertebral disc, the lateral portion of the caudal vertebral body with the UP and the lateral portion of the cranial vertebral body.

A long-handled high-speed drill (Black Max; Anspach) with a 1.8-mm matchstick-style cutting burr is used to initiate the resection of the UP. A triangular-shaped hole of 6 – 8 mm in transverse diameter and 9 – 11 mm in height is drilled. The drilling is advanced to the posterior cortical layer. Then a 2-mm ball-shaped diamond burr is used. Remnants of the osseous endplate are removed with the drill leaving the cartilaginous endplate untouched. Then the thinned posterior cortical layer and the posterior part of the lateral wall of the UP are removed by cautiously drilling under permanent rinsing. By this procedure bone spurs on the posterolateral endplate and the UP can be removed and the underlying nerve root is decompressed. A thin piece of the cortical bone of the lateral wall of the UP is left, serving as a landmark and as a protective layer for the underlying VA (Fig. 10.1a). At this stage the periosteum covers the nerve root, disc fragments and the lateral portion of the posterior longitudinal ligament (PLL).

The periosteum and the cartilaginous and degenerative fibrous tissue between the tip of the UP and the lower endplate of the cranial vertebral body is removed by using a 1- and 2-mm thin-foot Kerrison rongeur. Fi-

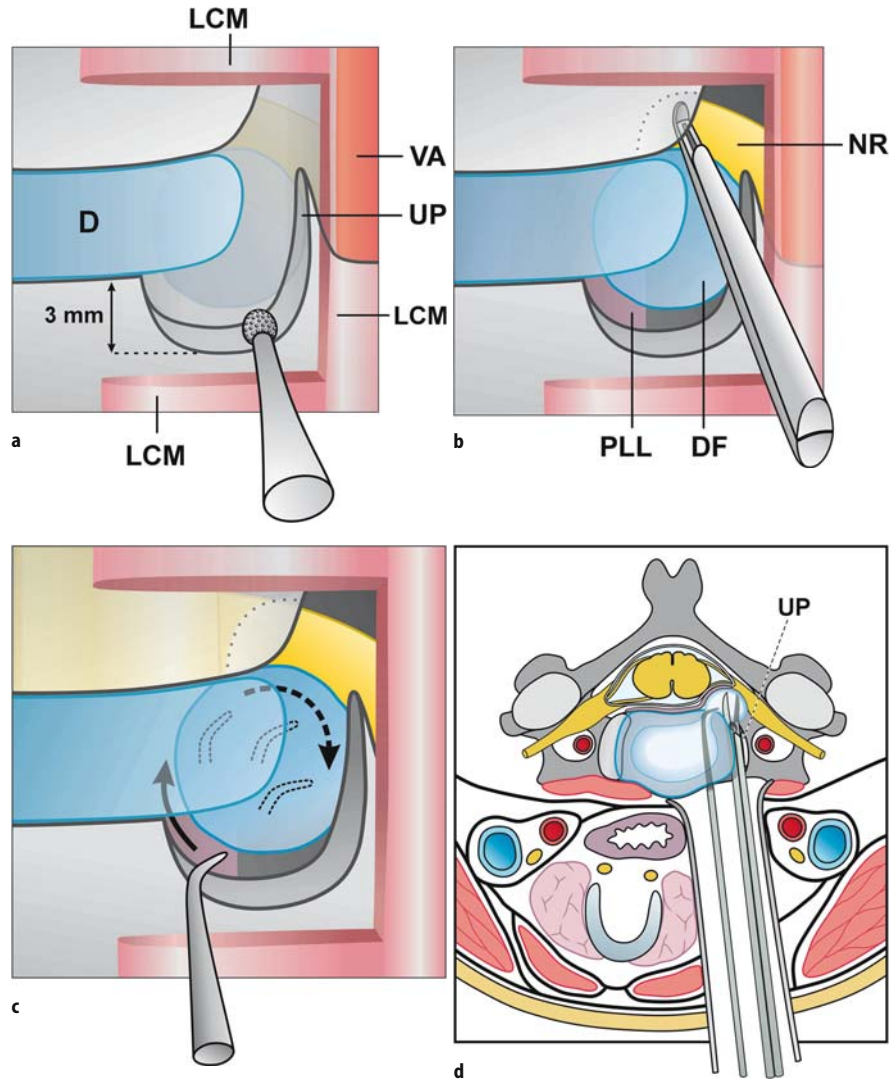


Fig. 10.1. Artist's drawings depicting microscopic anterior cervical foraminotomy. **a** The medial portion of the longus colli muscle (*LCM*) is excised and the lateral portion of the disc (*D*) and the uncinate process (*UP*) is exposed. The UP is drilled up. A thin piece of the lateral wall of the UP is left, serving as a landmark and protective layer for the underlying VA. Periosteum covers the nerve root, disc fragments and the lateral portion of the posterior longitudinal ligament (*PLL*). The form of the intervertebral disc (*D*) is maintained. The vertebral artery (*VA*) is not exposed. **b** Periosteum, cartilaginous and degenerative fibrous tissue between the tip of the UP and the cephalic endplate and osteophytes at the posterolateral cephalic endplate are removed using a 1- or 2-mm thin-foot Kerrison rongeur. Disc fragments (*DF*), parts of the nerve root (*NR*) and lateral parts of the PLL are exposed. **c**, **d** Microscopic and axial depiction of the last step of the operation. Herniated disc fragments are mobilised with a microhook and removed with a micropunch accomplishing the decompression of the nerve root

nal osseous decompression of the nerve root, caused by bone spurs or posterolateral osteophytes at the lower endplate of cranial vertebral body, is accomplished with a 2-mm thin-foot Kerrison rongeur (Fig. 10.1b).

In the case of foraminal stenosis caused by spondylotic disease the operation is accomplished at this stage. If there is a posterolateral disc herniation, the operation is continued by the removal of the herniated disc fragment.

10.9.5.1.3 Removal of the Herniated Disc

Herniated disc fragments may be visible now in front of the underlying nerve root. These fragments can safely be mobilised with a microhook and removed with a micropunch (Fig. 10.1c, d).

At this stage the lateral portion of the PLL covers the lateral margin of the thecal sac and the origin of the nerve root. The lateral margin of the PLL is elevated with a microhook and, selectively, if there is a hidden epidural disc fragment under the ligament, resected with a 2-mm thin-foot Kerrison rongeur. The disc fragment is then mobilised and extracted. The disc within the intervertebral space remains untouched and preserved.

The removal of disc fragments and the resection of the lateral portion of the PLL may be complicated by epidural bleeding from the anterior internal venous plexus and the venous plexus encasing the root. The bleeding can be stopped by cauterisation or by rinsing with hydrogen peroxide solution.

The nerve root can now be clearly visualised from its origin to its entrance into the intervertebral foramen. Now the foramen may be safely approached without removing the fragment of the lateral wall of the UP by passing a microhook inferiorly and superiorly to the nerve root into the foramen determining that the root is adequately decompressed.

10.9.5.2 Endoscopic Technique

Two different types of endoscopes were used: the MED system (Metronic-Sofamor Danek) and an Aesculap endoscope with a steering device (NeuroPilot; Braun–Aesculap, Tuttlingen, Germany).

The MED system set contains a rigid 25°-angled lens endoscope, length 100 mm and outer diameter 3 mm, which is mounted on a tubular retractor by means of a ring attachment with an integrated endoscope-cleansing device. Two standard sizes of retractors are available establishing a 16-mm or an 18-mm operative corridor. The retractor is anchored to the retractor arm. The endoscope does not have a built-in working channel. The surgical instruments were inserted adjacent to the endoscope through the tubular retractor. A camera head, a video integrator system that incorporates camera and xenon light source into one system, and video peripherals, such as a 19-inch monitor, a video recorder and a video printer, were assembled and connected to the endoscope (Fig. 10.2).

The Aesculap system set contains two endoscopes (0°- or 30°-angled endoscope, shaft length 181 mm, shaft diameter 2.7 mm) mounted on the steering device (NeuroPilot), which can be fixed to a pneumatic holding arm (Unitrac; Braun–Aesculap). After coarse adjustment of the endoscope intraoperatively, finest corrections or adjustments of the endoscope tip are possible in three-dimensional space by using the NeuroPilot steering device. The precise manoeuvring of the endoscope tip in submillimetre steps is facilitated by three set screws on the steering device, which allow easy and optimal positioning of the endoscope intraoperatively (Fig. 10.3).

10.9.5.2.1 Skin to Prevertebral Space

The surgical approach is performed macroscopically. A transverse skin incision of 2 cm is made at the intended site, two thirds medial and one third lateral to the medial border of the sternocleidomastoid muscle. The access to the cervical column is achieved in a similar fashion as described by Cloward [1]. The correct level is reconfirmed by lateral fluoroscopy. Approximately 5–6 mm caudal and cranial to the intervertebral disc space, the medial portion of the ipsilateral LCM is incised transversally over a length of about 10–14 mm. The incised portion is resected or, in some cases, kept

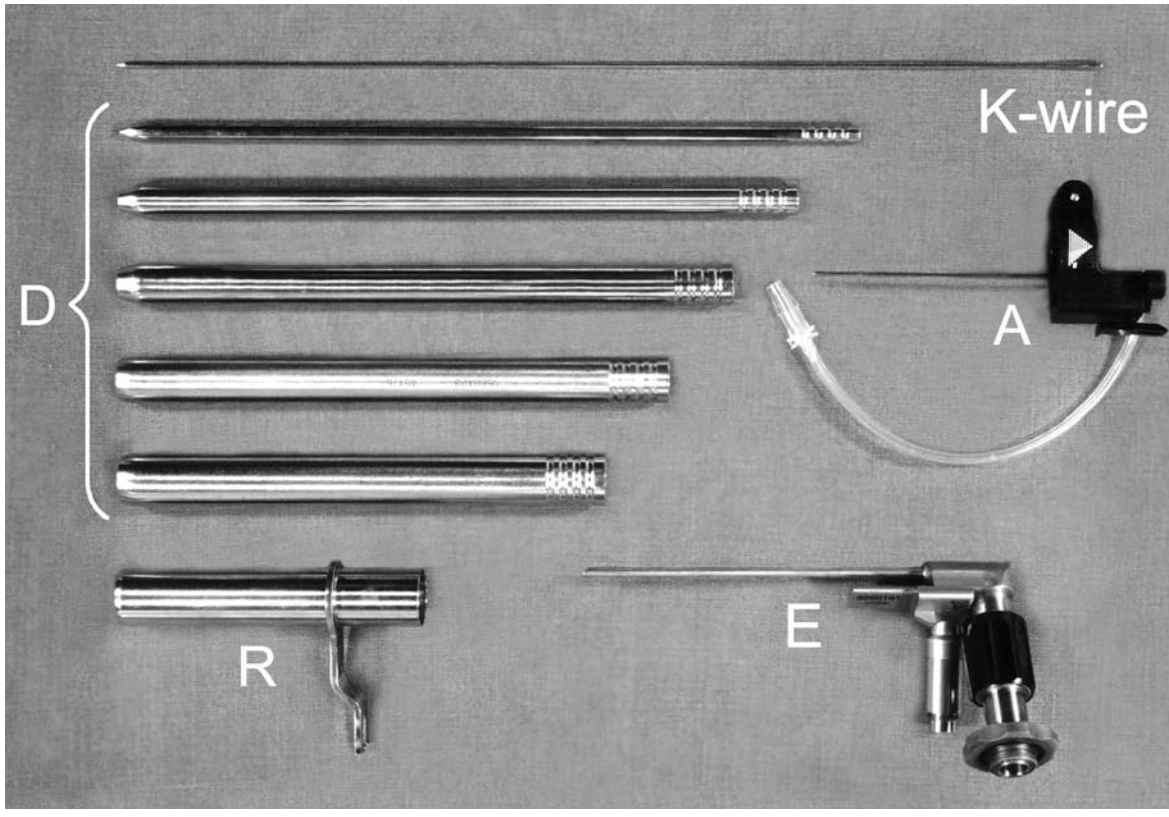


Fig. 10.2. Photograph showing parts of the MED system: rigid endoscope of 3.0 mm outer diameter and 25°-angled lens (*E*), 18-mm-diameter tubular retractor (*R*), ring attachment with endoscope-cleansing device (*A*) and K-wire and dilators (*D*)

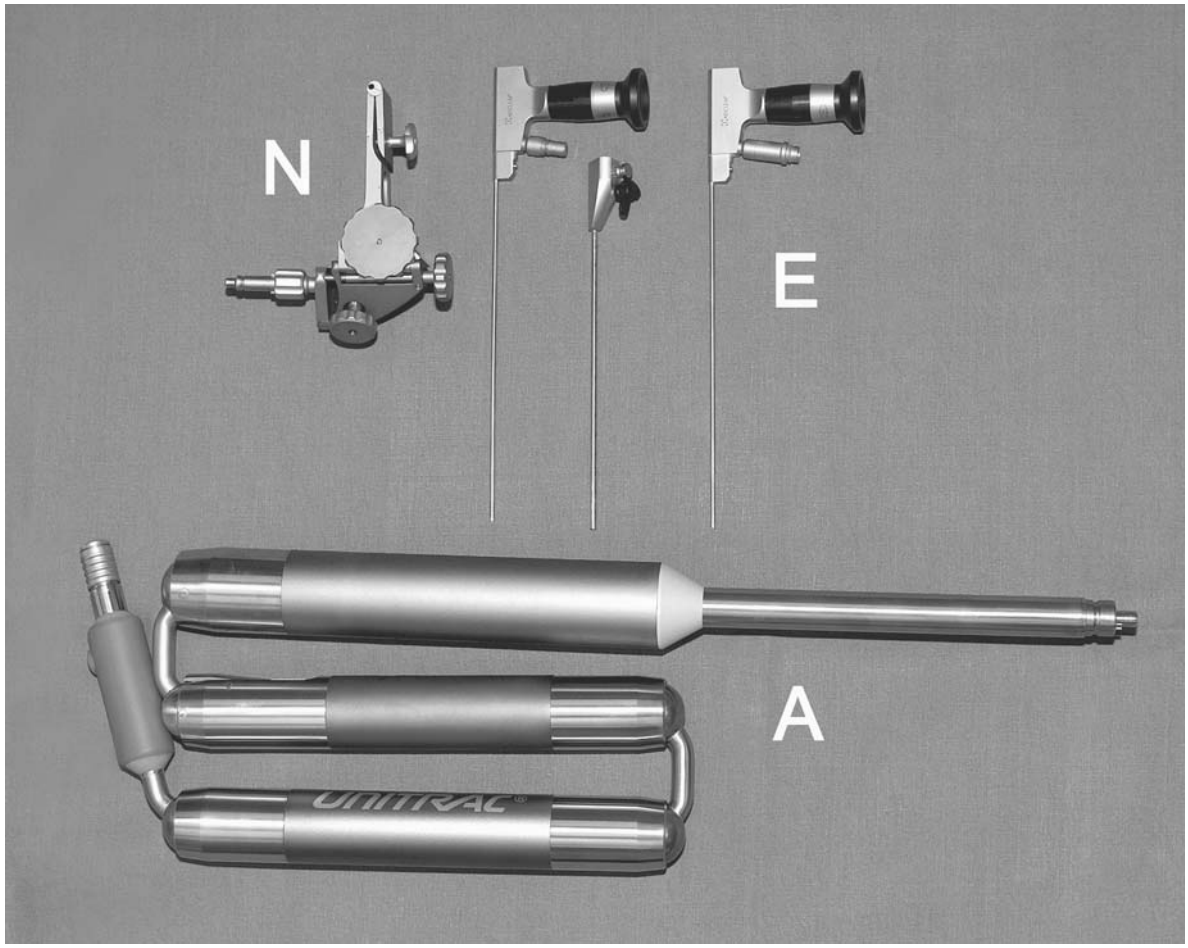


Fig. 10.3. Aesculap endoscope set: rigid endoscopes (diameter 2.7 mm, length 18.1 cm) with 0°- and 30°-angled lens (*E*), NeuroPilot endoscope steering device (*N*) and Unitrac pneumatic endoscope holding arm (*A*)

lateral and the lateral margin of the UP is deliberately exposed. At C7 care must be taken not to imperil the VA, where it runs between the transverse process and the LCM. The exposed field includes the lateral third of the intervertebral disc, the lateral portion of the caudal vertebral body with the UP and the lateral portion of the cranial vertebral body.

Using the MED system a K-wire was first placed through the incision to the target UP. Then the dilators were passed along the K-wire with slightly rotating movements being sequentially placed over each other. Constant pressure on the initial dilator ensured that the system did not migrate while the dilators were inserted. Finally, the retractor was placed over the final dilator and was anchored to the retractor arm. Then the dilators were removed. The retractor was adjusted parallel to the longitudinal axis of the UP. This procedure was performed under fluoroscopic guidance (Fig. 10.4).

Using the Aesculap system a standard retractor with slim blades was used.

10.9.5.2.2 Endoscopic Anterior Foraminotomy and/or Removal of the Herniated Disc

The operation is now continued under endoscopic visual control in the same way as the microsurgical procedure (Fig. 10.5a – c).

The operation can be performed at two adjacent levels on the ipsilateral side via the same skin incision.

10.9.6 Closure

At the end of the procedure the bone surface is sealed with small amounts of bone wax if significant oozing of blood is visible. To avoid any potential compressive material coming in contact with the nerve root or the spinal cord, haemostatic agents (e.g. Gelfoam, Surgicel) are not used. A wound drain is in most cases not necessary and therefore not inserted. Finally the retractor is removed, the platysma is closed with interrupted ab-

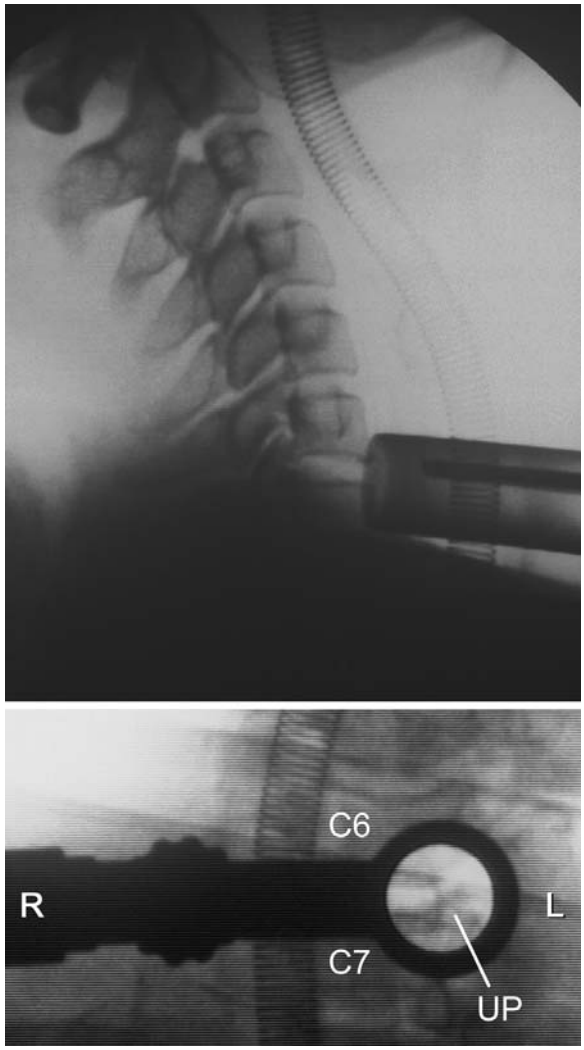
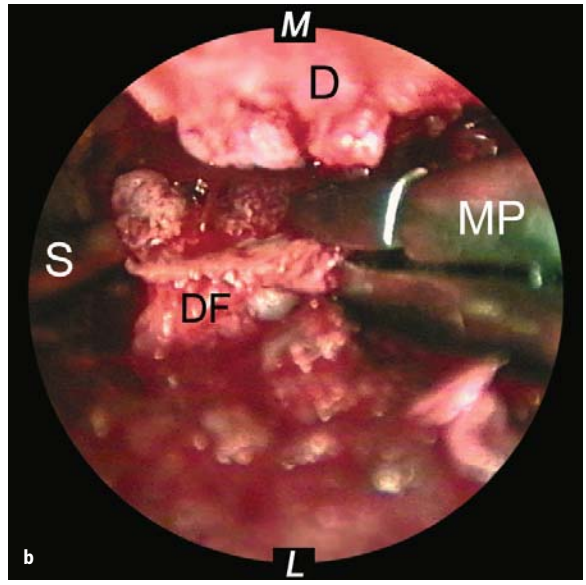
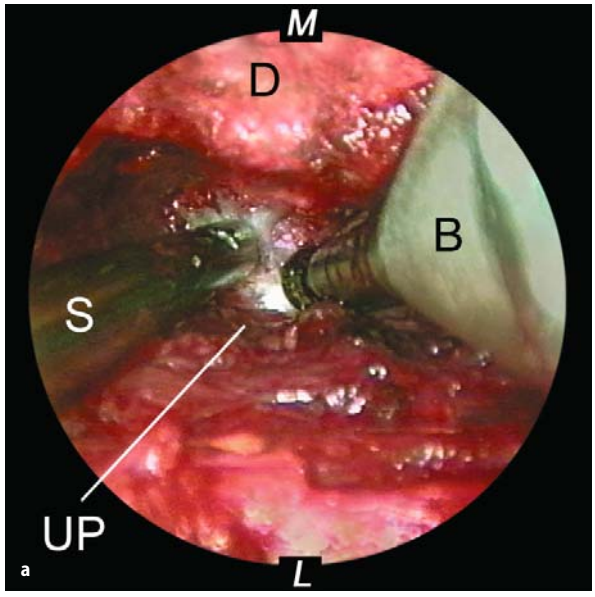


Fig. 10.4. Fluoroscopic images depicting the retractor and endoscope placement at C6-7 on the left side (*L*). Lateral (*upper*) and anterior posterior (*lower*) orthograde through the retractor, according to the longitudinal axis of the UP, showing the target area with UP (*UP*), lateral third of the disc and cephalic endplate

Fig. 10.5. Intraoperative photographs at C6-7 left. *M* Medial, *L* lateral. **a** Under endoscopic magnification the posterior cortical wall of the UP is drilled to unroof the foramen using a 2-mm ball-shaped diamond burr (*B*). The intervertebral disc (*D*) and the lateral wall of the UP are retained. *S* Suction. **b** The disc fragment (*DF*) is removed using a micropunch (*MP*). **c** The decompressed nerve root (*NR*) is seen from its origin at the thecal sac (*T*) to its entrance into the intervertebral foramen behind the lateral wall of the UP and the VA





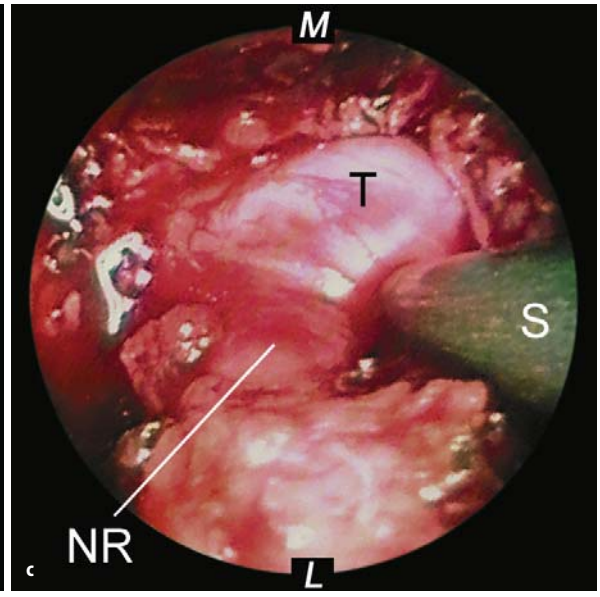




Fig. 10.6. Photograph showing a patient's neck 3 months after an endoscopic anterior foraminotomy at C6-7 right

sorbable stitches and then a subcuticular skin closure is made (Fig. 10.6).

10.10 Postoperative Care and Complications

Mobilisation of the patients was allowed 6 h after the operation, but the patients were advised to minimise activity and to avoid extensive motion of the neck for 14 days. Although patients could be discharged on the day after surgery or the procedure could even be performed on an outpatient basis, our patients were discharged for insurance reasons on day 8. Six weeks after surgery they were allowed to return to full activity.

One of the 87 patients who underwent microsurgical or endoscopic anterior cervical foraminotomy had a relapse of radicular pain 2 days after the operation and had to undergo repeat surgery.

In one patient, in the first endoscopic series, difficult arterial bleeding occurred while drilling parts of the lateral wall of the UP, but it could be controlled with Tachocomb (collagen fleece coated with fibrin components). A postoperatively performed angiography revealed no evidence of an injury to the VA.

A transient palsy of the recurrent laryngeal nerve was observed in five patients mostly after a C6-7 approach on the left side. Poor wound healing was observed in three patients. All of these minor complications resolved with no untoward effect.

One patient, who had previously undergone ACD and fusion at the affected level, experienced a Horner's syndrome. Although heavy scaring rendered the approach difficult in this case, it could generally be performed without major obstacles.

There were no spinal nerve injuries, spinal cord injuries or deaths associated with this procedure.

10.11 Results

In our series anterior cervical foraminotomy was equally successful using the microsurgical or endoscopic technique. Success was measured by a reduction on the pre- and postoperative neck disability index (NDI) data [14], the visual analogue scale (VAS) data concerning radicular pain, the patient satisfaction and the absence of analgesic medication.

The NDI score showed an average absolute improvement of 44.7 %, from a mean preoperative score of 28.4 to 14.7 after surgery ($P > 0.05$). The VAS scores showed an average absolute improvement of 96.3 % compared to baseline scores ($P > 0.05$); the preoperative VAS score was 6.75 and the postoperative VAS score was 0.25. The VAS-based outcomes concerning relief from radicular pain were excellent in 91 % and good in 9 % of the patients. Fair or poor results were not observed in these series.

In 51 of the 65 patients who initially experienced motor weakness, the weakness did not immediately improve after surgery, but did improve with physical therapy till normalisation in 37 patients. Fourteen patients (16.6 %) retained persistent, slight motor weakness (grade 4). Of the 73 patients who initially presented with numbness, 55 regained normal sensation. Eighteen patients (20.6 %) are left with a residual numbness, largely in the distal portion of the corresponding dermatome.

In one patient radiographic follow-up data 3 months after surgery showed evidence of delayed instability and significant loss of disc height at the level of surgery. In this case an ACD and fusion of the affected level was performed.

The overall subjective patient satisfaction rate with this surgical procedure was 95.6 %. Seventy-nine patients (90.8 %) returned to work or a baseline level of physical activity within 6 weeks postoperatively (Figs. 10.7, 10.8).

10.12 Critical Evaluation

The advantages of this technique are the direct access to the offending lesion, the complete decompression of the affected nerve root, and the preservation of the disc and the motion segment with avoidance of a fusion procedure and its attendant potential problems. It allows patients a shorter hospital stay and to resume full activity sooner.

The endoscopic anterior foraminotomy is initially a more technically demanding procedure that requires practice in order to become familiar with the endoscope and the instruments, but it proved to be a viable

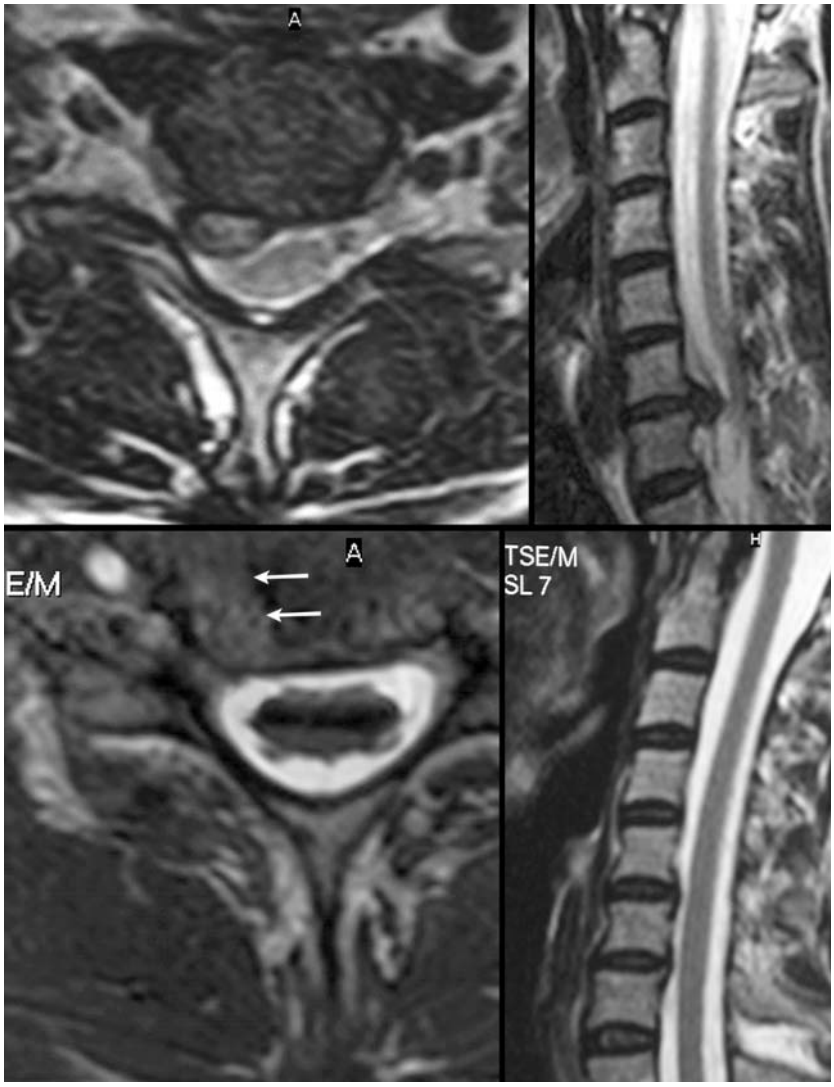


Fig. 10.7. *Upper* Preoperative axial (*left*) and sagittal (*right*) MR image of the cervical spine at C6-7 revealing a posterolateral disc fragment encroaching on the right C7 nerve root. *Lower* Postoperative MR images obtained in the same patient demonstrating decompression of the right C7 nerve root in the axial view (*left*) and in the sagittal view (*right*). *Arrows* indicate the drilled canal in the C7 vertebral body after anterior cervical foraminotomy

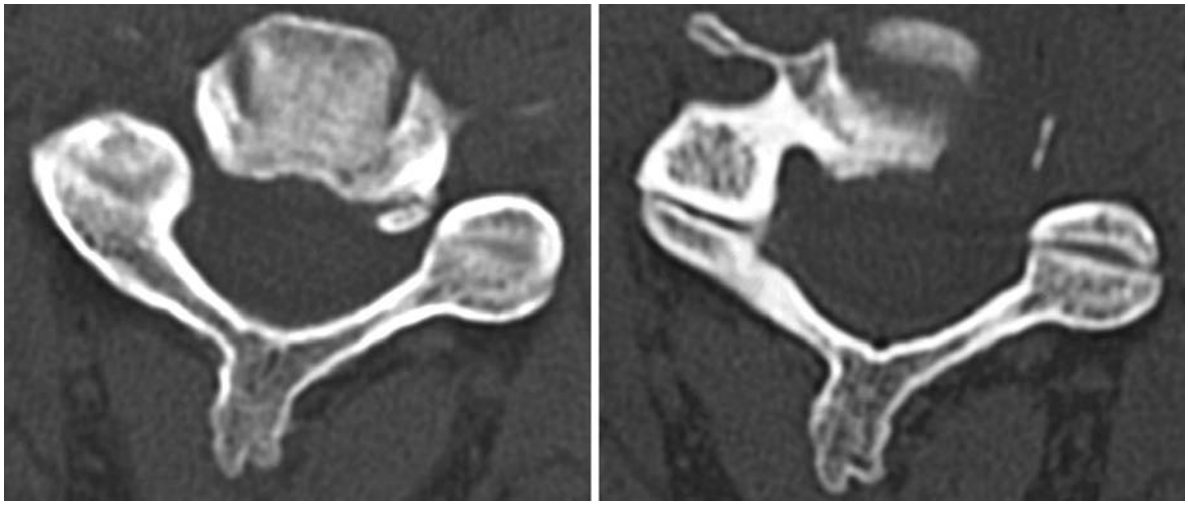


Fig. 10.8. *Left* Preoperative axial high-resolution CT scan obtained at C5-6, revealing a foraminal stenosis on the left side caused by an uncovertebral osteophyte. *Right* Postoperative CT scan demonstrating the enlarged neural foramen following anterior cervical foraminotomy. Parts of the lateral wall of the UP medial to the VA are preserved

minimally invasive technique. While the MED system, which was originally designed for lumbar use, turned out to be cumbersome in this procedure, the Aesculap system with the endoscope-steering device permits exact manoeuvring and adjustment of the endoscope in submillimetre steps in all three dimensions, thus providing exceptionally good visualisation and a more intense light.

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11 Functional Segmental Reconstruction with the Bryan Cervical Disc Prosthesis

J. Goffin

11.1 Introduction

Since the 1970s, technical advances in the design of large joint reconstructive devices have revolutionized the treatment of degenerative joint disease, moving the standard of care from arthrodesis to arthroplasty. In spite of these advances, few non-fusion options exist for the treatment of degenerative disc disease in the cervical spine. With the exception of lateral to far lateral disc herniations where lamino-foraminotomy via a dorsal approach [1, 8] or microforaminotomy via a ventral approach [10] might be alternatives, traditional treatment options have been discectomy (ACD) or discectomy and fusion (ACDF).

The concept that interbody fusion of the cervical spine leads to accelerated degeneration of adjacent disc levels due to increased stress from the fusion is widely postulated [9]. Simple mechanics dictates that if the adjacent levels move the same amount, global motion of the cervical spine will be reduced. If magnitude cervical motion is maintained, non-fused discs will need to displace to greater extremes at a higher stress than prior to the arthrodesis. Therefore, reconstruction of a failed disc with a functional disc prosthesis should offer the same benefits as decompression and fusion while simultaneously providing motion and thereby protecting the adjacent level discs from the abnormal stresses associated with fusion by maintaining physiological motion and kinematics.

Given the multiple theoretical advantages of functional disc replacement, numerous groups have sought to design a successful intervertebral disc prosthesis. Most of these efforts, until now, have been focused on the lumbar spine. The unique features of the cervical spine anatomy, the complex biomechanical loads and motions, and the unique tissue biomechanical properties may explain, at least in part, this relative lack of cervical focus. On the other hand, reduced loading conditions and the relative simplicity of the exposure make the cervical spine an excellent candidate for this procedure.

11.2 Theoretical considerations

The success and long-term stability of a prosthesis depend on both the device design and the methods used to implant the prosthesis. The artificial disc should provide an immediate postoperative stable interface to the vertebral bodies and, ideally, subsequent biological ingrowth of bone to ensure long-term stability. It should have adequate strength and durability to prevent structural failure due to overloading and high-cycle fatigue, should be biomechanically and biochemically compatible, and should have adequate dimensions to resist subsidence or migration into the vertebral bodies [4]. Clinical experience with large joints replacements has shown that significant problems can occur as a direct result of wear debris-induced osteolysis [14]. A similar problem might be encountered in the spine. Thus, minimal wear debris should be produced by the prosthetic joint [4].

11.3 History

In 1962, Fernstrom from Uddevalla, Sweden, introduced a spherical intercorporeal endoprosthesis, which was inserted into the center of the evacuated disc space after lumbar laminectomy [5]. Fernstrom was focused on the lumbar spine, but also used his endoprosthesis in a number of patients with cervical degenerative lesions. The cervical prostheses were stainless steel spheres with diameters of 6 – 10 mm and the prosthesis size was chosen to be 1 mm larger than the intradiscal height. Eight patients were operated and a total of 13 prostheses were inserted in the cervical spine after anterior discectomy. Because of hypermobility, migration, and subsidence of the ball into the cancellous bone of the adjacent vertebrae the technique was eventually abandoned [4].

In 1964, Reitz and Joubert from Durban, South Africa, reported their own experiences with the Fernstrom prosthesis in a series of 32 patients operated upon for intractable headache and cervico-brachialgia [13]. The spherical prosthesis preserved mobility of the interver-

tebral disc segment, but the reported follow-up of these patients was less than 1 year.

In 1985, Alemo-Hammad reported on the use of in situ cured methyl methacrylate inserted after anterior cervical discectomy in a series of five patients [2]. The resulting concave lens-shaped mass was said to allow motion. Alemo-Hammad reported satisfactory results at 24–36 months follow-up, although no evidence of motion preservation was provided.

Steffee designed his own artificial disc and he reported in 1989 on a patient who received two of his prostheses at the upper and lower levels of a three-level construct in which the central disc level was fused using autograft [17].

During the years 1989–1991, the Department of Medical Engineering at Frenchay Hospital in Bristol, UK, developed an artificial joint which was designed to be inserted in the cervical intervertebral space after discectomy (the prosthesis was known as the "Cummins" artificial cervical joint, or the "Bristol prosthesis", or the "Frenchay prosthesis"). This artificial joint is made of stainless steel and represents a ball-and-socket-type joint. A stable interface is assured by mechanical fixation with locking screws placed ventrally and by compression against small ridges in the joint by the vertebral bodies on either side [4]. In 1998, Cummins, Robertson, and Gill published their results with a series of 20 patients who were operated upon between 1991 and 1996. Two of this group of patients received two artificial joints at C3-4 and C6-7, and at C2-3 and C6-7, respectively. So the duration of follow-up ranged from 3 to 65 months. At the end of this follow-up period, movement of the joint was demonstrated on flexion-extension X-ray films in 16 of the patients (80%) with an average flexion-extension range of motion of 5°. Subsidence into the vertebral bodies did not occur and no wear debris was seen. Osseous incorporation of the prosthesis was not demonstrated.

With regard to pain relief, 16 of the 20 patients reported improvement. Complications occurred in a number of these cases. There were five partial screw pullouts and two broken screws. The high profile of the ventral flanges of the joint produced dysphagia in almost all patients, and this dysphagia was persistent and significant in four of them [4].

At the 29th Annual Meeting of the Cervical Spine Research Society in Monterey, California, in November 2001, Robertson et al. presented a new series of 15 patients with radiculopathy and/or myelopathy, who received disc replacement with the Bristol prosthesis [15]. At 2 years follow-up these 15 patients demonstrated satisfactory motion of the artificial disc on flexion-extension radiographic images and a number of them improved with regard to their neurological signs and symptoms.

In 2002, Wigfield et al. presented a series of 12 patients who received a modified version of the Bristol prosthesis. The articulation was converted to a ball-in-trough design from the original ball-in-socket design to allow more physiological motion and the profile of the device was reduced to mimic that of commercially available anterior cervical plates. This modified prosthesis is available in several markets as the Prestige cervical disc system. The 1-year results were compared to a group of 13 patients who received during the same period a classical interbody fusion. The patients who received the artificial cervical joint were those most at risk of developing adjacent-level disease were a standard fusion procedure to be performed. The indications for cervical joint replaceent thus included presentation with radiculopathy and/or myelopathy with radiological evidence of neural compression by osteophyte or herniated disc material, in the presence of an adjacent surgically created or congenital cervical fusion. An alternative entry category was for patients with evidence of asymptomatic disc degeneration adjacent to the symptomatic disc targeted for surgery, even if there had been no previous surgery. In the fusion group a significant increase in adjacent-level movement was demonstrated at 12 months follow-up compared with the group of patients in whom artificial cervical joints were placed. The increase of movement occurred predominantly at intervertebral discs that were preoperatively regarded as normal. An overall reduction in adjacent-level movement was observed in patients who underwent disc replacement, although this was compensated for by movement provided by the artificial cervical joint itself. Based on this data, it appears that the Prestige device is able to prevent hypermobility at adjacent levels in the short term, however, long-term follow-up data will be required to understand if the device is able to alter the degenerative cascade [19, 20].

In 2001, Pointillart from Bordeaux, France, described his experience with a new low-profile disc prosthesis, implanted after single-level cervical discectomy. The concept of this artificial disc was influenced by the use of unipolar hip replacements. The prosthesis has a titanium base, which is firmly secured by two screws to the caudal vertebral body after all soft and cartilaginous material has been removed from the rostral endplate of this body. The carbon sliding surface at the rostral side of the prosthesis interfaces with the remnants of disc tissue, left in place on the caudal endplate of the rostral vertebral body. A clinical trial was performed on five male and six female patients, operated on in 1998 and 1999. Radiographically, all mobility of the operated level had disappeared 1 year postoperatively as the result of spontaneous fusion in all cases [12].

At the 16th Annual Meeting of the European Section of the Cervical Spine Research Society in June, 2000, in London, Jackowski from Birmingham, UK, presented the results of a number of laboratory tests carried out on his viscoelastic-jacketed hydrogel prosthesis. As far

as is known, this prosthesis has not yet been used in a clinical setting.

Whereas the previously mentioned artificial discs were basically developed as spacers, which could also provide motion, a next generation of disc prostheses for the cervical spine has been designed to allow not only motion, but provide elasticity.

From 1997 to 2002, the Spinal Dynamics Corporation (Mercer Island, Washington) developed and tested the Bryan Cervical Disc prosthesis in both in vitro and in vivo environments. Medtronic, which acquired Spinal Dynamics in October 2002, has made the prosthesis available in multiple markets worldwide.

11.4 Structural and Functional Objectives of the Bryan Cervical Disc Prosthesis

The design objectives were based on established principles and methods that have been validated for large joint reconstructive devices, including:

- The device should be semiconstrained over the normal range of motion and thus be able to function synergistically with the remaining anatomic structures (annulus, ligaments, facets, and muscles).
- The device should utilize precise bone preparation techniques, combined with porous bone ingrowth fixation to be mechanically stable within the interspace.
- The device should provide adequate range of motion in all degrees of freedom to permit restoration of normal function.
- The device should withstand the loads and stresses encountered in the activities of daily living.
- The device should provide long-term useful life in a biological environment and prevent tissue ingrowth into the articular surfaces.
- The device should provide elasticity.
- The prosthesis should be part of a system that includes instrumentation and a surgical technique that ensures accurate placement of the prosthesis with minimal resection of supporting bone and soft tissues.
- The device should utilize materials with proven success and biocompatibility.
- The device should permit conversion to fusion.

11.5 Description of the Bryan Cervical Disc Prosthesis

The Bryan Cervical Disc prosthesis has a biconcave articulation (one articulation between the artificial nucleus and the concave rostral artificial endplate and a second articulation between the artificial nucleus and the concave caudal artificial endplate). The two concave/convex titanium endplates have an inner ridge and central post that act in tandem to limit the range of motion to that of a normal spine. The external surfaces of the shells have an aggressive porous texture which provides short-term stability and a long-term ingrowth surface. To enhance the likelihood of ingrowth, instrumentation is provided to prepare a precision cavity so that no gap or soft tissues exist between the implant and the bone. The interior surface of the shells is concave and highly polished. This surface is designed to articulate with a polymeric nucleus via contact occurring over a conforming spherical surface.

The nucleus is axially symmetrical with an approximately elliptical cross-section. There is a hole through the center of the nucleus that fits over the shell posts during prosthesis assembly. The shell post and the nucleus hole do not contact during normal motion, but will act as a soft stop when the normal range of motion is exceeded. The spherical surfaces of the nucleus and the conforming interior surface of the shells articulate during normal motion.

The axially symmetrical shape of the nucleus and the shells are designed to permit the coupled motions of the cervical spine. That is, as the vertebrae and shells move in flexion, extension, lateral bending, axial rotation, or combinations of these motions, the nucleus is free to rotate and translate, as required, between the shells.

A wire loop attaches a polymeric sheath to each shell to enclose the nucleus and create a sealed inner compartment. The wire is seated in a circumferential



Fig. 11.1. Bryan Cervical Disc prosthesis



Fig. 11.2. Expanded view of Bryan Cervical Disc prosthesis

groove on the outside of the shell, over the sheath, and is fastened with laser welds. There is a hole, or port, at the apex of each shell through the post and into the interior of the closed compartment, allowing access for ethylene oxide gas during device sterilization. Immediately before implantation, the device is filled with saline through the ports and the ports are permanently closed with titanium plugs. The sealed compartment not only provides containment of the saline lubricant to reduce friction and wear (Figs. 11.1, 11.2), but also reduces the likelihood of wear debris release and fibrous tissue ingrowth into the articular surfaces.

11.6 Biocompatibility of the Bryan Cervical Disc Prosthesis

All materials used in the Bryan Cervical Disc prosthesis and its implantable accessories have a documented history of use in human implants. The metallic materials used in the implant are pure titanium or titanium alloy. The polymer materials are proprietary composites of polyurethanes with silicone modification. These materials have been used in long-term implants since the early 1990s, primarily in cardiovascular devices.

Testing in accordance with ISO (International Standards Organization) 10993-1 was conducted previously on the raw materials. Confirmatory testing included cytotoxicity, sensitization, genotoxicity, implantation, chronic toxicity, and implantation of finished devices in two animal models.

11.7 Mechanical Testing of the Bryan Cervical Disc Prosthesis

The prosthesis was evaluated in multiple loading modes to establish safety under in vivo biomechanical conditions. Custom cervical spine simulators were developed to evaluate the long-term functionality and durability of the Bryan Cervical Disc prosthesis following 10,000,000 cycles of flexion/extension and 10,000,000 cycles of lateral bending. Tests were performed in serum at 37° C to mimic the in vivo environment. The average mass loss was less than 2% and all devices were fully functional. Every sheath was able to maintain air pressure, indicating that any particulate that was formed would be retained rather than released into the surrounding tissues.

Additional static and fatigue testing was performed on the shells and nucleus to assess design robustness prior to any clinical investigations. For example, compression fatigue testing of the nucleus and shell in multiple loading modes demonstrated that mechanical failure of the device should not occur under physiological loading. Mechanical testing of the porous coating demonstrated that the strength of the coating is adequate and characterization shows that it possesses a microstructure appropriate to allow for bony ingrowth [16]. Cadaver models were used to assess the ability of the prosthesis to resist shear loads.

11.8 Animal Testing of the Bryan Cervical Disc Prosthesis

First generation prostheses were implanted into six adult male chimpanzees in a survivor study developed to assess device safety. The chimpanzee survivor model was chosen primarily due to similarity to human anatomy and biomechanics. The use of these animals was quite conservative, as their normal daily activity level is significantly greater than that of humans. The results of the study showed that the animals were able to move, climb, and resume their normal activities soon after waking from the anesthesia and that the device performed as intended with no perceptible migration. However, consistent bony ingrowth was not observed in this first study.

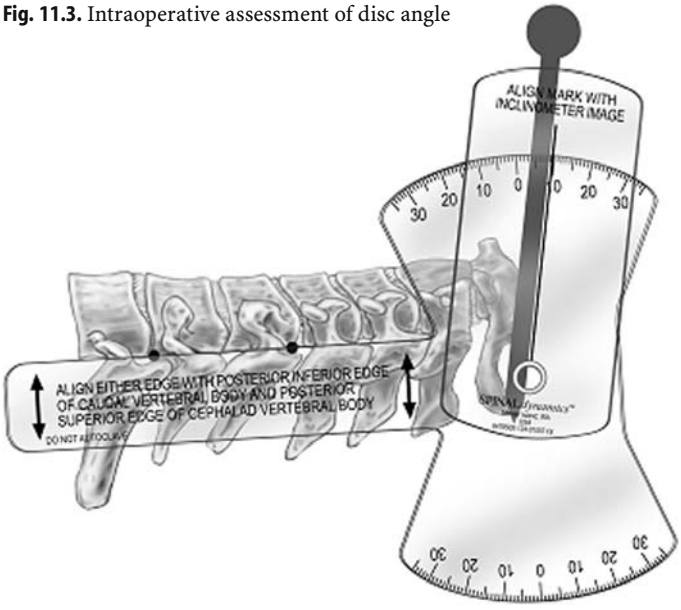
Following several implant design improvements, an additional 3-month study was conducted. Using fluorochrome labeling techniques, it was demonstrated that the use of a modified porous coating and an improved bone preparation process resulted in bony ingrowth into the coating of the shells. Motion of the device was also demonstrated using dynamic fluoroscopic techniques. Minimal particulate material was observed in periprosthetic tissue biopsies, and the biological response was indicative of a stable orthopedic implant.

A third animal study was performed in goats to evaluate the effect of particulates that may be produced by the device on local and distant tissues. A limited number of polymeric particles (2 – 4 per cm^2) were observed at the 6- and 12-month time points, however, there was no evidence of an inflammatory reaction. Furthermore, no metallic or polymeric particles were identified in any of the distant tissue samples.

11.9 Surgical Technique

The prosthesis is implanted using a set of instruments that prepare a precision cavity in the bony endplates at the operative level. While the technique may seem complicated in initial cases, use of the instruments avoids approximations and guesswork so that prosthesis positioning is both accurate and precise. In brief, a preoperative CT or MRI is used to review the anatomy at the op-

Fig. 11.3. Intraoperative assessment of disc angle



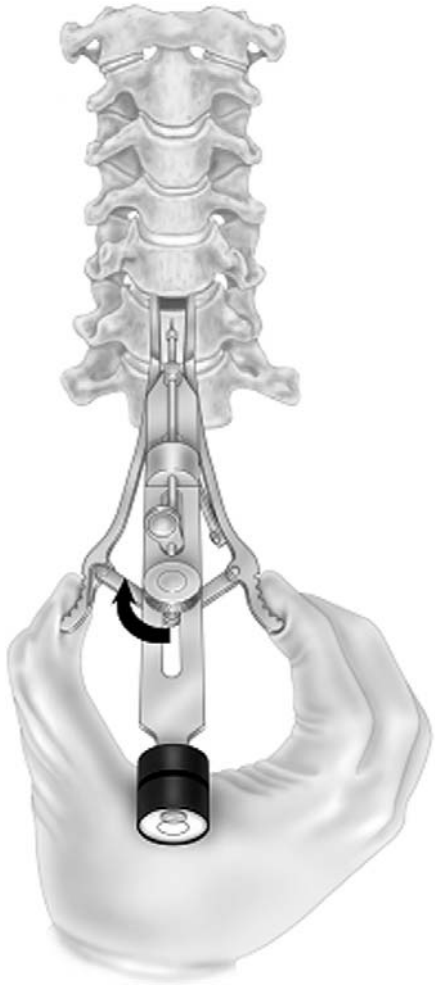


Fig. 11.4. Determination of right/left disc space center

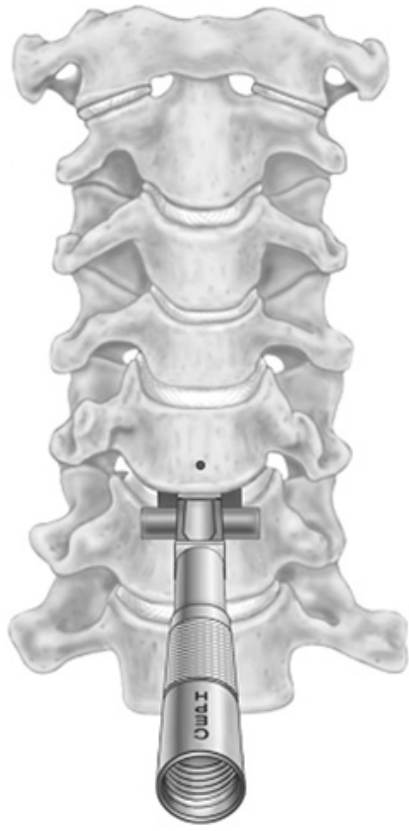


Fig. 11.5. Top view of sagittal wedge placed in the disc space

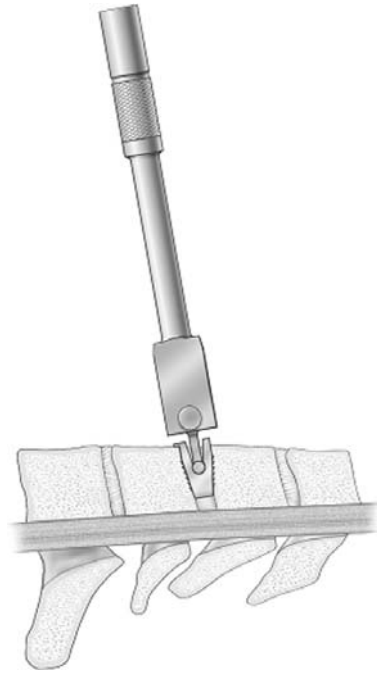


Fig. 11.6. Lateral view of sagittal wedge

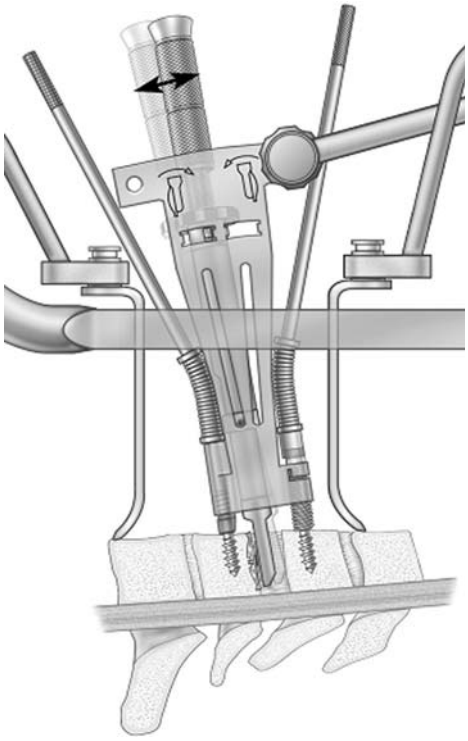


Fig. 11.7. Preparation of bony cavities with milling handpiece

erative level and estimate the prosthesis size. The patient is positioned on the operating table in the supine AP position and stabilized. Disc space angle is assessed using lateral fluoroscopy (Fig. 11.3). ACD is then performed using a stereotactic frame to hold table-mounted retractors. The right/left center of the disc space and rostral/caudal center of the disc space are determined (Figs. 11.4 – 11.6). A guide is mounted to the anterior surface of the rostral and caudal vertebral bodies and the corresponding endplates are trimmed using a fluted cutter. A separate disc is then used to create a concavity matching the exact geometry of the prosthesis (Fig. 11.7). With slight distraction and subsequent compression, the prosthesis is positioned into the milled concavities, capturing each shell inside a ridge of bone. This tight fit provides immediate AP and lateral stability. No restrictive postoperative management, such as collar or brace, is necessary.

11.10 Preliminary Clinical Experience with the Bryan Cervical Disc Prosthesis

The first implantation of the Bryan Cervical Disc prosthesis was performed at the University Hospital Gasthuisberg, Department of Neurosurgery, of the Catholic University of Leuven, Belgium, on 5 January 2000. It was the start of the first prospective multicenter European Clinical Trial, involving centers from the UK (London), France (Strasbourg and Bordeaux), Germany (Erlangen), Sweden (Gothenburg), and Italy (Rome). This first trial enrolled patients with single-level degenerative disc disease of the cervical spine. The objective was to determine whether the disc prosthesis and the associated decompression can provide relief from objective neurological symptoms and signs, improve patient functionality, decrease pain, and provide long-term stability and normal range of motion, thereby protecting the adjacent discs from the abnormal stresses caused by interbody fusion. Patients with symptomatic cervical radiculopathy and/or myelopathy were implanted with the Bryan prosthesis after a standard anterior discectomy was performed. The effectiveness of the device was assessed by evaluating each patient's pain, neurological function, and range of motion at the implanted level at scheduled follow-up periods up to 2 years postoperatively.

Ninety-seven patients with radiculopathy and/or myelopathy due to a disc herniation or spondylosis were enrolled and the enrollment was completed in June 2001. Patients were operated at the C4-5, C5-6, and C6-7 levels. The five available sizes of disc prosthesis (14 – 18 mm) have been used in the study. The surgical procedure has a learning curve: the first operation, performed in Leuven, required 4 hours of surgical time. Currently, it is the time required to complete the discectomy and decompression that indicates the duration of the whole operation. Precision preparation of the endplates and inserting the prosthesis requires only 15 – 20 minutes, leading to normal operation times for one-level cases of 90 minutes.

The preliminary results of this first European trial have been presented at a number of scientific meetings and a preliminary report has been published [6]. Up to now (summer 2003), 73 of the 97 single-level patients have received their 24 months follow-up. Of the 73, 45 of these were scored excellent for clinical success at 2 years follow-up using the modified Odom's criteria. The preliminary clinical results have been very satisfactory and exceeded the targeted success rate at 6, 12, and 24 months. Radiological analysis shows a flexion/extension range of motion of more than 2° in about 90 % of the patients at the 6-, 12-, and 24-month time points (Figs. 11.8 – 11.11). The mean flexion/extension range of motion was about 8° at each follow-up point. No case of subsidence of the prosthesis was encountered and stability has been maintained. A few patients from those who had already reached the 2-year follow-up point were chosen at random and asked to undergo a spiral-CT examination, which showed bony ingrowth from the adjacent vertebral bodies into the porous coating of the shells of the prosthesis. At the same time paravertebral bony deposits were detected in the ventrolateral regions



Fig. 11.8. Flexion lateral view of patient at 24 months



Fig. 11.9. Extension lateral view of patient at 24 months



Fig. 11.10. Neutral lateral view of patient at 24 months



Fig. 11.11. AP view of patient at 24 months

in some of these cases, whereas others had no or almost no such deposits. Taking into account their anatomical distribution these deposits probably reflect a type of heterotopic ossification associated with surgical trauma of the longus colli muscles, similar to that frequently observed in total hip prosthesis surgery, where prophylactic use of anti-inflammatory medication for 10 – 14 days postoperatively has been effective in reducing or eliminating this bone formation [3, 7, 11, 18]. Further examination of the frequency of this recent

finding and its possible functional impact is necessary and has been started, as well as consideration of the prophylactic use of anti-inflammatory medications to avoid this ossification. One patient with severe preexisting osteophytosis demonstrated at 1 year follow-up a spontaneous fusion at the operated level. The clinical significance of this finding with regard to the concept of the use of a prosthesis in cases of significant preexisting spondylosis is not clear at this point, nor is its possible correlation with ossification in the region of the longus colli muscles.

Long-term follow-up remains necessary, not only to evaluate the performance of the prosthesis in a clinical setting, but also to assess the impact of the prosthesis on the development of adjacent level degeneration. Commitments have therefore been made with those patients who were operated on in Leuven, Belgium, to follow them prospectively once every 2 years through 10 years postoperatively. Ten consecutive patients of this initial one-level trial, who were operated on in Leuven, Belgium, at the C5-6 level, were also examined by videofluoroscopy for flexion-extension motion at 1 year postoperatively and demonstrated normal mobility both at the operated level and at the adjacent disc levels.

In the middle of 2001 a two-level clinical trial was initiated in a number of European centers to study the efficacy of using the prosthesis to treat bilevel disease. Thirty of 39 patients have reached the 12-month follow-up point. Twenty-one of these 30 patients were rated as excellent using the modified Odom's criteria. Motion greater than 2° was measured in 84% of patients and the average motion was 8°.

11.11 Conclusions

The preliminary clinical experience with the Bryan Cervical Disc prosthesis has been very satisfactory, even exceeding the results obtained with interbody fusions. However, long-term follow-up will be necessary, not only to prove continuous motion at the operated level in the long run, but also to assess the protective influence of the prosthesis on adjacent-level disc degeneration seen in fusion cases.

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12 Microsurgical Total Cervical Disc Replacement

H.M. Mayer

12.1 Terminology

Total disc replacement of the cervical spine is promoted as a new alternative to spinal fusion in degenerative disorders [4]. With the latest implant generation it can be performed in a microsurgical technique similar to the ones described in Chapter 9.

12.2 Surgical Principle

Total disc replacement of the cervical spine requires an anterior surgical access. Decompression of the spinal canal in cervical disc herniations and/or spinal and foraminal stenosis is performed through a small 3-cm skin incision with the help of a surgical microscope [6, 10, 11]. The disc is removed after interbody distraction which is held by so-called retainer screws anchored in the vertebral bodies. Since the accuracy of decompression as well as the preparation of the "implant bed" are critical for the overall outcome, the use of optical aids such as a surgical microscope or loupes is mandatory. After discectomy and decompression of the neural structures, a probe implant is inserted into the disc space and two keels are cut in the midline of the adjacent vertebrae. The total disc implant (Prodisc C; Synthes, Oberdorf, Switzerland), which is anchored through endplate-fins, is then introduced in the same way as the placement of a cage (see also Chapter 9).

12.3 History

A vast number of patents and surgical methods for total disc replacement of the spine have been published in the last 50 years [13]. In the cervical spine the concept of total disc replacement was inaugurated recently by Bryan [4]. Although there are only few clinical reports and no evidence-based data available, cervical disc replacement becomes more and more popular as an alternative to cervical fusion.

12.4 Advantages

As compared to anterior discectomy and interbody fusion using modern cage technologies there seem to be no further technical advantages. (For advantages of anterior discectomy and interbody fusion, see Chapter 9)

The yet non-proven, hypothetical advantages could be:

1. Minimally invasive approach
2. Low perioperative and operative morbidity
3. Distraction of the disc space
4. Preservation of segmental motion
5. "Protection" of the adjacent segment from accelerated degeneration (which can occur following rigid fusion)
6. Option for future fusion in case of failure
7. No postoperative bracing necessary

12.5 Disadvantages

The already know disadvantages of the described disc implant are:

1. No correction of segmental kyphosis or other deformities
2. Not indicated in unstable segments
3. Not indicated in patients following laminectomy or other procedures which have weakened the posterior tension band system
4. Not indicated in patients suffering from osteopenia or osteoporosis
5. No long-term results available yet

Potential disadvantages could be:

1. Incidental spontaneous fusion
2. Luxation and extrusion of the implant
3. Implant subsiding

12.6 Indications

Single- and multiple-level degenerative cervical disc disease C3-7 with or without:

1. Soft disc herniation
2. Spondylosis with osteophytes
3. Loss of disc height
4. Age between 18 and 60 years
5. Unresponsive to conservative therapy

12.7 Contraindications

1. Posterior element pathology (facet osteoarthritis, postlaminectomy, etc.)
2. Segmental macroinstability (e.g., subluxation, spondylolisthesis)
   a. Translation > 3 mm
   b. Angular motion > 11°
3. Segmental kyphosis
4. Predominant posterior spinal canal compression
5. Prior surgery at the level to be treated
6. Osteoporosis (DEXA with T-score ≥ –2.5) or other osteopathies
7. Known allergy against nickel, cobalt, chromium, molybdenum, or polyethylene

12.8 Patient's Informed Consent (see also Chapter 9)

In addition to the information about general complications of cervical spine surgery, the patient has to be informed that total disc replacement is an innovative technique with a lack of long-term results. It is still recommended to treat the patient under "study conditions" with close postoperative follow-ups.

The patient must be informed about the risk of nerve and spinal cord injury and disturbances due to the access (indirect spinal cord contusion due to vigorous hammering on the chisel; this complication can be avoided by drilling techniques for the keel preparation) or due to postoperative changes (e.g., implant luxation, extrusion, subsiding).

There is a potential risk of spontaneous fusion postoperatively which may not necessarily be associated with clinical symptoms.

12.9 Surgical Technique

12.9.1 Positioning

The patient is placed on their back on a flat table (Fig. 12.1). An adjustable head and neck holder can be recommended but is not mandatory. It is important that lateral and AP fluoroscopy is possible. The shoulders should be fixed with drapes and slightly pulled caudally in patients with short necks and in lower cer-

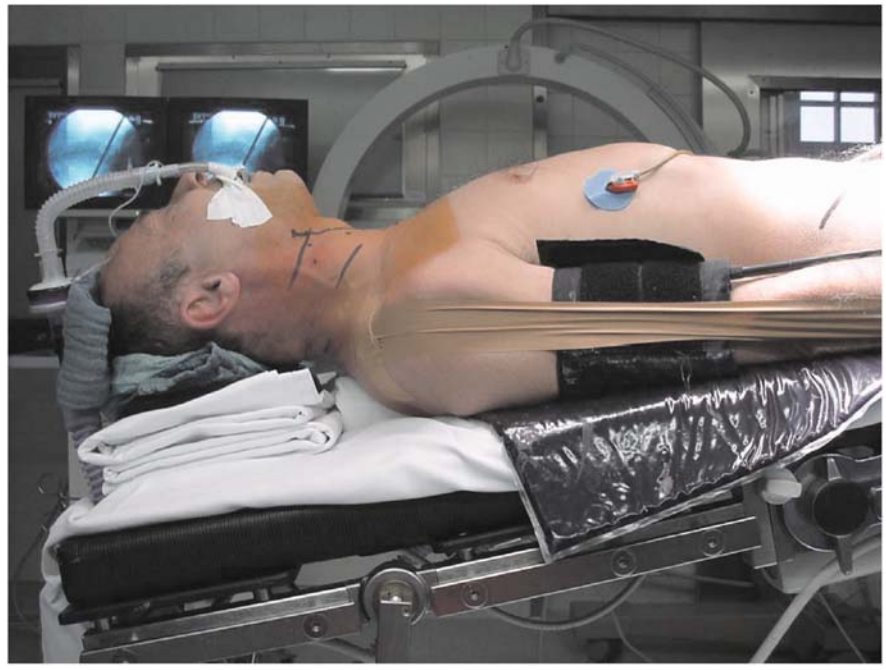


Fig. 12.1. Neutral positioning of the patient

vical spine approaches (C6-7 to T1). The neck should be supported by a roll to support the natural cervical lordosis. It is important to tilt the table so that the orientation of the disc space is in a 90° angle to the horizontal line.

The side of the approach should be according to the surgeon's preference. From C2 to C6 we prefer the right-sided access. There is weak evidence from the literature that a left-side approach from C6 to T1 diminishes the risk of recurrent laryngeal nerve irritation. If there has been previous surgery, the access should be from the contralateral side. If there is associated unilateral foraminal stenosis, the contralateral approach allows for an oblique view and easier decompression.

12.9.2 Skin to Spine

A transverse skin incision provides the best cosmetic result. It can be performed for one-level (3 cm) to three-level (6 cm) cases (Fig. 12.2). The incision should cross the midline by about 1 cm to better center the disc implant. The platysma is then cut transversely and mobilized in a cranial and caudal direction. The superficial neck fascia is dissected and blunt finger dissection along the anterior-medial border of the sternocleidomastoid muscle is performed to expose the prevertebral space medial to the common carotid artery and the jugular vein. Sometimes, the thyroid blood vessels need to be mobilized or clipped and transected. Once the longus colli muscle is exposed, the midline orientation is easy. However, it can be altered by anterior osteophytes which can lead to an asymmetry of the longus colli orientation. The disc space to be treated is then marked under fluoroscopic control. After dissection of the longus colli insertions, the soft tissue spreader is inserted.

The retainer screws for interbody retraction are screwed into the middle to upper/lower third of the adjacent vertebral bodies (Fig. 12.3). In Prodisc C implantations, the distance between the retainer screws and the endplate should be at least 6 mm. If double-level disc replacement is intended, the retainer screws should be placed off midline.



Fig. 12.2. Variable transverse skin incisions centered over the disc space(s) to be treated



Fig. 12.3. Retaining screws in adjacent vertebral bodies

12.9.3 Discectomy and Decompression

The anterior annulus is incised and the disc space is cleared with curettes. With the help of the microscope the deeper portion of the disc is removed in between the medial borders of the uncinate processes. The use of a surgical microscope to perform discectomy in the posterior third of the disc space and decompression of the cervical spinal canal is absolutely mandatory (Fig. 12.4). Three-dimensional vision and magnification of the very small posterior part of the disc space are the main advantages. The different structures of peripheral annulus fibrosis, posterior longitudinal ligament, disc herniation, and dura cannot be identified with the naked eye. Safe opening of the posterior longitudinal ligament and dissection from the underlying dura is not possible without the help of magnification.

The posterior longitudinal ligament is then removed with 0.5 – 2 mm Kerrison rongeurs with thin footplates. Care has to be taken not to damage the subchondral endplates. Only the posterior and lateral osteophytes are resected by undercutting of the dorsal rim of the vertebral bodies.

If there are no significant osteophytic spurs posteriorly or if there is no reason to suspect a subligamentous disc herniation, the posterior longitudinal ligament can be preserved as part of the posterior tension band system. Hemostasis of the bone is performed with a diamond drill, whereas the blood vessels in the posterior longitudinal ligament can be coagulated. Epidural bleeding is managed with Gelfoam or Floseal. After complete removal of the disc and decompression of the neural structures, the implantation process is started.



Fig. 12.4. NC 33 (Zeiss, Oberkochen) high-end surgical microscope



Fig. 12.5. Intervertebral distractor to restore disc height. Retainer screws in place

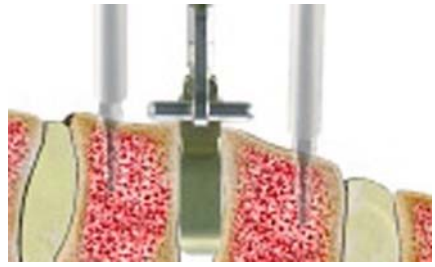


Fig. 12.6. Prodisc C trial implant in place

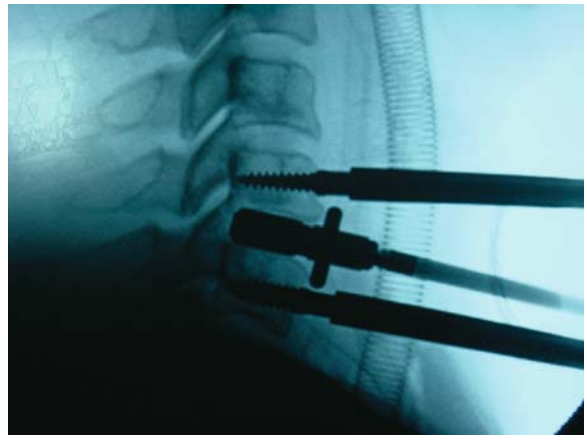


Fig. 12.7. Lateral X-ray showing a correct position of the trial implant

12.9.4 Implant Size and Positioning

The disc space is distracted with a special intervertebral distractor (Fig. 12.5). The retainer screws are blocked with the vertebral body retainer and keep the disc space open. A trial implant of an adequate size is inserted under fluoroscopic control (Fig. 12.6), and the correct position of the trial implant is verified (Fig. 12.7). A properly sized implant should cover most of the intervertebral area. The distance between the probe implant and the anterior and posterior rim of the vertebral body should be ideally about 1 – 2 mm.

12.9.5 Preparation of Implant Bed

Once the ideal implant size has been determined, the channels to take the central fins of the original implant are cut into the adjacent vertebral bodies. The trial implant's adjustable stop prevents extrusion of the device posteriorly. The cut can be performed by a parallel chisel (Fig. 12.8a, b) with the help of a guided high-speed drill. It is recommend to prepare the fin channels with a high-speed drill.

Once the channels are cut, checks must be made with the surgical microscope that the cuts are deep enough, and the surgeon has to ensure that there are no remaining bone particles within the channel.

12.9.6 Implantation

The original Prodisc C implant (Fig. 12.9a) is now mounted on the application instrument (Fig. 12.9b) and gently inserted into the intervertebral space under lateral fluoroscopic control. The application instrument is removed and the surgical field is irrigated with saline solution (Fig. 12.10). The retainer screws are removed and bleeding from the bone is managed with bone wax. An X-ray control in two planes is performed to document the exact placement of the implant (Fig. 12.11a, b). A drain is place into the prevertebral space and the wound is closed with resorbable sutures.

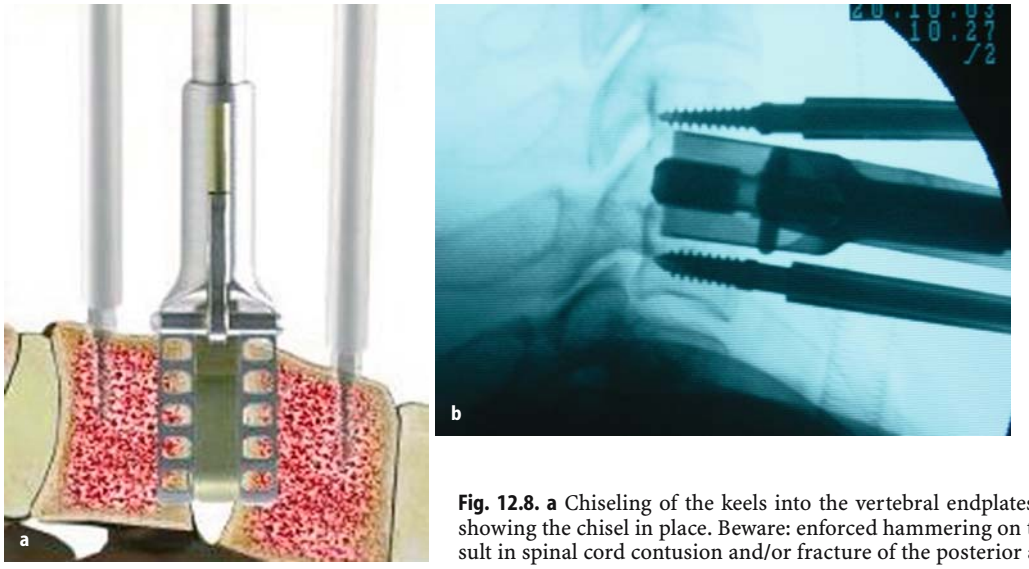


Fig. 12.8. a Chiseling of the keels into the vertebral endplates. **b** lateral X-ray showing the chisel in place. Beware: enforced hammering on the chisel can result in spinal cord contusion and/or fracture of the posterior apophyseal ring

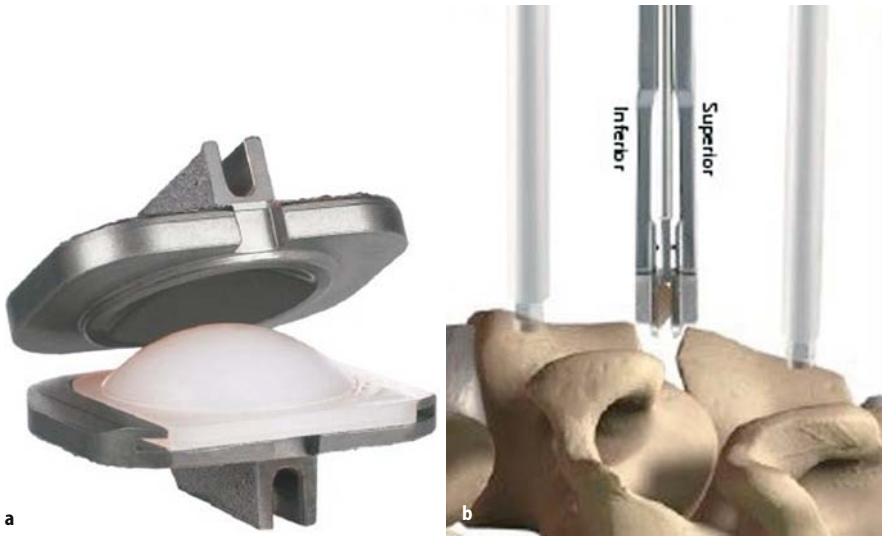


Fig. 12.9. a Original Prodisc C implant. **b** Insertion into the intervertebral space



Fig. 12.10. Implant in place

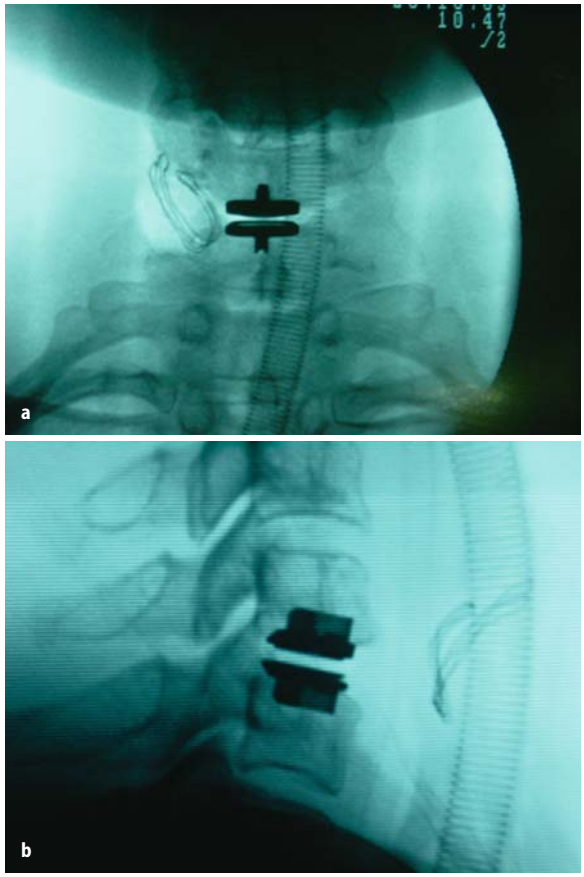


Fig. 12.11. Postoperative AP (**a**) and lateral (**b**) X-rays showing perfect position of the implant

12.10 Postoperative Care

In very sensitive patients, a soft cervical collar is recommended for the first 48 hours. All other patients do not require a cervical brace. The patient is allowed to get out of bed the same day and is mobilized ad libitum in the following days. Usually the patient leaves the hospital 1 – 4 days after surgery. We recommend that they return to daily activities as quickly as possible. However, forceful flexion/extension should be avoided for at least 4 – 6 weeks. We allow cycling and swimming from the third postoperative week onward. Other sports such as running, tennis, golf, etc. should be avoided for 12 weeks.

12.11 Hazards and Complications

12.11.1 Injuries to Neural Structures

The use of the microscope reduces the rate of these complications which ranges between 0.1 % and 3.3 % [2, 3, 5]. Especially in patients with sclerosis of the soft central and hard peripheral bone, there is a considerable risk associated with chiseling. With forceful hammering the spinal cord can suffer from indirect contusions. There is also a risk of iatrogenic posterior apophyseal ring fracture in patients with soft "central" and sclerotic peripheral vertebral bone structure. Brachial plexus injury due to prolonged traction of the shoulders has also been described.

12.11.2 Injury to Soft Tissues and Blood Vessels

Prolonged retraction of anatomic structures which are not sufficiently mobile is probably the most common cause of postoperative dysphagia and hoarseness. It is thus recommended that the cuff pressure of the tracheal tube is decreased to 20 cm H_2O upon insertion of the soft-tissue retractors [1, 7, 9].

12.12 Conclusions

Among all "spine arthroplasty" techniques, total disc replacement is the most advanced technique. Also in the cervical spine, total disc replacement seems to be the first, and probably most easily realizable technique. New implants for total cervical disc replacement have been developed in recent years. In a patent research a total of eight patents specific for cervical disc replacement could be identified [13]. The implantation tech-

nique for Prodisc C, one of two implants currently under a controlled clinical evaluation in multicentric studies, has been described in this chapter. The amount of available clinical data does not allow us to give a detailed evaluation of the benefits and risks of this technology, however, preliminary clinical experience supports an optimistic view for this new technology.

We must realize that the standards and clinical results of anterior interbody fusion in the cervical spine are hard to beat. As compared to the lumbar spine, cervical discectomy and interbody fusion is a highly successful procedure [2, 8]. Especially in monosegmental procedures, functional and clinical results with average success rates of 85 – 90 % will be hard to achieve by total disc replacement. There are also a number of open questions which have to be answered for the technology to stand the proof of time:

1. Is the implantation procedure as less invasive and as safe as an interbody fusion with a cage?
2. Can the achieved or preserved segmental mobility be maintained in the long term?
3. Will it be possible to restore and retain the physiologic curvature of the cervical spine?
4. What will be the rate of spontaneous fusions?
5. How does the implant behave in the long-term?

The reader must realize that this chapter, as well as a number of others, describes a technique "in evolution".

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Microsurgical Posterior Approaches to the Cervical Spine

13

P.H. Young, J.P. Young, J.C. Young

13.1 Terminology

Decompressive approaches posteriorly to the cervical spine include:

1. Posterior laminectomy (unilateral or bilateral)
2. Multilevel, bilateral laminectomy and partial facetectomy
3. Laminoplasty
4. Posterior microlaminotomy-foraminotomy (keyhole)

13.2 Surgical Principle

Classic neurosurgical and orthopedic exposures of the spinal canal designed for a wide variety of pathological processes, involved a wide decompressive laminectomy, sometimes including an associated decompression tactic (such as a facetectomy). Modifications of the laminectomy approaches for multilevel diseases have included the various laminoplasty techniques. Modern refinements of these techniques, especially the application of the operating microscope, have been introduced in an attempt to reduce the postoperative morbidity and long-term complications associated with these approaches.

The less invasive keyhole laminotomy-foraminotomy has been applied extensively for the posterior decompression of individual nerve roots affected by lateral soft disc protrusions or spondylotic spurs projecting into the foramen. The addition of the operating microscope to this procedure limits the perioperative morbidity associated with the soft tissue and bony opening and enhances the safety with which this procedure can be performed around sensitive neurostructures. The posterior microlaminotomy-foraminotomy (keyhole) fits the definition of a minimally invasive technique.

13.3 History

Approaches for posterior decompression (Table 1):

Author (year)	Procedure
Traditional	
1. Northfield (1955) [23]	Simple bilateral laminectomy extending one segment above and below pathology
2. Rogers (1961) [30]	Extensive bilateral laminectomy (C1–T1)
3. Scoville (1961) [33]	Limited bilateral laminectomy (to symptomatic levels) with bilateral complete facetectomy
4. Stoops and King (1962) [36]	Extensive bilateral laminectomy and complete facetectomy
5. Bishara (1971) [3]	Addition of medial facetectomies
6. Fox et al. (1972) [13]	Addition of dural plasty
7. Schneider (1982) [32]	Addition of dentate ligament sectioning
8. Epstein and Janin (1983) [7]	Addition of spur removal
Less invasive	
9. Williams (1983) [39]	Microcervical foraminotomy
10. Henderson et al. (1983) [16]	Posterolateral foraminotomy
11. Aldrich (1990) [1]	Posterolateral microdiscectomy
12. Hudgins (1990) [17]	Posterior microlaminotomy

13.4 Advantages

The advantages of the posterior microsurgical approaches are that they:

1. Provide the most direct approach to pathological processes occurring within or posterior to the spinal cord and nerve roots and/or in the posterior aspects of the spinal canal and/or foramen
2. Provide easy access to foraminal pathology (soft disc herniations and spondylotic spurs) without the need for an extensive discectomy
3. Do not always necessitate or result in a fusion with motion segment loss as with anterior approaches
4. Permit immediate access to the facets for unlokking in traumatic dislocations

13.5 Disadvantages

The disadvantages of the posterior microsurgical approaches are that they:

1. Permit no (or only very dangerous) exposure to pathological processes located anterior to the spinal cord and/or nerve roots
2. Are incapable of adequately decompressing even single level severe anteriorly directed spondylotic bars, retropulsed bone or disc fragments, etc.
3. Require a longer postoperative recovery than the anterior approach (with greater muscle discomfort, delayed mobilization, etc.)
4. If directed at decompressing anteriorly located pathology, have an increased risk of catastrophic, neurological complications, including quadriplegia, when compared to the anterior approach
5. Involve more difficult (and dangerous) operative positioning than the anterior approach (particularly in patients with instability)
6. If performed at multiple levels, can result in instability or increased spinal mobility leading to subsequent disc deterioration and/or facet spondylosis
7. If performed at multiple levels, may result in the long-term development of severe neck deformity (such as Swan neck deformity) due to disruption or compromise of ligamentum nuchae, paraspinous muscles, and/or apophyseal joints

13.6 Indications

Indications for a posterior microlaminotomy-foraminotomy include:

1. A significant lateral soft disc herniation and associated root compression with appropriate severe radicular symptoms and signs
2. Osteophytic root compression with appropriate radicular symptoms and signs as above
3. Foraminal disc or spur compression of a root with corresponding radicular symptoms not relieved by appropriate conservative measures

13.7 Patient's Informed Consent

Careful preoperative evaluation of patients with pulmonary disorders, cardiac abnormalities, and other processes that lead to an elevated thoracic venous pressure should be thoroughly evaluated to prevent intraoperative bleeding due to engorged epidural veins. All non-steroidal anti-inflammatory medication and aspirin-containing compounds are stopped 7 – 10 days prior to surgery. An arterial line, urethral catheter, and central venous line (or triple-lumen catheter) should be considered for intraoperative cardiorespiratory monitoring. Thigh-high ice wraps or anti-embolism stockings are also routinely applied.

Routine preoperative preparation should include an accurate assessment of the patient's neck range of motion, especially noting the degrees of painless flexion and extension. This information is vital in determining allowable movements during intubation.

A general anesthetic is administered utilizing a flexible endotracheal tube. During intubation in patient's with significant cord or radicular compression, a neutral position of the head and neck is maintained to avoid compressing an already compromised spinal canal or foramen. If significant instability exists or a difficult intubation is anticipated, fiber-optic-assisted intubation is performed. The use of long-acting muscle paralyzing agents is strictly avoided. A single dose of a broad-spectrum antibiotic is administered upon the induction of anesthesia. Intravenous steroids are administered if significant spinal cord or root manipulation is anticipated. Intraoperative somatosensory evoked responses may be a useful adjunct in high-risk posterior cervical procedures.

13.8 Surgical Technique

13.8.1 Anatomical Landmarks

The posterior elements of C1–T2 can be easily palpated in the midline of the posterior spine with the neck bent slightly in flexion. The characteristics of the individual spinous processes are as follows:

- C2 is longer and bulkier than C3 or C4
- C2, C3, and C4 are always bifid
- C5 is almost always bifid
- C6 is frequently bifid but usually shorter and more slender than C7
- C7 is never bifid and more prominent than T1
- T1 is slightly less prominent than C7 but more prominent than T2

The general position of the facet joints can be palpated approximately two finger-breadths off the midline. The external occipital protuberance is located just above the attachment of the ligamentum nuchae as a contoured protuberant bony ridge that extends several centimeters on each side of the midline.

13.8.2 Positioning

Positioning is represented in Fig. 13.1. Due to the significant risk of air embolism, ischemia complications, and increased instability, the sitting position has been abandoned for routine use in posterior cervical procedures. If the sitting position is deemed absolutely necessary in morbidly obese patients or patients with reduced ventilatory capacity, then Doppler ultrasound is essential for continuous venous air embolism monitoring.

The prone position for posterior spine surgery demands firm yet adjustable cervical spine fixation, a degree of cervical flexion for optional visualization of the interlaminar spaces, the prevention of pressure on eyes or other sensitive facial structures, and the maintenance of adequate ventilation with minimal abdominal compression.

In the absence of significant instability, the patient is turned from the supine to the prone position (following the initiation of general anesthesia) taking care to maintain the neck in a neutral position. Particularly in spondylotic myelopathic patients, the surgeon should stabilize the head to be certain that the head, neck, and shoulders are moved synchronously to avoid stretching a stressed spinal cord against a ventral ridge.

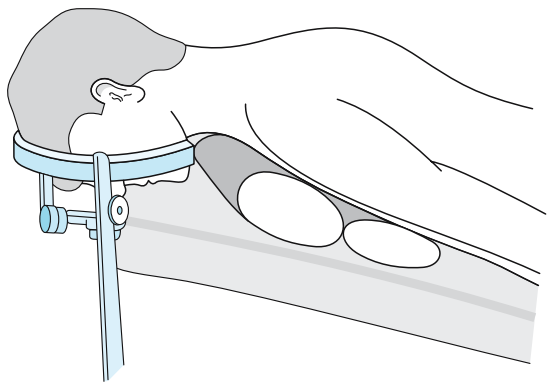


Fig. 13.1. Positioning in the prone position for posterior microlaminotomy-foraminotomy procedures

Rolled blankets or padded cushions are applied along the lateral margins of the chest and abdomen to avoid thoracic or abdominal compression (with subsequent elevation of vena caval pressure and secondary engorgement of the epidural venous plexus). A padded horseshoe headrest is utilized with the forehead placed on the toe and the malar eminences on the heels. Special caution is taken to prevent pressure on the orbits and any possibility that intraoperative motion might displace the original position resulting in orbital compromise. Ideally, the neck should be slightly flexed (20°) and angled in a reverse Trendelenburg position. Extreme flexion (to enlarge the interlaminar space) should be absolutely avoided as it tenses the spinal cord across the disc spaces and may produce spinal cord ischemia. The chin is positioned slightly backward in the direction of the occiput. Free access to the endotracheal tube and other monitoring devices must be maintained.

Cervical traction, preoperatively in place for patients with instability, should be maintained throughout the positioning process. Following placement in the horseshoe headrest, a slightly reduced amount of traction can be reinstituted for stabilization during the operative procedure. Patients manifesting marked degrees of cervical instability or patients requiring rigid postoperative external stabilization are placed in a halo ring and vest prior to positioning. The stability associated with a halo vest provides a comfortable margin of safety and ease in positioning these patients from supine to prone. Following placement in the prone position, the posterior bars of the halo can be loosened or removed to increase access to the posterior spine region. Additional traction can alo be applied to the halo ring if necessary to add displacement or change alignment during the operative procedure. Following placement in the prone position, a lateral cervical spine radiograph is obtained to evaluate proper alignment. Adjustments in positioning by changing the position of the horseshoe ring or adding tension to the traction device may be necessary.

Skin folds on the lower cervical and upper thoracic region are stretched free by applying bands of adhesive tape extending from the paracervical region to the shoulders and upper thorax. If intraoperative fluoroscopy or radiography is planned, the patient's arm should be positioned at the sides, with care taken to prevent peripheral nerve compression or thoracic outlet retraction.

13.8.3 Incision

Using spinous processes as anatomical landmarks, a midline skin incision is made extending across the motion segment(s) of interest. For a single disc or nerve root exposure, a 3-cm incision centered on the disc space of interest may be adequate to expose the appropriate interlaminar space. Larger incisions extending over several or multiple segments may be necessary for multilevel exposures. Cautery hemostasis rather than hemostat retraction should be used along the skin margins to preserve the midline. The spinous process to C7 is used as the primary landmark, permitting the enumeration of the segments above and below in order to precisely identify the level(s) of interest and limit the size of the incision. If doubt exists as to the level, a needle should be inserted into the supraspinous ligament and radiographic confirmation obtained.

13.8.4 Superficial Exposure

The superficial fascia is incised in the midline to the level of the ligamentum nuchae, which marks the attachments of the trapezius, rhomboid, and levatus scapulae muscles along the spinal access. For a unilateral single-level interlaminar exposure, the ligamentum nuchae is incised just off the midline ipsilaterally to the site of interest in a curvilinear fashion, beginning at the cranial margin of the cephalad and ending at the lower margin of the caudal spinous process. This produces a flap of ligamentum nuchae hinged on the spinous processes encompassing the interlaminar space(s) of interest. This is done in an attempt to spare injury to the bulk of the supraspinous and interspinous ligamentous complex. For bilateral single-level interlaminar exposures, the same technique is repeated on the contralateral side. For multilevel interlaminar exposures, the ligamentum nuchae incision is extended in a similar paramedian fashion to include the segments of interest (again sparing the midline supraspinous and interspinous ligamentous complex).

Dissection along the margin (or through the center) of this deep fascia is bloodless, as this avascular plane avoids penetration into the erector spinae muscle mass. Excessive penetration into or disruption of the erector spinae muscles should be avoided as this can lead to segmental denervation. In the setting of a multilevel decompression, this can be a factor in the development of permanent kyphosis and other more severe deformities.

13.8.5 Exposure of the Interlaminar Space

The paraspinous muscles attached to the spinous processes, lamina, and apophyseal joints of interest are sharply and carefully dissected in a subperiosteal plane using a soft gauze sponge and a Cobb or curved periosteal elevator (Fig. 13.2). Due to the fragility of the posterior elements in the cervical spine, this maneuver should be done under direct vision without significant downward force applied to the underlying laminae. This is obviously of even greater importance in those situations were significant posterior element instability exists. If a wider than normal interlaminar space exists, extreme caution should be exercised in its exposure to avoid penetration though an often thin ligamentum flavum with catastrophic results. Little or no bleeding is encountered if the dissection is in the subperiosteal plane along the spinous processes and laminae.

This dissection should continue laterally until the lateral portion of the facet joint capsules are identified. Significant oozing may be encountered at the junction between the interlaminar space and apophyseal joints or in the soft tissue surrounding the apophyseal joints capsules where segmental arteries and their venous plexuses supplying adjacent facet joints, transverse processes, and posterior elements are located. Care should be taken during exposure and hemostasis not to disrupt the articular capsules of the apophyseal joints.

For multilevel exposures, the subperiosteal dissection should proceed in a caudal-rostral direction as the muscle attachments to the spinous processes insert obliquely from below. Particularly with multilevel dissections, the integrity of the erector spinae muscles should be protected to avoid denervation and significant postoperative morbidity.

A self-retaining retractor is applied using a narrow serrated blade to reflect the paraspinous muscle mass

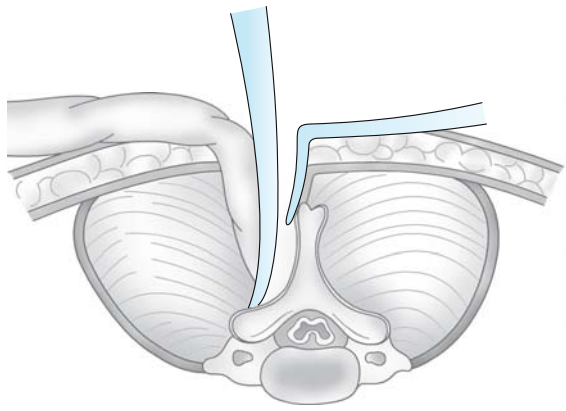


Fig. 13.2. A subperiosteal dissection of the muscular and ligamentous tissues is accomplished along the laminae of interest. This is carried lateral to the facet joint

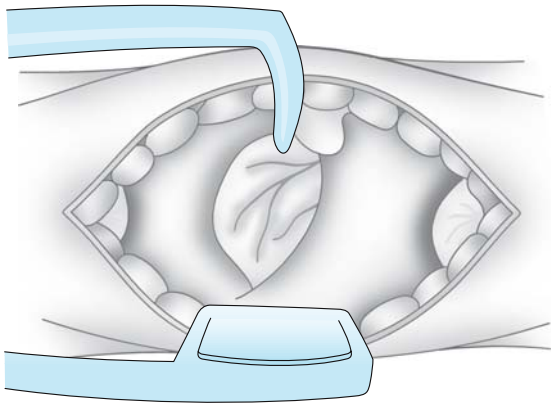


Fig. 13.3. A self-retaining retractor is inserted to reveal the interlaminar space(s) of interest

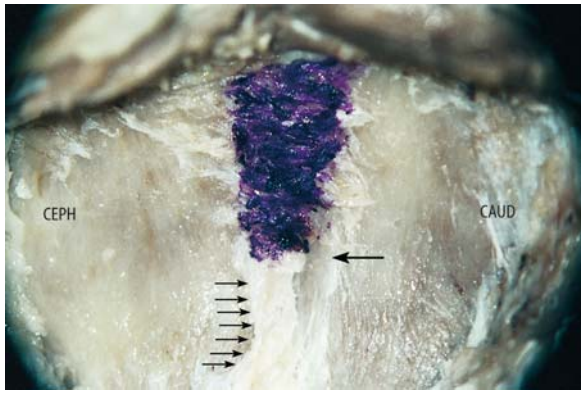


Fig. 13.4. Exposure of the interlaminar facet junction (*large arrow*). The ligamentum flavum has been colored. The facet joint extends laterally (*small arrows*). *CEPH* cephalad, *CAUD* caudad

from the interlaminar space(s) of interest (Fig. 13.3). Generally, serrated blades can be fixed beneath the muscles in a more stable position than smooth ones. For unilateral exposures, a pronged retractor (such as Williams, Caspar, or McCulloch) is inserted with the prong against the supraspinous and interspinous ligamentous complex. Care should be taken not to lacerate or penetrate this midline ligamentous complex, particularly at its deeper portions, to avoid entering the spinal canal. Total disruption of this important ligamentous complex significantly interferes with dynamic neck stability.

13.8.6 Laminotomy-foraminotomy

The interlaminar space is carefully identified and cleared of overlying soft tissue particularly at its lateral apex. The medial facet/interlaminar space apex junction is identified (Fig. 13.4). Using the high-speed drill (Midas M8), a partial laminotomy-facetectomy is performed beginning at the junction between the most lateral aspects of the interlaminar space (the apex) and the most medial aspect of the facet joint. The medial one-third to one-half of the facet is progressively removed, as is a similar amount of the adjoining cranial and caudal laminae. A 2- to 3-cm round or oval opening is thus created (Fig. 13.5).

The posterolateral portion of the superior lamina and the medial part of the inferior articular facet are moved first. This enlarges the apex of the interlaminar space, and permits the progressive removal of the medial side of the superior facet and the lateral corner of the inferior lamina flush with the inner aspect of the pedicle. The nerve root is located directly above the pedicle and immediately under the superior facet. A distinct layer of loose fibrous tissue containing epidural veins lies immediately beneath the thin lateral part of the ligamentum flavum, and progressive incision of the ligament carefully in a medial direction will safely expose the lateral portion of the dura. The position of the

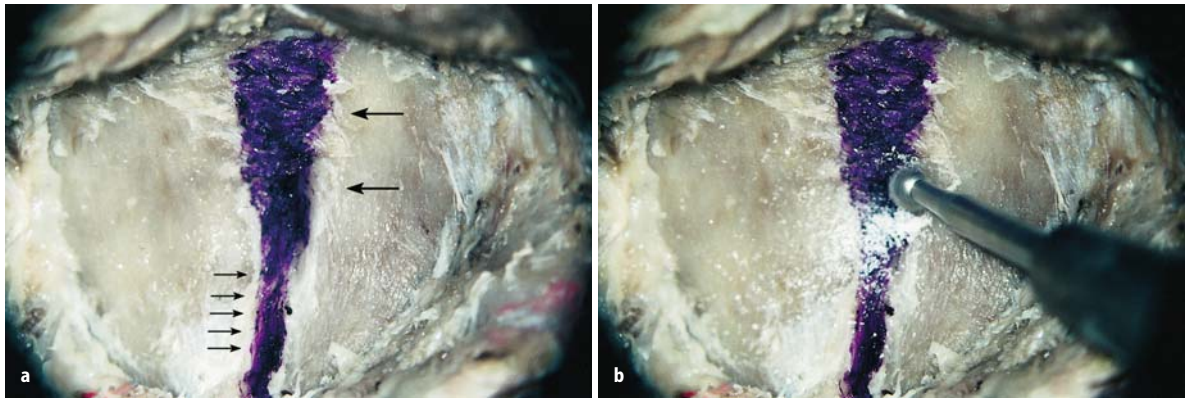


Fig. 13.5. The location and size of the keyhole microlaminotomy-foraminotomy. **a** Ligamentum flavum (*large arrow*) and facet joint capsule (*small arrow*) are colored. **b** The laminotomy-foraminotomy is begun at the junction between the interlaminar interval and the facet joint

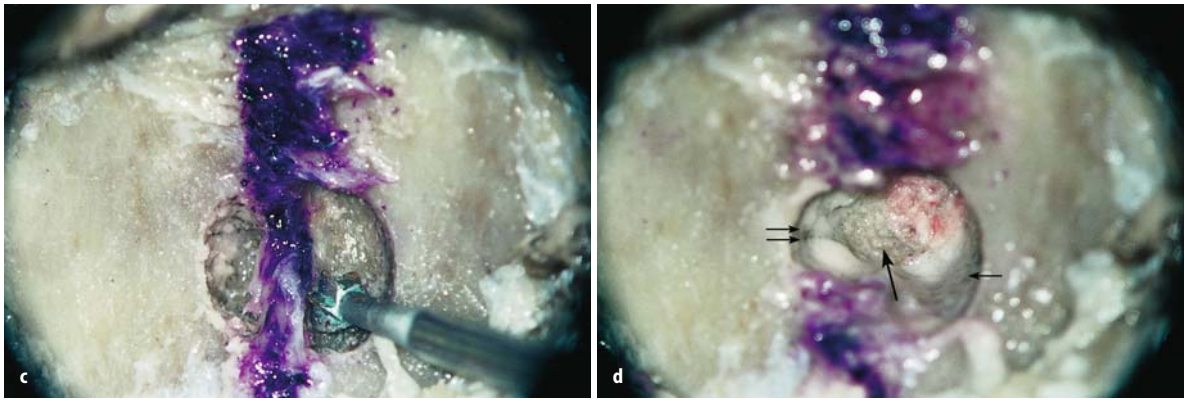


Fig. 13.5. (contin.) c The medial one-third to one-half of the facet is progressively removed with a high-speed burr. **d** Superior (*single arrow*) and inferior (*double arrow*) facet bone is removed until ligamentum flavum and/or perineural tissue (*large arrow*) is identified

spinal canal and the lateral dura margin is used as an anatomical landmark, establishing a clear plane of dissection along the proximal nerve root and lateral epidural venous structures. Progressive lateral dissection can then proceed along the root as it enters the foramen (Fig. 13.6).

The medial border of the pedicle should be identified early and followed anteriorly to the floor of the spinal canal to establish an epidural plane between the lateral dura and the posterolateral vertebral body below. Staying in this same space, rostral dissection can proceed to identify the plane between the disc space and the anterior surface of the nerve root axilla (Fig. 13.7).

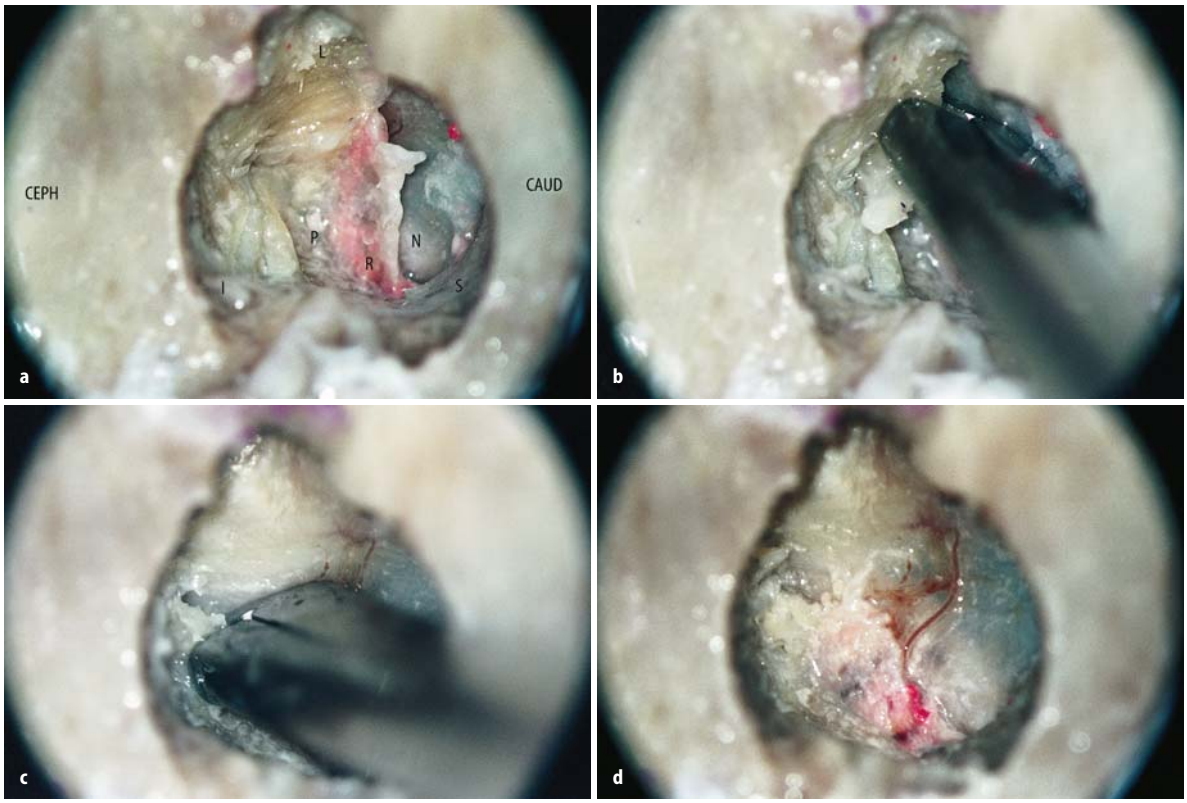


Fig. 13.6. Exposure of thecal sac and nerve root. **a** Initial landmarks after bone removal: superior facet (*S*), inferior facet (*I*), cephalad lamina (*CEPH*), caudal lamina (*CAUD*), ligamentum flavum at apex of interlaminar interval (*L*), perineural tissue above nerve root (*P*), proximal nerve root (*N*), radicular vessel (*R*). **b** Removal of lateral ligamentum flavum with rongeur. **c** Foraminotomy into inferior facet with rongeur. **d** Exposure of foramen and nerve root

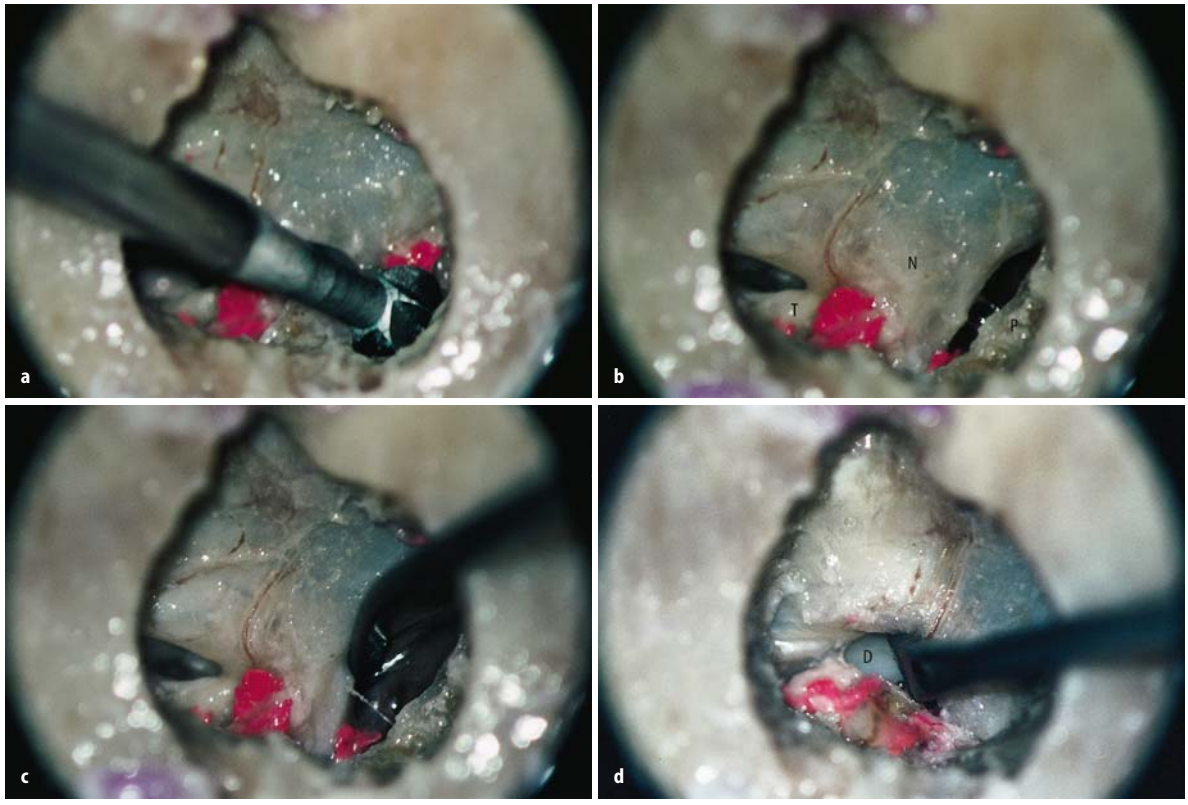


Fig. 13.7. Proximal foraminotomy. **a** Removal of superior facet down to pedicle using high-speed burr. **b** Foraminal anatomy: nerve root (*N*), pedicle (*P*), perineural tissue (*T*). **c** Probe along pedicle with retraction of root. **d** Probe superior to root to identify disc space (*D*)

Following this initial exposure, the posterior foraminal wall is then removed, utilizing a plan of dissection between the perineural tissue and the bone of the anterior aspect of the superior facet to avoid mechanical pressure on the root. Further removal of the inferior facet permits direct visualization of both superior and inferior pedicles, and allows palpation along the first 5 mm of root laterally into the foramen (Fig. 13.8).

One of the most important technical points is the establishment of the plane of dissection in the foramen between the nerve root sleeve and the extradural tissue composed of fat, fibrous tissue, and epidural veins. In spondylotic root compression, dense root sleeve perineural adhesions are a common finding with tethering of the root to the foramen. This must be retracted away from the nerve root against the bony canal and with

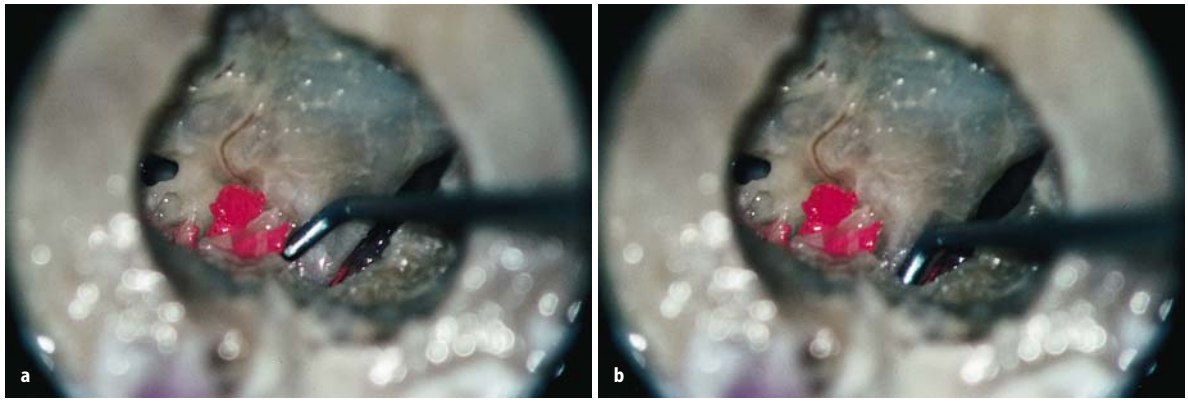


Fig. 13.8. Distal foraminotomy. **a**, **b** Nerve hook passed into foramen to assess size.

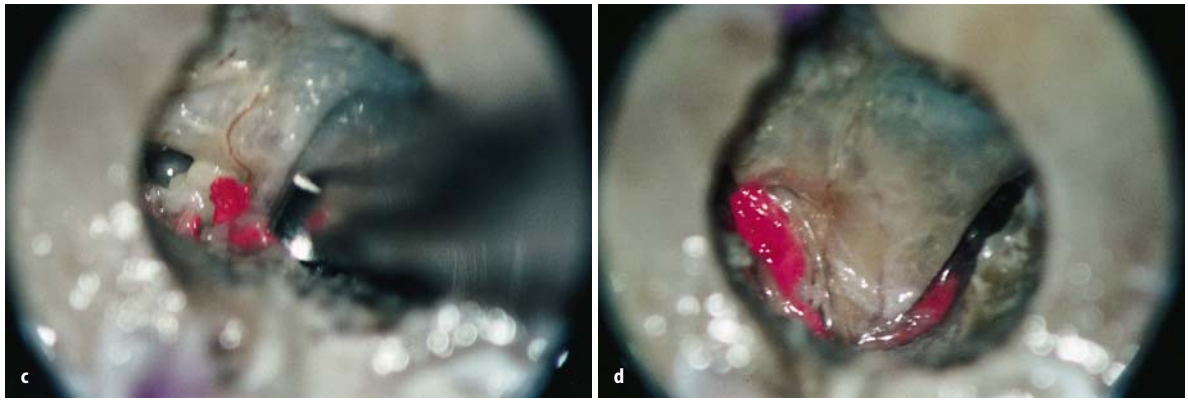


Fig. 13.8. (contin.) c Resculpturing of foramen by undercutting inside wall with rongeur. **d** Distal foramen exposed

careful use of bipolar coagulation. This provides better exposure of the nerve root and helps in the identification of the extruded disc or spur beneath it. Using cranial or caudal retraction of the nerve root, access to the posterior surface of the vertebral disc is achieved (Fig. 13.9).

In soft disc sequestrations, the disc fragment has most often extruded through the annulus and posterior longitudinal ligament lateral to the dural sac. When the compressed root has been exposed, it is gently retracted upward or downward and the extruded disc fragments removed with a small disc rongeur, suction, or a small nerve hook. Soft sequestered fragments are generally multiple, and present anteriorly and inferiorly or superiorly to the nerve root or in the axilla. Fragments cephalad to the root are more common than those caudad. Retraction of the nerve root while exploring for sequestered fragments or exposing spurs should only be done with care and restraint. It is not advisable to enter the disc space from this approach.

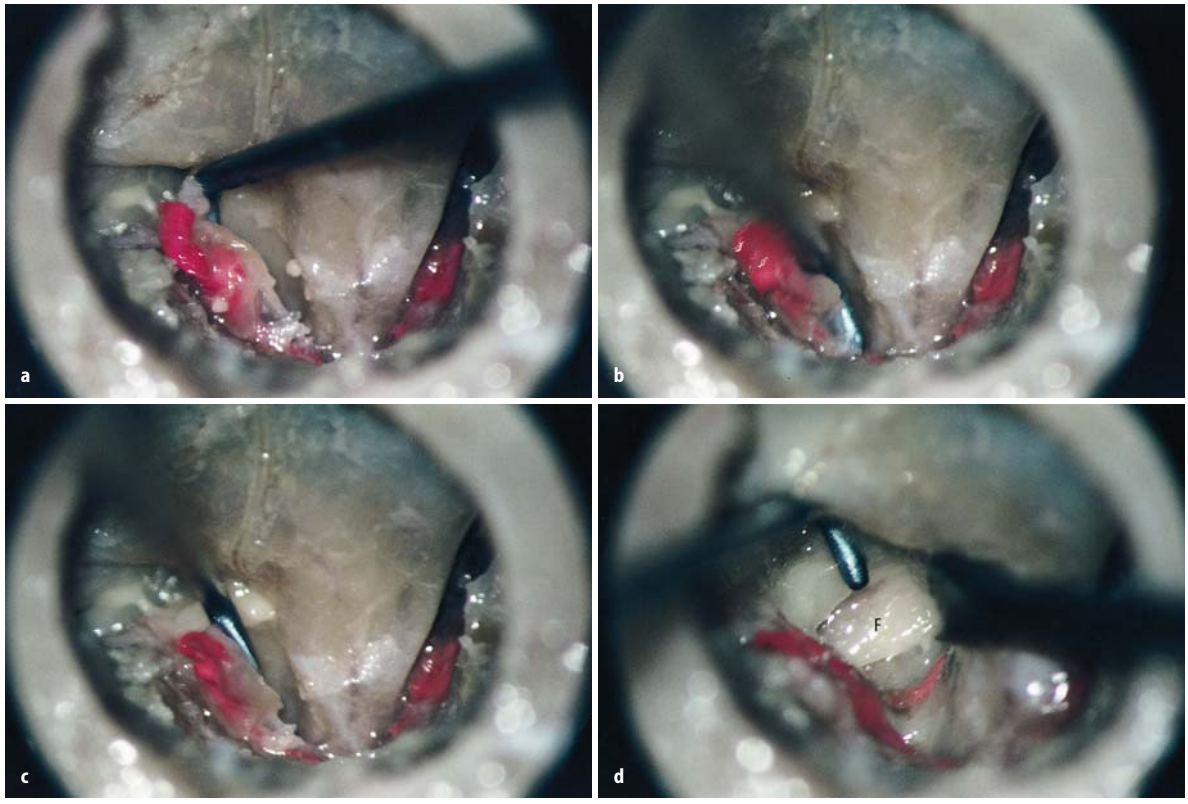


Fig. 13.9a–d. Search for soft disc fragments. Dissection of perineural tissue and probing of space between nerve root and disc space to retrieve soft disc herniated fragments (*F*)

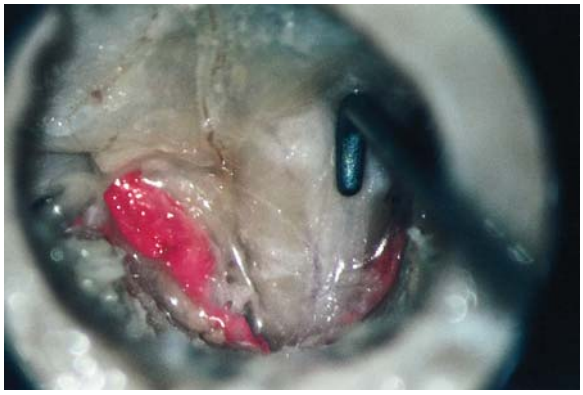


Fig. 13.10. In the absence of muscle paralyzing agents, root compression or traction will trigger an "evoked response" muscle contraction warning the surgeon of impending root injury

If an anonymous bifid root is present with separate ventral and dorsal dura root sleeves (35 %), sequestered fragments may be wedged between the roots generally obscuring the motor root, which lies inferior to a larger sensory root. In addition, the dura covering of the smaller motor root is quite thin. Failure to recognize the situation can result in motor root injury when disc fragments are grasped. If muscle paralyzing agents are avoided, compression, traction, or coagulation of motor roots results in immediate muscle contraction and this response can be used as an intraoperative "evoked response" of impending root injury, telling the surgeon to back off (Fig. 13.10). When adequately decompressed, the root sleeves fill with CSF and expand with CSF pulsations.

When using a small foraminotomy opening, it may on occasion be necessary to further explore the foramen for spurs or sequestered disc fragments. In this situation, the opening should be enlarged inferiorly by removing more of the superior lamina of the vertebrae below. However, under no circumstances should more than 50 % of the facet be removed [28, 29]. Spurs projecting into the anterior aspect of the foramen from the uncovertebral process of the vertebral bodies are often associated with dense perineural fibrous adhesions that bind the root to the lateral bony canal. Careful separation of these adhesions with a small blunt hook is necessary prior to any attempt at spur removal. The removal of spurs in this region should be done under direct visualization. If spurs, particularly anterior spurs, are not really visualized, one should be content with a posterior decompression alone. It is particularly inadvisable to attempt the removal of hard spurs or ridges located anteriorly to the thecal sac along the disc space.

13.8.7 Hemostasis

Epidural bleeding is frequently encountered from the perineural plexus around the nerve root in the foramen or from the epidural plexus in the lateral spinal canal. This may require the use of bipolar coagulation and the placement of Gelfoam. Care must be taken during coagulation around the dural sleeve of the nerve root or directly on the dura overlying the cord as there may be postoperative numbness, paraesthesia, pain, or paresis related to underlying root or cord thermal or electrical injury. The packing of these venous plexuses with Gelfoam achieves immediate hemostasis but obscures further exploration.

13.8.8 Closure

Following absolute hemostasis a small piece of wet Gelfoam or fat is placed loosely in the laminotomy defect to take up the dead space.

The self-retaining retractor is carefully removed avoiding unnecessary abrasions of the surrounding muscle ligamentous tissue by the serrated blades or pronged hook. The paraspinous muscles are carefully inspected under the operating microscope for hemostasis. In the absence of dural penetration, the paraspinous muscles are injected with 5 – 10 cc 0.5 % Marcaine which relieves postoperative pain and muscle spasm in addition to restoring the muscle to its normal paraspinous anatomical location. If penetration of the dura has occurred during the operative procedure, this maneuver should be omitted as the intradural leak of Marcaine may lead to temporary but frightful spinal cord or root paralysis.

The deepest portion of the ligamentum nuchae is reapproximated using 00 PDS (or similar absorbable suture). Further layers of the nuchae are reapproximated using a 00 Dexon (or similar absorbable suture). The subcutaneous tissue is closed in a single layer with three or four absorbable sutures. The skin is approximated with staples.

13.9 Postoperative Care

Depending on the nature of the procedure, the patient is placed in a soft cervical collar or another more rigid device immediately after surgery and permitted to ambulate as soon as postanesthesia recovery permits. An anti-inflammatory medication, mild muscle relaxant, and analgesic are prescribed in the immediate postoperative period. Depending on the type of procedure and the number of spaces involved, the soft collar is

progressively removed at 2 – 4 weeks after surgery and the patient is instructed to begin general neck motion. Normal mobility is restored by 1 – 3 months postoperative with a mild progressive neck exercise program.

13.10 Hazards and Complications

13.10.1 Intraoperative Catastrophes

The following complications may occur from a minimally invasive posterior approach:

1. Spinal cord injury with resultant quadriplegia, tetraplegia, or paraplegia due to unwarranted attempts at the removal of disc fragments or spurs located along the anterior aspect of the spinal canal and nerve roots
2. Spinal cord injury due to spinal cord compression or contusion resulting from inadvertent penetration of an instrument into the spinal canal
3. Spinal cord injury from a vigorous placement of instruments into the spinal canal in the performance of bony removal during the laminotomy/laminectomy
4. Reflex symptomatic dystrophy following partial nerve root or cord injury
5. Inadequate removal of the sequestered disc or spondylotic bars with persistent spinal cord or radicular compression
6. Increase in myelopathic findings due to inadequate stabilization in turning a patient from the supine to the prone position for positioning at surgery
7. Spinal cord injury due to loosening of a head immobilization device intraoperatively
8. Intraoperative ischemia due to blockage or expulsion of an endotracheal tube
9. Instability as a result of a wider than necessary decompression with total facet removal (particularly in the younger patient)
10. Leakage of CSF due to an advertent dural laceration or faulty dural repair
11. Formation of a postoperative meningocele due to inadvertent dural laceration or inadequate dural repair
12. Laceration of the vertebral artery as it ascends through the foramen transversarium or over the lateral portions of C1
13. Postoperative compressive hematoma in the subdural or epidural space following closure with poor hemostasis
14. Deep paraspinous or epidural wound infection
15. Air embolism or cerebral ischemia from procedures performed in the sitting position
16. Corneal damage due to compression of the orbits in positioning
17. Compression of the peripheral nerves while on the operating table in a prone position

13.10.2 Common Postoperative Complications

1. Superficial wound infection
2. Paraspinous muscle spasm; chronic with diminished neck mobility and pain

13.11 Results

A review of reported results for both posterior and anterior approaches in treating root compression due to a bony spur are comparable [18, 24, 37]. For spondylotic radiculopathy, long-term success using the anterior approach can be expected in an average of 76% of patients [14, 25, 38], where the posterior approach is successful in 68% [2, 5, 10, 20]. There is no statistical difference between these results suggesting that the issue of the need for osteophyte removal versus performing a simple nerve root decompression will remain a controversial point of discussion depending on the surgeon's personal perspective [4, 8, 9, 21, 26]. In addition, overall there is a 90 – 92% chance that the patient will receive at least a satisfactory outcome and only a 2 – 5% chance that the outcome will be less than satisfactory with either procedure [19, 27].

For soft disc herniations, anterior and posterior approaches have similarly good short-term results in 74 – 100% of cases (average 82%) [31, 34]. Long-term good results vary from 63 – 71% (average 68%) with a recurrence rate of 10 – 18% (average 14%) for the anterior approach [15, 22, 35] and from 0 – 11% (average 6%) for the posterior approach [11, 12]. Generally better results are obtained in patients undergoing surgery at one level only [6].

13.12 Critical Evaluation

It can be simply stated that reported results suggest that satisfactory improvement can be expected utilizing the posterior microsurgical keyhole approach for radiculopathy secondary to spur formation or soft disc herniation.

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14 Microsurgical C1-2 Stabilization

D. Fassett, R.I. Apfelbaum

14.1 Terminology

Spinal Instability was best defined by White and Panjabi [19] as the inability of the spine to maintain structural integrity and prevent neurological injury under physiological loads.

An *Atlantoaxial Transarticular Screw* is a screw placed through the pars interarticularis of C2, across the lateral mass articulation between C1 and C2, and into the lateral mass of C1.

The *Pars Interarticularis* is that portion of the vertebra that connects the superior and inferior facet articulations. C2 is a transitional vertebra, unlike those below it. In the case of C2, the pars interarticularis connects the inferior joint, which is the facet joint between C2 and C3, and the superior joint, which is the lateral mass articulation between C2 and C1.

Throughout the text, *atlas* and *C1* are used as synonymous terms; similarly, *axis* and *C2*; *dens* and *odontoid process of C2*; and *pars interarticularis* and *isthmus* or *pars intermedia* are used synonymously.

14.2 Surgical Principle

In the human spine, the atlantoaxial articulation is the most mobile joint and, subsequently, potentially the least stable. The articulation between the lateral masses of C1 and C2, with a flat joint surface and loose capsular ligaments, allows for significant axial rotation between these vertebrae but does not provide much stability. In addition, no strong posterior ligaments provide stability because the ligamentum flavum ends at C2 and is replaced superiorly by the thin and lax atlantoaxial and atlanto-occipital membranes.

The main stabilizing force between C1 and C2 is the atlanto-dental complex. The odontoid process of C2 articulates with the anterior ring of C1 in a manner that allows for axial rotation, but anterior-posterior movement between these vertebrae is prevented by the transverse ligament (transverse portion of the cruciate ligament), which holds the odontoid in the anterior ring of the atlas and prevents the odontoid from translating posteriorly into the spinal canal. Incompetence of either the transverse ligament or the odontoid can result in atlantoaxial instability with canal compromise possible.

Because of the devastating potential of spinal cord injury at this level, surgical stabilization is often advocated for atlantoaxial instability. The principle of the surgical procedure described in this chapter is that immediate stabilization of this joint can be achieved by placing a screw through the C1-2 articulation. This protects against future spinal cord injury and provides the restriction of motion that is essential for bone grafting to succeed, resulting in long-term stability. In addition, with certain modifications of the technique originally described by Magerl [14], atlantoaxial transarticular screws can be placed with a minimally invasive approach using a smaller exposure.

14.3 History

One of the first reported surgical treatments of atlantoaxial instability was performed in 1910 by Mixter and Osgood who wound a silk thread around the posterior elements of C1 and C2 as a means to stabilize the articulation [16]. A number of posterior wiring and bone-grafting techniques including those popularized by Gallie [6, 15], Brooks [3], and Sonntag [4] followed. Although posterior wiring and bone-grafting techniques produced adequate fusion rates, they often required prolonged halo immobilization and activity restrictions.

In 1976, Magerl [14] developed the technique of atlantoaxial transarticular screw fixation, which has revolutionized the treatment of C1-2 instability. This technique provided immediate stability using a screw placed through the atlantoaxial articulation and reduced the need for supplemental orthosis. Although it was an improvement on the posterior wiring and bone-grafting techniques, Magerl's original technique required an extensive open exposure from the occiput down to the upper thoracic spine to provide the proper trajectory for screw placement. The technique was sub-

sequently modified into a less invasive technique with smaller incisions by using guide tubes that could be tunneled through subcutaneous tissues to the surgical site [1].

14.4 Advantages

The main advantage of atlantoaxial transarticular screw fixation over posterior wiring procedures alone is the immediate stability provided by transarticular screws. Without this, posterior wiring procedures require a rigid external orthosis to achieve satisfactory fusion rates. With this improved stability, supplemental orthosis is not necessary in most cases and patients can return to a normal lifestyle more quickly. Multiple studies have documented the biomechanical superiority of transarticular screws in comparison with wiring techniques [10, 12, 17], and clinical series have demonstrated better fusion rates with this construct [11, 18].

14.5 Disadvantages

In our opinion, placement of atlantoaxial transarticular screws is one of the most challenging spinal surgeries to learn and master. There is a significant learning curve before most surgeons are comfortable with and capable of safely performing this procedure. For this reason, we suggest that an inexperienced surgeon works with a surgeon skilled in the technique to master the procedure before attempting it alone.

Among the more difficult things to learn about this procedure is the unique and complex spinal anatomy in this area. Performing this procedure safely requires an understanding of the anatomy of the C2 pars interarticularis (Fig. 14.1). Because the vertebral artery runs beneath the pars of C2, an inappropriate screw trajectory can have devastating consequences. Small modifications in screw trajectory must be made based on the unique anatomy of each patient to avoid complications, but understanding these subtleties requires some experience.

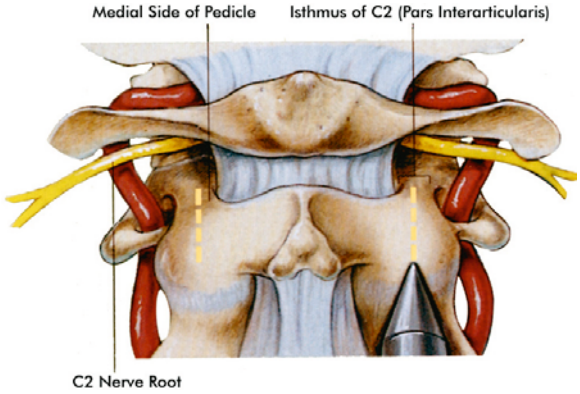


Fig. 14.1. The C2 pars interarticularis is the key landmark for safe passage of transarticular screws

14.6 Indications

A wide variety of pathologies can lead to atlantoaxial instability by violation of the atlanto-dental complex. Inflammatory disorders, such as rheumatoid arthritis, affect the synovium between the odontoid and the C1 anterior ring with possible pannus formation and transverse ligament laxity or disruption. Traumatic instability is also common because of either non-union of odontoid fractures or disruption of the transverse ligament. Congenital anomalies, such as Down's syndrome, Morquio's syndrome, and other disorders, may have instability from congenital ligament laxity or incomplete formation of the dens. Iatrogenic instability can also result from anterior decompression of the spinal canal with odontoidectomy. Individuals with atlantoaxial instability are at significant risk for spinal canal compromise, which can have devastating consequences including progressive myelopathy or quadriplegia with relatively mild trauma. For these reasons, surgical stabilization is often warranted with atlantoaxial instability.

The preoperative evaluation of all patients should include a thorough neurological assessment with a focus on myelopathic changes. Radiographic evaluation begins with plain films including AP (transoral) and lateral views in neutral, flexion, and extension positions. A number of measures can be used to assess atlantoaxial instability. The atlanto-dental interval (ADI) represents the space between the anterior ring of C1 and the dens. Enlargement of this space can represent inflammatory changes in the area with pannus formation or may indicate transverse ligament laxity with the odontoid separating from the anterior ring of C1. An ADI interval of 4 mm or greater has been associated with atlantoaxial instability in adults [2, 5, 9]. The posterior atlanto-dental interval (PADI) approximates the width of the spinal canal at this level and is measured from the posterior aspect of the dens to the ventral aspect of the C1 posterior ring. Many clinicians place more emphasis on the PADI than the ADI, with a PADI less than 14 mm indicating possible instability and canal compromise [2, 5, 9]. Dynamic studies are especially valuable in assessing atlantoaxial instability, because there is essentially no movement between C1 and C2 in the sagittal plane on flexion and extension under normal conditions. Although there are exceptions, the dis-

location increases with flexion and reduces with extension in the majority of atlantoaxial instability cases.

MRI can be performed to evaluate the spinal cord for extrinsic compression or cord changes suggestive of cord trauma and should always be done if neurological abnormalities are found. CT scanning, with 1-mm or smaller cuts from the occiput through C2, is highly recommended if transarticular screw fixation is being considered. In addition to the axial images, sagittal and coronal reconstructions are helpful in determining whether a safe pathway exists through the C2 pars interarticularis for transarticular screw placement. The CT reconstructions are helpful for preoperative planning because they allow the surgeon to visualize the unique three-dimensional anatomy and make fine adjustments in screw trajectory. The fine-cut CT images can also be loaded into stereotactic guidance packages for preoperative planning and intraoperative navigation.

14.7 Contraindications

Contraindications to transarticular screw placement include a small pars interarticularis of C2 or an incompetent lateral mass of C1. The C2 isthmus must be of a size to accommodate the screws that will be placed. In most cases, we use 4.0-mm outer diameter transarticular screws. An ectatic vertebral artery looping closely beneath the C2 pars is commonly associated with a thinned or small pars interarticularis. Infrequently, erosion of the C1 lateral mass prevents screw placement because of lack of distal screw fixation after the screw crosses the C1-2 lateral mass articulation.

The preoperative evaluation of the fine-cut CT images is the key to determining whether a safe pathway exists for screw placement. We have found that a stereotactic workstation is also very valuable in preoperative evaluation. Reformatting the CT images on the workstation in the multiple planes of the screw trajectory allows for better assessment of the bony anatomy. The stereotactic system can often be used for intraoperative navigation in addition to preoperative planning.

14.8 Patient's Informed Consent

In addition to the standard items included in informed consent, such as infection and anesthesia complications, the patient should be informed of the potential for vertebral artery injury, the possibility of suboptimal screw placement requiring revision surgery, and the potential need for external orthosis postoperatively. We have had vertebral artery injury in 2.8 % of cases, with most of these occurring early in our learning curve. The majority occurred without any sequelae to the patient, but two patients needed endovascular procedures to obliterate an arteriovenous fistula that resulted and one patient died as a result of bilateral vertebral artery injury. Approximately 4 % of our patients needed revision surgery for suboptimal screw placement, again mostly early in our clinical experience. We generally do not put these patients in external orthosis postoperatively. However, in situations where only one transarticular screw can be placed or when poor bone quality is encountered, external orthosis in the form of cervical collar, Minerva brace, or halo vest may be needed.

14.9 Surgical Technique

14.9.1 Anesthesia

In cases of atlantoaxial instability, the spinal canal is at risk for compromise during positioning and intubation. Most patients with atlantoaxial instability can be intubated with standard techniques involving head extension for visualization of the vocal cords because the anterior–posterior subluxation of C1 and C2 is reduced with head extension. However, a small group of patients will increase subluxation with head extension, and spinal canal encroachment could occur with extension maneuvers. Patients at risk for iatrogenic injury with intubation can be identified by preoperative evaluation of the flexion and extension plain radiographs. Any patient that increases subluxation or has canal narrowing with head extension should be intubated in the neutral position with awake fiberoptic intubation preferred. Fluoroscopy at the time of intubation can also aid in avoiding iatrogenic injury.

14.9.2 Positioning

Proper positioning is *critical* for optimal placement of atlantoaxial transarticular screws. The first goal of positioning is to reduce the normal cervical lordosis to provide a better trajectory to the entry site at C2. To accomplish this, the patient is positioned prone in a "military tuck" position with rigid pin fixation to the skull. To achieve this position, the lower cervical spine is extended, the upper cervical spine and head are neutral or slightly flexed, and the head is translated in a dorsal direction (Fig. 14.2). The posterior translation maneuver typically brings the atlas back into better anatomic position with respect to the axis, allowing for optimum screw trajectory across the C2 pars interarticularis into the lateral mass of C1. Lateral fluoroscopy should be available from the start of positioning and is used to gauge the anatomic alignment of C1 on C2.

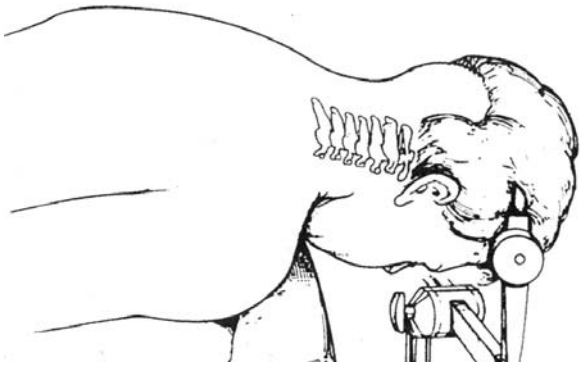


Fig. 14.2. Patient is positioned in a "military tuck" position with the lower cervical spine in slight extension, the upper cervical spine and occiput in neutral or slight flexion, and the head translated dorsally. This maneuver usually places C1 into anatomic reduction with C2 and provides the optimum trajectory for transarticular screw placement

14.9.3 Surgical Exposure

Magerl's original technique involved a midline posterior opening from the occiput down to the upper thoracic spine. This large opening was required to obtain the proper trajectory for screw insertion. Modifications to this original technique have since minimized the exposure needed. Instead of opening the paraspinous tissues down to upper thoracic levels, only a 4- to 5-cm midline opening over C1 and C2 and bilateral stab incisions at the cervicothoracic junctions for subcutaneous tunneling of instruments to the entry site at C2 are necessary (Fig. 14.3). The sagittal location of the stab incisions can be determined by placing a K-wire or other long straight instrument along the side of the neck and visualizing it on lateral fluoroscopy. The K-wire angulation is adjusted to approximate the proper angle for screw trajectory through C2 into C1 and the skin incisions are marked to obtain this trajectory. The stab incisions are approximately 1.5 cm in length and located approximately 2 cm off the midline on each side, in line with the sagittal axis of the pars interarticularis.

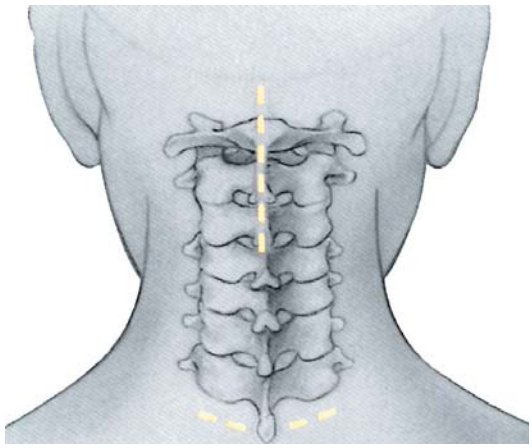


Fig. 14.3. A 4- to 5-cm midline incision is made over C1 and C2, and bilateral stab incisions are placed near the cervicothoracic junction for tunneling of instruments to the screw entry site at C2

The posterior hairline is shaved in a midline strip to the level of the inion and the posterior neck and back is prepared from the inion down to approximately T6. The lower lumbar region is also prepared over the posterior iliac crest for harvesting of iliac crest autograft. The initial exposure is focused on C1 and C2 with the midline incision carried down to the dorsal fascia. The dorsal fascia is subsequently opened in the midline and the paraspinous muscles are separated in the midline avascular plane, which minimizes blood loss. As the paraspinous muscles are opened, a finger can be used to palpate the posterior occiput and spinous processes of C1 and C2. Lateral fluoroscopy can also be used to gain orientation during the exposure, thereby helping to keep the incision to a minimal length.

The posterior bony elements are exposed from the lower occiput at the foramen magnum down to the superior portion of the spinous process of C3. The dissections at C1 and C2 are carried laterally in a subperiosteal fashion using Bovie cautery and periosteal dissectors to expose the lamina. Care is taken not to disrupt the ligamentous tissues between the spinous processes of C2 and C3 because these tissues, in addition to anchoring the posterior tension band to provide spinal column support, also help support the final posterior wiring construct. Soft tissues between the occiput, C1, and C2 are cleared away to fully expose the posterior ring of C1 and the posterior portion of C2.

The posterior arch of C1 is exposed bilaterally to approximately 1.5 cm off the midline. Upwardly angled curettes are used to define the upper and lower margins of the C1 ring with care taken to avoid the vertebral artery laterally on the superior surface of C1. Vigorous bleeding can occur at the lateral margins of the C1 and C2 dissections where venous channels are encountered. This bleeding can typically be controlled with either bipolar cautery or tamponade with thrombin-soaked Gelfoam pledgets. In our experience, Gelfoam powder made into a slurry with thrombin solution is the most effective hemostatic agent in this region. Gently pressing the slurry into the bleeding region with a cotton pledget often immediately produces hemostasis. C1 must be completely dissected free from underlying soft tissues in the epidural space to allow for safe passage of sublaminar cables later in the procedure.

The soft tissues are stripped off the spinous process and lamina of C2 in similar fashion. Dissection along the superior margin of the C2 lamina is carried laterally with curettes until the pedicle of C2 is encountered. The pars interarticularis of C2 is then defined with careful

blunt dissection using a small periosteal elevator. Visualization of the C2 pars interarticularis is crucial for safe passage of transarticular screws as it serves as the key landmark for screw trajectory. The surgeon's ability to conceptualize the three-dimensional anatomy of the C2 isthmus in terms of width, height, and angulation is of utmost importance for safe screw passage and avoidance of vertebral artery injury.

14.9.4 Transarticular Screw Placement

After C1 and C2 are exposed, stab incisions are made at approximately C7 to serve as the entry site for tunneling of instruments to the C2 entry site. As mentioned earlier, the location of the stab incisions can be confirmed by placing a straight instrument beside the neck and simulating the proper instrument trajectory while visualizing on lateral fluoroscopy. A 1.5-cm stab incision is made through the skin, subcutaneous tissues, and dorsal fascia. Incising the latter is important to allow placement of the guide tube. Indeed, the opening in the dorsal fascia must often be expanded with a hemostat to accommodate passage of the drill guide tube. Once the drill guide tube with obturator tip is placed through the opening in the dorsal fascia it is easily advanced through the underlying soft tissues to the entry site at C2. The soft tissues are flexible, allowing for adjustments in the trajectory of the drill guide tube.

The C2 entry site is typically 2 – 3 mm above the inferior margin of the C2 facet at the midpoint of the C2-3 facet. The entry site can be adjusted based on the unique anatomic characteristics of the C2 pars. Stereotactic guidance systems as discussed below can assist with determination of entry point and trajectory. A sharp obturator is passed through the guide tube to mark the C2 entry point and create a starter hole.

After the entry point is determined, the inner drill guide is placed in the guide tube and a calibrated drill is passed through this guide to the starter hole. The drill is initially advanced a few millimeters along the proper trajectory. The medial/lateral angulation of the drill is then optimized by visualizing the pars interarticularis of C2 and keeping the drill coaxial to the pars in this plane. The cephalic-to-caudal angulation is determined with the aid of fluoroscopy, with the C1 tubercle serving as an approximate fluoroscopic aiming target and an instrument such as a Penfield 4 dissector or small sucker tip placed on the top of the pars to assist its fluoroscopic identification (Fig. 14.4). The drill is slowly advanced through the pars under direct fluoroscopic visualization along its idealized path. As the drill is advanced through the pars, it is placed as dorsally as possible. Ideally, the drill bit should cross the C1-2 lateral mass articulation at the midportion or posterior half of this joint to allow for maximum screw purchase into the lateral mass of C1. The surgeon should be able to feel the drill crossing the C1-2 articulation and entering the C1 lateral mass. When the drill bit reaches the anterior cortex of the C1 lateral mass, the depth of penetration can be read on the calibrated inner drill guide and serves as an estimate of screw length. At this point, the fluoroscopic image should be saved and transferred to the storage monitor screen. This image serves as a reference with which we can compare the trajectory of our tap and screw placement and the trajectory of the drilled hole.

After the drill bit is backed out, the inner drill guide is removed and the tap is introduced through the outer guide tube to the C2 entry point. The entire course of the pilot hole through C2 and C1 is tapped, with intermittent lateral fluoroscopy used to confirm that the trajectory is correct. After tapping is completed, 4-mm fully threaded screws are placed (Fig. 14.5). The screw length is determined from the calibrated drill measurement and corroborated with preoperative planning measurements. We use fully threaded screws for this application, as lag screws provide no benefit. To con-

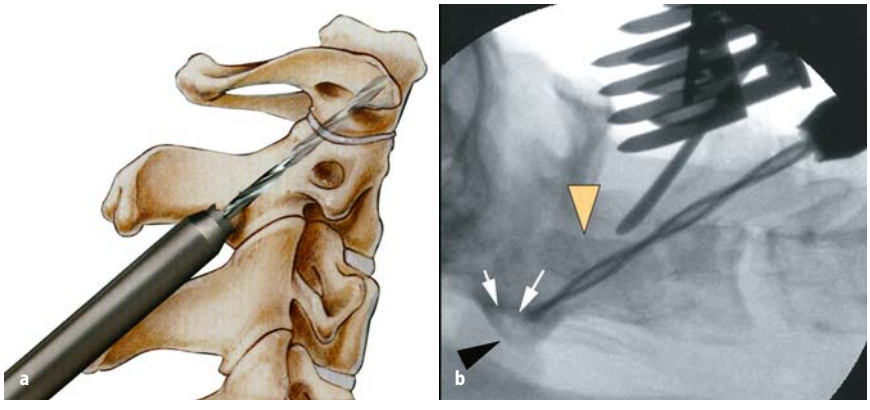


Fig. 14.4. a The drill bit is placed through the drill guide tube and a starter hole is drilled under direct fluoroscopic visualization through the C2 pars, across the C1-2 lateral mass articulation, and into the anterior cortex of the lateral mass of C1 (*white arrows* on **b**). **b** Fluoroscopic image showing a Penfield 4 dissector on the dorsal surface of the pars, where it serves as a landmark as the drill is advanced. The drill should be passed just below this instrument and is usually aimed at the upper half of the anterior arch of C2 (*black arrowhead*). It ideally crosses the C1-2 joint (*yellow arrowhead*) near its midsection

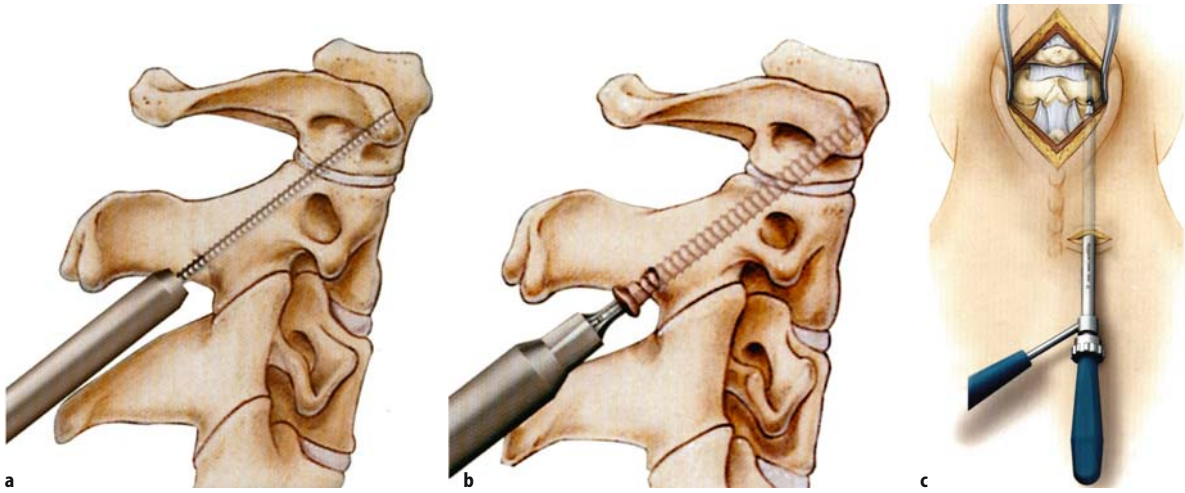


Fig. 14.5. The entire course of the starter hole is tapped (**a**) and then a fully threaded transarticular screw (**b**) is placed through the guide (**c**) using the same trajectory

firm stability after screw placement, we press on the C1 posterior arch while visualizing a lateral fluoroscopic image. C1 and C2 move independently when instability is present but should move as one unit after transarticular screw placement.

14.9.5 Placement of Bone Graft

As with all spinal instrumentation, atlantoaxial transarticular screws can eventually fail because of stress. Their role is not for long-term stabilization but to stabilize C1 and C2 until bony fusion can be accomplished. Historically, we have used iliac crest autograft and a posterior Sonntag wiring construct to secure the bone graft between C1 and C2. To optimize the likelihood for bone fusion, the mating surfaces between the graft and vertebrae should be decorticated and contact maximized without gaps. We use a high-speed drill to flatten the posterior and inferior aspect of the arch of C1 and perforate it in multiple places. The graft is then notched so it approximates both the posterior and inferior aspects of C1. At the C2 end, the graft is notched in a V-shaped manner to straddle the spinous process and shaped to maximize contact to the spinous process of C2 and the C2 lamina, with the cortices of both of these surfaces also perforated with the air drill (Fig. 14.6).

14.9.6 Use of Stereotactic Guidance

We attempt to use stereotactic guidance on most cases. The fine-cut CT images can be loaded into most stereotactic guidance packages and most systems have special software packages designed specifically for spinal navigation. The greatest difficulty is registration and accuracy. We find that only 60 % of cases have sufficient accuracy to be of value for intraoperative navigation.

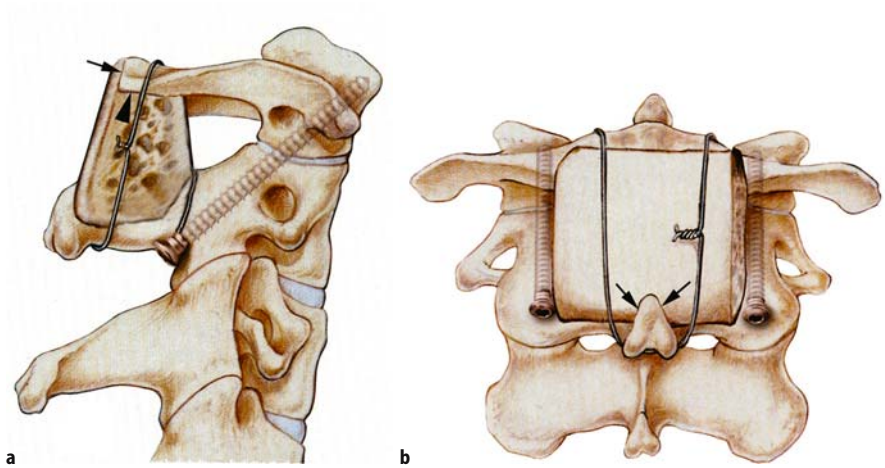


Fig. 14.6. Lateral (**a**) and posterior (**b**) views of the bone graft and wiring construct. The superior edge of the bone is notched to fit snugly against both the posterior surface (*arrow*) and inferior surface (*arrowhead*) of the C1 posterior ring as seen in **a**. A V-shaped notch is also cut in the inferior edge of the bone graft to fit over the spinous process of C2 (*arrows* in **b**)

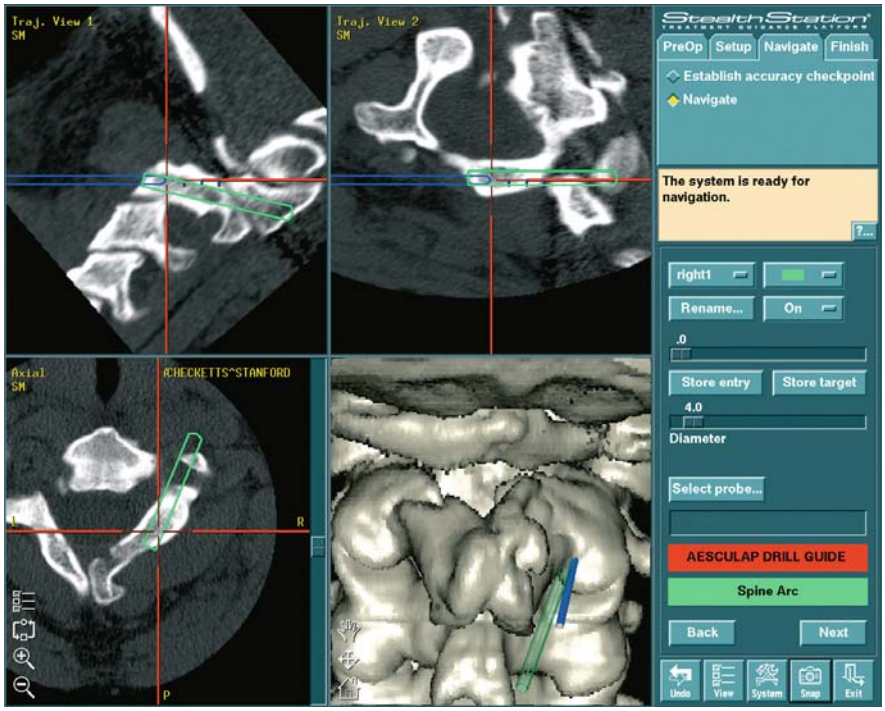


Fig. 14.7. A stereotactic workstation can be a valuable tool for both preoperative planning and intraoperative navigation. The CT images can be reconstructed in the multiple planes of the proposed screw placement to ensure that a safe pathway exists. In the *two upper panels*, the proposed screw pathway (*green rectangle*) has been placed on orthogonal trajectory views. The pointing tool is indicated by the *blue line*. The three-dimensional model (*lower right*) is very useful in defining the entry site and trajectory for drilling

The main role for navigation in this procedure is as a guide for crossing the C2 pars interarticularis and avoiding vertebral artery injury. If the guidance system does not correlate with what the surgeon visualizes, conventional techniques without navigation should be used. When using stereotactic guidance, the surgeon should not rely solely on the computer guidance but should consider the landmarks on C2 and the lateral fluoroscopic images. Even if the registration accuracy is not sufficient for intraoperative guidance, we still find the stereotactic workstation a valuable tool for preoperative planning and visualization of the unique anatomy of each individual case. The three-dimensional views that show the entry site and optimal path for the screw greatly facilitate accurate screw placement at surgery (Fig. 14.7).

14.9.7 Closure

We copiously irrigate the surgical sites with saline and bacitracin solutions and close in multiple layers. We typically place loose sutures through the muscle layers to reapproximate but not strangulate them. The dorsal fascia is probably the most important layer of closure and is closed with closely spaced (3 – 5 mm apart) interrupted zero Vicryl sutures. Meticulous closure of this layer may prevent superficial infections from tracking down to contaminate the hardware. The subcutaneous tissues can be closed in multiple layers depending on the patient's body habitus, and the skin is closed with a running stitch. We prefer not to leave any drains in place as they may serve as a pathway for infection. Rather we insist on meticulous hemostasis before closure.

14.10 Postoperative Care

Most patients stay in the ICU overnight and in the hospital for 2 – 3 days. Patients are mobilized on postoperative day one. As mentioned previously, we do not use external orthosis for most patients after transarticular screw fixation. However, in patients with poor bone quality or suboptimal screw placement, external orthosis with cervical collar or halo immobilization may be beneficial. We obtain both plain films and fine-cut CT scan to evaluate the construct postoperatively (Fig. 14.8). The plain films are used as comparison for long-term follow-up studies. The CT scans with reconstructions are used to assess screw placement and determine whether any revisions or supplemental orthosis are needed.

We mobilize patients on postoperative day one to avoid complications such as pneumonia and deep venous thrombosis. In our experience, pain control after transarticular screw fixation is usually easily accomplished with IV and then oral narcotics. The immediate stability provided by transarticular screws eliminates pathological motion and reduces pain, allowing patients to mobilize early after surgery. We avoid traditional NSAIDs as these drugs inhibit the inflammatory cascade and may impede bone healing.

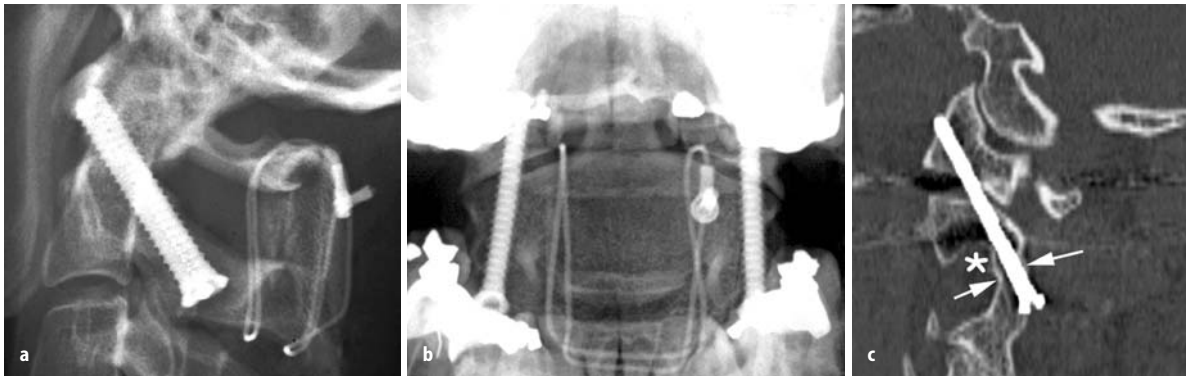


Fig. 14.8. Plain films (**a**, **b**) and fine-cut CT scan (**c**) are obtained postoperatively. On the CT scan, note the narrow, safe intraosseous pathway through the isthmus of C2 (*arrows*) through which the screw must be passed to avoid the vertebral artery, which is in the region marked by the *asterisk*

14.11 Hazards and Complications

14.11.1 Vertebral Artery Injury During Screw Placement

Vertebral artery injury can occur during drilling but most commonly occurs during tapping across the C2 pars interarticularis. The vertebral artery is in close proximity to the C2 pars and can be lacerated by either the drill or the tap if the pars is violated. If vertebral artery injury occurs, it will present with vigorous pulsatile bleeding as the instrument is removed from C2. If this occurs, we recommend that the transarticular screw be placed through the drilled pathway as planned. The screw will tamponade bleeding and seal the defect. We consider vertebral artery injury caused by placement of the first screw a contraindication to placement of the contralateral transarticular screw. In this situation, we recommend either a single transarticular screw with the posterior wiring construct or another screw technique that does not risk the vertebral artery on the other side, such as the direct C1 and C2 screw placement technique advocated by Harms in which the screws are connected outside the bone [13].

Vertebral artery injury and suboptimal screw placement are the main complications specific to this procedure. We have had eight vertebral artery injuries, approximately 3% of cases, while placing atlantoaxial transarticular screws, with one fatal outcome [7, 8]. The vast majority of vertebral arterial injuries occurred early in our experience, and with careful technique and proper planning this complication can be avoided or minimized.

14.12 Conclusions

In our experience with over 400 transarticular articular screws in over 200 patients, we have had a 97% fusion rate. Other series have confirmed close to 100% fusion rates with transarticular screws in combination with posterior bone graft and wiring techniques [11, 18]. With experience and proper judgment, this procedure can be performed safely achieving excellent fusion rates and clinical outcomes.

In addition to improving the fusion rates for posterior bone graft and wiring procedures, the procedure allows for early mobilization without the need for supplemental immobilization.

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Thoracic/Thoracolumbar Spine

General Techniques (Ch. 15 – 19) 129
Deformities (Ch. 20 – 22) 164
Fractures (Ch. 23 – 27) 203

Microsurgical Anterior Approach to T5–10 (Mini-TTA)

15

H.M. Mayer

15.1 Terminology

This chapter describes a microsurgical modification of the conventional thoracotomy to approach the anterior thoracic spine from T5 to T10. It is called "Mini-TTA" (TTA, transthoracic approach).

15.2 Surgical Principle

The anterior thoracic spine is approached from the right side through a limited thoracotomy with a 4- to 6-cm skin incision depending on the number of levels to be treated. The thoracic cavity can be opened either by resection of a small part of the rib ("window" technique), by a rib flap ("open-door" technique), by a single osteotomy of one rib ("sliding" technique), or by an intercostal approach (Fig. 15.6). A specially designed soft tissue spreader is used to retract the ribs, the ipsilateral lung, and, if necessary, the diaphragm (see also Chapter 16). With the use of a surgical microscope or an endoscope for thoracoscopy, a mono- or bisegmental anterior exposure of the thoracic spine can easily be achieved.

15.3 History

The technique was developed from the microsurgical approaches described for the exposure of the lumbar spine and lumbosacral junction (Mini-ALIF; see Chapter 45). A soft tissue spreader, which can also be used for transperitoneal exposure of L5–S1, has been modified by adding different blades for retraction of the thoracic contents as well as of the ribs. The first patient was operated on by the author on 6 March 1996.

15.4 Advantages

- Small skin incision
- Small, less traumatic thoracotomy
- Less trauma to the rib cage with window, sliding, or intercostal technique
- No cosmetic alterations
- Short ICU stay
- Better illumination and magnification of surgical field
- Safe dissection of tissues anterior and in the spinal canal
- No laboratory training necessary

15.5 Disadvantages

- Exposure limited to one or two segments with surgical microscope
- Individual learning curve
- Long instruments
- Limited manipulation of the motion segment (e.g., reduction)
- Limited options for anterior instrumentation

15.6 Indications

This approach has been used in patients with the following indications:

- Thoracic disc herniations
- Fractures
- Spondylodiscitis/spondylitis
- Palliative treatment of monolocular malignant tumors
- Enucleation or marginal excision of benign tumors or tumor-like lesions
- Anterior biopsies of lesions providing no indication of their malignant or benign nature

15.7 Contraindications

There are no absolute contraindications for this approach. However, decisions should be made on an individual basis in the following patients:

- Patients with previous thoracotomy or thoracoscopic surgery
- Patients with a condition following pleural empyema
- Patients in whom single-lung ventilation is not possible
- Patients with severe or acute respiratory insufficiency
- Patients with vascular diseases or malformations of or in the thoracic cavity

15.8 Patient's Informed Consent

Information about approach-specific risks and hazards should contain the following points:

- Postoperative pain due to resection of the rib and alteration of intercostal nerve (post-thoracotomy syndrome)
- Injury of intrathoracic blood vessels with hemothorax and repeated surgery
- Injury to the esophagus and the mediastinum with infection (mediastinitis)
- Injury to the thoracic duct with chylothorax
- Injury to the lung, postoperative pneumothorax
- Postoperative atelectasis
- Injury to the diaphragm and lesion of retroperitoneal structures (bowel, spleen, etc.) with diaphragm hernia, peritonitis, and retroperitoneal bleeding
- Injury to the pericardium and heart with postoperative scarring
- Injury to splanchnic nerves
- Pleuritis

15.9 Surgical Technique

15.9.1 Preoperative Planning

All data necessary for a meticulous preoperative planning can be obtained by AP and lateral X-ray of the thorax and thoracic spine as well as by magnetic resonance imaging (MRI). It is mandatory to have a clear impression of the pathology to be treated as well as of the topography of the anatomic region where the pathology is located. The radiologist should be asked to mark the level of T12 or L1 on a MRI-scout view of the whole spine in the sagittal plane (Fig. 15.1). This facilitates intraoperative localization especially of soft tissue pathology, such as thoracic disc herniations. In patients with variations of the lumbosacral junction (sacralization of L5 or lumbalization of S1) it is recommended to mark L5 on the MRI-scout view (i.e., the vertebra suprajacent to the last intervertebral space!).



Fig. 15.1. MRI in sagittal plane with marked vertebral body

Size and localization of the thoracic blood vessels, such as the aorta or the azygos/hemiazygos system, should be analyzed preoperatively. Involvement of these blood vessels in the pathology (e.g., tumors, spondylitis with prevertebral soft tissue involvement) must be assessed as well.

Selective intubation and unilateral ventilation is helpful during surgery through a mini-thoracotomy. This should be clarified with the anesthesiologist preoperatively. If unilateral ventilation is not possible or contraindicated (especially in older patients or in patients with pulmonary problems) this must not be a contraindication to the microsurgical approach. The retractor system described below is able to retract a ventilated lung as well.

15.9.2 Positioning

The patient is placed on the operating table in a left lateral position (Figs. 15.2, 15.3). The approach is from the right side. The cranial and caudal parts of the operating table can be tilted (if necessary) in order to achieve a right convex bending of the thoracic spine. However, care must be taken that the level of pathology (e.g., intervertebral space, vertebral body) shows an orthograde projection onto the skin level in a lateral fluoroscopic view. Both legs are bent about 80° at the knee joints, supported with soft cushions, and fixed with a tape. The lower (left) arm is stretched out and a small soft towel roll is placed under the axilla in order to prevent lesions to the brachial plexus. The upper (right) arm is placed in 90° elevation, the elbow is bent slightly, and the forearm is placed on an armrest. The ulnar sulcus must be free, and both arms should be placed without pressure or tension.

The position of the body of the patient is held by two soft pads from behind: one supports the buttocks and the other the neck. A third one is placed from anterior to fix the pelvis below the anterior superior iliac spine (Fig. 15.3). Because of this fixation, the patient can be tilted with the operating table in the horizontal plane if necessary during the operation. The head of the patient is supported by a gel cushion and placed in a neutral position.

The operating table must be radiolucent from the lumbosacral junction to the level of the pathology to be treated. This is mandatory because fluoroscopic control of the level to be approached is paramount to avoid exploration of the wrong level and to place the skin incision in the right place. During the operation, the operating table usually does not need to be tilted in the frontal plane.

If higher thoracic levels must be approached, the upper (right) arm must be placed in maximum elevation. (*Cave*: do not overstretch the brachial plexus!)



Fig. 15.2. Positioning of the patient



Fig. 15.3. External support and fixation of the patient on the operating table

15.9.3 Localization

The skin incision is determined by localizing the level to be approached in projection to the skin level. If the pathology cannot be visualized directly by fluoroscopy (e.g., disc herniations), the level must be determined by counting the vertebral bodies from L5 up to the target level. (*Cave*: make sure, that L5 in the lateral fluoroscopic view is really L5.) Lumbosacral anomalies may be a pitfall (see above). The level to be approached is marked on the skin with lateral fluoroscopic projection. If a disc space is approached (e.g., disc herniations, spondylodiscitis), then the orientation of the disc space as well as the anterior and posterior borders are marked. If a vertebral body is the surgical target (e.g., tumors or fractures) then the silhouette of the vertebral body should be drawn onto the skin under fluoroscopic control. This facilitates the placing of the skin incision according to the size of the exposure which is needed (Figs. 15.4, 15.5). The skin incision is marked parallel to



Fig. 15.4. Localization of the pathologic vertebra in projection onto the skin surface

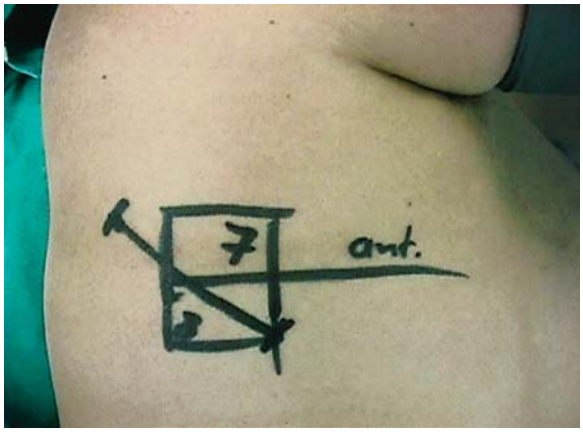


Fig. 15.5. Skin incision

the orientation of the rib or the intercostal space underneath and should be centered over the pathologic level (Fig. 15.5).

15.9.4 Surgical Steps

15.9.4.1 Exposure of the Rib or Intercostal Space

Exposure of the "target rib" or intercostal space to enter the thoracic cavity is easy at the middle and lower thoracic levels. Through a 4- to 6-cm skin incision, the lateral part of the serratus muscle is exposed and split parallel to the orientation of its fibers. Thus the underlying rib or intercostal space are exposed. At levels above T7 the latissimus dorsi muscle has to be retracted or incised anteriorly to expose the rib. The "target rib" is always determined by the localization of the skin incision and not by the conventional method (rib two levels above the pathology).

15.9.4.2 Mini-thoracotomy

15.9.4.2.1 Intercostal Approach

In young patients with an elastic rib cage and a monosegmental pathology (e.g., thoracic disc herniation), thoracotomy can be performed by an intercostal approach. The intercostal muscles are split close to the superior rim of the caudal rib and the thoracic cavity is entered after splitting of the visceral pleura. The intercostal space can be opened with the rib spreader in order to give sufficient exposure (Fig. 15.6a).

15.9.4.2.2 "Window" Technique

Subperiosteal dissection is performed and the intercostal muscles are dissected first from the superior rim of the caudal rib and then from its caudal rim. Due to the oblique insertion of the external intercostal muscles, dissection is facilitated if the muscles are detached from posterior to anterior at the inferior rim and from anterior to posterior at the superior rim. Thus, trauma to the intercostal blood vessels and nerve is minimized. The rib is exposed over a length between 4 and 6 cm. With a curved dissector, the rib is isolated from its periosteal bed. Osteotomies are performed at the anterior and posterior borders of the exposed part and the rib is taken out (and preserved for grafting if necessary). Thus a "window" of 5 – 6 cm length and 3 – 4 cm width is created, the size depending on the width of the excised rib (Fig. 15.6b).

15.9.4.2.3 "Open-door" Technique

The thoracic cavity can also be entered through a rib flap. In this alternative exposure, the intercostal mus-

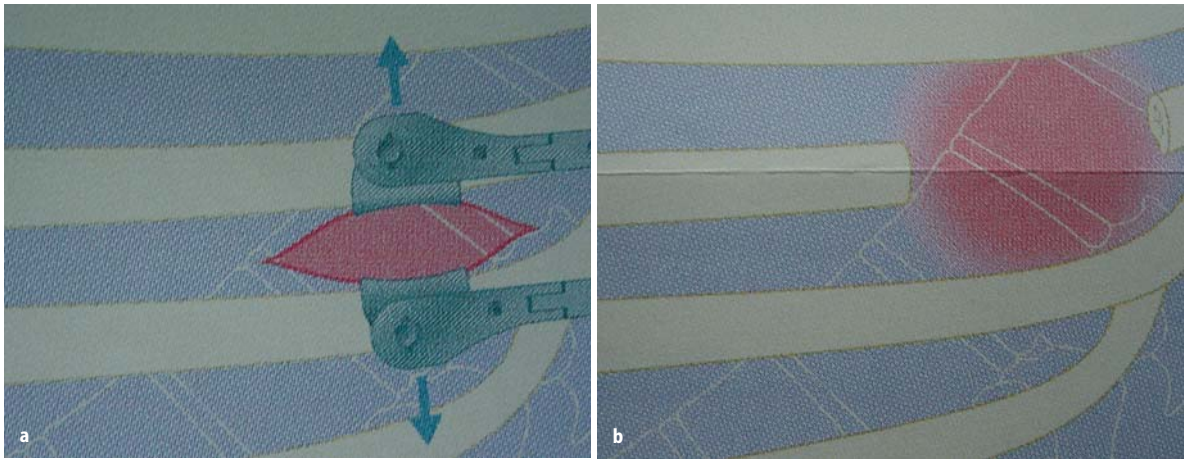


Fig. 15.6. a Intercostal technique. **b** Window technique.

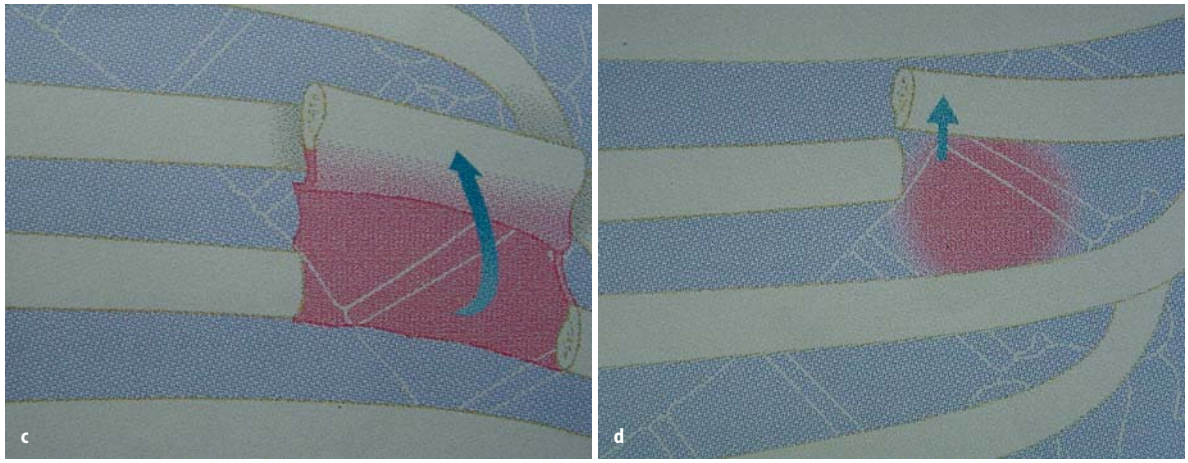


Fig. 15.6. (contin.) c Open-door technique. **d** Sliding technique

cles are only detached from the superior rim of the rib. The osteotomies are performed the same way as described above, however the osteotomized part of the rib is opened (like a door) in order to enter the thoracic cavity (Fig. 15.6c). At the osteotomy sites, small drill holes are set to facilitate transosseous sutures at the end of the operation. This technique can be used if no bone grafting is necessary and if an intercostal exposure is not recommended for anatomic reasons (e.g., stiff rib cage, osteoporotic bone).

15.9.4.2.4 "Sliding" Technique

This is another alternative which gives sufficient monosegmental exposure without rib defect. Only one osteotomy is performed and when spreading the intercostal space, one rib "slides" over the other to give a wider exposure as compared to an intercostal approach (Fig. 15.6d). This technique can be used in the lower thoracic spine and at the thoracolumbar junction (see Chapter 16).

15.9.4.3 Exposure of the Target Area

After rib osteotomy the visceral pleura is incised and the thoracic cavity is opened. The rib retractor is inserted. The retractor blades are available in different sizes (Fig. 15.7). The bladescan be rotated in the retractor and thus be adjusted to the individual anatomic situation (Fig. 15.8). In patients being ventilated unilaterally, the collapsed lung can be retracted with an inflatable balloon mounted on a blunt lung blade which is fixed on the rib retractor (Fig. 15.9).



Fig. 15.7. Rib retractor blades

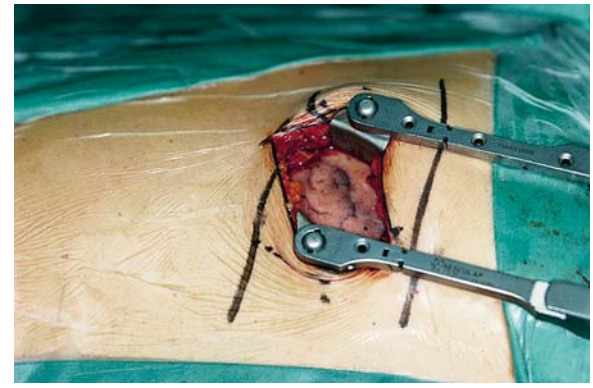


Fig. 15.8. Rib retractor in situ

15.9.4.4 Exposure of the Thoracic Spine

The procedure is then continued with the help of a surgical microscope ("microsurgery"; Fig. 15.10) or an endoscope ("open" thoracoscopic surgery). Thus, the anterolateral circumference of the thoracic spine can be

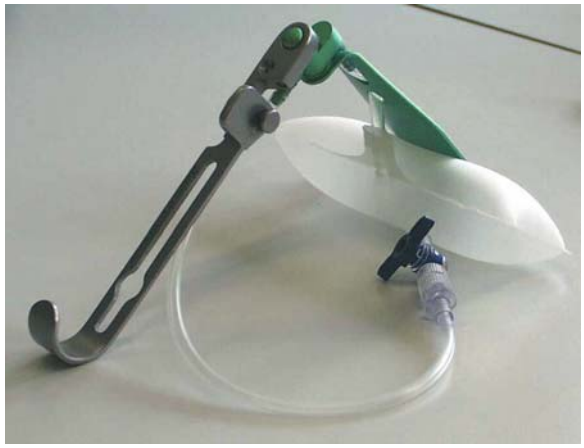


Fig. 15.9. Lung blade with inflatable balloon

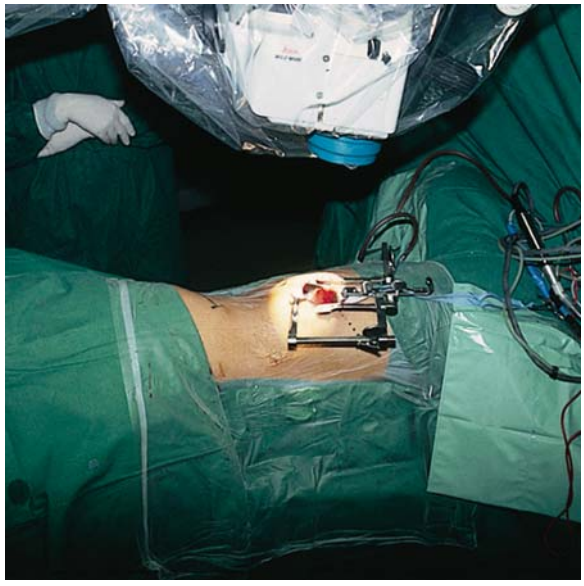


Fig. 15.10. Surgical microscope centered above the target area



Fig. 15.11. Pleura scissors

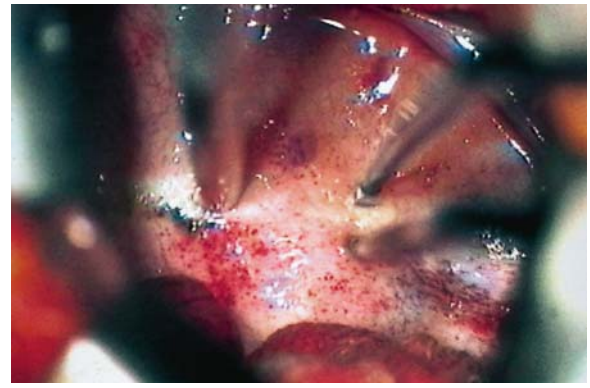


Fig. 15.12. Blunt dissection of the anterolateral thoracic spine with bipolar coagulation

exposed. The rib head(s) of the level(s) to be approached are identified. The correct level is identified by intraoperative fluoroscopic control.

The pleura parietalis is opened in a T-shaped manner longitudinally anterior to the rib head and at a 90° angle to the rib head. Special pleura scissors have been developed for this purpose (Fig. 15.11). Blunt dissection of the anterolateral circumference is performed with peanut swabs (Fig. 15.12). If necessary, the segmental vessels can be closed with ligaclips, cut and dissected from the surgical field.

15.10 Surgical Strategies

15.10.1 Thoracic Disc Herniations (Figs. 15.13a, b, 15.14)

- Identification of disc level
- Opening of pleura (as described above)
- Removal of rib head and radiate ligaments with rongeurs and high-speed drill
- Opening of the disc space posterior third underneath the rib head
- Removal of 3 – 5 mm of adjacent vertebral bodies
- Identification and drilling of superior border of pedicle until dura can be identified
- Tracing the dura and removal of posterior third of the intervertebral disc including the herniated part and the posterior longitudinal ligament

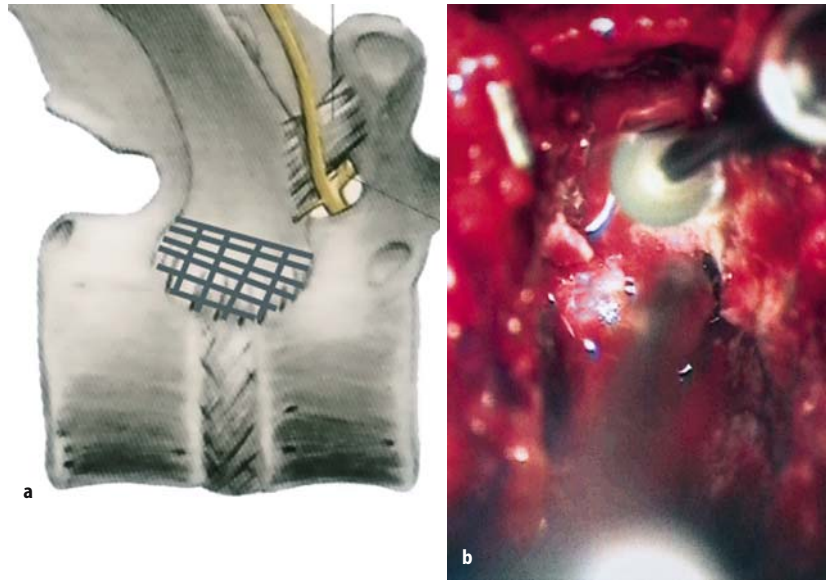


Fig. 15.13. a Drawing shows amount of necessary removal of rib head (*lined area*). **b** Drilling of vertebral bodies



Fig. 15.14. Disc herniation at T5 – 6 before (*left*) and after (*right*) Mini-TTA

Cave:

- Achieve hemostasis without compression of the spinal cord (e.g., careful bipolar coagulation of epidural veins, Surgicel, Gelfoam, cottonoid patties, etc.)
- Resect the posterior longitudinal ligament until the decompressed dura is identified clearly
- Avoid injury to foraminal structures (segmental nerve and blood vessels)
- Restrict removal of parts of the vertebral bodies or pedicle to a minimum

15.10.2 Partial and Complete Corpectomy (e.g., Fractures, Tumors, Spondylitis)

- Identification of the target vertebral body and the adjacent discs
- Ligation and dissection of the segmental vessels on the target vertebral body
- Removal of the adjacent intervertebral discs (see above) and "isolation" of the target vertebra
- Identification of the pedicle and removal to identify the dura
- In spondylitis cases identify the intercostal nerve after removal of corresponding rib head



Fig. 15.15. Hockey-stick dissectors

- Trace the nerve down into the spinal canal to identify the thecal sac
- "Shell out" the target vertebra with a high-speed drill (fractures) or by piecemeal removal with rongeurs (tumors, spondylitis)
- Decompression of the spinal cord by displacing the posterior part of the "vertebral body shell" into the "shelled out" part with hockey-stick dissectors (Fig. 15.15)
- In spondylitis cases identify the layer between infected tissue and the dura
- Completion of decompression across to the base of the opposite pedicle
- If necessary prepare graft bed for fusion or vertebral body replacement

Cave:

- Extremely careful dissection is necessary because of obscured normal anatomy by posttraumatic (organized) hematoma (fractures), pleural adhesions, and prevertebral abscesses (spondylitis)

15.11 Postoperative Care

A chest tube is placed in all patients. If the amount of drainage fluid is less than 100 cc within the last 24 hours, the chest tube is closed for 6 hours. When a control X-ray of the lung shows a normal picture, it can be removed. This is usually between 24 and 72 hours postoperatively depending on the type of surgery. Following the operation, the patient can be extubated in the operating room. It is rarely necessary to perform postoperative artificial ventilation except for patients with significant obstructive lung disease or after a prolonged operating time. The patients remain in the ICU until the chest tube is removed. Postoperative pain is controlled by non-steroidal anti-inflammatory medication as well as by a patient-controlled analgesia (PCA), usually with morphine-type analgesics. The patients are mobilized on the fist postoperative day irrespective of the type of surgery. Respiratory therapy begins immediately after the patient is awake and ready to cooperate.

15.12 Complications and Hazards

Besides the well-known complications of conventional thoracotomy, the following potential intraoperative complications may be faced:

- Inadequate exposure due to wrong positioning and/or localization
- Direct or indirect injury to lung, thoracic duct, azygos/hemiazygos vein, segmental vessels, aorta or heart, intercostal vessels, intercostal nerves, and sympathetic chain/splanchnic nerves
- Spinal cord injury or ischemia
- Dural tears

Control of vascular injuries is most demanding through a limited transthoracic approach. The surgeon should always be prepared to enlarge the surgical field to a conventional thoracotomy if such complications cannot be managed adequately.

15.13 Critical Evaluation

This approach represents a modification of the conventional thoracotomy described for the treatment of pathologies of the anterior thoracic spine. As far as our preliminary experience shows, mini-thoracotomy lead to a reduction of intra-and postoperative morbidity in the type of diseases treated so far. Trauma to the rib cage and muscles covering the anterolateral part of the thorax is diminished. The postoperative ICU stay is short as is the time in hospital. The same is true for intraoperative blood loss, incision pain, and cosmesis. These data are comparable to data obtained with a closed thoracoscopic technique (see Chapters 18, 20–23). As compared to closed thoracoscopic techniques, the learning curve is flat for surgeons trained in open thoracotomies. The only difference is the size of the approach and the use of optical aids for illumination and magnification (surgical microscope or endoscope).

The approach, however, seems to be ideal only for patients with mono- or bisegmental pathology. Excision of herniated discs, palliative excision of malignant tumors, decompression of the spinal canal in tumors, spondylitis, and fracture cases can be achieved without major difficulties. The same is true for biopsies or drainage of prevertebral abscesses.

However, technical skills must be acquired by surgeons not familiar with the use of a surgical microscope or endoscope. Exposure is possible, but more difficult, in patients in which single-lung ventilation is not possible.

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1. Bauer R, Kerschbaumer F, Poisel S (eds) (1991) Orthopädische Operationslehre, vol I: Wirbelsäule. Thieme, Stuttgart
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16 Microsurgical Anterior Approach to the Thoracolumbar Junction

H. M. Mayer

16.1 Terminology

A microsurgical modification of the transthoracic-retroperitoneal approach to pathologies of the thoracolumbar junction (T11–L2) is described.

16.2 Surgical Principle

The surgical principles follow the principles described in the previous chapter. The anterolateral aspect of the thoracolumbar junction is approached through a 4- to 6-cm skin incision from the left side. A mini-thoracotomy is used to approach the spine at the base of the diaphragmatic insertion on the left side. The approach is then extended into the retroperitoneal cavity through dissection of the diaphragm on the vertebral bodies of T12/L1 without detaching the diaphragmatic insertion in a circumferential way. The soft tissue spreader described in Chapter 15 is used to retract the ribs as well as the ipsilateral lung. It is completed by a diaphragm blade which holds the retroperitoneal contents downward and retracts the incised diaphragm. Since a high retraction force has to be applied because of the intra-abdominal contents, the diaphragm blade can be fixed on the vertebral body L1 or L2 with a U-shaped integrated K-wire. As described in the previous chapter a surgical microscope or an endoscope is used to illuminate and magnify the target area (see Chapter 15). This approach is mainly used for anterior decompression of the spinal canal and anterior interbody bone grafting in fractures.

16.3 History

The technique was developed from the microsurgical approach described above. The first patient was operated on by the author on 4 April 1997.

16.4 Advantages

- Small skin incision
- Small less traumatic thoracotomy
- Less trauma to the rib cage with window, sliding, or intercostal technique
- No cosmetic alterations
- Short ICU stay
- Better illumination and magnification of surgical field
- Safe dissection of tissues anterior and in the spinal canal
- No laboratory training necessary

16.5 Disadvantages

- Exposure limited to one or two segments with surgical microscope
- Individual learning curve
- Long instruments
- Limited manipulation of the motion segment (e.g., reduction)
- Limited options for anterior instrumentation

16.6 Indications

The approach has been used in patients with the following indications:

- Disc herniations at the thoracolumbar junction (T10/11/12)
- Fractures (T10–L1)

It can also be used for the treatment of:

- Spondylodiscitis/spondylitis
- Palliative treatment of monolocular malignant tumors
- Enucleation or marginal excision of benign tumors or tumor-like lesions

- Anterior biopsies of lesions providing no indication of their malignant or benign nature

16.7 Contraindications

There are no absolute contraindications for this approach (see also Chapter 15). However, decisions should be made on an individual basis in the following patients:

- Patients with previous thoracotomy or thoracoscopic surgery
- Patients with pleural empyema
- Patients in whom single-lung ventilation is not possible
- Patients with severe or acute respiratory insufficiency
- Patients with vascular diseases or malformations of the thoracic cavity
- Patients with previous operations of or around the diaphragm
- Patients with previous retroperitoneal approaches from the left side (e.g., kidney, spleen)

16.8 Surgical Technique

16.8.1 Preoperative planning

Preoperative planning and preparation includes AP and lateral X-rays of the thorax and the thoracolumbar junction. Magnetic resonance imaging (MRI) is mandatory. Identification of T12 or L1 follows the same criteria as described in the previous chapter. Selective intubation and unilateral ventilation is helpful but not necessary for the approach to the thoracolumbar junction.

16.8.2 Positioning

The patient is placed on the operating table in a right lateral position (see Figs. 15.2 and 15.3). The approach is from the left side. The operating table is tilted in the coronal plane in order to achieve a left convex bending of the thoracolumbar junction. Care must be taken that the level of pathology (e.g., intervertebral space, vertebral body) shows an orthograde projection onto the skin level in a lateral fluoroscopic view. Both legs are bent about 80° at the knee joints, supported with soft cushions, and fixed with a tape. The lower (right) arm is stretched out and a small soft towel roll is placed under the axilla in order to prevent lesions to the brachial plexus. The upper (left) arm is placed in 90° elevation, the elbow is slightly bent, and the forearm is placed on an armrest. The ulnar sulcus must be free, and both arms should be placed without pressure or tension.

The position of the body of the patient is held by two soft pads from behind: one supports the buttocks and the other the neck. The table is then tilted about 20° backward. The head of the patient is supported by a gel cushion and placed in a neutral position.

The operating table should be radiolucent from the lumbosacral junction to the level of the pathology to be treated to avoid exploration of the wrong level.

16.8.3 Localization

The skin incision is determined by fluoroscopy. The C-arm is placed in the AP position over the target level and the projection of the vertebral body or disc space onto the skin is marked. If a vertebral body is the surgical target (e.g., tumors or fractures) then the superior/inferior as well as the anterior/posterior borders are drawn onto the skin under fluoroscopic control. The skin incision is marked parallel to the orientation of the rib or the intercostal space underneath the drawing of the target area and should be centered onto the pathologic level.

16.8.4 Surgical Steps

16.8.4.1 Exposure of the Rib or Intercostal Space

The approach is primarily transthoracic. Exposure of the "target rib" or intercostal space to enter the thoracic cavity is easy at the thoracolumbar junction. A 4- to 6-cm skin incision is placed over the target area and the inferior lower parts of the anterior serratus muscle as well as the superior aspects of the oblique external abdominal muscle are exposed and split parallel to their fiber orientation. Thus the underlying rib or intercostal space is exposed.

16.8.4.2 Mini-thoracotomy: Intercostal Approach

If no bone graft is needed, an intercostal approach is preferred at the thoracolumbar junction (Fig. 16.1). Usually the rib cage is more elastic at this level even in older patients. The intercostal muscles are split close to the superior rim of the caudal rib and the thoracic cavity is entered after splitting of the visceral pleura. The intercostal space can be opened with the rib spreader in order to give sufficient exposure.

The other types of thoracotomy techniques are described in the previous chapter.

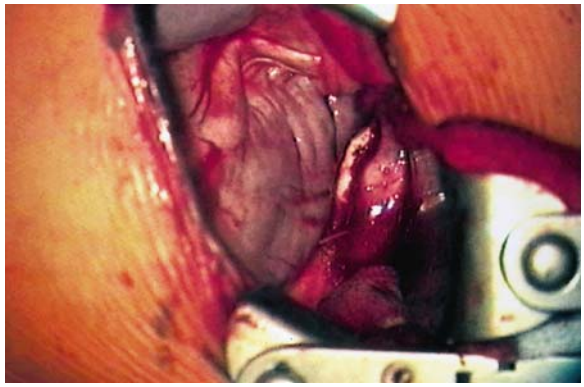


Fig. 16.1. Exposure of the diaphragm with intercostal technique

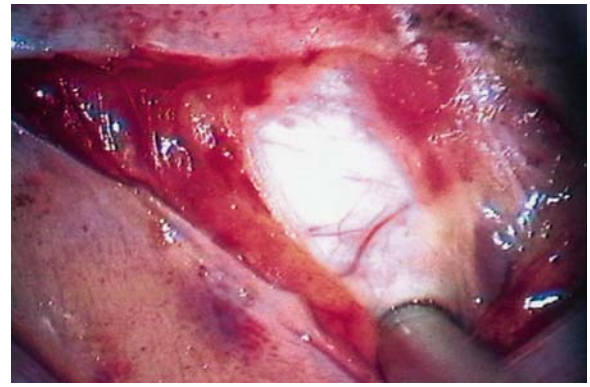


Fig. 16.2. Dissection of the base of the diaphragm

16.8.4.3 Exposure of the Target Area

Thoracotomy at the thoracolumbar junction leads to exposure of the diaphragm. Since the insertions of the diaphragm at the lower ribs underlie anatomic variations, it can be necessary to dissect the insertion of the diaphragm from the infrajacent rib. However, in the majority of cases the thoracotomy is located superior to the lower anterior insertion of the diaphragm. When the rib retractor is opened, the surgeon should take care of the insertion of the diaphragm in the costodiaphragmatic recess anterior to the thoracotomy. If forceful retraction is performed, the diaphragm might tear in the recess. The diaphragm can now be retracted with modified Langenbeck hooks. The base of the diaphragm is exposed as well as the anterolateral circumference of the lower thoracic segments.

16.8.4.4 Exposure of T10–L2

The procedure is continued with the help of a surgical microscope ("microsurgery") or an endoscope ("open" thoracoscopic surgery). First the parietal pleura superior to the base of the diaphragm is opened longitudinally anterior to the head of the 11th and 12th rib (see Fig. 15.8). Blunt dissection of the anterolateral circumference is performed in the way described above.

Dissection of the diaphragm starts at the base (Fig. 16.2). To avoid lesions to retroperitoneal structures, the diaphragm should be carefully elevated by subperiosteal preparation of the lateral parts of the crus sinister from the vertebral body. It can then be carefully elevated and split from the level of the vertebral body about 3 – 4 cm in a vertical direction. The author recommends first "lining" the split by bipolar coagulation to avoid bleeding. As soon as retroperitoneal fat tissue is visualized, the dissection is continued with peanut swabs. Thus, the anterolateral circumference of T12, L1, and usually the superior half of L2 can be exposed. The segmental vessels are exposed, "isolated" bluntly with a dissector, clipped, and dissected. Care has to be taken not to injure the thoracic duct. In most of the cases where the approach is extended to L1/L2 the superior insertions of the psoas muscle on the left side have to be dissected from the vertebral body. As soon as the lower vertebral body of the target area is exposed, the diaphragm blade is inserted with the help of the blade holder (Fig. 16.3). The diaphragm blade is fixed onto the vertebral body by a U-shaped K-wire which is integrated in the blade (Fig. 16.4). The blade is then connected to the counter-spreader which is fixed on the rib holder (Fig. 16.5). Thus, the target area is sufficiently exposed.



Fig. 16.3. Blade holder with inserted diaphragm blade





b K-wire inserted in the diaphragm blade

Fig. 16.4. a Diaphragm blade and U-shaped K-wire



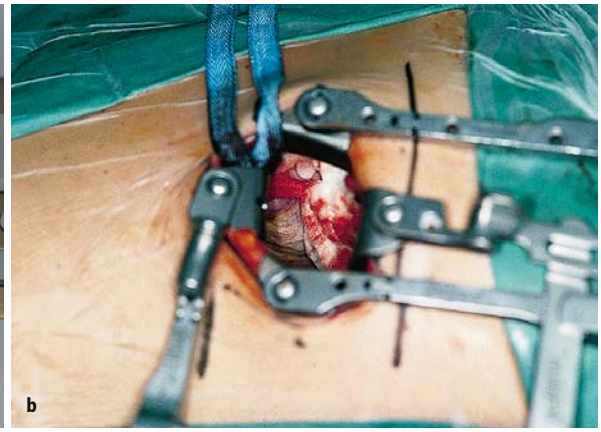


Fig. 16.5. a Complete retractor system for the thoracolumbar junction (surgeon's view). **b** Retractor system in situ

16.9 Surgical Strategies

The basic surgical strategy is described in Chapter 15. For anterior decompression in fracture cases, the anterolateral circumference of the fractured vertebral body is exposed first (Fig. 16.6). The posterolateral third of the fracture area is resected with the help of chisels and high-speed burrs (Fig. 16.7). The posterior fragment which usually occupies the spinal canal is decreased in size by the high-speed burr until only a thin bony layer occupies the spinal canal (Fig. 16.8). This layer is then carefully luxated into the "hollow" posterior part of the vertebral body with the help of the hockey-stick dissec-

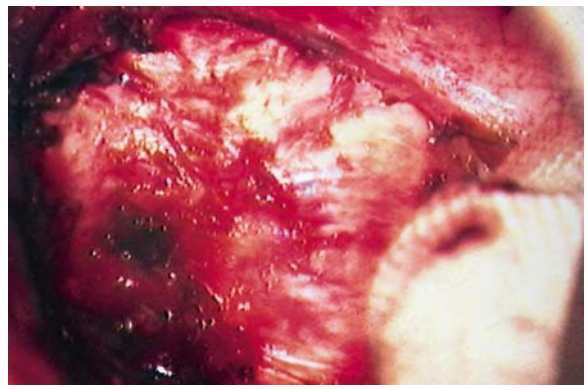


Fig. 16.6. Exposure of the fractured vertebra

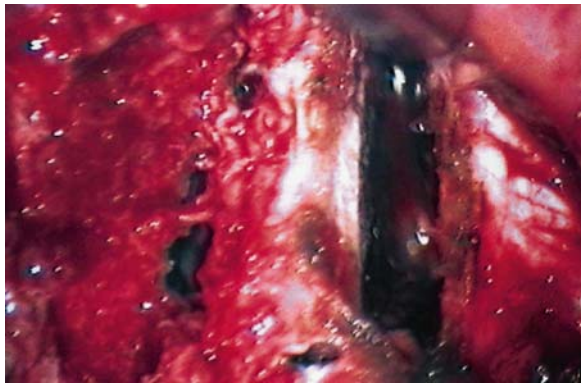


Fig. 16.7. Resection of fragmented bone

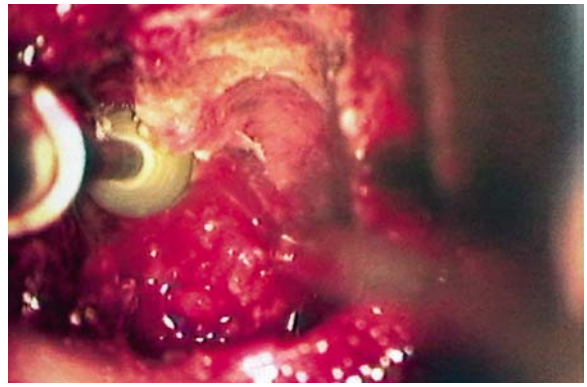


Fig. 16.8. Volume reduction of the fragment with a high-speed diamond drill

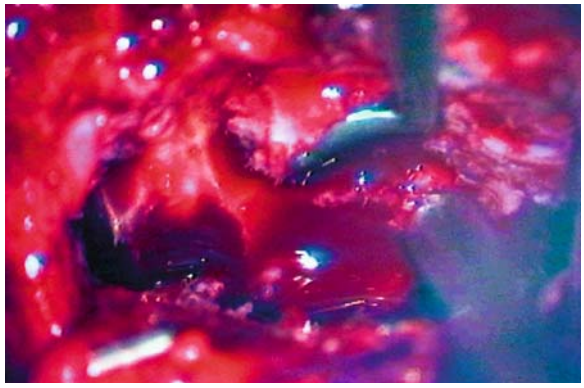


Fig. 16.9. Removal of the rest of the fragment from the spinal canal with the help of a hockey-stick dissector

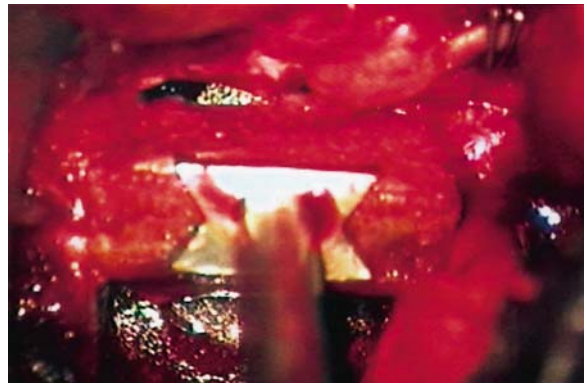


Fig. 16.10. Grafting with tricortical bone from the iliac crest

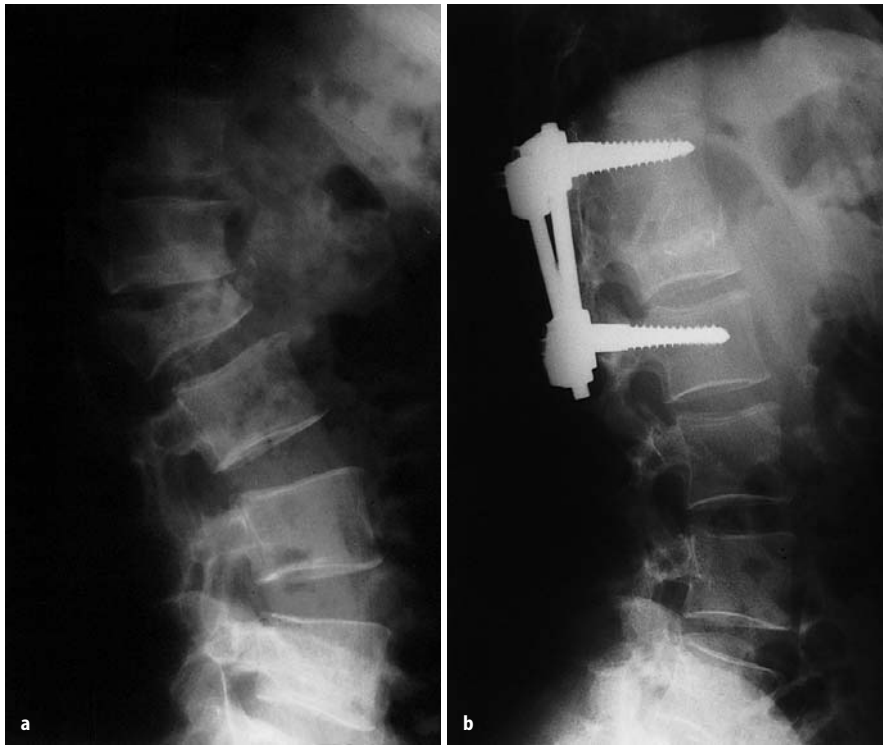


Fig. 16.11. a L1 fracture preoperatively. **b** L1 fracture after posterior reduction and anterior fusion

tor (Fig. 16.9). It thus can be removed carefully with the rongeur. The preparation of the graft bed is then completed and a tricortical bone graft from the iliac crest can be inserted press-fit (Fig. 16.10). Figure 16.11 shows an example of an L1 fracture after posterior reduction and instrumentation followed by anterior fusion (Fig. 16.11).

16.10 Postoperative Care

See Chapter 15.

16.11 Complications and Hazards

See Chapter 15.

16.12 Critical Evaluation

The anterior approach to the thoracolumbar junction has been known to be the most traumatizing approach to the spine. It has included circumferential dissection of the diaphragm, excision of a rib, and often wide incision or detachment of the psoas muscle. Since the majority of pathologic changes in this anatomic region are fractures, which occur predominantly in young patients, the need for diminishing iatrogenic trauma in these patients is evident. The approach which has been described in this chapter represents one possible solution to the problem of minimizing surgical trauma. Other options will be described in Chapters 20 and 23.

The advantages are obvious and have been described extensively in the previous chapter. The major problem arising from this limited exposure is the lack of adequate manipulation of the spine to correct kyphotic or scoliotic deformities from anterior, as well as the lack of adequate implants, including application instruments, which are adapted to a limited surgical approach.

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17 Anatomic Principles of Thoracoscopic Spine Surgery

U. Liljenqvist

17.1. Anatomy of the Thoracic Wall with Respect to Endoscopic Approaches

17.1.1 Muscles of the Thoracic Wall

The muscles of the pectoral girdle attach the upper limb to the trunk. Of relevance to endoscopic approaches to the thoracic spine are the serratus anterior, the pectoralis major, and the latissimus dorsi muscles, the latter forming the muscular boundary of the anterior and the posterior axillary line (Fig. 17.1).

The serratus anterior covers the side of the thoracic wall and forms the medial wall of the axilla. It origins widely with its digitations from the first eight ribs inserting into the scapula. The digitations are bluntly dissected during trocar placement.

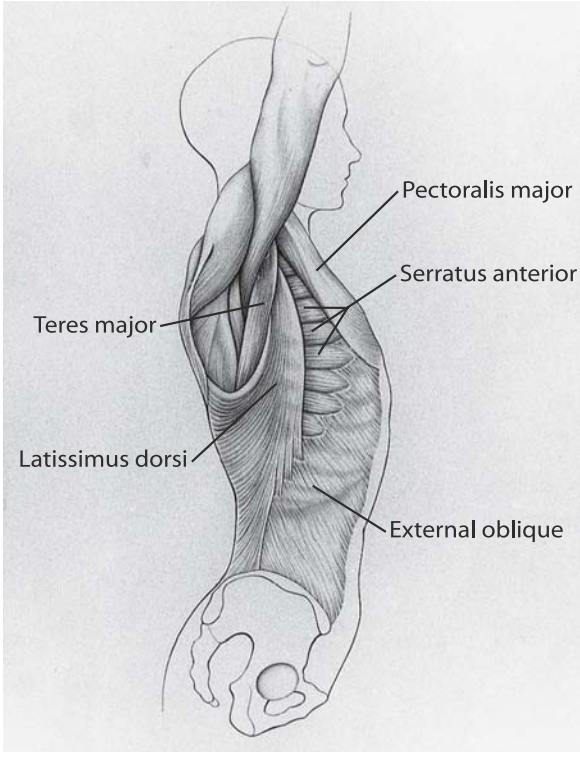


Fig. 17.1. Muscles of the thoracic wall from a lateral view

The pectoralis major consists of a clavicular head and a sternocostal head, the latter forming the anterior muscular boundary of the anterior axillary line and constitutes the anterior border for trocar placement.

The latissimus dorsi is characterized by its wide origin ranging from the seventh thoracic spinous process with its fleshy origin in the thoracic region down to the sacrum, becoming aponeurotic in the lumbar and sacral region. It forms the muscular boundary of the posterior axillary line and the posterior border for trocar placement. However, a far posterior access is sometimes necessary and blunt dissection of this muscle becomes inevitable.

The external oblique, part of the anterior abdominal wall, origins with its digitations from the fifth to the twelfth rib and spreads out with its fleshy part inserting into a wide aponeurosis that joins the aponeurosis of the internal oblique below the costal margin. During trocar placement the fibers of the external oblique need to be bluntly dissected.

17.1.2 Mammary Gland

The mammary gland is located in the subcutaneous tissue of the anterior thoracic wall and overlies the pectoralis major extending laterally and inferiorly to the serratus anterior and the external oblique. It origins quite constantly with its base between midline and midaxillary line and from the second to the sixth rib, irrespective of its size. During trocar placement, care must be taken not to injure the mammary gland.

17.1.3 Intercostal Spaces

The intercostal muscles span the ribs and need to be dissected during trocar placement. The external intercostals run obliquely downward and forward and extend from the superior costotransverse ligament posteriorly to the costochondral junction anteriorly where they are replaced by the anterior intercostal membrane. The fibers of the internal intercostals pass obliquely downward and backward, extending anteriorly to the

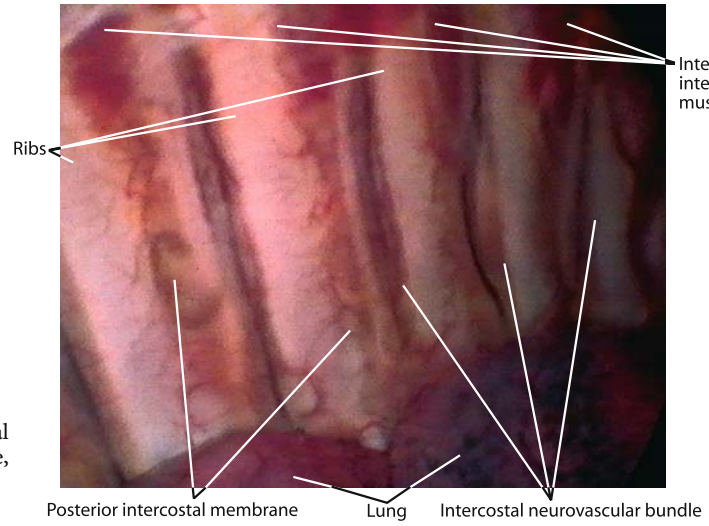


Fig. 17.2. Right-sided thoracoscopic view of the chest wall showing the internal intercostal muscles, the intercostal neurovascular bundle, and the posterior intercostal membrane

sternum. Posteriorly, they are replaced by the posterior intercostal membrane (Fig. 17.2).

The inner muscular layer is formed by the transverse muscle of thorax at the front, the subcostals at the back, and the innermost intercostal muscle at the side of the rib cage.

Between the internal intercostals and the inner layer, the intercostal neurovascular bundle passes along the inferior rim of each rib (Fig. 17.2). The order from above downward is: intercostal vein, intercostal artery, and intercostal nerve, running in the sulcus costae. The trocars should, therefore, always be placed at the lower boundary of each intercostal space in order to avoid injury to the neurovascular bundle. Small collateral branches of nerves and vessels running at the superior rim of the ribs are of subordinate importance and can be ignored.

17.1.4 Diaphragm

The diaphragm is a thin sheet of muscle that originates from the xiphisternum in the front (pars sternalis), from the upper lumbar vertebrae (pars lumbalis) at the back, and from the lower six ribs in between (pars costalis).

The diaphragm curves up into two domes, with the right one higher than the left due to the liver. During full expiration the right dome can move up as high as the fourth intercostal space and the left dome to the fifth rib. This must be borne in mind during trocar placement in order not to penetrate the diaphragm, thus endangering liver or spleen on the left.

17.1.5 Anatomic Considerations in Trocar Placement

In thoracoscopic spine surgery, the trocars are usually placed within the axillary lines. It is advisable to mark the borders of the latissimus dorsi posteriorly and the pectoralis major anteriorly to avoid transmuscular trocar placement, even if a rather posterior access is sometimes necessary. However, blunt dissection of the intercostal muscles and the serratus anterior proximally or the external oblique distally is inevitable in approaching the spine thoracoscopically (Fig. 17.1).

The skin incisions should follow the natural tension lines of the skin, running nearly parallel to the ribs. The length of the skin incision varies between 10 and 20 mm, depending on the size of the trocars (normally between 7 and 20 mm). The subcutaneous and muscular tissue is bluntly dissected. The thoracic cavity is entered riding on the superior rim of the corresponding rib, perforating the endothoracic fascia and parietal pleura with a blunt clamp (Fig. 17.3). The interpleural space should first be examined with the fingertip to exclude any pleural adhesions before the trocar is inserted. Flexible ports are widely used since the risk of irritation of the intercostal nerves is smaller than with rigid ones. Normally, the first port is placed in the sixth or seventh intercostal space irrespective of the planned procedure since it gives a good view of the entire hemithorax and the risk of injuring the diaphragm and its adjacent organs is minimal. The remaining ports, usually between two and four, are placed under direct thoracoscopic control.

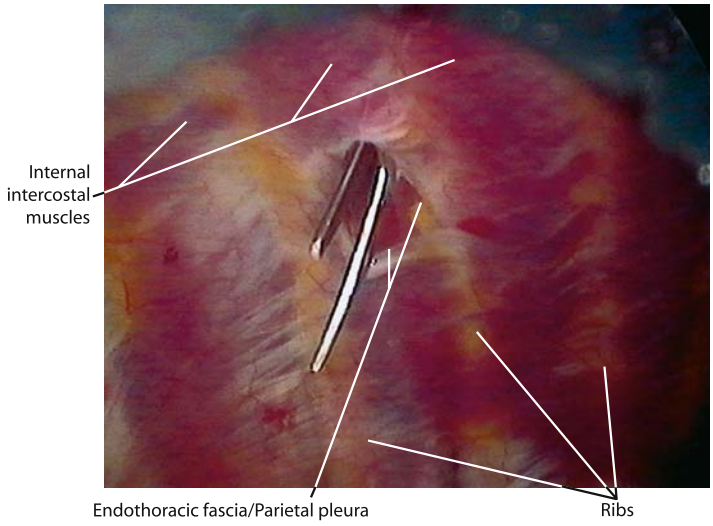


Fig. 17.3. Perforation of the intercostals muscles, the endothoracic fascia, and the parietal pleura prior to trocar placement (right-sided thoracoscopic view)

17.2. Thoracoscopic Anatomy

17.2.1 Internal Chest Wall

After entering the thoracic cavity, single-lung ventilation is established and the lung slowly collapses. The internal chest wall and its structures become visible (Fig. 17.2). Laterally, the thoracic wall is covered by the innermost intercostal muscles crossing more than one intercostal space. The lower internal chest wall is clothed posteriorly by the subcostal muscles, an inconstantly developed group of muscles, also spanning more than one intercostal space.

The sloping ribs can be identified by a narrow layer of fatty tissue, but are not directly visible (Fig. 17.3). More medially, the proximal parts of the ribs become visible with the internal intercostal muscles spanning the intercostal spaces. Posteriorly, they are replaced by the posterior intercostal membrane covering the fibers of the external intercostal muscles. The intercostal neurovascular bundles run along the inferior rim of the ribs (Fig. 17.2).

After further collapsing of the lung (either spontaneously or by manual lung retraction), the heads of the ribs and the anterior vertebral column become accessible (Fig. 17.4). By counting the ribs, the desired level can be identified. However, the first rib is rarely visible since it is surrounded by fatty tissue. It can be found by direct palpation and by localization of the adjacent subclavian vessels (Fig. 17.5).

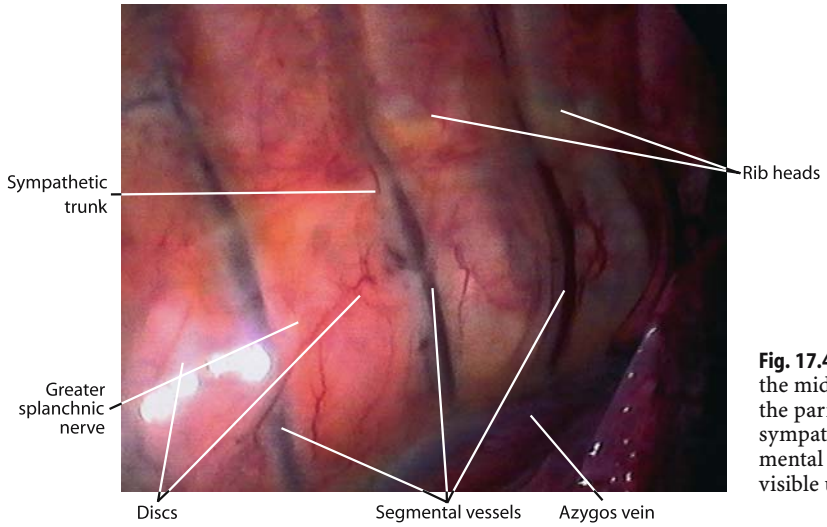


Fig. 17.4. Right-sided thoracoscopic view of the midthoracic vertebral column covered by the parietal pleura with the rib heads, the sympathetic trunk, the discs, and the segmental vessels draining into the azygos vein visible underneath

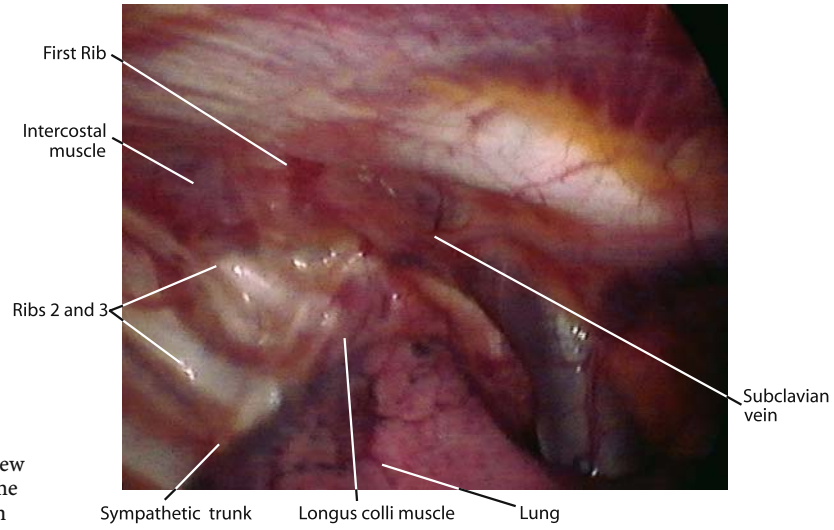


Fig. 17.5. Right-sided thoracoscopic view of the upper thoracic spine showing the first three ribs and the subclavian vein

17.2.2 Costovertebral Joints

The ribs articulate with the vertebral column in two places, i.e., by their tubercles (costotransverse joints) and by their heads (joints of the rib heads). Typically, each rib head possesses two articular facets and articulates with two vertebral bodies – the upper rib facet with the lower costal facet of the vertebra above and the lower facet with the upper facet of its own vertebra – spanning the corresponding disc space (e.g., the fourth rib articulates with the vertebral bodies of T3 and T4; Fig. 17.4). Therefore, the rib head needs to be removed in order to gain access to the epidural space (e.g., as in thoracoscopic discectomy). At T1, T11, and T12, however, the ribs articulate exclusively with their own vertebral body (Fig. 17.6). At these levels, removal of the superior portion of the pedicle is sufficient to enter the spinal canal.

Each rib head is attached by ligaments to the vertebral bodies or disc spaces. These structures have to be divided before the proximal part of the rib can be removed, which is necessary to gain access to the epidural space between T2 and T10. The intraarticular ligament links the ridge between the two rib head facets with the outer fiber of the intervertebral disc. The radiate ligament reinforces the joint capsule and consists of an upper and lower part, running to the cranial or caudal vertebra, as well as a central part which runs horizontally across the intervertebral disc to the anterior longitudinal ligament.

The costotransverse joints are attached by the costotransverse ligaments, of which the superior band runs to the transverse process of the cranially adjacent vertebra.

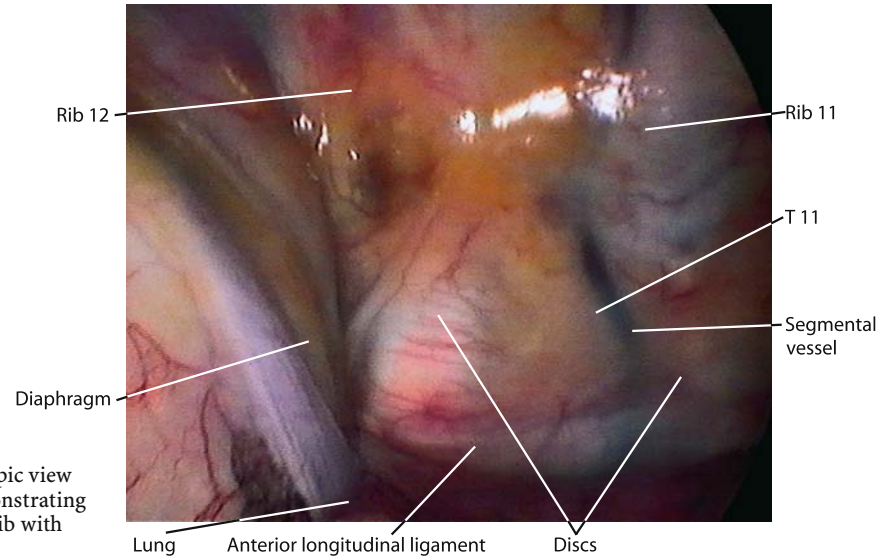


Fig. 17.6. Right-sided thoracoscopic view of the lower thoracic spine demonstrating the articulation of the eleventh rib with T11

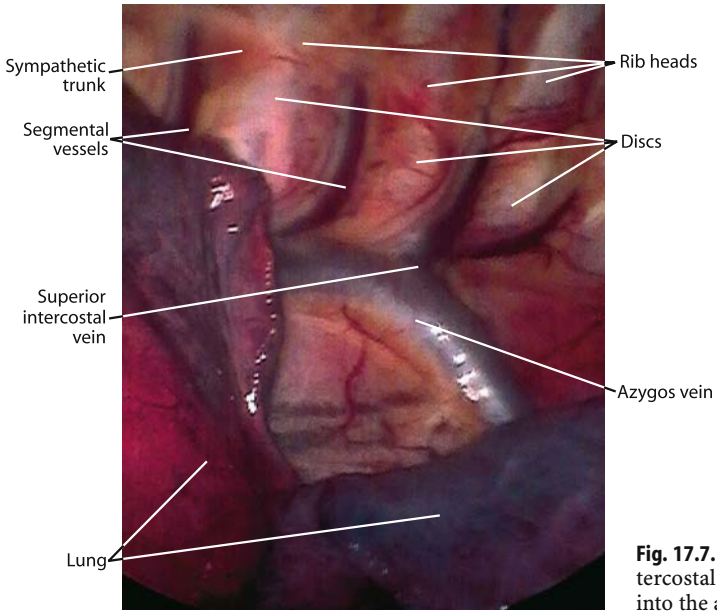


Fig. 17.7. Right-sided thoracoscopic view of the superior intercostal vein crossing the vertebral body of T4 and draining into the azygos vein

17.2.3 Pleura

The pleura consists of a thin fibrous membrane that clothes the entire thoracic cavity with its parietal and visceral layers. The parietal pleura is attached to the internal thoracic wall by the endothoracic fascia (Fig. 17.3). It covers the vertebral column and the mediastinum including the vessels and nerves (Fig. 17.4). The parietal pleura needs to be divided to gain access to the vertebral column. During dissection, it can easily be elevated in order not to injure the segmental vessels or the splanchnic nerves.

17.2.4 Vessels

On the right side, the segmental veins caudal to T4 empty directly into the azygos vein (Fig. 17.4). The second to fourth intercostal veins form the superior intercostal vein that normally crosses T4 before draining into the azygos vein. This typical formation of veins serves as an additional anatomic landmark (Fig. 17.7). The first intercostal vein empties directly into the brachiocephali vein. The azygos vein crosses the right main bronchus before joining the superior vena cava, which later divides into the left and right brachiocephalic vein. The segmental arteries originate from the thoracic aorta.

On the left side, the upper five segmental veins empty into the accessory hemiazygos vein and the lower into the hemiazygos vein. Both communicate with each other and drain into the azygos vein at the level between T7 and T9. However, neither of the hemiazygos veins are visible due to the descending thoracic aorta that runs close to the vertebral column.

17.2.5 Sympathetic Trunk

The thoracic sympathetic trunk runs just laterally to the vertebral column, crossing the heads of the ribs (Figs. 17.4, 17.7). It originally possessed 12 ganglia, however, due to fusion of adjacent ganglia, there are normally fewer. Branches from each ganglion form the greater splanchnic nerve (fifth to ninth ganglia) and the lesser splanchnic nerve (tenth and eleventh ganglia) (Fig. 17.4). They cross the vertebral column in the lower thoracic spine and join the azygos or the hemiazygos vein before passing the diaphragm.

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Principles of Endoscopic Techniques to the Thoracic and Lumbar Spine

18

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18.1 Terminology

This chapter describes the principles of endoscopic surgical techniques of the thoracic and lumbar spine. Endoscopes are rigid (straight or angled) or flexible systems that provide visualization, light, and magnification to anatomical areas thereby avoiding larger open incisions. Current spinal endoscopic exposures include: (1) posterolateral (arthroscopic microdiscectomy, AMD) and interlaminar (microendoscopic discectomy, MED; Medtronic Sofamor Danek, Memphis, TN) approaches for lumbar discectomy and neural decompression; (2) transperitoneal and retroperitoneal laparoscopic techniques for lumbar interbody fusions; (3) lateral and prone thoracoscopic methods for anterior release in scoliotic and kyphotic deformity, discectomy for decompression/fusion, and anterior thoracic instrumentation; and (4) lumbar epiduroscopy for lysis of adhesions in pain management.

18.2 Surgical Principle

The principal purpose of these minimally invasive endoscopic techniques is to approach the spine through portals rather than larger skin incisions. At the target site, the same operative procedure is performed using an endoscopic approach as is performed using an open approach, the difference being a smaller, less invasive access. Benefits include decreased soft tissue disturbance leading to lesser postoperative scarring, pain, and reduced ultimate healing time.

18.3 History

In 1807, in Frankfurt, Germany, Bozzini was the first recorded individual to use an endoscope. Known as the "Lichtleiter", this device used candle illumination to examine body orifices [7]. Lens and light amplification improvements followed. In 1901, Ott used a cystoscope to visualize structures within the pelvis [38]. Kelling, in 1902, was the first to induce pneumoperitoneum in dogs [25]. Oxygen, followed by carbon dioxide, was used for insufflation. In 1938, Veress developed the insufflation needle that bears his names and is still in use today.

Throughout the 1920s, Jacobaeus, in Sweden, was the first to perform both laparoscopic and thoracoscopic procedures in humans [19, 20]. He used a cystoscope and a heated platinum lighting loop. Intrapleural pneumolysis was performed on patients with tuberculosis.

A "myeloscope" was first used to visualize the spinal cord in 1932 [6]. In 1938, a myeloscope was used to view the dorsal nerve roots of the cauda equina and was associated with a high rate of morbidity [40]. In 1946, aspiration biopsies of the disc space were performed in patients with sciatica [30]. Craig utilized the posterolateral approach to obtain vertebral body specimens through a cannula to protect the surrounding anatomical structures [9]. Discography was introduced by Smith in 1964, subsequently leading to the injection of chymopapain [50]. In 1973, Kambin modified Craig's instruments to perform an indirect percutaneous canal decompression through a posterolateral extracanal approach [22]. He subsequently coined the term "triangular working zone" (the optimal portal entry area: inferior to the exiting nerve, lateral to the traversing nerve, and superior to the caudal adjacent vertebral body) through which a 6.5-mm cannula can be positioned to avoid injury to the surrounding neurological structures [23, 24]. In 1975, Hijikata developed instruments for percutaneous nucleotomy [16]. Hausman, in 1983, used a nucleoscope to assess for the presence of retained fragments after open discectomy [15]. In 1991, Schreiber and Leu were the first to carry out a biportal percutaneous discoscopy [49].

With improvements in medical management of tuberculosis, closed biopsy techniques, and general anesthesia for open techniques, interest in thoracic endoscopic approaches had waned from 1960 to 1990. In the early 1990s, renewed interest was experienced in thoracoscopy for the inspection and treatment of pleural diseases and for endoscopic pulmonary resection. During

these procedures, the excellent visualization of the thoracic spine was recognized.

Thoracoscopic spine procedures began with the drainage of an intervertebral disc abscess [31, 42]. The majority of thoracoscopic procedures are performed in the lateral decubitus position which requires a dual lumen endotracheal tube for selective lung ventilation. Indications include: anterior release of large (greater than 80°) and fixed (corrects to less than 60° with push-prone views) curves; Scheuermann's kyphosis greater than 90° which fails to correct to less than 50° with hyperextension over a bump; anterior fusion in skeletal immaturity to decrease the incidence of postoperative crankshaft; and decompressive discectomy and corpectomy. Endoscopic anterior instrumentation has been developed. The problems encountered include difficulties performing compression or distraction and rod rotation.

The recent introduction of the prone position for thoracoscopic spinal procedures offers benefits including a more familiar orientation, gravity-assisted retraction, gravity-assisted correction of kyphosis, the elimination of the need for repositioning, and the use of a standard single-lumen endotracheal tube [27, 52]. Simultaneous posterior exposure and prone thoracoscopic release as been reported [29].

In 1991, Obenchain and Cloyd described laparoscopic lumbar discectomies [37]. Transperitoneal laparoscopy is performed in a supine position accessing L3-4, L4-5, and L5-S1. Laparoscopic instrumentation with BAK cylindrical interbody devices (Sulzer Spine Tech, Minneapolis, MN) was first reported in 1995 [57]. Retroperitoneal, lateral disc exposure can be used for access to L4-5 and above [5]. Thalgott has described a balloon-assisted endoscopic retroperitoneal gasless (BERG) technique allowing the use of conventional instruments and avoiding the complications of carbon dioxide insufflation [53]. Lateral endoscopic retroperitoneoscopy has been described with an apparently reduced risk of small bowel adhesions and autonomic plexus dysfunction [34]. Performed in the lateral decubitus position, the intra-abdominal contents "fall away" from the spine.

Midline, posterior, interlaminar lumbar endoscopy (MED) was proposed and developed by Foley and Smith [12]. A tubular retraction system can be used with either an endoscope or a microscope. The tube can be angled to allow bilateral bony and ligamentous decompression under the midline while preserving the supraspinous and interspinous ligaments and the contralateral musculature [39].

Endoscopy within the spinal canal, "epiduroscopy" with navigation of the flexible scope via the hiatus sacralis, has seen some clinical interest and early application [46]. Determining the underlying pathology in chronic pain syndrome has often proved elusive. Morphological changes have been identified primarily in the form of epidural adhesions that may or may not be relevant to the generation of pain. Lysis of adhesions with mechanical instruments or a holmium:YAG laser and direct administration of medications can be performed [32, 46].

18.4 Technical Equipment

The endoscope consists of optical fibers and a light source. Each fiber in the coherent bundle delivers a separate piece of visual information to a camera and a video-integrated system. The camera processes the multiple image components into picture elements that are called "pixels". To increase picture quality and clarity, the number of optical fibers and pixels would have to be increased. Given the size constraints of an endoscope, an increase in the number of optical fibers would require a decrease in fiber size. However, if the fiber becomes too small, the capacity to transmit light is significantly impeded. Presently, the maximum number of pixels in a camera system given the size constraints of the straight 10-mm-diameter thoracic or lumbar endoscope is 30,000. Zero and 30°-angled scopes are most commonly used. Flexible scopes, for intradiscal and intracanal navigation, contain pull wires to allow bending and steering capability. Some endoscopes contain suction and irrigation ports. Within the epiduroscope, the imaging bundle diameter is 1.2 mm with 10,000 camera pixels with visualization that is not always optimal.

Imaging advances have assisted minimally invasive strategies. Fluoroscopy is utilized in laparoscopic and posterolateral and interlaminar lumbar endoscopic procedures. In laparoscopic interbody fusions, the exact midline of the disc must be identified using a true AP fluoroscopic image with symmetrical pedicles and flat endplates. Radiation safety precautions should be followed to minimize the risks while working under fluoroscopy. Total exposure time should be kept to less than 1 min, and image memory rather than continuous fluoroscopy should be used. To decrease scatter, the beam should be collimated. Lead of at least 0.5 mm thickness should cover the chest, abdomen, thyroid, gonads, marrow organs, hands, and eyes. Total whole body exposure should be less than or equal to 5 rem or 1 – 1.7 min/case [47].

Frameless stereotaxy, developed in 1992, was initially designed for intracranial use. The technique links the anatomy to a preoperatively acquired image. In endoscopic approaches, navigational systems have been difficult to apply because of problems with registration (precisely correlating anatomical landmarks with image reference points). External landmarks are not reli-

able as implanted fiducials for registration. A frame, attached to a percutaneously placed pedicle screw can serve as a stable, fixed reference. The frame of reference is placed percutaneously and a CT scan is subsequently performed. Registration, using the geometry of the frame as fiducials, has been successful when used with endoscopic spine surgery [2, 3].

Intraoperative nerve monitoring can assess for nerve compression or irritability. Mechanically elicited EMG activity recorded in the muscles innervated by the lumbar nerve roots can alert the surgeon to nerve proximity.

18.5 Advantages

The advantages of endoscopic over traditional techniques include diminished pain, improved healing, and enhanced visualization. The entire operating team is able to watch the monitor during the procedure.

Using posterolateral AMD, local anesthesia with intravenous sedation is possible. However, not all patient are able to tolerate the prone lying position for the length of time required for the surgery. The minimal dissection of the posterior paraspinal muscles decreases postoperative pain and narcotic use. In addition, by avoiding direct canal entry, there is a decreased epidural vein disruption and decreased perineural scarring [8]. Lastly, should reherniation occur, preferential migration of the disc material through the posterolateral arthroscopic portal area might be less likely to cause neurological impingement.

With thoracoscopy, it is possible to visualize from T4 to L1 and thoracoscopic right or left approaches are possible. Compared to open procedures, thoracoscopic techniques cause less acute and chronic postoperative pain and intercostal neuralgia with improved pulmonary function [10, 36]. In addition, improved shoulder girdle strength and range-of-motion [36], decreased cost, and reduced hospital stay have been reported with the thoracoscopic technique [10, 14].

In retroperitoneal endoscopy, the peritoneum is left intact decreasing the postoperative complications related to manipulation of the bowel and disruption of the peritoneum. During these approaches, the intact peritoneum serves as a retractor aiding in the control of the bowel.

18.6 Disadvantages

Spinal endoscopic procedures are technically demanding, and require a dedicated effort to safely overcome the "learning curve." The vascular or thoracic surgeon and the spine surgeon should train together in the laboratory before performing live surgery on humans. The surgeon should always be prepared to convert the case to an open procedure with open laparotomy and thoracotomy instruments and vascular instruments close at hand.

Lateral thoracoscopy requires a double-lumen endotracheal tube and high airway pressures. Tube dislodgement and tracheal tears are possible complications. When approached from the convex side of a scoliotic curve, single-lung ventilation must occur in the smaller lung on the concave side of the curve. Large scoliotic curves (greater than 90°) result in a smaller chest cavity limiting the space available to perform the endoscopic procedure [36]. Patients with right idiopathic scoliosis have a more posterior aorta [51]. An open approach allows for a circumferential exposure of the spine to place a finger around the side opposite to protect the far-side vasculature during placement of screws. With thoracoscopic fusion, such protection is not possible.

Prone thoracoscopy uses double lung ventilation with decreased tidal volumes and increased respiratory rate. There is less anesthetic preparation time with prone versus lateral thoracoscopy [27,52]. Postoperative oxygen requirements are decreased with double-lung versus single-lung ventilation [52]. The lateral position must be used for discectomy above T4 using an axillary portal anterior to the pectoralis major.

In transperitoneal laparoscopy, insufflation is required for visualization. In order to maintain pneumoperitoneum, the use of suction is limited. Carbon dioxide insufflation can cause elevation of the mean arterial pressure and hypercapnia (secondary to increased CO_2 absorption and decreased diaphragm movements) and CO_2 embolism. Despite a Trendelenburg positioning and the use of multiple ports, the small bowel remains a problem. Vascular mobilization can be difficult. Routine preoperative magnetic resonance imaging or CT scanning can be used to classify vascular anatomy [28]. The iliolumbar vein, should be identified, mobilized, and ligated for exposure to the L4-5 level. If the bifurcation of the great vessels is above the L4-5 disc space, a laparoscopic approach to L4-5 is technically easier. With lateral retroperitoneal laparoscopy, the psoas is often very large. A muscle splitting approach through the psoas may lead to injury of the genitofemoral nerve or elements of the lumbosacral plexus.

In AMD, the L5-S1 is difficult to approach, particularly in the male patient with a high-riding iliac crest.

18.7 Indications

These are no different than for open procedures.

18.8 Contraindications

Previous operative interventions may create scarring which effects tissue mobilization and visualization. Laparoscopic procedures are unable to visualize the neural elements and are unable to address spinal canal stenosis. Fusion for internal disc derangement with tall discs is a relative contraindication as it is more difficult to obtain adequate disc distraction. The larger interbody devices that would be required for fusion of tall disc spaces cannot be delivered laparoscopically.

Thoracoscopic procedures are usually contraindicated in those patients who have undergone multiple anterior thoracic procedures with expected scarring and adhesions. Patients with neuromuscular deformity and a history of pneumonia or empyema may have thick pleural adhesions. Those patients with restrictive lung disease will be unable to tolerate single-lung ventilation.

Arthroscopic lumbar microdiscectomy is not recommended when disc fragments have migrated or in cases of cauda equina. Obesity represents a relative contraindication, as arthroscopic cannulas might have insufficient length.

18.9 Complications

Lateral thoracoscopy requires single-lung ventilation. Correct placement of the double-lumen endotracheal tube followed by confirmation with fiberoptic bronchoscopy is necessary. The tube can be dislodged when turning the patient from the supine to the lateral position. Intercostal neuralgia after thoracoscopy is not uncommon, occurring in approximately 7% of patients [33]. Softer, flexible trocars have helped reduce the development of intercostal neuralgia.

Perforation of the diaphragm and parenchymal lung injury are best avoided by directly visualizing the instruments when introduced into the chest cavity. The sixth or seventh intercostal space is the safest region for entry for the first thoracic port. All subsequent port placements should be performed under direct visualization. With endoscopic instrumentation, screw pullout at the cephalic screw is usually the result of poor screw placement and unicortical purchase. Tension pneumothorax secondary to over advancement of a guide wire during instrumentation has been reported [45].

Laparoscopic complications include vascular and peritoneal/visceral injuries. In a study comparing laparoscopic versus mini-open approach, the complication rate was 20% in laparoscopic versus 4% in mini-open [56]. Sixteen percent of the laparoscopic approaches have been considered "inadequate", allowing one rather than two cages to be placed [56]. Approximately 10% of laparoscopic procedures require conversion to open for repair of vessel lacerations or to close tears in the peritoneum [11, 43]. During laparoscopy, the insufflation pressure should be decreased to 10 mm Hg or less during stages within the case to check for areas of venous bleeding that could otherwise go unrecognized at case completion. Retrograde ejaculation rate among males is high after laparoscopy: 16–25% [11, 28] compared to a 6% rate with mini-open [21]. Avoiding monopolar electrocautery and limiting the degree of dissection along the left side of the aorta and the left iliac artery may help to minimize the risk of ejaculatory dysfunction [28]. Ureteral injury has been reported [13]. During transperitoneal laparoscopy, the sigmoid colon mesentery is approached from the right. The right ureter, traveling over the right iliac artery, must be identified before making the posterior peritoneum incision. In lateral endoscopic transpsoas approaches, a 30% rate of transient paresthesias in the groin/thigh region has been reported [4].

After AMD, 16% of patients may experience moderate to severe hyperpathia secondary to dorsal root ganglia irritation from mechanical pressure of the cannula or local space-occupying fluid extravasation within the triangular working zone [41]. This complication occurs more commonly in procedures lasting over 90 min [41]. Typically, the symptoms are transient and improve with administration of a steroid with a tapering dose.

18.10 Conclusions and Critical Evaluation

Thoracoscopic procedures have been compared to open procedures in clinical and laboratory studies. Thoracoscopic discectomy for release/fusion is equal to the open technique in the percentage of disc removal (76% for open, 68% for thoracoscopic) [18] and in the adequacy of the biomechanical release [54]. In scoliosis anterior release/fusion, the percent curve correction, blood loss, and complication rate are similar when comparing open and endoscopic methods [17, 36, 52]. The endoscopic technique was 28% more expensive, reflecting the expensive disposable tools [35]. Thoracoscopic release procedures require a 50% longer operating time compared to open thoracotomy [51]. The "learning curve" demonstrates improvement in operating times with early thoracoscopic release taking 29 min/disc level, improving to 22 min/level with experience [35]. Thoracic disc excision for radicular and myelopathic patients have demonstrated a 70% clinical success with a mean operative time of 173 min, blood loss of 259 cc, and average hospital stay of 4 days [1].

There is no significant difference between mini-laparotomy versus laparoscopic approach when comparing analgesia requirements, time to resuming oral intake, or the length of hospitalization [44, 56]. The complication rate was significantly higher in the laparoscopic group, 20% versus 4% [56]. Laparoscopy cost more ($1,374/case on average) [44]. Laparoscopic operative time averages 167 min for single level and 215 min for multiple levels [28]. Average blood loss is 124 cc [28].

Posterolateral AMD has not reached "main stream" use within the spine surgery community. The technique continues to have vigorous advocates whose outcomes are similar to open microdiscectomy. A good to excellent outcome has been reported in 85–90% of patients and poor outcomes in 10%, [24, 55] with a complication rate of 3.5% after AMD [55].

Comparing MED and traditional open techniques for spinal canal decompression, one study reported 109 min/level average operating time for MED (versus 88 min/level for open). MED patients required an average 42-h postoperative stay (versus 94 h) and resulted in 68 cc blood loss (versus 193 cc) [26]. Less mechanically elicited nerve irritation was recorded on EMG monitoring with the MED technique [48]. Endoscopic spinal procedures are a relatively recent addition to the spine surgeons armamentarium. The techniques offer the surgeon enhanced visualization of the operative target site with less skin, soft tissue, and muscle disruption. While there are definite benefits, these procedures are technically challenging and there are associated risks (Tables 18.1–18.3).

As new modalities are developed, care should be directed to prevent inventing new indications to justify the technique. The core indications for surgical intervention should not change and should remain rooted in basic surgical principals. Expect and prepare for a "learning curve." Endoscopic technology will continue to evolve through merging with biomedical advancements in robotics and image guidance systems.

Table 18.1. Thoracoscopic spine summary

Improved visualization
Less tissue dissection to accomplish approach
Similar discectomy extent and release capability when compared to open thoracotomy
Large (greater than 90°) scoliotic curves create smaller available "working space"
Unable to perform a circumferential exposure for far-side tissue protection
Difficult but improving anterior instrumentation
Lateral positioning Double-lumen endotracheal tube Single-lung ventilation
Prone positioning Double-lung ventilation Simultaneous anterior/posterior procedures

Table 18.2. Laparoscopic spine summary

Anterior interbody fusion
Requires CO_2 insufflation Elevated mean arterial pressure Hypercapnia Embolism Unrecognized venous bleeding
No direct canal decompressive capability
Interbody graft size/shape limitations
Experience assisted the development of mini-open laparotomy techniques
Prone Transperitoneal L4-5 and L5-S1 Vessel mobilization Retrograde ejaculation Ureter injury
Lateral Retroperitoneal L3-4 and more cephalic levels Psoas, genitofemoral, and lumbosacral plexus injuries

Table 18.3. Lumbar posterior decompressive endoscopic summary

Posterolateral AMD Similar outcomes as microdiscectomy Minimize epidural dissection and scarring Hyperpathia, dorsal root ganglia irritation Not recommended: Migrated disc fragments Cauda equina Degenerative osteophyte formation with lateral recess stenosis
Interlaminar MED Bilateral decompression through a unilateral approach

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19 Biomechanical Requirements in Minimally Invasive Spinal Fracture Treatment

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19.1 Anterior Spinal Stabilization

Several instrumentation systems and operative techniques for the operative treatment of fractures of the spine have been developed and marketed in the past. The surgical goals are decompression of the spinal canal, reduction of spinal deformities, and maintenance of stable fixation of the spine to permit early mobilization.

Recent biomechanical studies have reported the mechanical characteristics and primary stabilities of several anterior, posterior, and combined instrumentation systems in worst-case models [10, 21, 33–37, 41]. Bone grafting and single ventral instrumentation has been shown to be more effective in restoring acute stability than single dorsal instrumentation [36]. Despite this, dorsal implants have become a staple in the treatment of fractures without neurological deficit for their decided advantages. In the treatment of fractures with spinal cord compression, posterior instrumentation may provide indirect decompression of retropulsed intracanal bone fragments with ligamentotaxis through distraction. However, reduction of intracanal bone fragments by indirect decompression leaves uncertain the degree of ligamentous continuity to the fragment, retropulsion of the fragment, and the displacement pattern of the fragment. These criteria are difficult to assess preoperatively and result in variable degrees of reduction. Short segment pedicle instrumentation techniques have also been associated with loss of reduction and instrumentation failures, particularly at the thoracolumbar junction [7, 10, 11, 22, 39].

Often a second anterior intervention is necessary and is associated with greater approach-related trauma, increased blood loss, a higher risk of infection, and the problem of screw hold in the ventral vertebral body. Also anterior surgery is technically demanding and is not generally a familiar procedure to orthopedic surgeons, especially under emergency conditions [12, 18, 42, 43].

Suitable anterior instrumentation systems, however, have demonstrated biomechanical in vitro superiority compared to single dorsal [36]. Also the direct anterior approach provides an optimal visibility environment for recovery of the neural tissue and allows reconstruction, alignment, and immediate stabilization of the anterior load-bearing column through strut grafting [1, 12, 18, 34–36, 41–43].

The desirable intervention seems to be an initial ventral decompression and stabilization endoscopically and thoracoscopically to minimize the approach and other complications related with conventional anterior intervention, and to maximize the advantage due to an optimal visibility environment for recovery of the neural tissue and stabilization.

A single endoscopic intervention and stabilization may also prevent a second-stage procedure with the result that hospital stay is shorter and return to work is sooner. Previous investigations have focused on degenerative diseases of the spine, showing the advantages of endoscopic techniques to be striking in safety and cost [2–5, 8, 9, 13–17, 20, 29–32, 38].

19.2 Minimally Invasive Anterior Techniques

Minimally invasive techniques are becoming more widespread in the surgical subspecialties. Standard open surgical procedures are being modified to become less invasive, with the intention to reduce recovery time, reduce morbidity, and ultimately expenditures. Improvements in technology have allowed the surgeon to encroach body cavities and create potential spaces, such as the retroperitoneum, by diaphragm splitting [2]. Improved fiber optics, light sources, and the advent of the 3-chip camera have resulted in improvements in visualization of the structures surrounding the spine. Although the goals of endoscopic surgery are to maintain or improve visualization and minimize the approach-related trauma, procedures must also prove efficacious and safe with at least equivalent results compared with their open surgical counterpart [2–5, 8, 9, 13–17, 19, 20, 23–25, 29–34, 37, 38]

The indications for endoscopic spinal surgery are degenerative diseases, infection, tumor, fracture, and ventral release for scoliosis and kyphosis. Preliminary

results are encouraging, but further testing of these new techniques against conventional open procedures will be important. [3, 20, 33 – 35, 37, 38]

The small incisions with reduced soft tissue dissection will reduce postoperative pain, hospital stay, costs, and improve cosmetic and functional results. Thoracoscopic vertebrectomies and reconstruction of the spine are technically feasible procedures being performed with excellent clinical results [3, 20, 33 – 35, 37, 38]. This minimally incisional technique provides a feasible alternative to thoracotomy or to posterolateral approaches for thoracic vertebrectomy and vertebral body reconstruction or replacement.

Especially in fracture treatment with the necessity of spinal decompression, sometimes over several vertebral segments, long-distance overbridging by strut graft and stabilization plays an important factor, but accommodated instrumentation systems are lacking until a new system has been developed [3, 5, 20, 25, 29, 33 – 35, 37, 38]

Formerly the Z-plate (Medtronic Sofamor Danek, Minneapolis, USA) was used [5]. The Z-plate normally is intended for an open implantation technique. Only time-consuming improvisations, such as screw fixation with twine to prevent loosening, allow its applicability in these cases [5]. Furthermore reduction through a single anterior approach in combination with this implant is not possible without an initial or transitorily posterior intervention. This adds to complication rates and sacrifices the posterior spinal musculature directly or through longer-term atrophy.

McAfee, Regan and Bühren [5, 25, 29] concluded that the limiting factor in the wide application of the endoscopic technique is the absence of a commercially available internal fixation system for this endoscopic approach. This agrees with the results of Connolly who compared the video-assisted thoracic surgery (VATS) technique with the open procedure in a comparative biomechanical test performed with a porcine corporectomy model [6].

The established standard for thoracoscopic intervention at the moment is performed after initial or transitorily transcutaneous dorsal intervention and reduction and secondary mono- or bisegmental ventral strut grafting with overbridging by four-point stabilization with the newly developed MACS TL (Modular Anterior Construct System Thoracic Lumbar; Aesculap, Tuttlingen, Germany) [3, 5, 20, 33 – 35, 37, 38].

19.3 Biomechanical Aspects

The challenge of endoscopic implants is to provide the same measure of mechanical stability provided by conventional systems while working within a smaller scale. In these cases, the overbridging implant contributes the most to the stability until healing is achieved. This also emphasizes the importance and necessity of enhanced screw hold in the adjacent vertebral bodies of the overbridging implant.

Four open biomechanical questions had to be discussed:

1. Is single anterior stabilization strong enough in contrast to posterior or combined instrumentation?
2. Which fixation technique is biomechanically necessary in cases of single mono- or bisegmental ventral stabilization?
3. Are newly developed approach-related smaller implant dimensions strong enough?
4. How to enhance the anterior screw hold, especially in osteoporotic vertebral bodies?

Biomechanical tests according to the recommendations for the standardization of in vitro stability testing of spinal implants have been performed with a corporectomy model to clarify the aforementioned questions [23].

19.4 Biomechanical Testing: Overview

19.4.1 Standardized Biomechanical Testing Conditions

All biomechanical tests were performed according to the recommendations for the standardization of in vitro stability testing of spinal implants using human spine specimens. Based on pure moment testing, these methods most readily allow the numeric comparison with other studies [41].

Six human specimens, T10-L2, were selected for each biomechanical test. Trabecular bone mineral density of the anterior vertebral body was measured by pQCT at each level in a horizontal plane (XCT-9600 A pQCT; Stratec, Birkenfeld, Germany). Before testing, the fresh-frozen specimens were thawed at room temperature. In preparation, surrounding soft tissue and muscle were dissected with care to preserve bone, discs, and spinal ligaments and during testing the specimens were kept moist with saline. T10 and L2 were potted in polymethylmethacrylate (Technovit 3040; Heraeus Kulzer, Wehrheim/Ts, Germany) for fixation in the custom spine tester (Fig. 19.1a) [40].

Testing in flexion/extension, lateral bending, and rotation was first performed on the intact specimens. Stabilization was performed after creating the appropriate defect (corporectomy or vertebrectomy) and strut grafting between the vertebral bodies proximally and distally.

Each device was implanted according to the insertion instructions provided by the manufacturer with maximal axial preload affected through the overbridg-

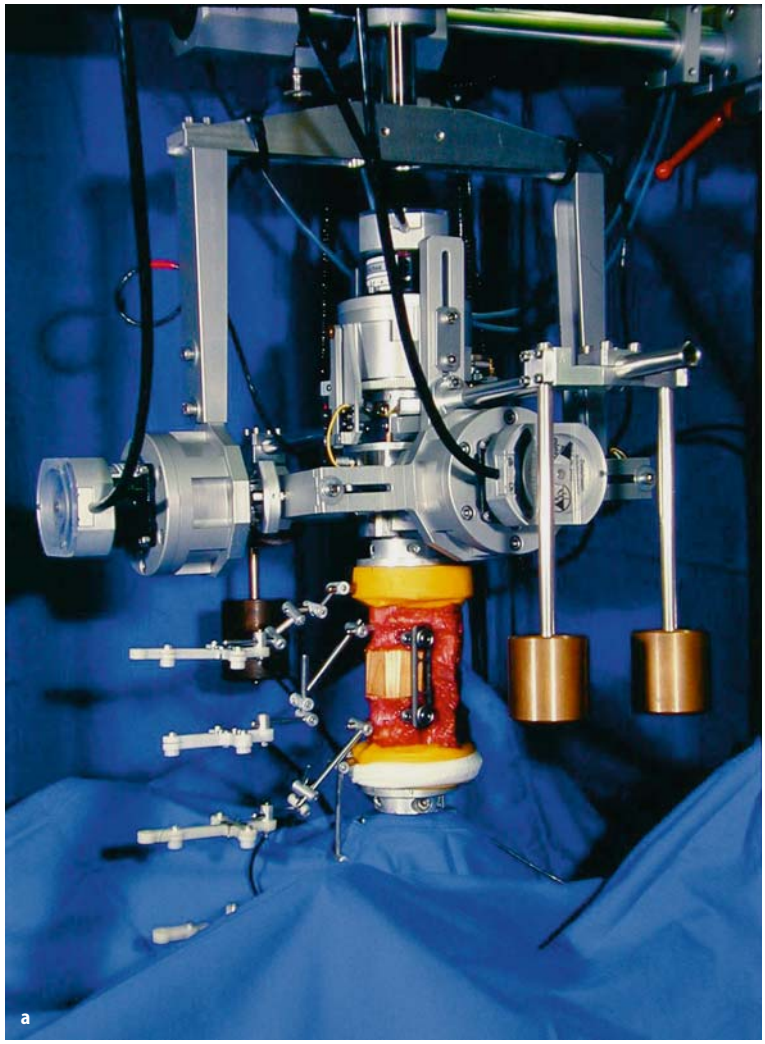




Fig. 19.1. a Spine tester. **b** MACS TL Polyaxialscrew XL system

ing implant on the strut graft. Proper placement was verified by X-ray.

Biomechanical testing was performed in a spine tester which provides controlled moment loading in one plane and unconstrained motion in free space [41]. Pure moments from –3.75 to 3.75 Nm were applied in flexion/extension (My), right/left axial rotation (Mz), and right/left lateral bending (Mx) at a constant rate of 1.7°/s without axial preload. Resulting three-dimensional displacements were measured intact and after corporectomy between all adjacent segments with an ultrasound motion measurement system (Cmstrao 1.0; Zebris, Isny, Germany). Data were recorded on the third cycle. From the load-deformation curves, range of motion (ROM) and neutral zone (NZ) were determined for the angles alpha, beta, and gamma around the *x*, *y*, and *z* axes for T11-L1 [26–28, 41]. Range of motion was defined as the angular deformation at maximum load. Neutral zone was defined as the mobility in unloading phases of the test cycle.

19.4.1.1 Is Single Anterior Stabilization Strong Enough in Contrast to Posterior or Combined Instrumentation?

19.4.1.1.1 Hypothesis

The first in vitro study investigated the biomechanical properties of single anterior, single posterior, and combined intervention in a worst-case model of corporectomy with clinically established systems [36].

Additionally the load sharing between the overbridging implant and supporting strut graft was measured indirectly by the axial compression force acting through the strut graft. Load sharing is perhaps the most important factor for bone healing and thus for avoiding implant failures.

19.4.1.1.2 Materials and Methods

Biomechanical in vitro testing was performed using the Fixateur interne as posterior instrumentation and the Kaneda SR as anterior system [36]. In order to measure the forces transmitted through the spinal column after corporectomy of a vertebral body, including adjacent discs, the resulting defect was replaced by a six-component load cell. This load cell provided the same contact area as a bone strut graft, such as tricortical iliac crest at its ends. The contact surface was rough. Its length was adjustable with thin metal slices in 1-mm steps.

Specimens were tested in the following sequence:

1. Intact spine
2. Corporectomy + ventral stabilization
3. Corporectomy + dorsal stabilization
4. Corporectomy + combined stabilization

19.4.1.1.3 Results

After corporectomy and stabilization of the defect by the various implant systems, ROM and NZ of T11-L1 under flexion/extension, axial rotation, and lateral bending moments were consistently smaller than in the intact spine during maximal load of 3.75 Nm [36]. No axial compression force through the construct was measured during maximal extension with single dorsal stabilization. The measured axial compression forces found their correlates in the evaluated primary stability parameter. This motion stress acting at the strut graft–endplate interface may lead to delayed bony ingrowths, pseudarthrosis, or mechanical failure.

19.4.1.1.4 Conclusion

This biomechanical investigation demonstrated that in cases of burst fracture, strut grafting and anterior spinal fixation in the class of the Kaneda SR system provide more stability and load sharing between instrumentation and strut graft in comparison to single dorsal instrumentation.

In cases of complex circumferential instability, a combined approach may be necessary for restoration of the spinal column. A combined approach in this study reduced ROM twofold in lateral bending, fourfold in axial rotation, and fivefold in flexion/extension compared to single dorsal stabilization [36].

The overall stability of the instrumented spine correlates with the axial compression force acting across the strut graft. Therefore, a single anterior stabilization is biomechanically more sufficient than its dorsal counterpart [36].

19.4.1.2 How to Perform a Stable Mono- or Bisegmental Anterior Stabilization?

19.4.1.2.1 Hypothesis

This second study focused on the type of anterior instrumentation. Mono- versus bisegmental stabilization and two-point versus four-point anterior stabilizations were compared, as illustrated in Fig. 19.2.

19.4.1.2.2 Materials and Methods

The following biomechanical tests have been performed with the HMA System (two-point instrumenta-

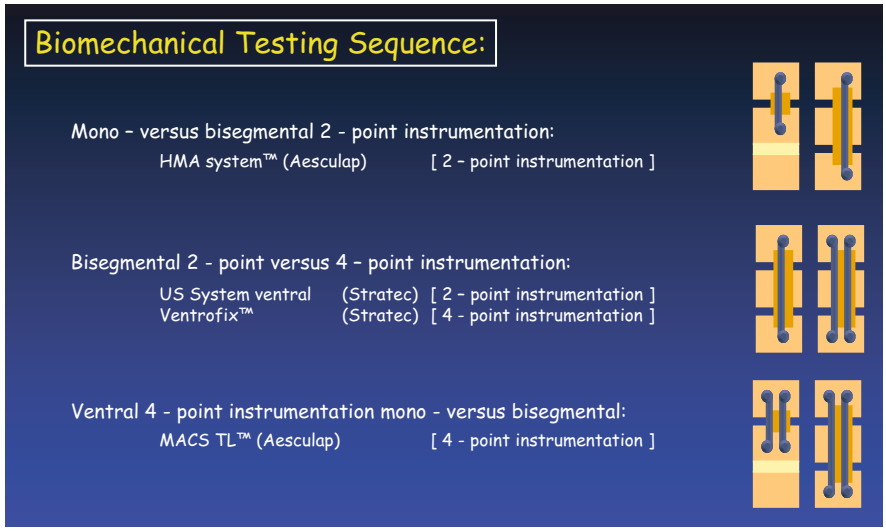


Fig. 19.2. Biomechanical evaluation

tion; Aesculap), the ventral US System with two and four screws (Ventrofix; Stratec, Umkirch, Switzerland), and the MACS (four-point instrumentation; Aesculap).

19.4.1.2.3 Results

Test sequence and the results are shown in Figs. 19.2 and 19.3.

19.4.1.2.4 Conclusion

A 1.5-fold decrease in primary stability was measured while stabilizing with two-point instrumentation, bisegmental compared to monosegmental stabilization.

Four-point ventral stabilization enhanced the overall ventral bisegmental stability by about 47 % in flexion/extension, 59 % in axial rotation, and 35 % in lateral bending in contrast to two-point bisegmental stabilization.

For all loading cases primary stability was nearly equal using a four-point stabilization of the MACS type ventrally for either monosegmental or bisegmental instrumentation.

19.4.1.3 Are Approach-related Smaller Implant Dimensions Strong Enough?

19.4.1.3.1 Hypothesis

A new thoracoscopically implantable four-point stabilization system for thoracolumbar fracture treatment with smaller implant dimensions has been developed (MACS TL; Aesculap) [3, 20, 33–35, 37, 38]. The hypothesis of this third section is that this new endoscopically anterior stabilization system improves the primary stability compared with an established conventional system combined within its smaller implant dimensions.

19.4.1.3.2 Materials and Methods

The Modular Anterior Construct System (MACS) allows an endoscopic approach and thoracoscopic instrumentation from T3 to L3. As a twin screw concept it consists of a rigid-angle stable monocortical anchorage due to two convergent polyaxial self-cutting screws in each vertebral body and a low profile plate or rods.

The clinically well established Ventrofix (Stratec, Umkirch, Switzerland) in comparison to the MACS was used for the biomechanical evaluation [33, 37]. Because two anterior systems have been tested, 12 human specimens T10-L2 have been randomized into the MACS group and the Ventrofix system group and the biomechanical tests were performed on 6 human lumbar spine specimens for each group. Specimens were tested in the following sequence:

1. Intact spine
2. Corporectomy + ventral stabilization
3. Corporectomy + USS dorsal

19.4.1.3.3 Results

In this study within the interbody graft and fixation devices, the MACS and the Ventrofix system showed stabilizing effects in the three primary directions in comparison with the intact spine [33, 37].

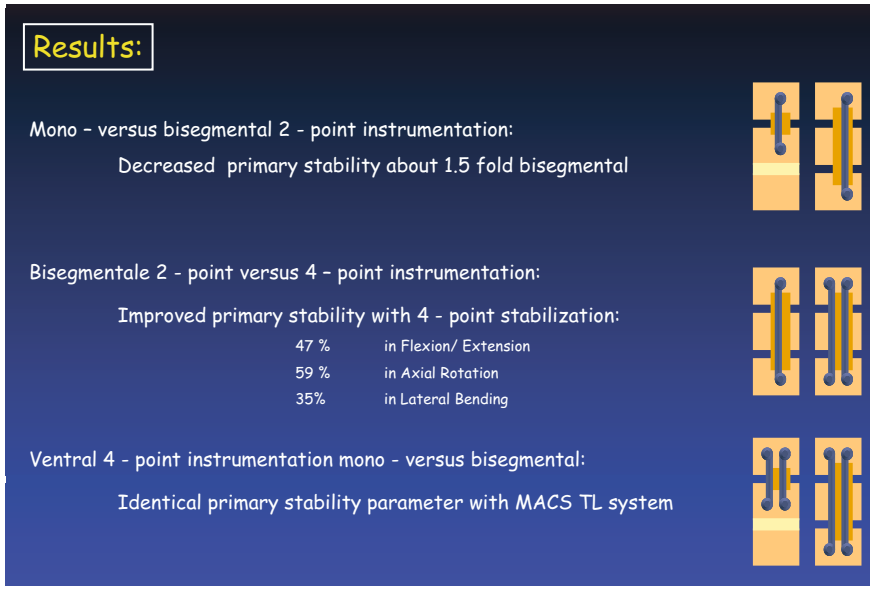


Fig. 19.3. Results

In flexion both systems achieved nearly the same ROM and NZ, however in extension the ROM of the Ventrofix was obviously higher. In left and right rotation there was no real difference concerning ROM and NZ at maximal load. In left and right lateral bending the results of the MACS were significantly better, achieving a high primary stability in comparison to the Ventrofix.

19.4.1.3.4 Conclusion

Overall, the primary stability of the endoscopically implantable MACS in comparison to the clinically well established Ventrofix system is equal or improved within smaller implant dimensions [33, 37].

19.4.1.4 How to Enhance the Screw Hold, Especially in Osteoporotic Vertebral Bodies?

19.4.1.4.1 Hypothesis

Screw fixation strength is a critical factor for the success of anterior spinal fixation, especially in osteoporotic vertebral bodies or those affected by metastases, but how can the screw hold be enhanced especially in osteoporotic vertebral bodies. In the case of poor initial screw hold, multisegmental stabilization is often mandatory, because there are no other options such as a "rescue screw" to achieve a rigid anterior fixation. These have been the reasons for developing a second anchorage device for the aforementioned MACS to be adapted for these circumstances. The new device is called MACS TL Polyaxialscrew XL [34, 35] (Fig. 19.1b).

The following study was investigated to clarify two questions:

1. Does the newly developed cementable Polyaxialscrew XL improve the primary stability of the anterior stabilization system when cemented or uncemented, compared to the conventional Twin Screw concept of the MACS TL system [34, 35].
2. Does the newly developed additionally cementable hollow screw dowel improve the primary stability of an endoscopically implantable anterior stabilization system and compensate for additional dorsal structure damage in a biomechanical in vitro model with increasing ventrodorsal instability [34, 35].

19.4.1.4.2 Materials and Methods

In the case of poor bone quality the Polyaxialscrew XL concept is an alternative to the Twin Screw concept of the MACS. The Polyaxialscrew XL can be implanted initially or as a second chance instead of the posterior screw of the Twin Screw concept. The self-tapping threaded hollow titanium screw dowel has a length of 30 or 40 mm. Through three slits along the longitudinal axis additional cementation after implantation is possible. Exactly 2 ml Osteopal (Merck, Germany) bone cement has to be used, a larger volume is not permitted by the cement applicator. Only this small amount of cement is needed to enhance the screw base, therefore potential problems with flowing off or cement heating do not appear to be of concern.

The significantly enhanced screw hold was demonstrated in axial pull out tests, in comparison to other screws, in a calf specimen before testing in a human model [34, 35]. Additional cementation enhanced the screw hold about 50 % in comparison with the uncemented XL Screw in an osteoporotic human specimen model [34, 35].

The new device was also tested biomechanically in the standardized biomechanical testing device [34, 35].

19.4.1.4.3 Results

The use of the uncemented XL Screw improved the overall stability in comparison to the Twin Screw by about 20 % [34, 35]. Additional cementation enhanced the overall stability in flexion/extension by about 41 %, in lateral bending by about 32 %, and in axial rotation by about 30 % in comparison with the Twin Screw system. In the case of ventral and dorsal instability the use of anterior stabilization with strut grafting and cemented MACS Polyaxialscrew XL system compensates for dorsal instability.

19.4.1.4.4 Conclusion

Specially adapted to the circumstances of osteoporotic bone, the Polyaxialscrew XL concept of the endoscopically implantable four-point MACS TL guaranteed a sufficient primary stability in thoracoscopic spinal surgery.

19.4.2 Conclusion

These biomechanical evaluations demonstrated the necessity of a ventral four-point stabilization of the MACS TL type for mono- or bisegmental instrumenta-

tion in endoscopic spinal surgery to achieve a sufficient ventral instrumentation.

The results demonstrated equivalent or improved primary stability between conventional open procedures and new, endoscopically implantable systems for different defect situations. As a consequence, the widely held reservation that an appropriately smaller device for endoscopic use necessarily would fail to meet stability requirements or fall short of that provided by established systems was proved unjustified.

Further experience is warranted and encouraged by published clinical results [3, 20, 38].

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20 Thoracoscopic Approaches in Spinal Deformities and Trauma

M. Dufoo-Olvera

20.1 Terminology

VATS: video-assisted thoracoscopic surgery

20.2 Surgical Principle

The evolution of surgical techniques has been parallel to the development of medicine and technology. In spine surgery, the complexity and delicate nature of the anatomy of the spine means that all new procedures are subject to a period of careful evaluation before being considered part of common practice in the treatment of spine-injured patients.

Development and discovery of new technical resources available to medical practice is a continuous process. Inclusion of microscopes and optical devices that can be inserted inside the human body through small incisions, and through which one can have a clear and amplified view of the surgical field, provide a benefit shared by the patients, physicians, and health institutions, since by improving quality of treatments, complication rates are reduced as well as the costs of the services rendered.

In spine surgery some of the optical resources mentioned have been included since the mid 1970s, as was the microscope in lumbar discectomy. In the 1980s the trend moved on with cervical and lumbar microdiscectomies assisted by lenses similar to the ones used in arthroscopic procedures. Finally in the 1990s, endoscopic techniques were incorporated, with which the thorax and abdomen surgeons had a great deal of experience. Currently there is a lot of work being done to optimize the use of the available resources, and a new stage is established in the history of spine surgery, giving opportunity for the creation and development of new surgical instruments and implants that are adapted to the new techniques of "minimally invasive surgical approaches."

By participating in the development of a new age in medical practice, one should give deep thought to some basic points to avoid making mistakes by just following a "fashion." The characteristics of the optical and surgical instruments have a limited use and institutions need adequate resources for their correct application and maintenance; one should never improvise. A multidisciplinary team should be gathered with enough training in the surgical procedure, anesthesiologists, thoracic surgeons, etc., and the surgeon must have enough formal training in the procedure to be performed.

The goals of "minimally invasive surgery" are to avoid damage to the tissue adjacent to the surgical field, to be considered as a feasible option to be familiar with in order to solve many of the problems at the outset, and to make the technique commonly used by spine surgeons.

The current concept in minimally invasive surgery is to cause the least damage to the tissues during surgical approaches. Video-assisted thoracic surgery (VATS) is a new procedure now being used in the spine when an anterior approach is indicated.

The anterior approach in spine surgery has long been accepted, its main advantage being that the vertebral structure has the major resistance to axial loads in its anterior portion and that the vertebral bodies and their soft structures, when deformed and retracted, present difficulties for a balanced recovery of the spinal axis [2, 4, 8–10, 15].

Diseases that rotate and deform the vertebral segments with severe functional and esthetic changes such as scoliosis, Scheuermann's kyphosis, hemivertebrae, and crankshaft deformities, can be treated with the VATS technique [31, 33].

Thoracic spine fractures due to axial compression and flexion with fragment displacement into the spinal canal have a high incidence of neurological damage, probably due to the narrow space available for the spinal cord and the nerve roots. Although stability is compromised to a lesser degree, the VATS anterior approach is a good option to perform treatment for both problems, decompression and stability restoration [34, 51].

The thoracoscopic technique is a new procedure for treating spine problems through an anterior approach. Direct thoracoscopy and video-assisted thoracoscopic techniques have been used for a long time by thoracic surgeons, pneumologists, and cardiologists with excellent results, so we should take advantage of that experience and use it to gain another useful tool in our practice [20,26].

20.3 History

It is generally accepted that the thoracoscope was originally a direct descendent of the cystoscope. Improved through the years in its optical mechanism and light source, it was used in the thoracic cavity in many tuberculosis cases as an instrument for exploration, diagnosis, and, latterly, as a therapeutic instrument to dissect pleural adhesions along with galvanocautery. Jacobaeus, a Swedish physician, is known as the pioneer of this technique.

One feature in the use of the direct thoracoscope is that visualization of the surgical field is limited to the surgeon, reducing the opportunity to receive any assistance from his surgical team. This problem is solved thanks to the technological development of video systems that allow a complete projection of the field onto the monitor. This fact generated widespread development of the minimally invasive technique and was broadly developed by different medical specialties, such as abdominal surgery, urology, gynecology, gastroenterology, and thoracic surgery [3, 16].

In 1991, Obenchain gave the first report of a lumbar disc resection through laparoscopy and, in 1994, Rosenthal reported a new technique for the removal of protruded thoracic discs using microsurgical endoscopy, and proposed the term microsurgical endoscopic technique (MET) [44]. The term video-assisted thoracic surgery (VATS) used by thoracic surgeons has been adopted since the beginning of its application in spine surgery. There are several subsequent reports of other procedures, such as the treatment for scoliosis, Scheuermann's disease, tumor resections, spinal decompression in fractures and nerve roots in degenerative processes, and, recently, in anterior approached stabilization systems and costal resection for correction of thoracic deformities [11, 46].

As you can see, the story does not end here; it has just begun.

20.4 Advantages

The advantages of minimally invasive surgical procedures can be divided into two groups, those related to the patient and those related to the surgical procedure itself.

20.4.1 Advantages for the Patient

- Small surgical wounds that cause less pain and allow early mobilization of the patient postoperatively.
- Avoidance of resecting costal arches that cause referred pain, frequently to the shoulder, and that limit respiratory movements producing restrictive alterations to respiratory function, including atelectasis.
- Pleural drains remain for shorter periods of time, and may not even be necessary [13, 23, 41].
- Shorter hospitalization and lower costs related to hospitalization [40].
- Decrease in postoperative complications.

20.4.2 Technical Advantages

- Magnified view of the surgical field with perspectives that can only be achieved through the endoscope's position, for example, viewing of the anterior and lateral surface of the vertebral body opposite to the site of the surgical approach.
- Adequate identification of blood vessels that may be easily displaced without cutting them, considerably reducing perioperative blood loss.
- Zooming in to the corporectomy with a frontal view of the dural sac and the origin of nerve roots.
- Considering the reduced trauma applied to adjacent tissues, a posterior approach can be performed when necessary.

20.5 Disadvantages

Some of the problems that could be considered as disadvantages are related to thoracotomy working habits. Reduced tactile feedback for the surgeon, the observation of a bleeding vessel and the feeling of being unable to apply digital pressure to it, as well as difficulties in repairing the dural sac are some examples of the changes the spine surgeon must learn to control.

It is also important to consider that the procedure requires interaction with multidisciplinary groups trained in the VATS technique, anesthesiologists, thoracic surgeons, etc., as well as non-medical assistant personnel, a factor that to date has limited its application in hospitals that could otherwise take advantage of this opportunity [50].

20.5.1 Limitations

At present, endoscopic surgery has its limitations, since it can only offer safe access to the thoracic segments from T1 to T12, and to the lumbar segments from L4 to S1, but there is much work being done in the development of newer techniques to reach the whole extent of the spine.

20.6 Indications

The indications for the use of this technique are almost the same as those for thoracotomy.

When attempting correction of deformities of the spine, the anterior approach has proved to be much better than the posterior approach. In the case of rigid scoliosis of more than 75° and three-dimensional deformities, soft tissues can be released to modify the frontal plane, the sagittal profile, and rotation, and the risk of neurological damage is decreased compared to when distraction forces are applied dorsally. The more recent techniques with the thoracoscopic approach allow the correction of thoracic deformities by partial resection of the costal arches [6, 12, 18, 27, 38, 43, 47, 49, 52].

In Scheuermann's disease, a sufficient reconstruction of the anterior spine can be achieved by releasing the structures that limit extension.

In neuromuscular congenital anomalies or skeletal immaturity that requires anterior fusion by arthrodesis, the endoscopic surgical procedure has many more advantages over thoracotomy.

Cases of neural tissue compression at the thoracic spine due to herniation of the intervertebral disc are very infrequent, but of great technical difficulty due to the risk of neurological damage, and may be considered as a specific indication for endoscopic surgery.

For spinal cord and nerve root decompression of traumatic, degenerative, or tumoral etiology, endoscopy has several advantages since it allows release and sufficient neurological exploration, it reduces risks, compared to thoracotomy, in patients with a deteriorated general status, and, in some cases, allows for anterior stabilization with the application of bone grafts and anterior fixation systems, avoiding the need for second surgery [8, 32, 40].

In all cases, the option of using a new technique will be directly related to the surgeon's capability, the problems to be solved, and the technological developments that provide new instruments and implants.

20.7 Contraindications

The main contraindications of these techniques are directly related to the inability to collapse a lung because of adhesions and the complications of single-lung ventilation. Other contraindications could be recent or active septic problems, or previous pleurostomy or thoracotomy [20].

20.8 Patient's Informed Consent

All patients undergoing a surgical procedure by the VATS technique must be aware of the etiology of their disease, the natural evolution, available treatment options, the risks involved in spine surgery, and the characteristics of thoracoscopic procedures, including the possibility of it leading to open surgery, before giving their signed consent (see also Chapter 18).

20.9 Surgical Technique

It is recommended that the operating room is large enough to accommodate all the hardware, such as monitors, so that in case you have to convert to an open procedure you will be able to mobilize all the instruments required, which must always be readily available [19, 21, 45].

20.9.1 Patient Positioning

The operating table must be radiolucent allowing biplanar fluoroscopic control. The patient is laterally positioned, depending on the side chosen to work on; the right-sided approach is recommended unless any technical contraindication prevents it (Fig. 20.1). The patient is positioned and padded by two cushions attached to the table, one on the dorsal and one on the ventral side. The legs are protected by soft cushions in order to avoid complications due to pressure and it is recommended that the lower knee is flexed at an angle of 45° in order to improve stability. Once the knees are protected from each other with a blanket, they are fasten with adhesive tape. It is also recommended that the pelvic area is fastened in the same way. The lower arm must be protected to avoid pressure and the upper one should be positioned on a support with the elbow flexed at 90°, being careful to avoid excessive traction of the shoulder. In this way, the patient can be placed in the Trendelenburg position or rotated without falling from the table. In some cases, the placing of a cushion in the medial thoracic area under the patient is recommended. This allows elevation at this point of the spine which opens the intervertebral spaces preventing the risk of neurological damage due to distention while folding the table [28].

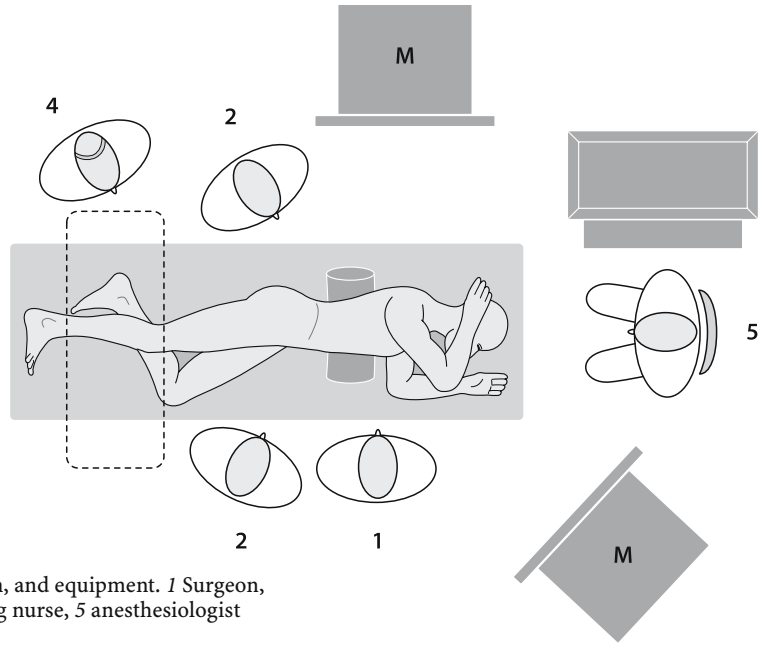


Fig. 20.1. Positioning of patient, surgical team, and equipment. *1* Surgeon, *2* first assistant, *3* second assistant, *4* assisting nurse, *5* anesthesiologist

20.9.2 Anesthetic Preparation

In some cases, local anesthesia might be recommended for thoracoscopic procedures. In the VATS procedures on the spine, endotracheal general anesthesia is indicated with a double-lumen tube or bronchial blockers to induce collapse of the lung on the operative side [14, 22, 24, 36, 40].

20.9.3 Surgical Team Positioning

The positioning of the surgical group (Fig. 20.1), in relation to the patient's position, must be as follows. The surgeon stands on the anterior side of the thorax, which allows him/her to have a frontal view of the spine. To his/her left is the first assistant, who should be a thoracic surgeon. In front of them, on the posterior side of the thorax, stands the second assistant and to his/her left is the assisting nurse [44].

The relevance of this distribution is the need to have more space for the monitors and the freedom to move all the surgical instruments including the video camera and the endoscope. There can be different placings, but we consider that factors such as the size of the supporting rack for the monitors and the available space determine the most comfortable position for working. We prefer to have a monitor right in front of the surgeon to improve the movement coordination with the patient's position, and the second monitor to be placed at an angle to the patient, but right in front of the second assistant (Fig. 20.1).

20.9.4 Instruments

The surgical instruments can be divided into two types, one related to the VATS technique and the other specialized for spine surgery.

The video equipment includes a high-resolution monitor, a light source with a halogen or xenon lamp with intensity control, a high-definition endoscopic video camera, and a VCR. All this equipment usually comes included on a single rack that can be positioned anywhere in the room. It is highly recommended to have a second monitor for better observation by the assistant surgeons. The standard telescope for the endoscopic procedures is a rigid tube of 10 mm diameter with a double function containing all the lens systems and usually a fiberoptic light source. The angles of the lenses may be of different degrees, but usually 0°- and 30°-angled lenses will be enough.

It is not necessary to insufflate gas in the thorax. This is the reason why the trocars through which all the surgical instruments will be introduced should not be sealed. They should be available in different diameters and lengths, 10 – 12 mm diameter and 50 mm length. The equipment should include a bipolar and monopolar electrocoagulator, and a good suctioning system which might be combined with irrigation. Hemostatic clip appliers are very useful for segmental vessel hemostasis. Scissors and clamps are required to have a connecting system to the electrocoagulator which will improve all the hemostatic procedures. A fan-shaped spreader is most frequently used because it allows easy introduction and can be angled inside the thorax. The

design of the special equipment for spine surgery is very similar to that used in conventional surgery, but longer, approximately 300 mm in length, and marked on its surface to calculate depth. Another useful instrument is the drill that must have the appropriate length to reach the vertebral structures and it must have speed control [1, 5].

20.9.5 Surgical Steps

There is no established approach pattern for thoracoscopic techniques. VATS procedures are being constantly modified according to new options of treatment, giving rise to variations in place and size of the incisions used by different surgeons.
Landreneau and colleagues have described several basic principles for the VATS technique [20]. The first strategy consists in orienting the instruments and the thoracoscope in the same direction, facing the site of the injury within a range of 180°. This positioning avoids the mirror image, and incisions must be far enough away from each other to prevent blocking of the instrument's range of motion.

It is recommended that the incision to place the cannula with the thoracoscope is made in the medial axillary line at the level of the seventh or eighth intercostal space, and the other incisions are made in the anterior auxiliary line, being distributed throughout the different intercostal spaces according to the level of the problem. Three incisions are usually enough to place the lung spreader or diaphragm, suction, and the main instrument. During the surgery it is sometimes necessary to change the position of the instruments in the portals.

Previous to the surgical procedure, a strategic plan must be agreed on in order to determine the levels requiring the surgical work. We must remember that with the VATS technique, the thoracic spine is divided into three regions, the upper one from T1 to T5, the middle one from T6 to T9, and the lower region from T10 to L1. Each of these regions has very particular anatomical characteristics, which is why, when deciding on the approach side, the patient's type of problem must be considered. The right side offers many technical advantages to the surgeon. By modifying the operating table position, the lung and the abdominal viscera displacement will improve the surgical field. In the case of the upper region this will be achieved by lowering the feet of the patient below the level of the head, in the middle region this will be by ventral rotation, and in the lower region this will be achieved using the Trendelenburg position.

20.9.6 Trocar Positioning in the Thorax

The trocars are placed using as a reference the intercostal levels crossed by the anterior, medial, and posterior axillary lines. Their number is directly related to the need for portals to introduce surgical instruments, as follows:

- The endoscope with the camera, which must be the only instrument held by the second assistant already positioned close to the dorsal region of the patient.
- The retractor or the aspiration tube must be held by the first assistant placed to the left of the surgeon.
- There must be two spaces for the equipment the surgeon might need, who is facing the spine frontward.
- Instruments might need to be alternated through the holes during the operation, therefore, we suggest that all the trocars have the same diameter.

To approach the middle vertebral region, especially when the work will only take place at one level, as in the spinal cord canal decompression produced by fractures, a very comfortable distribution is the one called the inverted L (Fig. 20.2). This aligns three trocars on the anterior axillary line leaving one of the trocars directly in front of the selected vertebral level, and the other two, in the upper and lower positions, related to it. A fourth trocar is placed in the middle axillary line at the same intercostal space of the lowest trocar. To work in the upper or lower region of the spine the alignment must be kept on the anterior axillary line, modifying the fourth trocar according to the placement needs of the retractor in order to improve the surgical field.

In the approach for rigid scoliosis, Scheuermann's kyphosis, anterior epiphysiodesis in skeletally immature scoliosis to prevent "crankshaft deformity," and

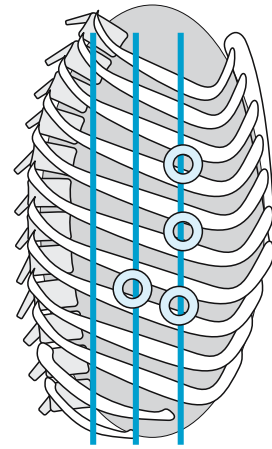


Fig. 20.2. Relation of the intercostal spaces to the axillary lines, inverted L position

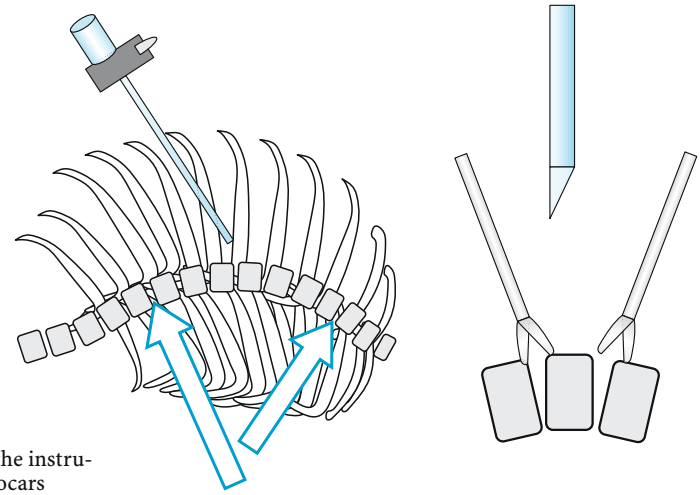


Fig. 20.3. In scoliosis, the perpendicular position of the instruments depends on an adequate orientation of the trocars

congenital hemivertebrae, the placing of the trocars aligned on the middle or posterior axillary line is recommended in the pursuit of two goals. The first is to keep one placed in the apex of the curve or in the center of the selected area, and the second one is to distribute three or four to have perpendicular access to the different levels of discectomy (Fig. 20.3).

For placing of the first trocar, a 10- to 20-mm incision is made at the selected intercostal space. Carefully dissecting and performing hemostasis in order to prevent later leaking into the cavity, the pleura is exposed and incised and then a finger is introduced to confirm manually that pulmonary collapse has occurred. The endoscope is introduced and the thoracic cavity is explored visually. Pulmonary collapse is confirmed and all tissues are checked for fibrosis and/or any adhesions that might complicate the VATS technique. The position of the central working area, for example, the fractured vertebrae or the apex of the curve, is located and confirmed by X-rays or fluoroscopy with a C-arm. Once all the above have been determined, the places for positioning the other trocars are defined, and you can proceed with the incision in the chest wall and penetration of the pleural puncheon under direct endoscopic visualization [2, 40].

20.9.7 Radiological Control of the Surgical Field

Radiographic localization of the segment where you are planning to work is most important, since it cannot be localized by direct palpation and consistency of the tissue. In deformities, angulation may be obvious and, in the case of fractures, we can occasionally find ecchymosis right underneath the pleura as a result of bone bleeding, but it is not an exact point of reference since the hematoma may be too large. Abscesses or tumoral processes may be identified by an increased volume, but it is always recommended to have radiological confirmation.

20.9.8 Surgical Technique for Deformities

In order to free all the soft tissues, begin by cutting the pleura with the monopolar cautery. There are two ways of doing this depending on the amount of space you need for working. You can cut it individually over the disc or make a lateral cut parallel to the spine crossing above the segmental blood vessels and including several levels. In both cases preservation of the vessels located over the vertebral bodies is highly recommended. The incision is then extended by blunt dissection on the anterolateral side of the disc until you expose the longitudinal anterior ligament and on the posterior side all the way to the edge of the costal head. With the monopolar cautery the fibrous ring of the disc is incised in order to make a window through which the content will be extracted with pituitary rongeurs. The tissue attached to the end plate of the superior and inferior bodies can be removed with a circular periosteotome or a non-cutting edge dissector. A drill can also be used carefully if you have adequate visualization of the contralateral segment of the fibrous ring. For cutting the anterior longitudinal ligament and the rest of the fibrous ring on the contralateral side, an instrument protecting the azygos vein must be placed before cutting with the monopolar cautery or scissors connected to the cautery. Another option is to use Kerrison rongeurs. Bleeding from the disc space is controlled by the application of any hemostatic product; we use Surgicel with very good results (Figs. 20.4, 20.5).

Other options include the resection of a hemivertebra or osteotomy of the vertebral body, which can be done with the surgical field exposed as indicated above. It is also possible to apply a bone graft in the disc spaces [7, 8].



Fig. 20.4. Preoperative X-ray image of a 17-year-old boy with Scheuermann's disease



Fig. 20.5. Postoperative X-ray image of the same 17-year-old boy with a posterior instrumentation



Fig. 20.6. Fifteen-year-old patient with idiopathic scoliosis. Courtesy of Dr. Sandoval VS

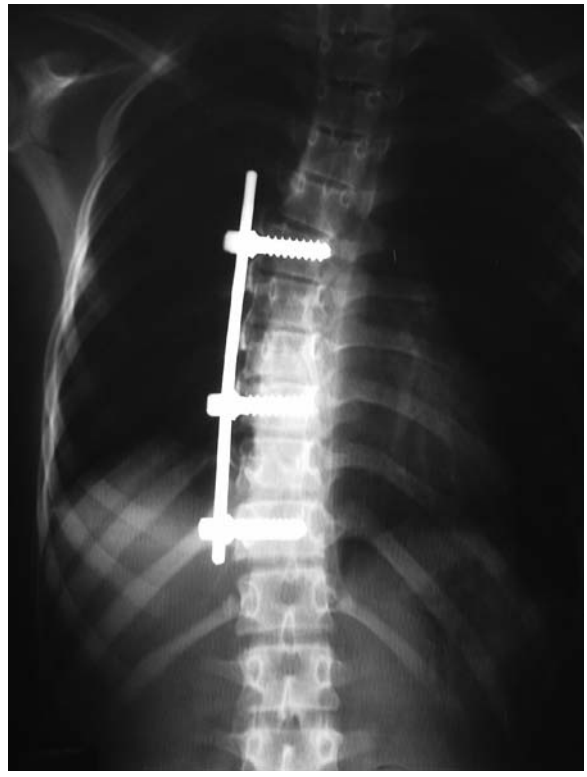


Fig. 20.7. Same patient postoperatively with thoracoscopic technique fixation with rod and screws. Courtesy of Dr. Sandoval VS

There are some options being used for anterior fixation with good results. Semirigid or rigid rods and metallic wiring, both being fixed to the vertebral body, with previous intersomatic grafting achieve a good arthrodesis [35, 39] (see also Figs. 20.6, 20.7).

20.9.9 Surgical Technique for Fractures

The first step is to radiographically locate the fractured vertebra. Occasionally you might observe some ecchymosis underneath the pleura as a result of the bleeding, but it is not an exact reference point since the hematoma may be very extensive. You then proceed to dissect the pleura using the longitudinal technique parallel to the axis of the spine, as described above, including the superior and inferior vertebral bodies up to the edge of their distal platforms from the fractured vertebrae. In some cases damage to the tissue makes identification of blood vessels difficult and they might easily bleed while being dissected during the exploration. We recommend being very careful, and once the bleeding vessels are located they must be secured with vascular clips.

The fibrous rings of the adjacent discs are identified up to the point of fixation at the end plate of the vertebral bodies. The head of the rib articulating with the superior platform of the fractured vertebra is also identified, and its insertions are separated and dissected with the drill for about 15 – 20 mm in length. The pedicle of the fractured vertebra and the intercostal nerve can now be seen, with a full visual identification of the fractured vertebral body.

We then proceed with the resection of the superior and inferior intervertebral discs, being careful to support the end plates of the healthy vertebral bodies, because fragments of the fracture might have moved during the operation and could cause some damage to the dural sac. Once the cleaning of the disc space is completed, you proceed to dissect the pedicle of the fractured vertebra using Kerrison rongeurs, which gives posterior access to the vertebral body and the anterior portion of the dural sac. Extraction of the bone fragments occupying the spinal cord canal can then take place.

Up to this point, you must continue according to the plan previously confirmed by CAT scan or MRI which determined if only the free bone fragments occupying the canal need be resected, keeping the rest of the vertebral body in place, or a full corpectomy be carried out (Figs. 20.8, 20.9). In both cases, the surgical sequence will be to explore the dural sac up to the visible borders and perform full hemostasis using Surgicel packing. The preparation of the platforms and the bed for the application of the bone graft will require the cylindrical drill to carve a small 1-mm-depth canal on the platforms, without exposing the cancellous bone tissue, in order to facilitate the orientation of placement and the stability of the graft. A hyperextension maneuver pressing the dorsal region will open the space allowing the insertion of the graft that must have been designed 4 or 5 mm bigger to ensure a close fit (Fig. 20.10).

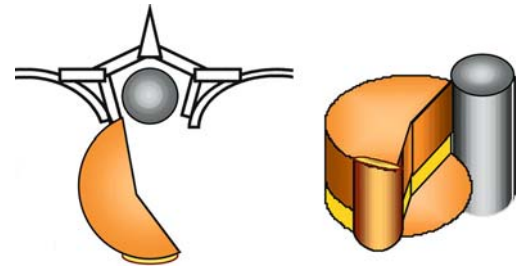


Fig. 20.8. Partial corpectomy to decompress the spinal cord canal



Fig. 20.9. Postoperative X-ray image of the partial resection of the vertebral body

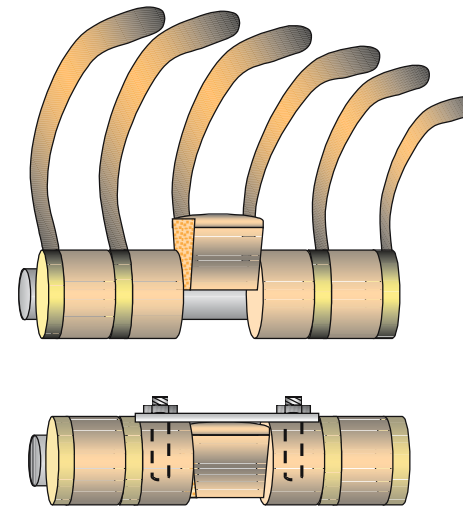


Fig. 20.10. Placement of a tricortical graft and anterior instrumentation with plate and screws

Vertebral stability compromised by the fracture and decompression are solved as follows. If you choose a partial resection of the vertebral body, up to one third of its volume, then no anterior graft need be placed and you can proceed with a posterior arthrodesis with an instrumentation system. If more than one third of the vertebral body or a complete corpectomy is necessary then an anterior graft will be placed. We use a tricortical iliac graft followed by a posterior arthrodesis with a fixation system (Fig. 20.11). We have recently been using an anterior fixation with a plate attached with screws to the superior and inferior vertebral bodies with good results so far (Fig. 20.12).

Currently there is a wide variety of fixation systems, rods or plates attached to the vertebral body with cancellous bone screws, taking into consideration that the thoracic spine is limited in its range of motion since it forms part of the thoracic cage. Even with corpectomies, stability achieved with these implants is very satisfactory.

Once surgery is finished you should confirm by visual exploration that there is no damage to the diaphragm or to the lungs, asking the anesthesiologist to partially inflate the collapsed lung. The instruments are removed and the trocar incisions sutured, leaving one to the pleurostomy cannula connected to the suction system. Then ask for full inflation of the lung and proceed to fix the cannula with stitches [7, 29].

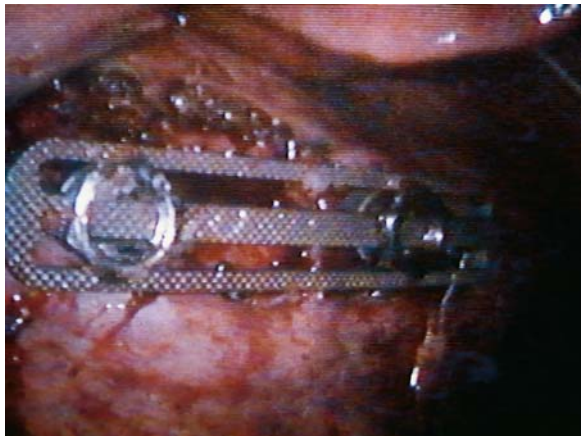


Fig. 20.12. Transoperative monitor image of the anterior plate already in place

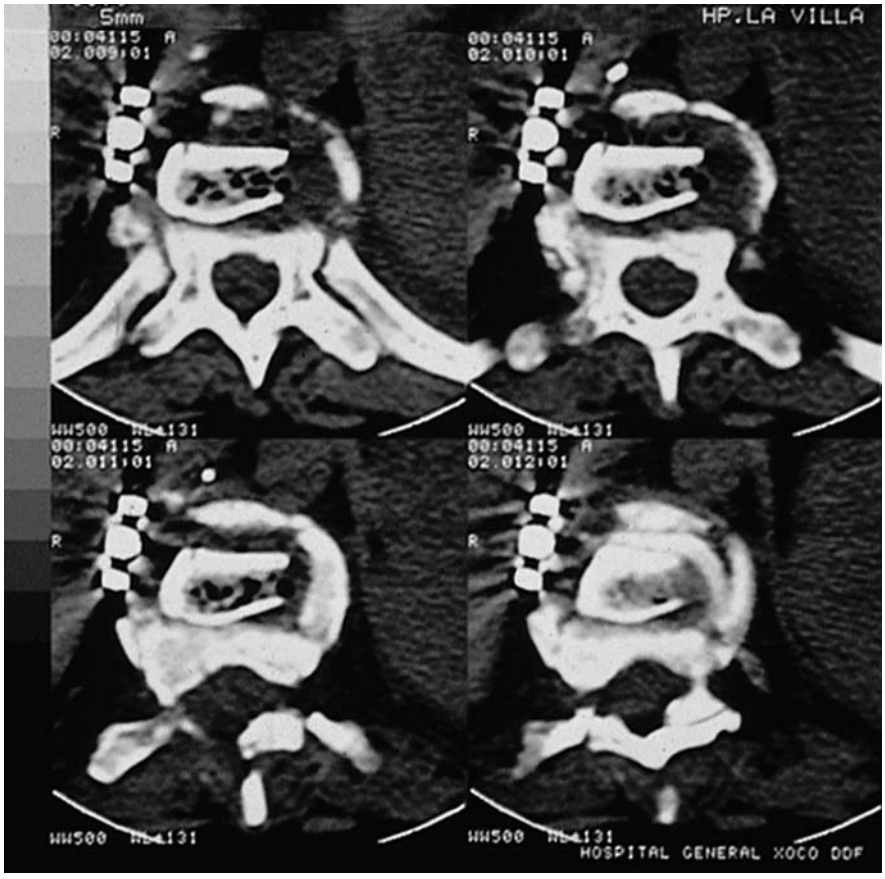


Fig. 20.11. Postoperative CAT scan image of the corpectomy and tricortical graft with anterior plate

20.10 Postoperative Care

The recovery period in the intensive care unit is less than the average since there is no significant blood loss, pain is minimal, and the ventilatory function is not compromised. The patient is kept in bed and follows an inhalotherapeutic program. Walking or sitting is allowed 24 hours later, protected by a thoracolumbar corset. The pleurostomy cannula is removed after control X-rays are taken, usually about 36 hours after surgery, and wound care is routine. In patients requiring second surgery for posterior fusion, the average timing for performing it is 36 hours after the first surgery.

20.11 Hazards and Complications

The complications with the VATS technique for spine surgery are basically the same as for open procedures, i.e., insufficient discectomy, damage to adjacent tissues due to slipping of instruments, excessive pressure on tissues and organs with the retractors, excessive tissue resection with consequent instability, and cautery burning. They are not characteristic of the procedure and must be considered to be the result of poor technique. The achievement of any skill requires time, and it is during this learning period that the surgeon must be extremely careful in order to avoid mistakes [25].

Some of the reported complications, such as difficulty in repairing dural sac tearing, must be evaluated and it may be appropriate to convert to an open procedure. Thoracotomy is mandatory from the start if there is any suspicion of dural damage.

Knowledge of VATS gives us another option to keep in mind when planning surgery of the anterior thoracic spine [17, 30].

20.12 Conclusion and Critical Evaluation

The concept of a minimally invasive approach to the thorax for diagnostic or therapeutic purposes has been known since the last century and the experience with VATS has had benefits in other fields of medicine. In spine surgery it has only been used for a few years, so it is too early for an evaluation of the results. All publications on treatment series are small and none of them has had enough follow-up time to evaluate long-term results.

Short- and medium-term results are very promising and we must consider that, in future, spinal cord decompression produced by a fracture may become a routine procedure with the VATS technique, the patient being discharged from hospital after just a few hours with a minimum of surgical intervention. Also anterior vertebral correction of deformities can be carried out without having to decided whether to perform a thoracotomy and a posterior fusion.

The actual results obtained with the thoracoscopic technique for spine surgery prove that this minimally invasive procedure has satisfied the expectations of a few years ago.

Experience obtained from other areas of surgery in which endoscopic surgical techniques are used, enhanced by the technical improvements of instruments and equipment, allows us to turn this procedure into a real tool to be considered as a routine method in the treatment of spine disorders where the anterior approach is indicated.

It is important to highlight the development of vertebral implants that can be applied by the thoracoscopic technique, which complete the cycle of the objective in spine surgery, “decompress, align, and stabilize.”

Mastery of this technique has turned into a reality the direct advantages to the patient by reducing the healing period and complications. Also surgical time and in-hospital stay have been reduced, with a direct impact on treatment costs [37, 42, 48].

As with any new procedure, the VATS technique for spine surgery underwent a period of observation until it was proved that it was indeed an effective and useful resource for the treatment of spine disorders.

While mastering the surgical technique, the surgeon must recognize the importance of working with a multidisciplinary team. Even though gaining access to the thoracic cavity with the thoracoscope does not represent greater technical difficulties, the close proximity of the different organs in the surgical field are still a potential risk for complications.

Careful planning of any surgical procedure is the key to obtaining a good final result, so it is very important to remember that the selection of patients to be treated with the VATS technique must be very careful. Every step should be analyzed and consideration given to the indications, limits, and contraindications for the technique.

Finally, it is very important to mention that the thoracoscopic technique is a procedure that requires a period of education and practice to be mastered. Candidates for learning this technique must be spine surgeons already experienced in open approaches to the thorax and abdomen. While it may be true that we have greatly improved the learning curve, we must not forget that it never ends.

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21 Thoracoscopic Techniques in Spinal Deformity

Daniel J. Sucato

21.1 Terminology

Thoracoscopy refers to the technique in which small incisions are made in the chest wall through which a video camera and small instruments are placed allowing for access, visualization, and manipulation of structures within the chest including the anterior spine. These small incisions serve as portals and the technique is also known as video-assisted thoracic surgery (VATS). The technique of VATS can be divided into a VATS anterior spinal release and fusion (VATS-RF) and a VATS anterior spinal fusion and instrumentation (VATS-ASFI).

21.2 Surgical Principle

The principle of the VATS approach to spinal deformity is that smaller incisions are used to access the spine, offering benefits over the more traditionally used thoracotomy approach. These advantages include improved cosmesis from smaller incisions, improved postoperative pain and pulmonary function because of reduced chest wall penetration and disruption, and finally visualization is thought to be improved when compared to a thoracotomy incision. The improved visualization is due to the use of an angled (30° or 45°) thoracoscope which allows for "looking around corners" and placing the thoracoscope deep into the chest with a close-up view of important structures.

21.3 History

Video-assisted thoracic surgery was first initiated and developed by general surgeons and cardiothoracic surgeons in the early 1990s. It was initially used to biopsy lung lesions, to treat pleural pathology including draining empyema, hemothoraces, and effusions, as well as ligating apical blebs. These initial surgical procedures, performed thoracoscopically, resulted in improvement in postoperative pain, yielded faster recoveries and shorter hospitalizations, and resulted in less decline in pulmonary function when compared to patients who had an open thoracotomy approach [10, 12, 19]. Today thoracoscopy is used extensively in cardiothoracic surgery to include all of the above procedures and also lobectomies for pleural diseases, treating mediastinal pathology, biopsy of intrathoracic structures, removing neoplasms, and performing thymectomies. Today, coronary artery bypass grafting has also been performed thoracoscopically [24, 52].

Spinal endoscopy began in the 1930s when spinoscopy and myeloscopy were used as diagnostic tools [3, 36]. In the mid 1970s and 1980s, endoscopic minimally invasive spinal surgery was developed [16, 25]. Thoracoscopy for spinal deformity began in the early 1990s. At that time Mack et al. described thoracoscopic approaches for diseases of the spine reporting on 95 patients who had a VATS thoracic disc excision for symptomatic herniation [23]. Horowitz et al. described performing VATS discectomies and Dickman described vertebrectomy and reconstruction using thoracoscopic techniques [6, 13]. Since that time others have carefully looked at the technique of VATS in the treatment of spinal deformity [4, 5, 14, 18, 22, 26, 27, 29, 31, 41, 44]. In the early 1990s VATS was utilized to perform anterior thoracic releases and fusions for thoracic curves in which a posterior instrumentation and fusion was performed concomitantly or in a staged manner [4, 27, 29, 33, 44]. Following the development of surgical techniques for VATS-RF for spinal deformity, surgeons have expanded the technique to include anterior instrumentation and fusion for thoracic curves initially reported by Picetti [35]. Although there are no long-term studies on this technique, this is a promising approach for anterior instrumentation and fusion for thoracic curves.

21.4 Advantages

A direct comparison of VATS to an open thoracotomy technique for spinal deformity demonstrates improved



Fig. 21.1. Clinical photographs of patients who have undergone anterior spinal fusion and instrumentation for scoliosis. **a** The four posterolateral portals are seen in a patient who has undergone a VATS-ASFI. **b** The large incision used for an open thoracotomy approach

cosmesis for the VATS patient since several smaller incisions are utilized compared to a single long incision (Fig. 21.1). An open thoracotomy approach results in greater disruption of the chest wall since access via this approach requires removal of a rib and leads to greater decline in postoperative pulmonary function [32, 49]. Although not well studied it is generally accepted that VATS leads to less chest tube drainage postoperatively and fewer chest wall adhesions, which may contribute to improved postoperative pulmonary function (Fig. 21.2). When performing a thoracoscopic release it is possible and effective to position the patient prone on the operating room table which makes repositioning unnecessary when it is time to perform the posterior instrumentation and fusion [2, 18, 20, 41].

The advantages of the anterior VATS-ASFI approach for spinal deformity must be compared to the posterior approach when performing an instrumentation and fusion for thoracic curves. Betz and others directly compared the anterior and posterior approaches and demonstrated that the coronal curve correction and coronal plane balance was very similar between the two groups, however, sagittal plane correction with improvement in the preoperative hypokyphosis was seen with anterior surgery [1]. Anterior surgery saved an average of 2.5 distal fusion levels, but there was a high incidence of pseudarthrosis in this group, primarily due to the use of a small diameter (3.2 mm) rod. All of the anterior procedures were performed using the traditional thoracotomy approach. Prospective studies are needed to directly compare patients with a VATS-ASFI to those who have had a posterior spinal fusion and instrumentation (PSFI) for thoracic scoliosis.

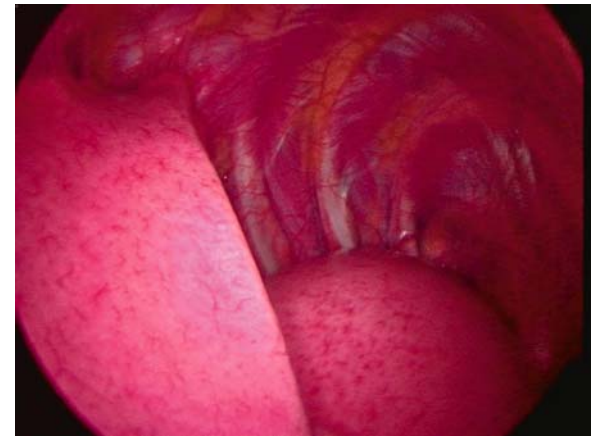


Fig. 21.2. Intrathoracic view showing minimal adhesions within the chest following a VATS-ASFI. Small adhesions are seen in the lower lobe with attachments to the posterolateral chest wall

21.5 Disadvantages

Video-assisted thoracic surgery is a relatively new technique for the spinal deformity surgeon and requires advanced training to acquire the skills necessary to allow the surgeon to perform the surgery safely and effectively. The appropriate training required is dependent on each surgeon's skill level, experience using endoscopic techniques (i.e., arthroscopy), and the case load for each surgeon. It is generally recommended that each surgeon attend teaching courses with hands-on aspects of the course allowing the surgeon to gain the skills necessary to perform this technique. The learning curve for performing an anterior release for spinal deformity was studied by Newton et al., demonstrating an improvement in the operative time without any change in the intraoperative blood loss when comparing their initial 35 cases to the second 30 cases [29]. Intraoperative cost continues to be greater in patients undergoing a thoracoscopic anterior release since many disposable items are utilized, including a harmonic scalpel, disposable plastic portals, and lung fan retractors. However, with greater surgeon experience and newer technology non-disposable items are more often used and the use of the harmonic scalpel continues to decline. Costs should decrease with time since VATS is less invasive, with less postoperative pain and improved postoperative pulmonary function. With the anticipated decline in patient's hospital stay, the overall cost of this procedure should fall. The learning curve for performing VATS-ASFI has been recently studied by Sucato et al. in a multicenter study demonstrating overall good radiographic outcomes and few major complications. The authors found that an initial experience of 30 cases allowed the surgeons to have a 90 % chance of avoiding complications [47].

In addition to the learning curve of each surgeon, there is a learning curve for the anesthesiologists to obtain and then maintain single-lung ventilation for these patients. VATS has traditionally been performed with the patient in the lateral position to allow for easy access to the spine. Single-lung ventilation of the dependent lung is usually obtained using a double-lumen endotracheal tube or Univent tube, which is technically more challenging and imparts significant physiological stresses to the patient because of the ventilation–perfusion mismatches which occur and the significant weight of the mediastinum on the ventilated lung leading to high airway pressures. These increase the risk for the "down lung syndrome" in which there is lung atelectasis, and the rare tracheal and bronchial rupture and pneumothoraces [11, 38, 51]. Although these occurrences are rare, reports of some of these complications have occurred in patients with adolescent idiopathic scoliosis in which malpositioning of the endotracheal tube resulted in excess air leakage into the chest resulting in pneumothoraces [43]. Newer strategies have been developed in an attempt to prevent these occurrences and include double-lung ventilation with the patient in the prone position [18, 20, 41].

21.6 Indications

The indications to utilize thoracoscopy in adolescent idiopathic scoliosis are exactly the same to those for utilizing an open thoracotomy approach. These generally fall into three main categories: anterior release and fusion for severe deformity, anterior fusion to prevent the crankshaft phenomenon in the skeletally immature patient, and finally anterior instrumentation and fusion. Although these indications for VATS are the same it can be argued that the threshold to perform an anterior procedure is lower for the first two indications because VATS is less invasive with a more benign postoperative course. For example, a severe stiff curve in the thoracic spine can be more easily performed through a thoracoscopic anterior release than when performed through an open thoracotomy incision.

The indication to perform an anterior release to "loosen" the spine and allow for improved correction with a posterior instrumentation and fusion has changed with improved posterior segmental fixation. This is especially true because of the utilization of thoracic pedicle screw fixation gaining better coronal and sagittal plane correction [17, 21, 50]. Traditionally it has been thought that a curve greater than 70° which fails to correct to less than 50° is a good indication for an anterior release to improve curve flexibility. Again, these are general guidelines and each case should be assessed individually to determine the severity of deformity and the goals of surgery. We would perform a VATS-RF for any thoracic curve greater than 80° that fails to correct to 60° and perform both surgeries in the prone position (Fig. 21.3).

The crankshaft phenomenon, first described in 1989, results in recurrent deformity due to continued anterior spinal growth in young patients following a posterior fusion [8]. This led to the use of anterior fusions to halt anterior growth and prevent the crankshaft phenomenon. The indications for anterior fusion, when performing a posterior fusion and instrumentation for scoliosis, are a skeletally immature patient with significant spinal growth remaining. This is generally agreed to be patients who are Risser 0, have open triradiate cartilage, are in the middle of their peak growth velocity, and in girls who are premenarchal [39]. The thoracoscopic approach provides excellent access for achieving an anterior fusion using autologous or allograft bone or bone graft substitutes to achieve anterior spinal arthrodesis.

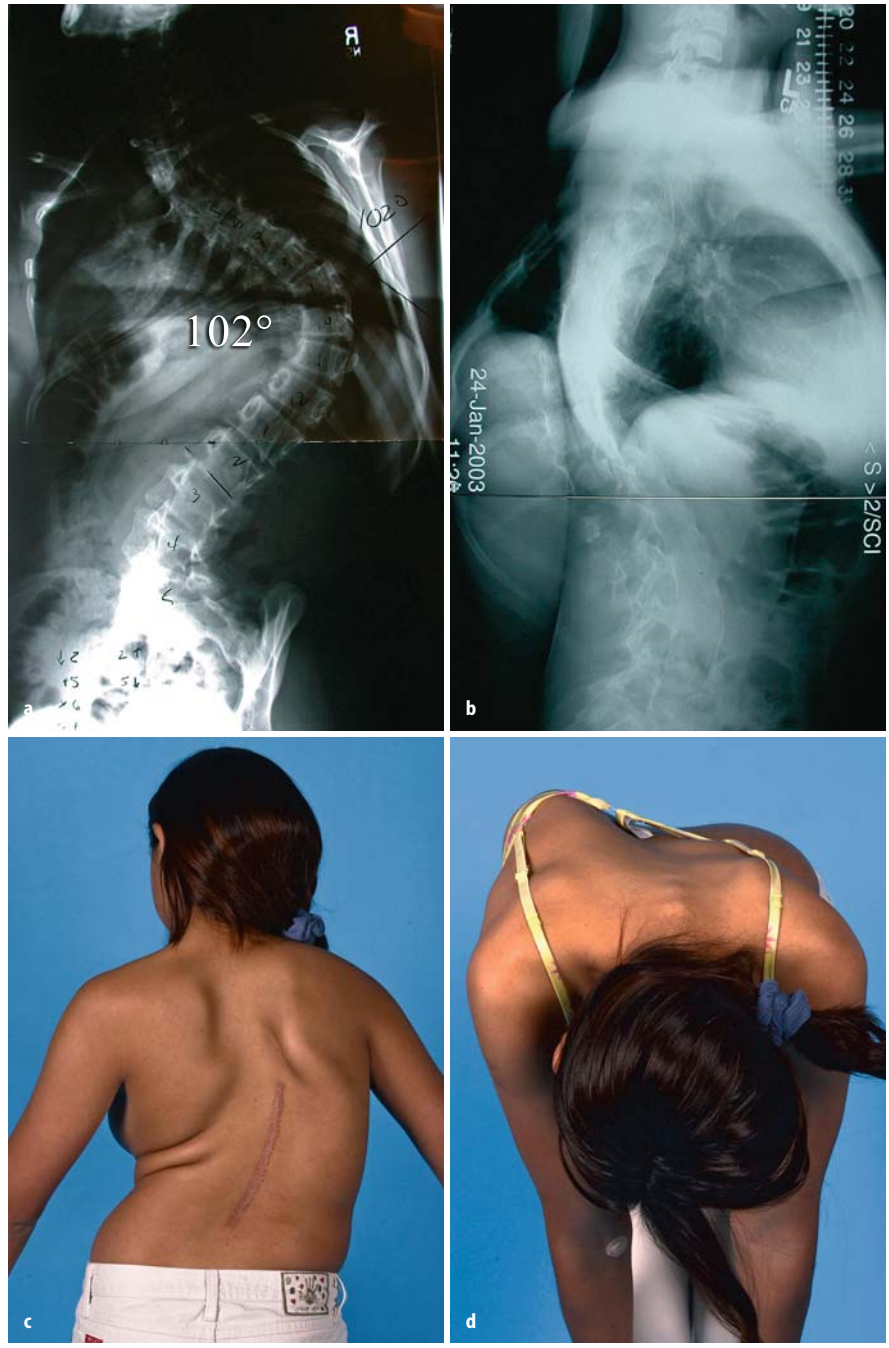


Fig. 21.3. VATS-ASFI and PSFI. Thirteen-year-old girl who had a previous history of a large syringomyelia treated with decompression and drainage with laminectomies from T9-L2. **a**, **b** Preoperative AP and lateral radiographs demonstrating a 102° stiff large curve with severe sagittal plane deformity and a large rib hump. **c**, **d** Preoperative clinical photographs; the posterior incision was from her previous surgery

Anterior instrumentation and fusion of thoracic scoliosis can be performed using thoracoscopic techniques with the thoracic curve types being the same as with an open technique. Only primary single thoracic curve types are amenable for anterior instrumentation and fusion using thoracoscopic techniques and include the Lenke 1 curve patterns. It is possible to safely and effectively perform a thoracoscopic fusion and place instrumentation from T4 to L1. When fusing and instrumenting to L1 it is necessary to partially incise the diaphragm to allow for a complete discectomy at T12-L1 and to safely place an L1 vertebral body. The anterior approach may provide advantages over the posterior approach because certain curve types allow for shorter fusion levels with anterior fusion, the paraspinal muscles are left unaltered, and finally the unfused portion of the spine may respond better with an anterior approach (i.e., selective fusion situation). From personal

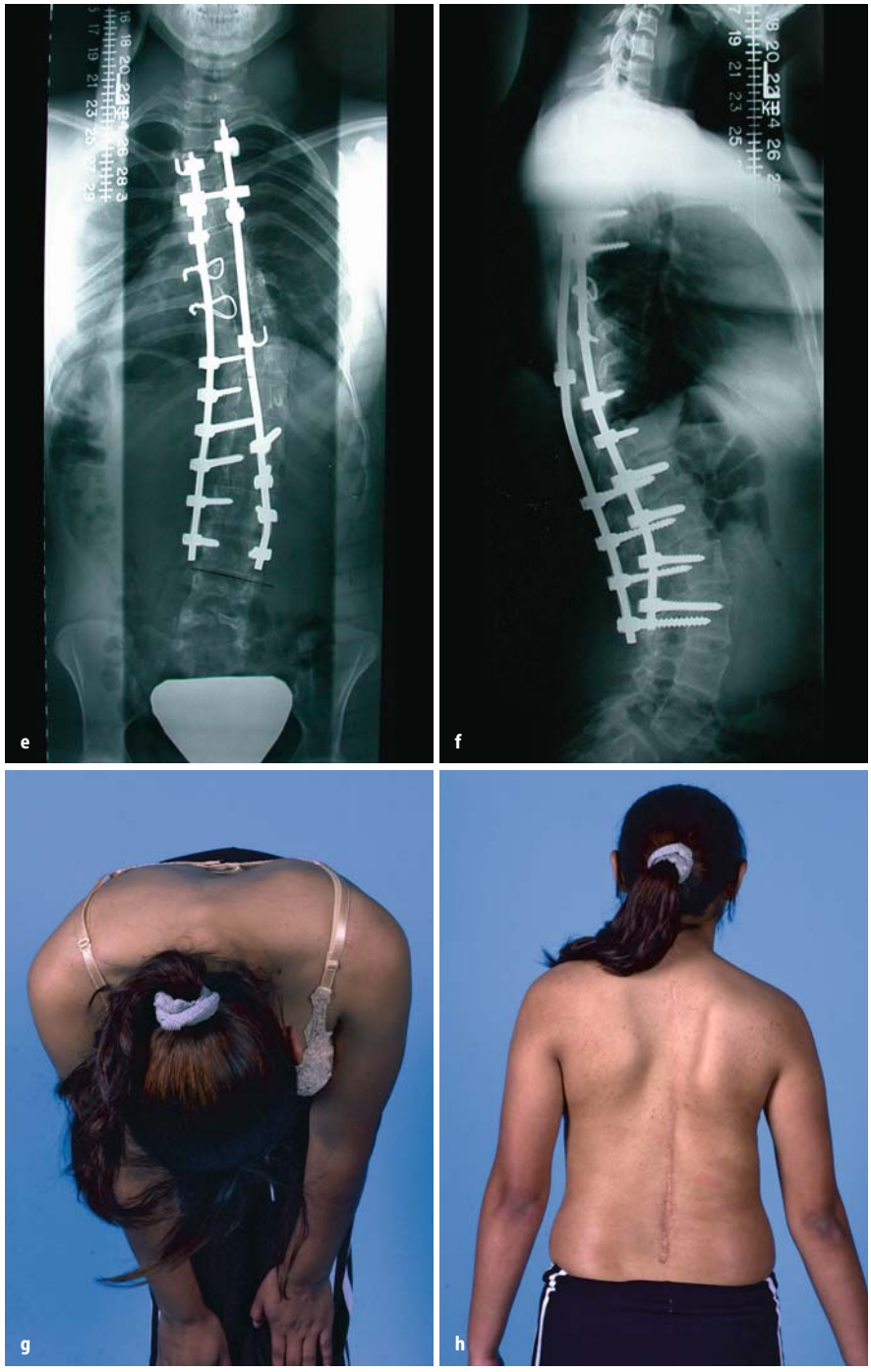


Fig. 21.3. (cont.) e, **f** Postoperative radiographs following a prone VATS-RF from T5-L1, followed by a PSFI from T4-L3. Excellent correction and balance are seen in the AP and lateral radiograph. **g**, **h** Postoperative clinical photographs

experience, the Lenke 1A curve, in which the lower aspect of the curve slowly drifts off to the right, allows for a more proximal lowest instrumented vertebra by at least one level and more often two levels when compared to a posterior approach (Fig. 21.4). The Lenke 1C curve pattern is also very amenable to anterior surgery, allowing one to often fuse to T11 providing excellent correction of the thoracic curve while avoiding any instrumentation into the lumbar curve thus allowing for better lumbar curve response leaving the patient in a well-balanced situation (Fig. 21.5).

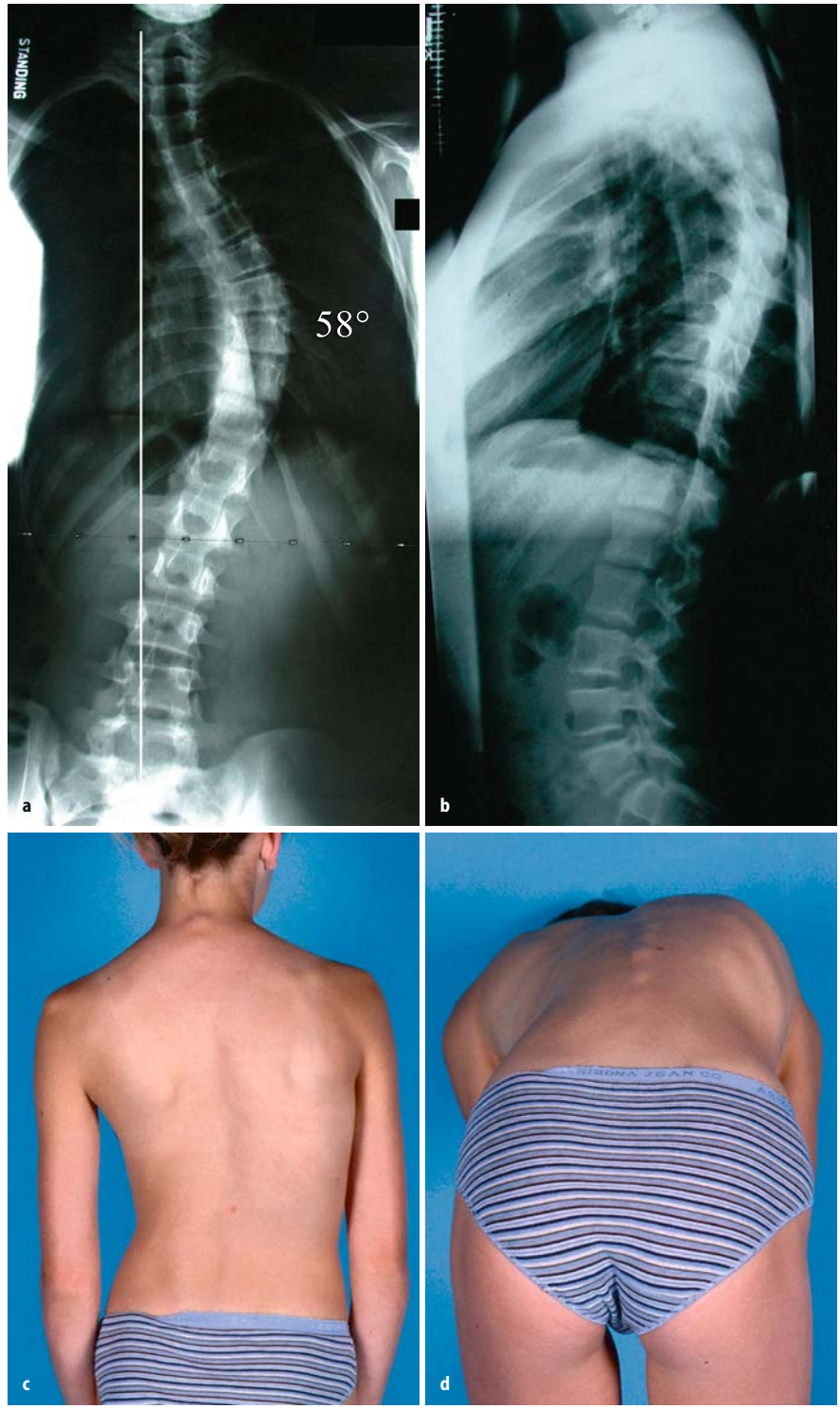


Fig. 21.4. Thirteen-year-old girl who underwent a VATS-ASFI. **a**, **b** Preoperative AP and lateral radiograph demonstrating a 58° right thoracic curve (Lenke 1A pattern). **c**, **d** Preoperative clinical photographs

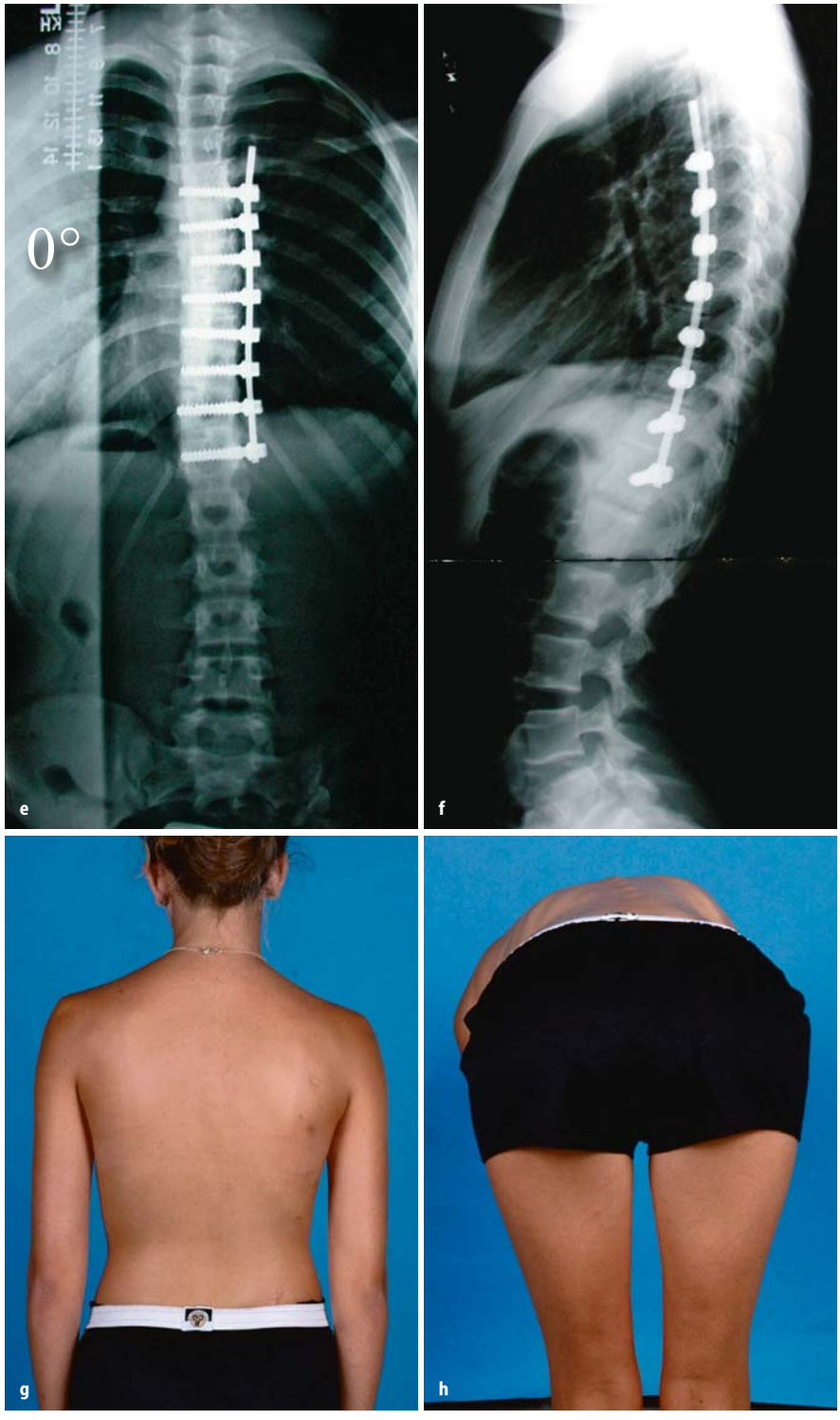


Fig. 21.4. (cont.) e, **f** Postoperative radiographs following a VATS-ASFI with complete coronal and sagittal plane correction. Surgery was performed from T5-T12. **g**, **h** Postoperative clinical photographs

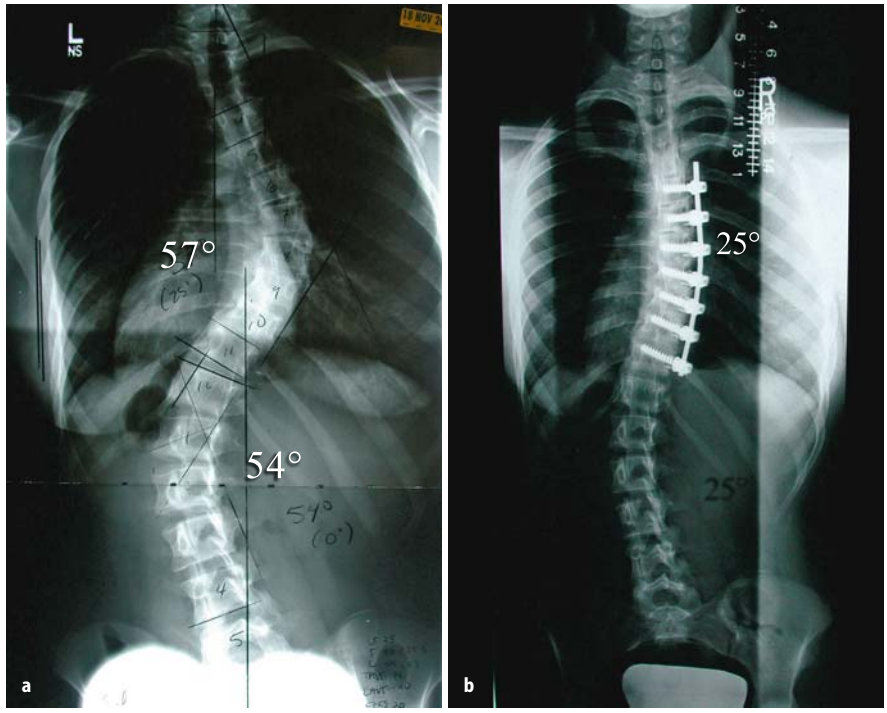


Fig. 21.5. Twelve and a half-year-old girl who underwent selective thoracic fusion with VATS-ASFI. **a** Preoperative radiograph demonstrating a right thoracic curve of 57° (bends to 25°) and a left lumbar curve of 54° (bends to 0°). This is a Lenke 1C curve pattern. **b** Postoperative radiograph following a VATS-ASFI from T5 – 11 showing moderate correction of a thoracic curve with a good response from the lumbar curve resulting in a well-balanced patient

21.7 Contraindications

The anterior approach, whether performed open or thoracoscopically, leads to a decline in pulmonary function immediately following surgery. Preoperative pulmonary function tests should be performed prior to anterior spinal surgery to ensure that there are no significant pulmonary issues prior to surgery. Forced vital capacity (FVC) or forced expiratory volume in 1 second (FEV-1) of less than 50 % of predicted may predispose one to significant respiratory problems following anterior surgery. Other contraindications related to pulmonary function include patients who fail to tolerate single-lung ventilation when performed in the lateral position. Certain large curves which place the thoracic spine against the chest wall are not well-treated using thoracoscopic techniques because there is no working room for the instruments to be placed. Relative contraindications are related to the experience of the surgeon and the size of the patient [9]. Early in each surgeon's experience it is most appropriate to perform anterior releases/fusions on larger patients with smaller curves to gain experience in the technique. The surgeon then moves on to perform anterior instrumentation and fusion thoracoscopically. Because of our experience, we routinely perform VATS-RF and VATS-ASFI in patients who are below 30 kg.

21.8 Patient's Informed Consent

Each patient must understand the risks involved with VATS-RF or VATS-ASFI. These include the added risks with anesthesia since single-lung ventilation is required for the patient who has this surgery performed in the lateral position. The consequences of an inability to tolerate single-lung ventilation include abandoning the procedure, open repair of tracheal and/or bronchial tears, and placement of bilateral chest tubes. The patient and family must also understand the risks of anterior surgery which include visceral injury to the lung, segmental blood vessels, aorta, esophagus, vena cava, azygos vein, etc. Many of these require an open thoracotomy procedure to fix the problem and some may place the patient's life in danger.

21.9 Surgical Technique

Although a variety of techniques are utilized by many different surgeons when performing thoracoscopic surgery, there are a few commonalities. The equipment necessary consists of an angled (30°or 45°) thoracoscope, which is most often 10 mm in diameter, a fan retractor to retract the lung, a suction device, soft blunt-tipped cotton dissecting probes, and long instruments, such as pituitary rongeurs, Cobb elevators, and curettes (Fig. 21.6).

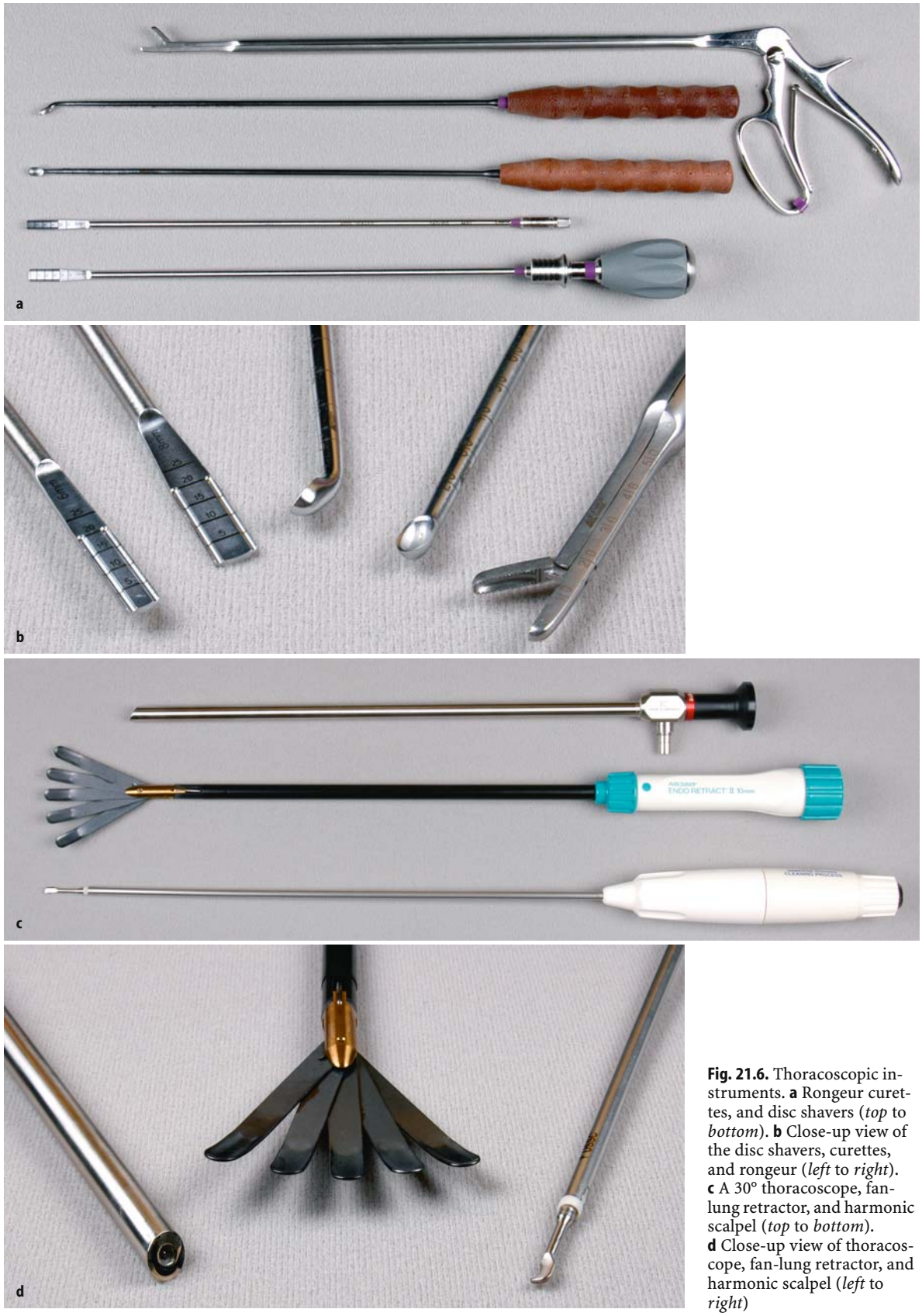


Fig. 21.6. Thoracoscopic instruments. **a** Rongeur curettes, and disc shavers (*top* to *bottom*). **b** Close-up view of the disc shavers, curettes, and rongeur (*left* to *right*). **c** A 30° thoracoscope, fan-lung retractor, and harmonic scalpel (*top* to *bottom*). **d** Close-up view of thoracoscope, fan-lung retractor, and harmonic scalpel (*left* to *right*)

A long cutting instrument is necessary to incise the pleura and is most often either a long-curve-tipped electrocautery device or the harmonic scalpel. These instruments can be also used to incise the disc; however, my preference is to use a regular scalpel blade on a long handle since it provides a better feel of the disc material and does not create the smoke seen with the electrocautery or harmonic scalpel.

21.9.1 Video-assisted Thoracic Surgery: Release and Fusion (VATS-RF)

21.9.1.1 Patient Positioning

Patient positioning is dependent on the size of the patient, the spinal levels to be released/fused, the pulmonary status of the patient, and the comfort level of the surgeon to perform thoracoscopy in the prone position. The lateral decubitus position is required when performing release/fusion proximal to T5 to allow for more proximal placement of portals, for those patients who are small and VATS-RF is challenging to perform, and for surgeons beginning to perform thoracoscopic techniques who are not familiar with the technique in the prone position. The prone position is generally better tolerated from a respiratory standpoint because it obviates the need for single-lung ventilation and is ideal for any patient who has compromised respiratory function [41]. It is also ideal for those patients who require three-stage surgery (anterior-posterior-anterior, most commonly for severe kyphosis). VATS-RF in the prone position should only be performed by those surgeons with good experience with thoracoscopy performed in the more traditional lateral decubitus position. We perform VATS-RF in the prone position routinely, only relying on the lateral position for VATS-AISF and for VATS-RF when release and fusion is required proximal to T5.

For VATS-RF in the lateral position single-lung ventilation is required to allow for deflation of the lung on the side the surgeon is working. The patient can be secured with a beanbag or rolls which support the patient. The arm should be prepared into the surgical field when performing an anterior release proximal to T4 to allow for more proximal portals. It is possible to get to the T1-2 disc in the lateral decubitus position using a portal that is placed in the axilla. This portal is placed just posterior to the pectoralis major muscle to avoid injury to the brachial plexus and to allow for good access to the proximal thoracic spine (Fig. 21.7). The surgeon may stand on the anterior aspect of the patient (my preferred position) or on the posterior side of the patient. When two assistants are present, one stands with the surgeon while the other assistant is on the opposite side of the table. A slight forward tilt of the table allows for the lung to move more anteriorly and allows for easier access to the spine.



Fig. 21.7. Clinical (**a**) and intraoperative (**b**) photographs of the axillary portal utilized in a young patient with neurofibromatosis. The portal is placed just posterior to the pectoralis major muscle which yields a safe placement. Access to the most proximal thoracic spine (up to T1) can be achieved





Fig. 21.8. Patient undergoing prone VATS-RF. **a** Patient position on a Hull-Relton frame. The monitor is directly opposite the surgeons. **b** Four portals placed in the mid to posterior axillary line gives good visualization of the spine

For VATS-RF in the prone position, single-lung ventilation is not required because gravity assists in moving the lungs anteriorly providing excellent access to the anterior spine. A regular endotracheal tube is placed to provide double-lung ventilation. To enable access to the spine the lung tidal volumes are decreased by approximately 40 – 60 % while the respiratory rate is increased to maintain good oxygenation and end-tidal CO_2. The patient is placed onto a standard spine table and positioned in the typical manner for posterior access to the spine (Fig. 21.8). For patients smaller than 40 kg, the chest is tilted posteriorly approximately 15° to allow for easier access to the spine. Three or four portals are placed in the midaxillary line for typical curve patterns but a more anterior placement may be necessary when there is significant loss of thoracic kyphosis or when thoracic lordosis is present. Respiratory complications are significantly less when VATS-RF is performed in the prone position primarily because placement of a double-lumen tube is unnecessary and single-lung ventilation is avoided [41].

Whether the patient is prone or lateral, portal incisions are placed directly over the thoracic ribs so that two portals are available for each incision by traveling proximal and distal to the ribs. Entrance into the chest is made with a hemostat and stiff portals are then placed. Insufflation is not required in the chest since the lung is either not ventilated (single-lung ventilation in the lateral position) or is being partially ventilated (prone position). Initial entrance into the chest with the thoracoscope most often demonstrates a partially inflated lung, however, due to resorptive atelectasis, lung deflation occurs relatively rapidly. Portal incisions are generally placed in a vertical line without attempting to offset the portals anteriorly or posteriorly. The initial portal is placed at the apex of the deformity and allows for visualization of the remaining portals via the thoracoscope; fine tuning of portal placement can be performed with respect to the proximal and distal ex-

tent planned fusion levels and portal placement. The thoracic spine levels can be accurately assessed within the chest cavity since the most proximal rib visualized is the second, the azygos arch (right chest) and the aortic arch (left chest) are most often over the T4 vertebral body, and the first vertebra that becomes obscured by the diaphragm is T12.

21.9.1.2 Spine Exposure and Discectomy

The parietal pleura is incised in a longitudinal fashion over the midportion of the vertebral bodies leaving the segmental vessels intact. Transverse incisions over the disc spaces are not recommended because they do not allow for adequate access to the disc, and anterior structures (azygos, aorta, esophagus in the proximal spine, thoracic duct on the right at the T12 level) are at risk for injury since the pleura provides protection and a boundary for the surgeon when it is left intact anteriorly. Following its incision in the longitudinal direction, the pleura can be gently teased posteriorly and anteriorly without injury to the segmental vessels. Ligation of the segmental vessels is a decision each surgeon must make, however, it is both safe and effective to preserve these vessels when performing a thoracoscopic anterior release procedure [44]. It is important to have good anterior retraction of the pleura when this is performed to protect the anterior structures and to allow for visualization past the anterior longitudinal ligament to the opposite annulus (Fig. 21.9). When traveling posteriorly, the pleura must also be retracted to provide optimal visualization and access to the posterior disc back to the rib head and to allow for rib head resection when necessary (Fig. 21.10). The annulus fibrosis is then incised beginning at the posterior margin of the vertebral body, extending all the way anterior to finish on the contralateral side of the anterior longitudinal ligament. The annulus can be incised using a harmonic scalpel, the electrocautery, or our preferred technique is to use a scalpel blade on a long handle (Fig. 21.11). This allows for complete incision of the annulus fibrosis without creating smoke within the chest and allows for better tactile feel of the disc in those patients who have soft bone and indistinct margins between the disc and vertebral body. The disc material is then disrupted with disc shavers (Medtronic Sofamor/Danek, Memphis, TN), which are sharp on the face of the blade but dull on the ends allowing for near-complete disruption of the disc without creating significant bleeding from the endplates. The disc material can then be removed with a large rongeur and a curette is used to disrupt the endplate and remove excess disc material (Fig. 21.12). At the completion of the discectomy a hemostatic agent [Surgicel (Johnson and Johnson, New Brunswick, NJ) or Gelfoam] is placed into the disc space while the remaining discectomies are performed.

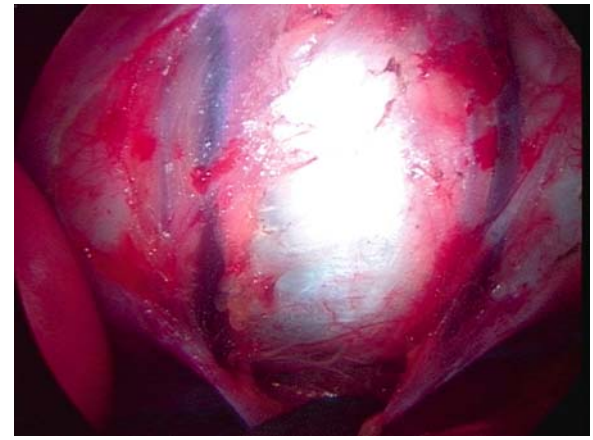


Fig. 21.9. Intrathoracic view during a prone VATS-RF illustrating the spine with segmental vessels intact and a good exposure to the disc

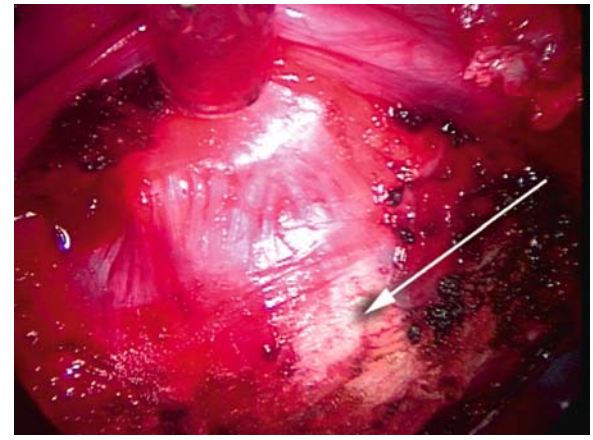


Fig. 21.10. Intraoperative view of the rib head (underneath the suction tip). The ligamentous attachment to the vertebral bodies can be easily seen. The spine is evident anterior to the rib head here at T5 (*arrow*)

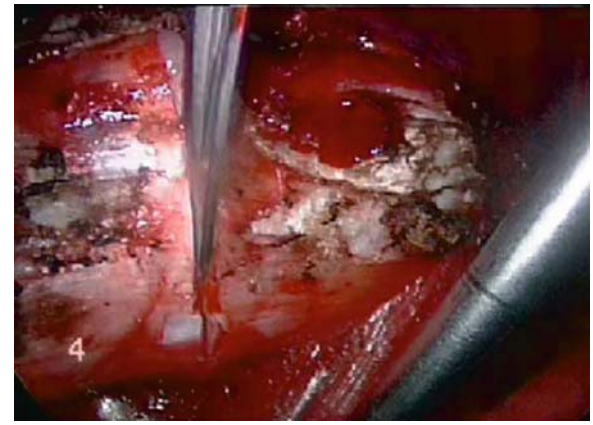


Fig. 21.11. Intraoperative view of incision of the annulus fibrosis using a number 15 scalpel blade

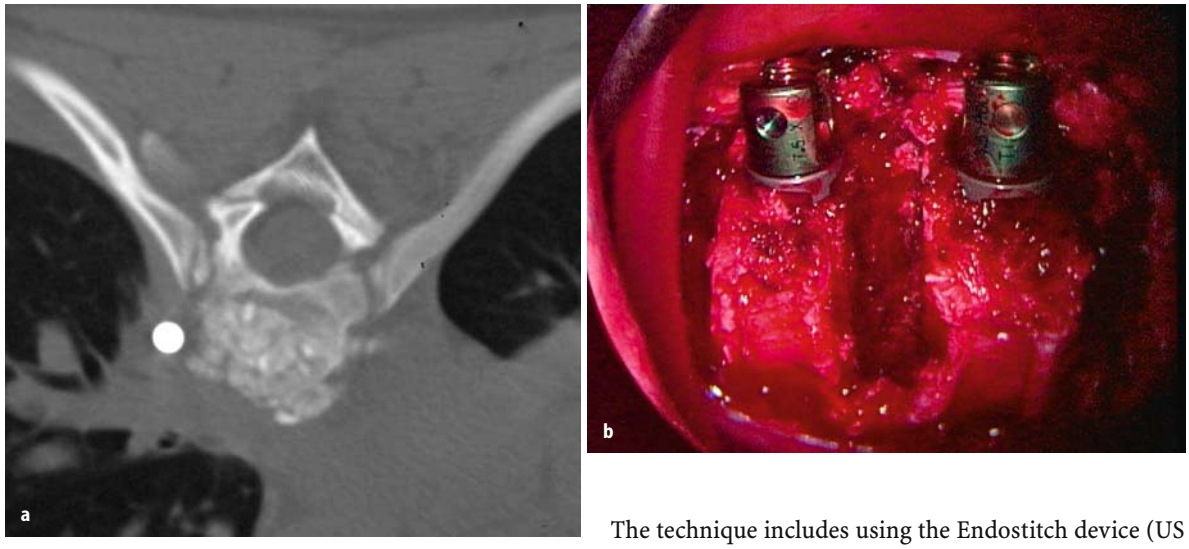


Fig. 21.12. Discectomy achieved using VATS. **a** CT scan following VATS-ASFI. The discectomy and bone graft can be seen on the axial CT image with near complete discectomy and bone grafting. **b** Intraoperative view following discectomy and placement of screws. The near complete discectomy is seen

Following completion of all of the intended discectomies, bone graft material is placed into the disc spaces. Alternatively, the bone graft material may be placed at the completion of each discectomy. The type of graft material is dependent on the goals of surgery and the type of graft material available. Generally, autologous bone should be used when solid anterior arthrodesis is mandatory (to prevent crankshaft, concern with fusion such as a patient with neurofibromatosis).

Bone graft materials are not always necessary. This may be in cases in which there is significant spine deformity, and the anterior release is performed to provide increased flexibility to the spine. In these cases, PSFI may achieve excellent correction and apposition of vertebral bodies, thus promoting good fusion circumferentially (Fig. 21.3).

21.9.1.3 Pleural Closure

The parietal pleural can be closed using thoracoscopic techniques. Pleural closure restores the normal anatomy, decreases total chest tube output, prevents intrathoracic adhesions to the lung, helps maintain bone graft material in the disc space, and may ultimately result in improved postoperative pulmonary function [46]. Each surgeon must decide whether it is important to learn this skill; however, it has been our experience that closure of the pleura takes 10 – 15 minutes, even in the most challenging circumstances, and significantly improves the postoperative course of the patient.

The technique includes using the Endostitch device (US Surgical, Norwalk, CT), and the suture material is 2 – 0 Vicryl. To begin a stitch is placed in the most proximal area of the pleura, and this is run in a continuous fashion to the middle of the area of surgery. This suture is then cut and left outside of the chest. Through the same portal another suture is started distally and run from distal to the middle to meet the previously placed suture. The two sutures are then tied outside the chest, and, using the Endostitch device in a closed fashion to allow for the straight needle to be used as a pusher, the knot can be pushed down to the spine. Four knots are then thrown and there is secure pleural closure. Pleural closure can be performed following VATS-RF or VATS-AISF surgery over the instrumentation (Fig. 21.13). A chest tube drain is placed in the inferior skin incision and tunneled into the next most proximal portal, so that at the time of discontinuation there is minimal risk of developing an air leak. The chest tube is secured and placed after advancing it into the upper aspect of the chest.



Fig. 21.13. Intraoperative view of pleural closure following VATS-ASFI. The screw heads can be seen through the transparent pleura. The pleural closure is achieved with an Endostitch suturing device

21.9.2 Video-assisted Thoracic Surgery: Anterior Spinal Fusion and Instrumentation (VATS-ASFI)

21.9.2.1 Patient Positioning

Unlike an anterior release and fusion without instrumentation, patients who are undergoing instrumentation must always be in the lateral decubitus position with single-lung ventilation. It is very important that the patient is in the direct lateral decubitus position and this should be checked frequently during the surgery, to ensure that proper orientation is maintained especially when placing vertebral body screws. The patient is stabilized using a bean bag on a radiolucent table to allow for fluoroscopic images.

Prior to preparing and draping the patient, fluoroscopy is used to outline the anterior and posterior edges of the vertebral bodies on the lateral image. The proximal and distal extent of the planned instrumented levels should also be marked. This is done using the AP fluoroscopy image and placing a long radiopaque instrument along the back and directly in-line with a well-placed screw in the proximal distal levels. These markings will assist the surgeon in placing the portals at the time of surgery.

After preparing and draping the patient the portal placement is very critical. We use a single anterior portal placement, usually in the anterior axillary line at the apex of the deformity so that it is centered over the apex of the deformity, allowing for good visualization both proximally and distally. In these often thin patients, it is possible to go above and below at least one rib and often two ribs to obtain excellent visualization of the spine. Following the initial placement, a guide wire is placed in the posterior axillary line directly over the vertebral bodies to ensure that these portals are placed precisely. There is a tendency to place the portals too anterior and too distal and is most likely to occur when placing the most proximal portal because of interference by the scapula. It is recommended that the second portal be placed first to allow for placement of the camera in this portal to fine tune the placement of the most proximal portal and then the remaining portals are placed. It is most common to require three or four posterolateral portals in addition to the single anterior portal during VATS-ASFI.

21.9.2.2 Spine Exposure and Discectomy

Following portal placement, the pleura is incised in the midvertebral body, (similar to VATS-RF) and the segmental vessels are ligated using electrocautery. It is important that hypotensive anesthesia is avoided during the anterior procedure and is especially important during the time of segmental ligation. Following ligation of segmental vessels, the pleura can really be teased back quite posteriorly (beyond the rib heads) and far anterior to allow for excellent visualization around to the annulus on the opposite side.

The annulus is then incised with a number 15 blade beginning at the anterior aspect of the rib head traveling all the way around past the anterior longitudinal ligament to the opposite side. Care must be taken to retract anteriorly. This can be performed using the fan retractor, placing a sponge anteriorly, or using a soft-tipped long retractor. The disc shavers are then used to break up the annulus and nucleus, and the rongeur and curettes are used to obtain a good discectomy. In the proximal thoracic spine the rib heads overhang the vertebral bodies significantly, and therefore rib head resections should be performed to obtain good discectomy, as well as uncovering a good starting point for the screw, and is most often performed at the T4to T7 levels. At the completion of discectomy, Surgicel is placed in each disc space.

21.9.2.3 Instrumentation and Bone Grafting

Accurate placement of screws is critical for this technique and is highly dependent on the type of visualization achieved using the thoracoscope and fluoroscopy (Figs. 21.14, 21.15). Good screw purchase is also dependent on good screw position, and the size and quality of the bone of the vertebral bodies. Screw purchase is often deficient when screws are placed too anterior and, therefore, it is important to visualize the rib head when starting screw placement. Screws can be placed either with or without a guide wire (Fig. 21.16). Guide wire placement must be performed with caution in these

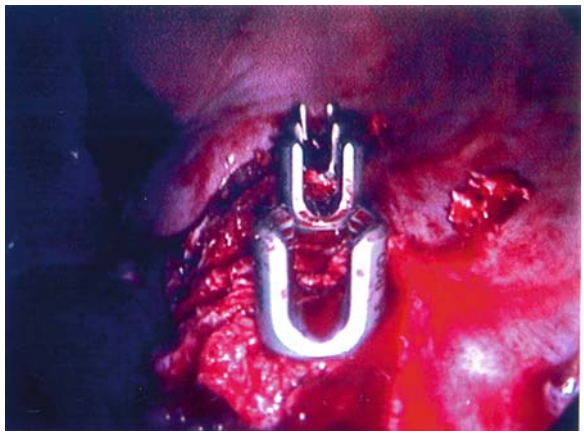


Fig. 21.14. The pipeline view achieved through placement of the thoracoscope in the posterolateral portal. The view demonstrates screws well-aligned, looking from proximal to distal. The fan retractor is shown retracting the diaphragm distally

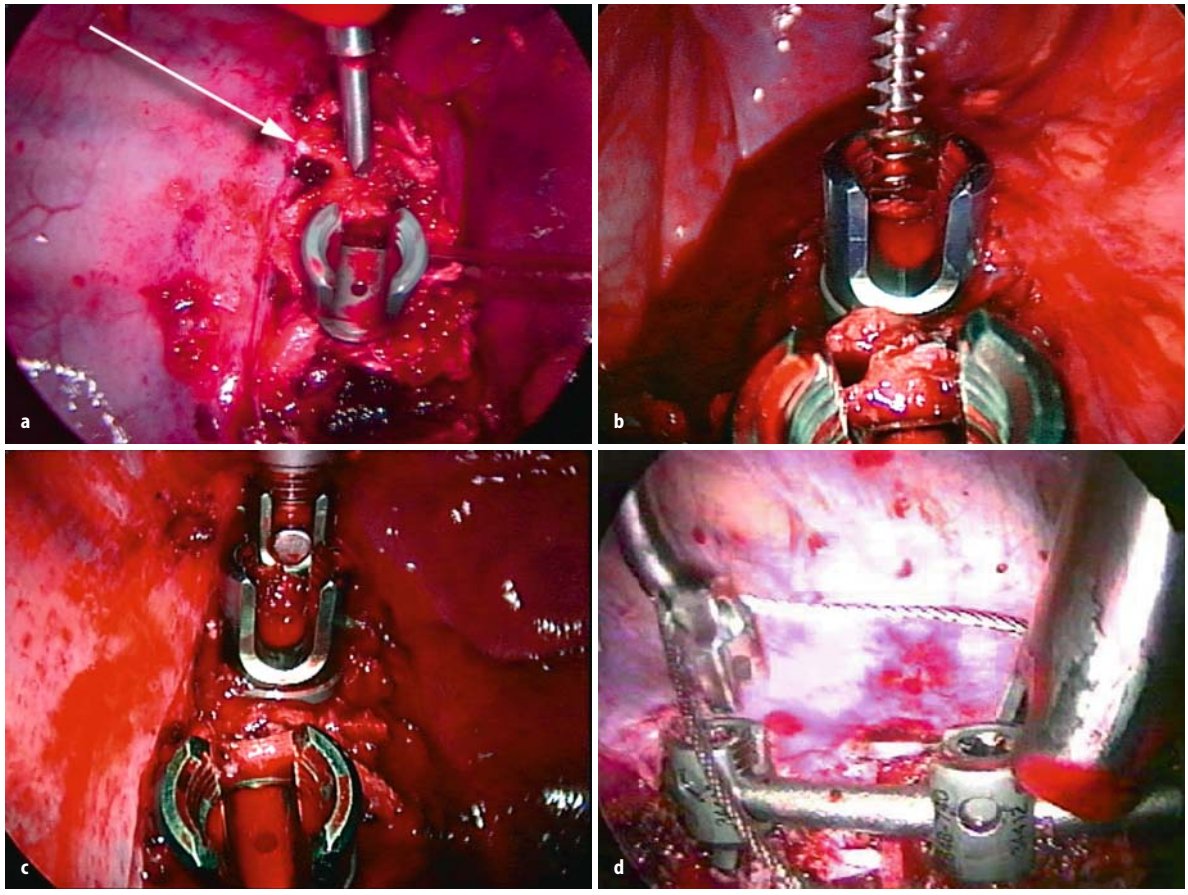


Fig. 21.15. Placement of screws. **a** Following initial screw placement, the awl is placed in the vertebral body and is positioned just anterior to the rib head (*arrow*). It is also placed in the midvertebral body with respect to the superior-inferior endplate. **b** The tap is placed in a more distal vertebral body inline with the previously placed screws. **c** Final position of the screw after placement. **d** After rod placement, compression is performed with the cable compressor

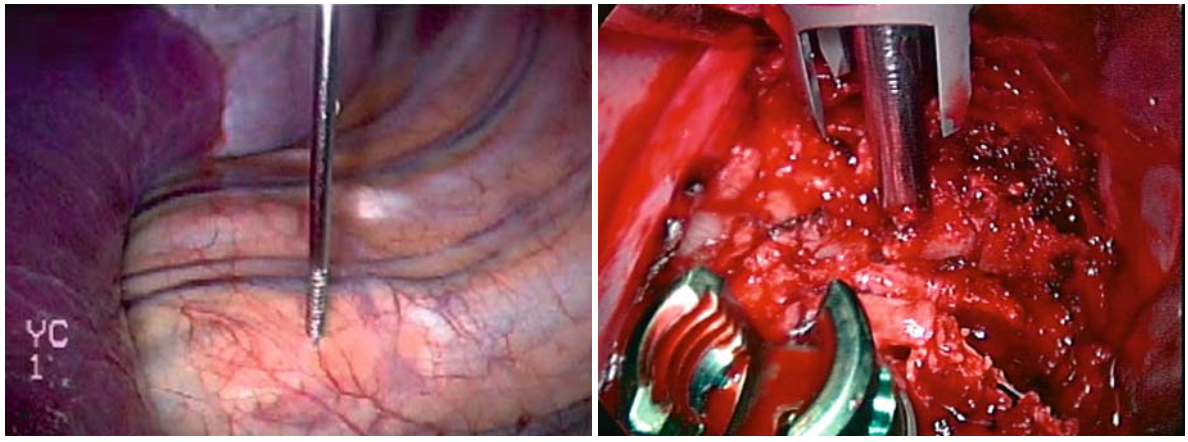


Fig. 21.16. Initial placement of screws. Two techniques are available. **a** Use of a guide wire placed in the midvertebral body. **b** Use of the awl staple without a guide wire

cannulated systems, since any instrument traveling over the guide wire has a tendency to advance the guide wire to the opposite chest. This may result in significant soft tissue injury including tension pneumothorax [37]. Our preferred technique is to first place a modified awl with the staple attached. This is followed by a tap to undertap by 5 mm of the intended screw diameter and then finally the screw is placed (Fig. 21.17). This

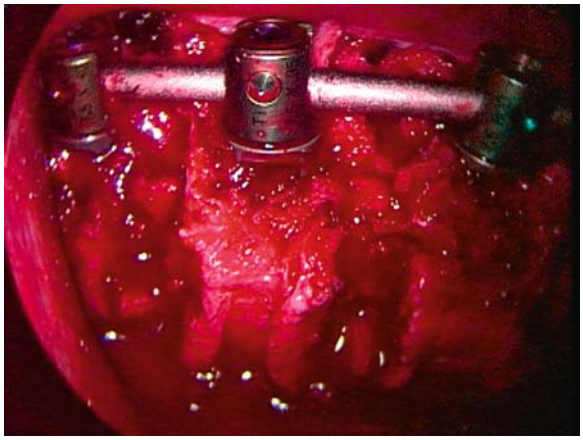


Fig. 21.17. Intraoperative view following completion of the instrumentation and bone grafting

offers excellent and safe placement of screws. The newer designed screws available today allow for placement of screws in a unicortical fashion [48]. This is important when placing anterior vertebral body screws, since it has been demonstrated that screws can be close to the aorta when placed in the thoracic spine [45]. This is most commonly due to the fact that the aorta is in close proximity to the left side of the vertebral bodies in adolescent idiopathic right thoracic scoliosis [40]. Bicortical screws can be placed and are safest in the most distal thoracic spine where the aorta is far anterior. It may be necessary, however, to have bicortical purchase in the more proximal thoracic spine, since it is here that screws most commonly cut out or plow through the vertebral body. It is very important that the proximal screws are directed parallel to the endplate, or aimed slightly distally, so that plowing of the screws is avoided during deformity correction.

Following the completion of screw placement, an appropriate length placed rod is delivered into the chest through a proximal or distal portal. We have developed a rod-measuring method that allows one to preoperatively measure the correct length [42]. Alternatively, rod-measuring devices are available in endoscopic instrumentation sets which measure the distance from the most proximal screw head to the most distal screw head prior to the placement of the rod. This generally overestimates the length of the rod because the scoliotic curve has not been corrected and the convex length of the spine is longer than what is expected following surgical correction and this should be taken into account. Following placing the rod into the chest, a rod grabber can hold the rod and place it into the screw heads. We generally place the rod in the distalmost screws and seat the rod in as many screws as possible without pushing down excessively. Usually, the rod can be seated in the distal three or four screws. The distal set screw is then completely tightened down onto the rod and the remaining set screws are placed loosely. Compression is then performed over these two or three levels and the rod is cantilevered down to the remaining screws. Compression then is performed at the remaining proximal levels following placement of the set screws (Fig. 21.17). Care must be taken not to stress the proximal screws either during the cantilever maneuver or during compression of the more proximal levels. Each case is individually assessed as to the type of screw purchase achieved at the time screws are placed. A radiograph at this point is recommended to assess the degree of correction achieved and whether to make adjustments (more or less compression) accordingly.

Bone graft is generally placed prior to placing the screws. Bone graft alternatives include obtaining segments of rib through the portals with the disadvantage of creating a flail chest if the entire rib is taken. An alternative method is to take the proximal or distal half of the rib, leaving the rib in continuity. Harvesting ribs does lead to more chest tube drainage and pulmonary issues postoperatively. We generally harvest iliac crest bone graft through a very small incision which provides abundant cancellous bone graft material which is good for packing in the disc spaces. It is very important to pack the bone graft to the contralateral side and all the way posteriorly to ensure solid arthrodesis (Fig 21.12). Following bone grafting and rod correction the chest should be irrigated and pleural closure is performed over the instrumentation. One of the keys to closing the pleura over instrumentation is that the pleura should be bluntly dissected off the chest wall posteriorly to allow the posterior aspect of the pleura to be free.

Patients are usually discharged from the hospital on postoperative day 4 or 5. When single-rod anterior instrumentation is used, a brace is generally worn for 3–4 months while the patient is up and walking around. A new dual-rod single-screw system is available, which provides improved stiffness of the construct and obviates the need for postoperative bracing (Fig. 21.18). Following good healing of the anterior fusion mass, patients are allowed full activities generally beginning 6 months after surgery.

21.10 Postoperative Care

When performing a VATS-ASFI, a PSFI is usually performed and the postoperative course is very similar to that of a PSFI alone. Serial chest X-rays are obtained, and the chest tube is placed for suction drainage. The time to discontinuation of the chest tube depends on the type of surgical procedure performed: the number of levels released and fused anteriorly, the adequacy of



Fig. 21.18. Dual-rod single-screw implant system in a fourteen-year-old girl following VATS-ASFI. **a**, **b** Preoperative AP and lateral radiographs demonstrating a right thoracic curve of 59° and a lumbar curve of 38°. Thoracic hypokyphosis is seen

the pleural closure, and the amount of chest tube drainage postoperatively. Generally, when good pleural closure is achieved, the postoperative chest X-ray reveals a hematoma underneath the pleura and gradual decrease in chest tube drainage is expected. The chest tube drainage drops considerably on postoperative day 2 and turns a serous yellow color. The chest tube drainage usually drops below approximately 80 cc for every 8-hour shift, and the chest tube is discontinued. Using this protocol there have been no instances in which the chest tube has had to be replaced at our institution. The patient is generally then out of bed and is advanced to walking activities with aggressive pulmonary toilet.

For those patients who have undergone VATS-ASFI, the postoperative protocol is very similar although more chest tube drainage may be present since more extensive surgery has generally been performed. However, if pleural closure has been completed, the drainage usually slows by the second postoperative day and removal is safe at this time. Aggressive pulmonary toilet is very important on these patients to prevent atelectasis and other pulmonary problems which can occur. The patients are out of bed on the first postoperative day and are walking on the second postoperative day following removal of the chest tube. When the single-rod instrumentation is used, the patient is usually measured for a brace on the second day following surgery and fitted with the brace on the third or fourth postoperative day; however, the patient should be out of the bed and walking prior to receiving the brace. The most common day to be discharged from the hospital is the fourth postoperative day, however, patients have left anywhere from the second to the fifth day following surgery.

21.11 Complications

Avoiding complications when performing VATS-RF or VATS-ASFI is dependent on each surgeon gaining the skill set required to be safe. This can be achieved through courses designed to provide the surgeon with hands-on experience. Visualization is probably the single most important factor when performing this surgery and is dependent on full utilization of the capabilities of an angled (30° or 45°) endoscope. Good visualization and timely surgery is also dependent on keeping the camera clean and dry, and keeping the chest free of excess blood since this obscures the operative field.

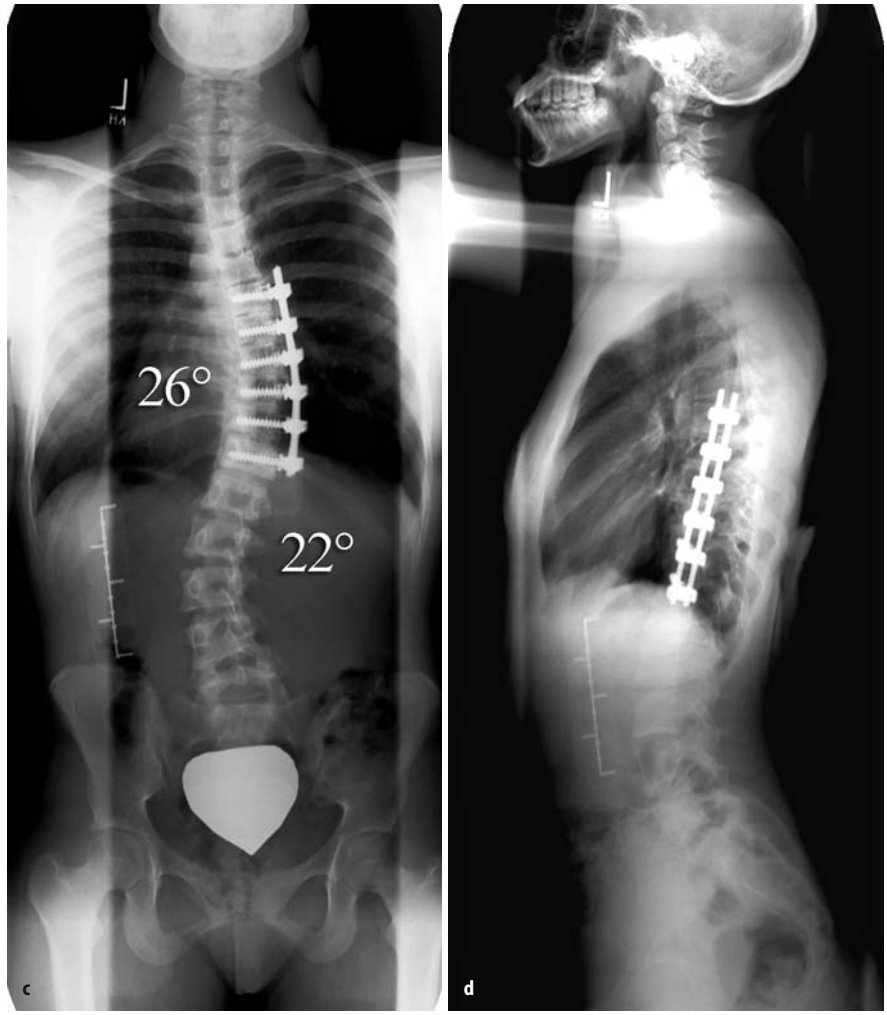


Fig. 21.18. (cont.) c, d Postoperative radiographs demonstrating a balanced spine in the AP and lateral radiographs. The dual-rod system is evident on the lateral radiograph

Complications can be divided into minor and major (those requiring reoperation or major change in the operative plan) complications and also divided into those that are associated with VATS-RF compared to those which are more often associated VATS-ASFI. Minor complications include postoperative atelectasis, need to replace the chest tube or perform a thoracentesis due to excess pleural effusion, and injury to a segmental blood vessel requiring repair. Major complications include major vessel (aorta, azygos, vena cava) injury, injury to the thoracic duct, neurological deficits (nerve root, spinal cord), cerebrospinal fluid leak, deep chest infection, excessive intraoperative bleeding, or other complications requiring conversion to an open procedure. We have no occurrence of conversion to an open procedure because of excessive bleeding or intraoperative complications. It is necessary for the surgeon to gain experience with controlling bleeding segmental vessels. The most important aspect to this technique is pressure along the vessel using a cottonoid followed by coagulation using endoscopic forceps. Bleeding may also occur with endplate excision, and packing each disc space with Surgicel prevents excessive endplate bleeding. Bone wax can also be used when bleeding occurs from the vertebral body cortex. Intraoperative injury to the thoracic duct is most commonly seen on the right side at the T11 – 12 area where the cisternae chyli coalesce to form the thoracic duct. Care must be taken to retract the pleura anteriorly at these levels to protect the thoracic duct as it travels from the right to the left side. When the milky white lymph fluid is seen, it is necessary to aggressively coagulate these areas using electrocautery. Postoperative chylothorax is a major problem which can usually be prevented when lymphatic fluid is seen intraoperatively. In addition to electrocautery, the area can be oversewn using the Endostitch device or using ligature clips. Postoperatively, if a chylous effusion is seen, the initial treatment is conversion to a non-fat diet or a trial of total parenteral nutrition (TPN). Reoperation to thoracoscopically ligate vessels can be performed, and has been successful in the general surgical literature [34].

Penetration into the spinal canal when performing discectomy is extremely rare. It is necessary to understand the anatomic landmarks when performing the discectomy, understanding the relationship between the vertebral body, spinal canal, and rib heads since the rib heads are used as the landmark for placing vertebral body screws. The rib head is more anteriorly located over the vertebral body and spinal canal in the more proximal thoracic spine when compared to the distal thoracic spine [53].

Pulmonary complications are relatively common and include postoperative atelectasis either on the contralateral lung or the ipsilateral lung. The "down lung syndrome" is a result of high airway pressures required for the patients who require single lung ventilation in the lateral decubitus position [7]. This can be avoided, when surgery is completed, by aggressive suctioning of the endotracheal tube to remove any mucous plugs. The ipsilateral lung can be atelectatic and due to inadequate reinflation of the lung at the completion of the procedure which should be visualized directly by the surgeon using the thoracoscope.

Those complications which are directly related to VATS-ASFI are guide wire migration which occurs when there is a bend in the wire and the placement of cannulated instruments pushes the wire to the opposite chest. This can result in tension pneumothorax, which has been reported, or injury to other intrathoracic structure such as the aorta, vena cava, azygos vein, or esophagus [4]. Although the guide wire provides for good direction when placing screws, the potential for problems is high and a significant amount of fluoroscopic guidance is necessary. The guide wire or screw may also be directed posteriorly into the spinal canal which can be avoided by visualizing the rib head and using this as the starting point to obtain good screw placement. This is an extremely rare complication and dependent on the surgeon's ability to visualize the implants as they are placed with good visualization through the thoracoscope as well as fluoroscopy. Accurate screw placement will allow for good screw purchase in the vertebral bodies without creating unsafe placement posteriorly, anteriorly, or too far on the opposite side.

21.12 Results

The clinical results of thoracoscopy in the treatment of spinal deformity can be divided into those following VATS-RF (together with a posterior instrumentation and fusion) and those following VATS-ASFI. The results of VATS-RF are generally very good and are dependent on the experience of the surgeon [29] and the type of surgery performed. Newton et al. compared their early and later experiences performing thoracoscopic releases in the lateral position, reporting that surgical time decreased, blood loss was similar, and the incidence of complications decreased in the later cases. The ability to achieve an adequate release has been demonstrated to be very good in several animal models using thoracoscopic techniques and comparable to an open thoracotomy approach [5, 15, 27, 28, 44]. Huntington et al. demonstrated that similar area of disc excision was achieved whether it was performed using thoracoscopic techniques (67 % of the endplate) or through a thoracotomy approach (71 %). Fusion at each disc space has been recently assessed and found to have 72 % of the disc spaces fused [30]. The amount of correction that can be achieved following a thoracoscopic anterior release and fusion appears to be very similar to when an open thoracotomy approach is used.

VATS-ASFI is performed at a few institutions on a routine basis and the early reports demonstrate overall good results. Much like the anterior release and fusion technique, there is a learning curve associated with this technique. Sucato et al. reported a multicenter review of the learning curve for VATS-ASFI and demonstrated that, overall, there was an approximately 50 % incidence of complications (mostly minor) with overall a 55 % correction of the thoracic curve [47]. A probability analysis of the 147 cases demonstrates that once each surgeon reaches 30 cases, there is a 90 % chance that no complications will occur. This threshold is significantly less today since the study included each surgeons original series of cases. The overall correction of the thoracic curve was 52 % with restoration of normal thoracic kyphosis. At our institution, there are 41 cases of VATS-ASFI performed, with overall 71 % thoracic curve correction for the Lenke 1 curve patterns in which full correction was attempted with two cases of fractured rod without symptoms. Comparative studies are still not available for this technique; however, for those performing this technique on a routine basis, the results appear to be very good and comparable to PSFI.

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Mini-open Endoscopic Excision of Hemivertebrae 22

R. Stücker

22.1 Endoscopic Excision of Hemivertebra

Endoscopic surgery, like thoracoscopy or minimally invasive retroperitoneal surgery, is now a well-accepted alternative to traditional methods and is used for a variety of spinal diseases such as idiopathic scoliosis, kyphosis, degenerative disorders, and spondylitis.

For adults, surgical tools and instrumentations are available even for multisegmental fusions. Spinal surgery for small children is less frequently performed, but there are a number of problems that need to be addressed by surgery, such as tumors, infections, and congenital and developmental deformities of the spine. Endoscopic surgery has proved to be of great benefit for adolescents and adults, especially in the reduction of morbidity and scar formation. Its usefulness for children has not been clearly shown. The author reports on a series of 13 children with various forms of hemivertebrae who were treated by a combined posterior and minimally invasive endoscopically assisted anterior approach. Eight children were under 5 years of age at operation.

22.2 Terminology

A hemivertebra is a defect of vertebral formation with a typical triangular wedge-shaped form. Posteriorly only one pedicle and one hemilamina are present. A hemivertebra is fully segmented, semisegmented, or nonsegmented. In a fully segmented hemivertebra there is a normal disc space and almost normal growth potential of the apophyseal ring above and below and the hemivertebra is completely separated from the adjacent vertebrae. A hemivertebra can also be semi- or nonsegmented with less or even no remaining growth potential. An incarcerated hemivertebra usually produces less deformity because the adjacent vertebrae have an trapezoidal form, therefore compensating for the size of the hemivertebra with almost no deformity remaining. A hemivertebra may be accompanied by an unsegmented bar on the other side and usually produces segmental kyphosis.

22.3 Surgical Principle

Excision of the hemivertebra is performed in two steps. The first step is performed in the prone position. The posterior parts including hemilamina, transverse process, and rib together with the complete pedicle are removed. The posterior wound is temporarily closed. The anterior part of the surgical procedure is performed in the lateral decubitus position under endoscopic control. Instead of multiple portals only one 4- to 5-cm-long incision is used. The endoscope is introduced through a separate stab incision and no special instruments are required.

22.4 History

In 1928 Royle reported on the removal of an accessory vertebra without the availability of modern segmental fixation [7]. In 1979 Leatherman and Dickson recommended a two-stage corrective procedure to avoid neurological complications [6]. Since then one-stage surgery has evolved to be the standard treatment for an isolated hemivertebra [1, 2]. More recently, a one-stage posterior hemivertebra resection was reported by some authors [8, 9].

22.5 Advantages

In the case of open hemivertebra excision, the anterior approach produces most of the morbidity associated with this type of surgery. A minimal incision and endoscopically controlled surgery offer less morbidity to this technically demanding procedure. In addition, better illumination and working under magnification contribute to the safety of the procedure. In case of problems, such as severe bleeding, surgery can easily be converted into a conventional open procedure.

22.6 Disadvantages

Performing endoscopic surgery on small children for spinal disorders requires expertise in spinal surgery and in endoscopic procedures. A long learning curve must be anticipated.

22.7 Indications and Contraindications

Endoscopic hemivertebra resection can be performed in the lumbar and thoracic regions. Indications for surgery are a progressive curve and the development of secondary curves. In the lumbosacral area increasing pelvic obliquity or trunk decompensation are indications for surgery. Relative contraindications for endoscopic procedures are previous surgery and revisions. In case of an intraspinal anomaly, neurosurgical intervention has to be considered before or together with hemivertebra excision.

22.8 Patient's Informed Consent

Besides typical complications some special side effects of hemivertebra excision need to be addressed. Sensory as well as motor deficits may occur as a consequence of nerve root entrapment or direct injury to the spinal cord. As a worst-case scenario even bladder and bowel paralysis or complete paraparesis is possible, although current literature suggests that it is rare. In addition, problems with fusion may occur, such as delayed union or pseudarthrosis. Because of insufficient primary stability of the instrumentation a cast and a brace have to be worn for 6 months.

Complications related directly to the anterior approach comprise pneumothorax, pleural effusion, and injury to ureter or other retroperitoneal structures. Temporary bladder or bowel dysfunctions after surgery can occur. Intraoperative bleeding most frequently occurs from epidural veins. Specifically, bleeding may sometimes occur during removal of the posterior wall of the hemivertebra and blood transfusions may be necessary.

22.9 Surgical Technique

Preoperative MRI and three-dimensional CT reconstructions before surgery are mandatory to assess the anatomy and rule out intraspinal anomalies (Fig. 22.1).



Fig. 22.1. Preoperative MRI shows a semisegmented hemivertebra at the lower lumbar region

In all cases patients are positioned prone on the operating table for the first part of the surgery. An arterial and central venous line are established and prophylactic antibiotics are given. A posterior skin incision is performed just over the hemivertebra. Usually the skin incision is between 6 and 8 cm long. The pedicle of the hemivertebra is identified by fluoroscopy, and the laminae of the adjacent vertebra are subperiosteally exposed. The hemilamina is removed and then the transverse process and ribs are sectioned. The pedicle is removed with a high-speed diamond burr. If a contralateral posterior bar exists it is sectioned with rongeurs. Since the dural sac together with the spinal cord is shifted toward the concavity, removal of the pedicle is a relatively safe procedue and can be done without touching the cord. In small children special pediatric supralaminar and infralaminar hooks are inserted one segment above and below the hemivertebra together with a rod. The hooks are loosely tightened to the rod. The wound is packed with sponges and temporarily closed with a running suture.

The patient is then positioned in the lateral decubitus position with the side of the hemivertebra upward (Fig. 22.2). A 4- to 6-cm incision is performed in the midaxillary line corresponding to the location of the

hemivertebra. The hemivertebra is always approached from the convexity. The location of the incision can easily be appreciated after having performed the posterior incision. Thoracic hemivertebrae and hemivertebrae in the upper lumbar region down to L2 are approached by thoracotomy and by a diaphragm-splitting approach. A small rib spreader is usually inserted (Fig. 22.3). Selective intubation is not performed. A small retractor is generally inserted for lung protection. Access to hemivertebrae in the lower lumbar region is obtained through a typical retroperitoneal approach. The abdominal muscles are separated by blunt dissection. For this location we use a self-retaining retractor with long blunt blades. In addition, the assistant holds a long retractor. A 6-mm-diameter endoscope with a 30° lens is introduced through a separate stab incision. A flexible holding arm is generally used to fix the endoscope. It is positioned opposite the hemivertebra. The surgeon stands in front of the patient while an assistant stands on the opposite side. Ideally, one monitor should be placed on either side to give both the surgeon and the assistant an optimum view. The bone collected from both the anterior and posterior approach is stored for later bone grafting. The first step during anterior removal of hemivertebrae is to resect the adjacent disc spaces (Fig. 22.4). The dissection has to be complete into the concavity. The resection of the hemivertebra is started with chisels. When the posterior wall is identified the resection is completed with the use of a diamond burr.

The posterior wound is opened again with the patient still in the lateral decubitus position and compression is performed between the adjacent laminae with the help of the supra- and infralaminar hooks. Compression is performed slowly and cord or nerve root compression should be avoided. In the case of a single fully segmented hemivertebra with two adjacent disc spaces it is necessary to add an anterior strut graft or a titanium cage to correct segmental kyphosis. In young children less than 3 years old it is usually easy to close the gap by simply performing posterior compression. For older children transpedicular fixation or anterior supplementary instrumentation may be used to increase stability.



Fig. 22.2. Lateral decubitus position for anterior part of surgery

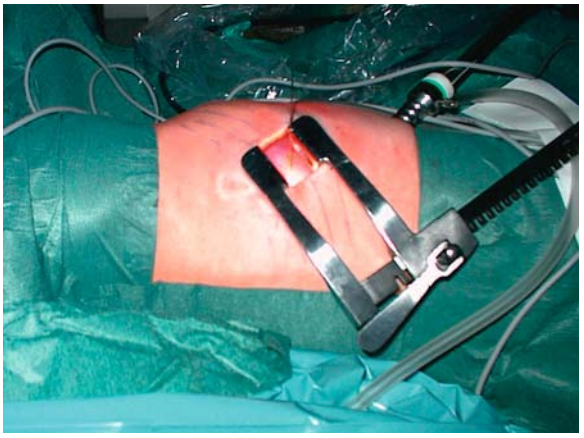


Fig. 22.3. A small retractor is inserted between ribs

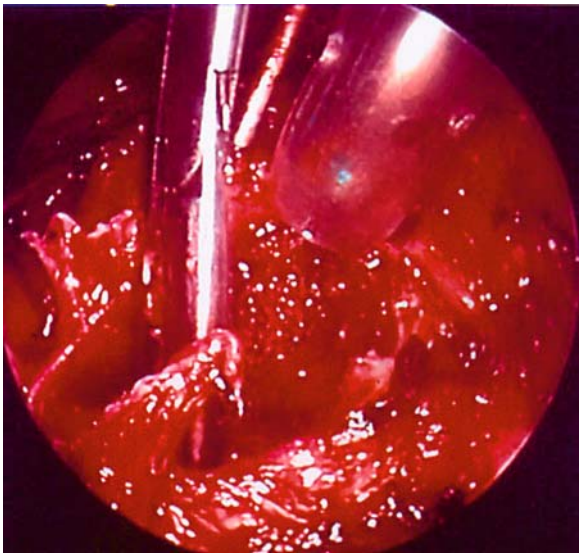


Fig. 22.4. Adjacent discs have already been removed. The anterior part of the hemivertebra can be removed with rongeurs, curettes, or a diamond burr

22.10 Postoperative Care and Complications

Since in small children compliance with postoperative management is poor, a plaster brace is applied immediately after surgery. It is then changed after 2 weeks. After 6 weeks the plaster cast is bivalved and a plastic removable brace is manufactured. For the first 6 weeks after surgery the parents are told not to allow standing or walking, while sitting is not restricted. After 6 weeks standing and walking is permitted with the aid of an walker to avoid falling. If residual flexible components of the curve are still present, brace treatment is continued (Fig. 22.5a, b)

22.11 Patients

From January 1999 to February 2003, 13 children (8 boys and 5 girls) with an average age of 4+11 years (1+3 to 12+6 years) had hemivertebra excision by a combined posterior and minimally invasive endoscopically assisted anterior approach. Eight of the 13 patients were less than 5 years old at the time of surgery. Details are given in Table 22.1.

22.12 Results

The index curve measured 45° (38 – 55°) preoperatively and 12° (5 – 18°) postoperatively, contributing to an average correction of 73 %. Improvement of secondary curves occurred in each case, but this was also dependent on additional congenital deformities which were present in 6 of the patients.

No neurological complications were found and no pseudarthrosis developed. In 5 of the 13 patients blood transfusion was required. No major hemorrhage or other complications were encountered during operation. Two patients developed pneumonia after surgery which resolved quickly with adequate therapy.

22.13 Critical Evaluation

Hemivertebrae can be resected by a combined anterior and posterior approach or by a posterior approach only. The advantage of a single posterior approach is to avoid anterior scars and repositioning during surgery. The advantage of an anterior approach is that resection of the hemivertebra and adjacent disc spaces is more complete, and correction and restoration of the sagittal

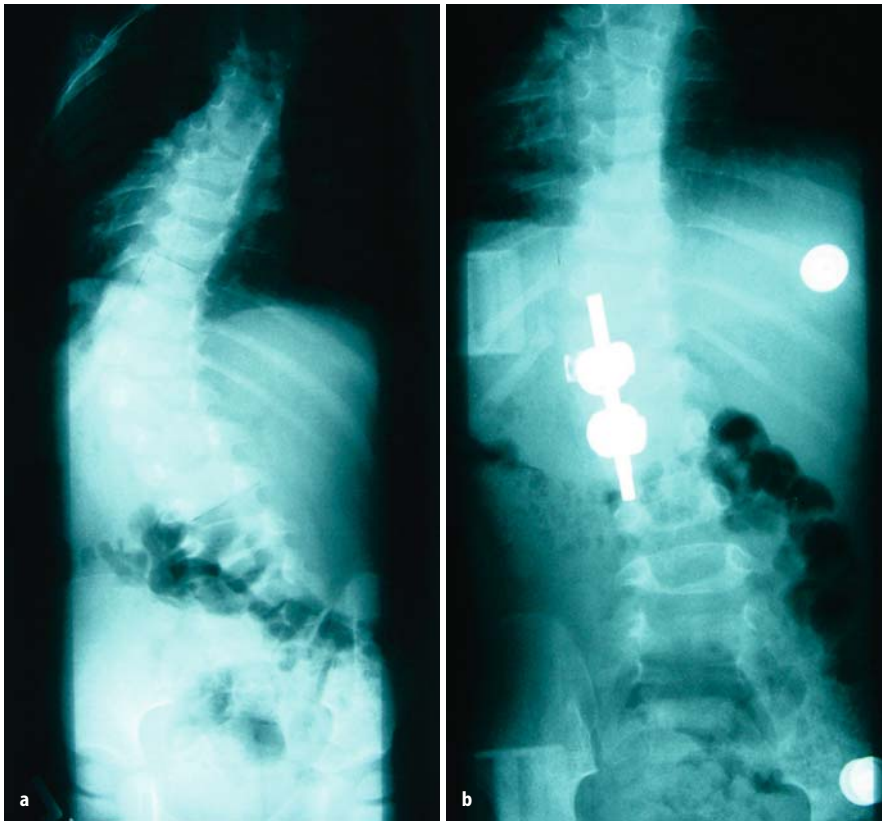


Fig. 22.5. a Preoperative X-ray of a 2+3-year-old girl with a fully segmented hemivertebra at L1 and a long flexible curve. **b** Postoperative X-ray showing complete correction of the congenital deformity with some flexible component remaining 1 year after surgery. Brace treatment was continued

Table 22.1. Patients' data. (*T* Thoracic spine, *L* lumbar spine)

Patient	Age (years+ months)	Gender	Location	Type of hemivertebra	Other abnormalities
K.K.	2+6	Male	T11	Fully segmented	Lumbosacral dysplasia
L.J.	6+6	Male	T11	Fully segmented	
M.S.	2+0	Female	T12	Semisegmented	Congenital bar and fused ribs upper thoracic region
F.M.	2+10	Female	T11	Fully segmented	
G.F.	5+5	Female	L4	Fully segmented	
G.A.	1+9	Male	L1	Fully segmented	
L.V.	5+6	Male	T12	Fully segmented	
C.E.	1+3	Female	L1	Semisegmented	Contralateral bar
G.M.	2+3	Female	L1	Fully segmented	Additional non-segmented hemivertebra at T6
M.S.	7+11	Male	L4	Semisegmented	
S.A.	4+2	Male	T10	Fully segmented	Contralateral hemivertebra T6
J.T.	2+7	Male	T7	Semisegmented	Contralateral bar and fused ribs
F.R.	12+6	Male	L4	Fully segmented	

contour better. It is now well accepted that hemivertebra excision should be carried out early before secondary structural curves have developed [1, 7]. In our experience it is easier and safer to remove hemivertebrae in small children than in adolescents. In children under the age of 3 years compression with a supra- and infralaminar hook is usually sufficient for correction and stabilization. Neurological complications after hemivertebra excision are rare [1–5, 7]. In our series of 13 patients treated by endoscopically assisted hemivertebra excision no neurological complications were encountered.



Fig. 22.6. This male patient had hemivertebra excision at T12 at the age of 2+6 years. At 2 years follow-up there is no residual deformity. Notice the small anterior scar after endoscopically assisted surgery

The introduction of a minimally invasive approach by endoscopically assisted surgery produces less morbidity. Besides less morbidity through smaller incisions, better illumination and working under magnification are major advantages of this procedure. To our knowledge, endoscopically assisted surgery has not been reported for hemivertebra removal. Early et al. [3] reported on the feasibility of anterior thoracoscopic spine surgery in children. In their opinion performing thoracoscopic spine surgery on patients under 20 kg is a relative contraindication. We have performed endoscopically assisted surgery on children weighing 10–15 kg without any significant problems (Fig. 22.6).

22.14 Conclusions

In children, excision of hemivertebrae with the help of an endoscopically assisted anterior approach is a safe procedure and can even be performed on very small children under the age of 5 years.

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Thoracoscopically Assisted Anterior Approach to Thoracolumbar Fractures

23

R. Beisse

23.1 Terminology

The term thoracoscopic-assisted anterior approach to thoracolumbar fractures describes an anterior approach to the thoracic (T5 – 10), as well as to the thoracolumbar junction (T11-L2) which is performed using a closed endoscopic technique. The synonymous terms used in other scientific publications are video-assisted thoracoscopic surgery (VATS) or thoracoscopic spine surgery.

23.2 Surgical Principle

The goal of thoracoscopic surgery in the treatment of fractures is the restoration of normal curvature and stability of the affected motion segment(s). This is usually achieved in a two-step procedure which includes posterior reduction and stabilization with a pedicle screw system. Anterior decompression of the spinal canal, reconstruction of the fractured vertebra, as well as augmented (anterior plate system) interbody fusion with autogenous bone graft or with a vertebral body replacement device is performed through a closed thoracoscopic anterior approach, which can be extended into the retroperitoneal space down to L3 if necessary.

23.3 History

Attempts at treating unstable fractures of the thoracolumbar junction by posterior reduction, decompression, and (transpedicular) bone grafting, result in an average loss of correction of 10° in long-term follow-up studies [15]. Anterolateral stabilization with the use of a plating system and intercorporeal fusion with autogenous bone graft offers biomechanical, as well as technical advantages in the reconstruction of the anterior column which has to share 80 % of the axial load on the motion segment [20]. However, the tremendous iatrogenic trauma at the thoracolumbar junction is the major disadvantage of this open surgical strategy [7, 8]. Most common discomforts are intercostal neuralgia, as well as post-thoracotomy pain syndromes [13]. Moreover, complete dissection of the diaphragmatic insertions from the anterior circumference of the thoracolumbar spine is often necessary [1, 5].

Mack, Regan, Rosenthal, and colleagues were the first to report the application of thoracoscopic surgical principles to an anterior approach to the thoracic and thoracolumbar spine [16, 22 – 24]. There have been several attempts to open up the retroperitoneal space [10, 17, 19] and the thoracolumbar transition of the spine for endoscopic surgery [6, 11, 12, 18]. The endoscopic approach technique to the thoracolumbar junction, used at the Berufsgenossenschaftliche Unfallklinik in Germany for 7 years (1996 – 2004), was published first in 1998 [2]. Since 1996 this endoscopic approach has been used in a total of 410 patients to perform partial corpectomy and discectomy followed by the reconstruction of the anterior column with vertebral replacement and anterior instrumentation.

23.4 Advantages

The following advantages are associated with a thoracoscopic anterior approach:

- Small intercostal surgical approaches without the necessity of rib resection or the use of rib retractors
- Excellent intraoperative view to the target area by the use of a high-resolution 30° optical lens system coupled to modern video-imaging equipment
- Efficient and safe anterior decompression of the spinal canal
- Treatment of oligo- and multisegmental pathology without additional surgical approaches
- Diminished blood loss
- Low peri- and postoperative morbidity due to reduced wound pain, early extubation, and accelerated rehabilitation

23.5 Disadvantages

- Increased monitoring of anesthesia and preparation due to double-lumen ventilation
- Long learning curve for surgeon and assistant
- Longer operating times initially.

23.6 Indications

The anterior thoracoscopic approach is indicated in the following situations (usually in combination with posterior instrumentation):

- Fractures of the thoracic spine located at the thoracolumbar junction from T4 to L3.
- Fractures classified as A 1.2, A 1.3, A 2, A 3B, and C according to the AO classification [11] with significant curvature disturbance of 20° and more in the sagittal or frontal plane.
- In fractures of types B and C, posterior instrumentation is mandatory. In other types it is optional.
- Posttraumatic, degenerative, or tumorous narrowing of the spinal canal.
- Discoligamentous segmental instability.
- Posttraumatic deformities.

23.7 Contraindications

A thoracoscopic approach is contraindicated in the following situations:

- Significant previous cardiopulmonary disease with restricted cardiopulmonary function
- Acute posttraumatic lung failure
- Significant disturbances of hemostasis

23.8 Patient's Informed Consent

The patient should be informed about the following approach-specific risks and hazards:

- Donor site morbidity due to harvesting of the bone graft from the iliac crest (see also Chapters 45, 46)
- Direct or indirect injuries to the aorta, vena cava, azygos vein or segmental vessels
- Blood loss from cancellous bone surface
- Injury to the heart and/or lungs
- Possibility of conversion to a conventional "open" thoracotomy
- Injury to the spinal cord, spinal nerves, and sympathetic trunk with neurological deficits (deafferentation syndrome) and sympathetic dystrophy
- Injury to spleen, liver, kidney, and ureter (thoracolumbar junction)
- Injury to the thoracic duct
- Pseudoarthrosis with loss of correction
- Implant loosening, implant failure
- Infections at the target area, as well as at the donor site
- Restricted pulmonary function due to fibrosis, scarring, atelectasis, or pleural effusion
- Diaphragmatic hernia
- Necessity for anti-thrombotic medication
- Necessity for blood transfusion in emergency operations with risk of immunodepression, anaphylaxis, as well as infection (HIV, hepatitis B, or cytomegaly virus)

23.9 Surgical Technique

23.9.1 Approach to Thoracolumbar Junction: Diaphragmatic Anatomy

The diaphragm originates from three locations, a sternal, a costal and a lumbar part, by means of crura and from arcuate ligaments. The sternal part arises by two fleshy slips from the dorsum of the xiphoid process. The costal part arises from inner surfaces of cartilages and adjacent portions of the last six ribs on either side. The right crus arises from the sides of the vertebral bodies of L1-3. The left crus arises from the sides of L1 and L2 vertebral bodies. The medial arcuate ligament covers the upper part of the psoas major muscle, attaching from the sides of first and second lumbar vertebrae to the tip of the L1 transverse process. The lateral arcuate ligament covers the quadratus lumborum and attaches from the tip of the L1 transverse process to the lower border of the 12th rib. Thus, both the crura and arcuate ligaments of the diaphragm are inserted below the T12-L1 disc space [11, 21].

Lesions located above the T12-L1 disc can be approached thoracoscopically from above without dividing the diaphragm as both crura and arcuate ligaments, which form the lumbar part of the diaphragm, are located below the T12-L1 disc space (Fig. 23.1). However, below the T12-L1 disc space, the spine is surrounded by the diaphragmatic crura, psoas muscles, and arcuate ligaments and thus in lesions located in this area require diaphragmatic detachment for adequate exposure.

The entire thoracolumbar junction can be exposed thoracoscopically with minimal diaphragmatic detachment. This is made possible by an anatomic peculiarity of the pleural cavity and the diaphragmatic insertion,

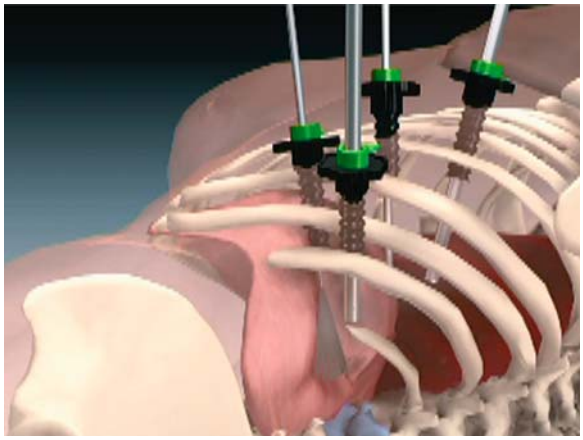


Fig. 23.1. Diaphragmatic anatomy at the thoracolumbar junction and the position of the portals

the lowest point of which, the costodiaphragmatic recess, is projected onto the spine with a perpendicular projection just above the inferior endplate of the second lumbar vertebra. Thus, with a diaphragmatic opening of about 4–6 cm, the entire L2 vertebral body can be exposed in the same way as with the conventional open techniques.

23.9.2 Access Technique

23.9.2.1 Instruments

The following instruments are necessary to perform thoracoscopic-assisted anterior approaches to the thoracic and lumbar spine:

- Routine surgical set for skin incision and preparation of the intercostal space
- Instruments for removal of bone graft from the iliac crest (e.g., oscillating saw, sharp dissector, chisels, mini-fragment set to reconstruct the iliac crest)
- Video-endoscopy: three-chip camera, 30°-angled rigid endoscope, xenon-light source, two monitors on opposite sides with the possibility of reversing the endoscopic picture, video recorder and printer, irrigation/suction unit, speculum (Aesculap, Tuttlingen, Germany)
- Instruments for the thoracoscopic dissection of the prevertebral anatomic structures, as well as for resection of bone and ligaments, osteotomes, hooks for dissection, hook probes, sharp and blunt rongeurs, Kerrison rongeurs, curettes, graft holder, reamers, mono- and bipolar probe (Aesculap)
- Instruments for implant placement, e.g., awl, screwdriver, plate set (MACS TL; Aesculap)
- Disposable instruments, lung retractor, clip applicator

23.9.2.2 Anesthesia

The procedure is performed with the patient under general anesthesia. Selected intubation with single-lung ventilation facilitates intrathoracic preparation. The positioning of the double-lumen tube is controlled by a bronchoscopic technique. A Foley catheter and a central venous line(s) are placed, as well as an arterial line for continuous blood pressure measurement.

23.9.2.3 Positioning

The patient is placed in a stable lateral position on the right side and fixed with a four-point support at the symphysis, sacrum, and scapula, as well as with arm rests (Fig. 23.2).

For the treatment of fractures from T4 to T8, a left-sided position is preferred, whereas for the approach to the thoracolumbar junction (T9-L3), right-sided positioning is preferred. We have moved away from prescribing fixed reference vertebrae for approaching from right or left. The decision on which side to choose for access is taken in each individual case based on the preoperative CT scans of the spinal section and the vascular situation of the aorta and the vena cava they show. When positioning the patient, care has to be taken that the upper arm is abducted and elevated in order not to disturb the placement and manipulation of the endoscope.

23.9.2.4 Localization

The target area (e.g., L1 fracture) is projected onto the skin level under fluoroscopic control and the borders of the fractured vertebra are marked on the skin (Fig. 23.3). The working channel is centered over the target vertebra



Fig. 23.2. Positioning the patient



Fig. 23.3. Localization of the target area and the skin incisions

(10 mm). The optical channel (10 mm) is placed between two and three intercostal spaces cranial to the target vertebra in the spinal axis. For fractures of the middle and upper thoracic spine, the optical channel is placed caudal to the target vertebra. The approach for suction/irrigation (10 mm) and retractor (10 mm) is placed approximately 5 – 10 cm anterior to the working and optical channel.

Before the operation starts, the position and free tilt of the C-arm has to be checked. Sterile draping extends from the middle of the sternum anterior to the spinous processes posterior as well as from the axilla down to about 8 cm caudal to the iliac crest.

Both monitors are placed at the lower end of the operating table on opposite sides in order to enable free vision for the surgeon, as well as for the assistant. The surgeon and cameraman stand behind the patient. The C-arm approach is between the surgeon and the cameraman. The assistant, as well as the C-arm monitor are placed on the opposite side (Fig. 23.4).

23.9.2.5 Approach and Placement of Portals

The operation is started with the most cranial approach (optical channel). Through a 1.5-cm skin incision above the intercostal space, small Langenbeck hooks are inserted. The muscles of the thoracic wall are crossed using a blunt, muscle-splitting technique and the intercostal space is opened by blunt dissection. The pleura is exposed, an opening into the thoracic cavity is created, the 10-mm trocar is inserted, and single-lung ventilation is started.

The 30° endoscope is inserted at a flat angle in the direction of the second trocar. Perforation of the thoracic wall to insert the second, third, and fourth trocars is performed under visual control through the endoscope, as shown in Fig. 23.5.

23.9.2.6 Prevertebral Dissection

The target area can now be exposed with the help of a fan retractor inserted through the anterior port. The

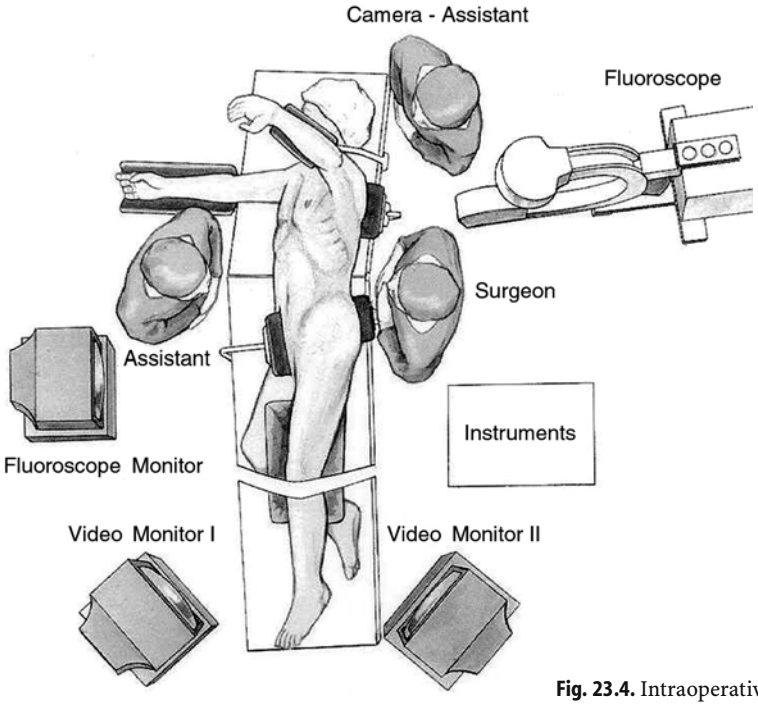


Fig. 23.4. Intraoperative setup of the operation team and equipment



Fig. 23.5. Placement of the endoscope and placement of retractor, suction/irrigation, as well as working channel under endoscopic control

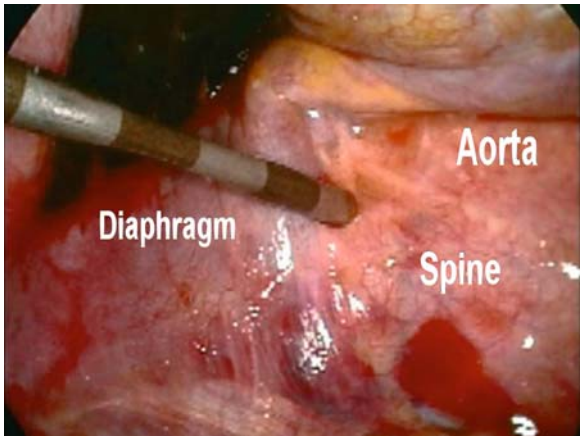


Fig. 23.6. Intraoperative view of the thoracolumbar junction. The retractor is placed on the diaphragm and a blunt probe is pointing out the anterior border of the spine

retractor holds down the diaphragm and exposes the insertion of the diaphragm on the spine. The anterior circumference of the motion segment, as well as the course of the aorta are palpated with a blunt probe (Fig. 23.6).

The line of dissection for the diaphragm is "marked" with monopolar cauterization. The diaphragm is then incised using endo-scissors. A rim of 1 cm is left on the spine to facilitate closure of the diaphragm at the end of the procedure. Retroperitoneal fat tissue is now exposed and mobilized from the anterior surface of the psoas insertions. The psoas muscle is dissected very carefully from the vertebral bodies in order not to damage the segmental blood vessels "hidden" underneath.

23.9.3 Case Example I

In the following an endoscopic monosegmental fusion T11 – T12 is described for a fracture of the twelveth thoracic vertebra type B 1.2 (AO classification) in a 26-year-old woman (Fig. 23.7a, b). Posterior reduction and fixation has been performed initially. We intend to perform an endoscopic monosegmental anterior reconstruction with lag screw fixation of the split fracture at the lower half of the first lumbar vertebra.

23.9.3.1 Exposure of the Spine

Figure 23.8 demonstrates the intraoperative situation after endoscopic exposure of the target area. The diaphragm is opened to access the retroperitoneal space (Fig. 23.8). The retractor is now placed into the gap in the diaphragm. Under fluoroscopic control, the first screw of the MACS TL plate system (Aesculap) is inserted into the caudal vertebral body (Fig. 23.9a, b).

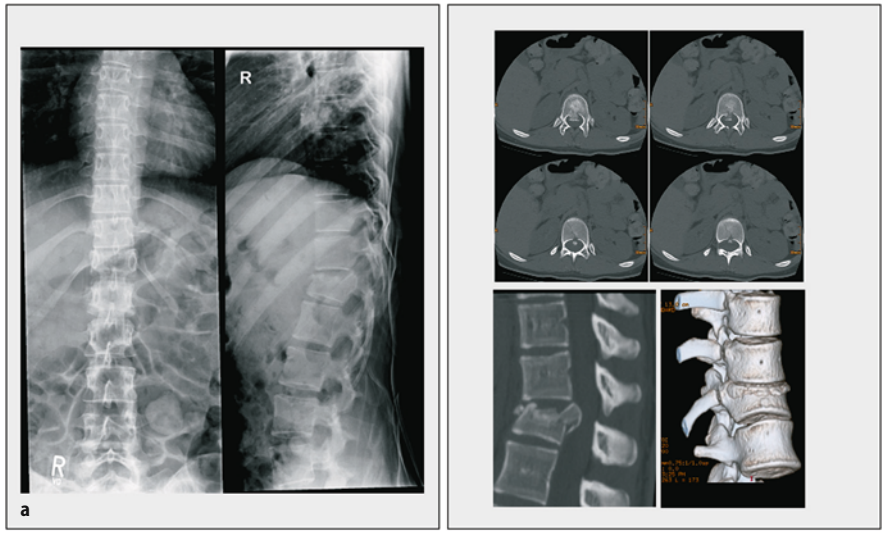


Fig. 23.7. Case example I. **a** Fracture of the T12 vertebra type B 1.2 (AO classification)

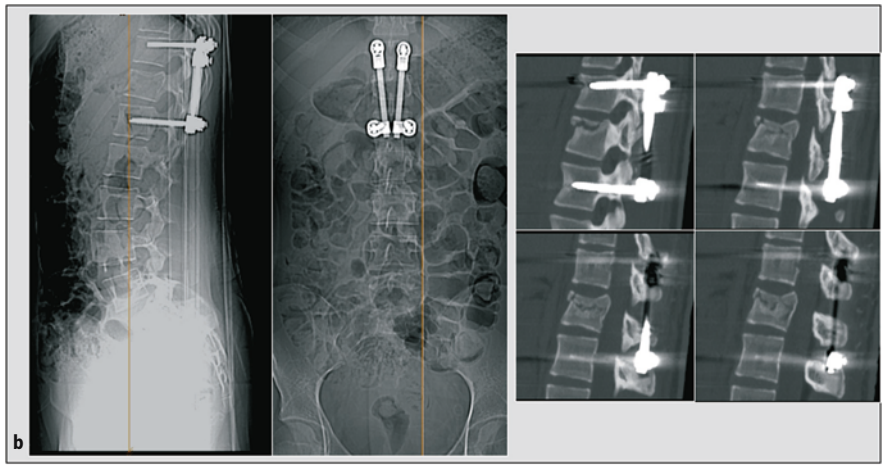


Fig. 23.7. (contin.) b Bisegmental posterior reduction and fixation using the Universal Spine System

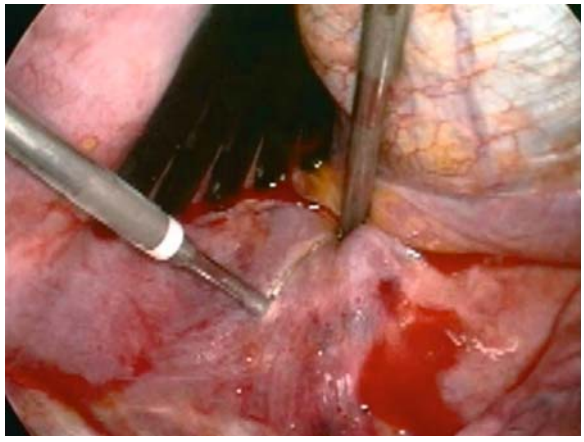


Fig. 23.8. Opening of the diaphragm to expose the retroperitoneal space

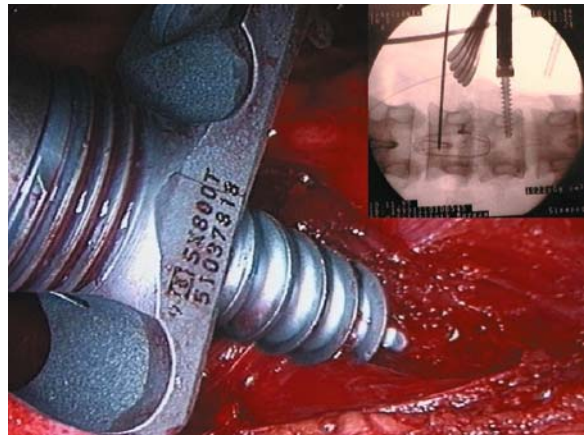


Fig. 23.10. Insertion of the first screw and the polyaxial dumping element

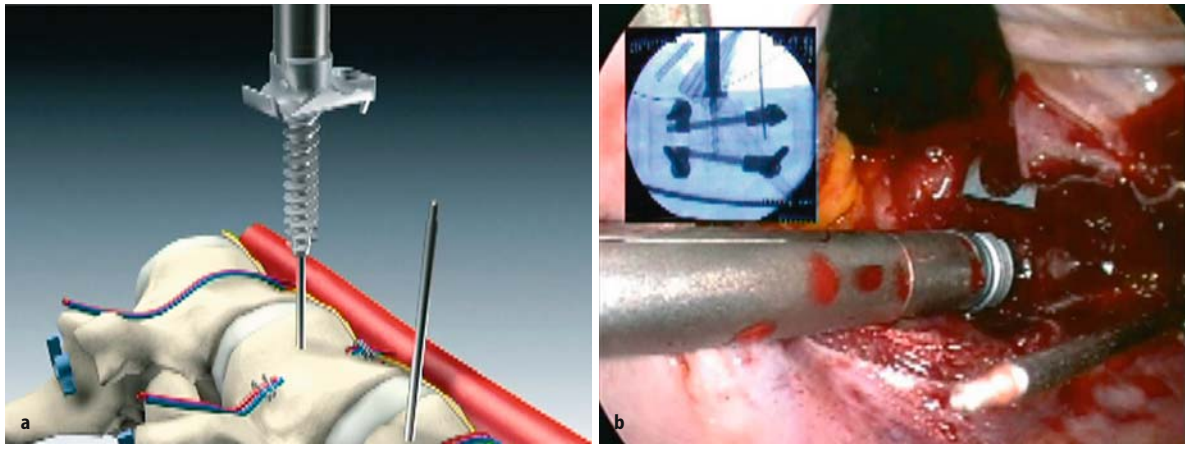


Fig. 23.9. Insertion of the first screw. **a** Three-dimensional model. **b** Intraoperative view

The cortical surface of the vertebral body is opened with a sharp trephine about 1 – 1.5 cm from the posterior border of the vertebral body infra- and supradjacent to the fracture (Fig. 23.10). A self-tapping screw is inserted under fluoroscopic control in the vertebra superior to the fractured one, as well as in the fractured vertebra. If there is an A 2 or A 3 fracture, it might be advisable to place the screw into the vertebra below the fracture. The segmental vessels of the fractured vertebra are mobilized, closed with vascular clips, and dissected.

23.9.3.2
Partial Corpectomy and Decompression of the Spinal Canal

The extent of the planned partial vertebrectomy is defined with an osteotome. The disc spaces are opened to define the borders. After resection of the intervertebral disc(s), the fragmented parts of the vertebra are removed carefully with rongeurs. Radical removal of non-fractured parts of the vertebral body should be avoided. If decompression of the spinal canal is necessary, the lower border of the pedicle should first be identified with a blunt hook. The base of the pedicle is then resected in a cranial direction with a Kerrison rongeur and the thecal sac can be identified. Now the posterior fragment which occupies the spinal canal can be removed (see Figs. 23.13 and 23.14; case example II).

23.9.4
Bone Grafting

Preparation of the graft bed is then completed and the length, as well as the depth of the bone graft are measured with a caliper. A tricortical bone graft is taken from the iliac crest. If the bone graft is longer than 2 cm, the iliac crest is reconstructed as described by Blauth et al. using a titanium plate [5]. The bone graft is prepared for insertion and mounted on a graft holder. The cortical bone is perforated with several burr holes to facilitate vascular in-growth and new bone formation. The working portal is removed and a speculum is inserted. This allows the insertion of a bone graft up to 1.5 cm in length into the thoracic cavity. If the bone grafts are longer, they are inserted without the use of the speculum, but with the help of Langenbeck hooks. In these cases, they are mounted on the graft holder inside the thoracic cavity. The bone graft is inserted by press-fit into the graft bed (Fig. 23.11a, b).

If slight reduction maneuvers are necessary, these can be achieved by manual pressure on the spinous processes of the involved segment thus creating a segmental lordosis. Then the MACS TL plate is inserted and mounted onto the screws. The stable-angled ventral screws are inserted using a target device (Fig. 23.12a, b).

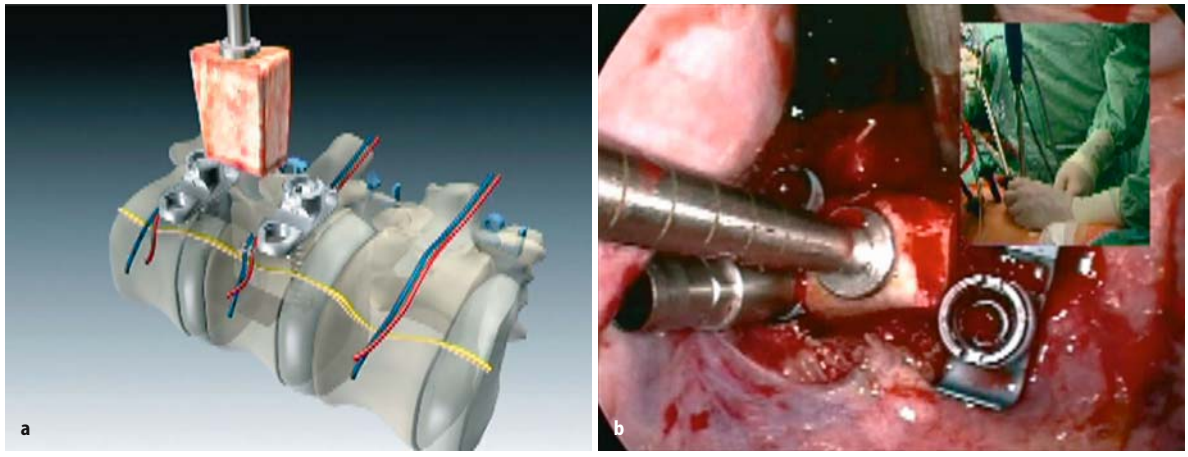


Fig. 23.11. Insertion of the bone graft after partial corpectomy and discectomy. **a** Three-dimensional model. **b** Intraoperative view

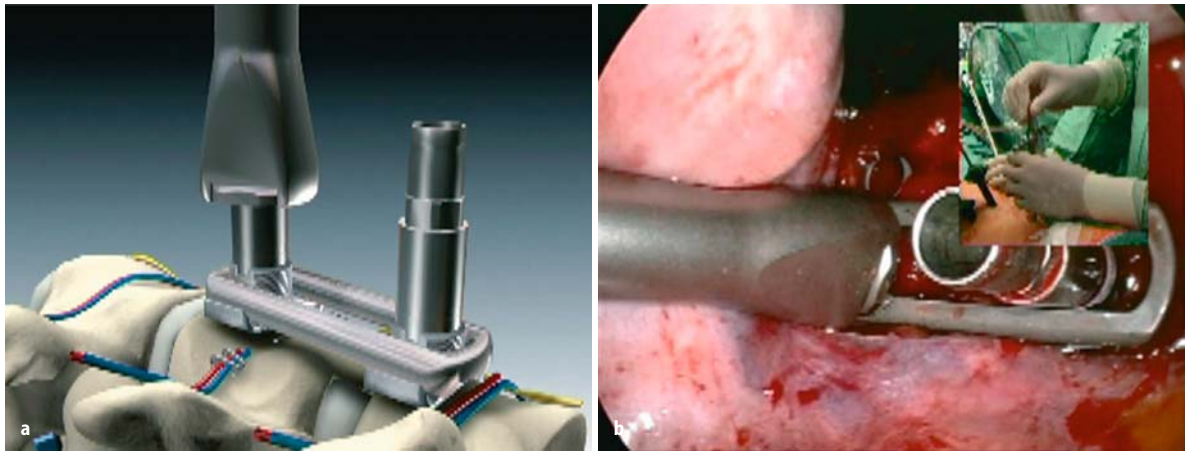


Fig. 23.12. Fixation of the MACS TL plate. **a** Three-dimensional model. **b** Intraoperative view

23.9.5 Closure

The retractor is rearranged and the gap in the diaphragm is closed with staples using an endoscopic technique (Fig. 23.13). The thoracic cavity is irrigated, blood clots are removed, and a chest tube is inserted with the end placed in the costodiaphragmatic recess. The portals are closed with sutures after removals of the trocars. Postoperative X-rays as well as CT scans show a perfect reduction (Fig. 23.14).

23.9.6 Case Example II

Figures 23.15 and 23.16 demonstrate a case of an unstable complete compression burst fracture of the first lumbar vertebra with severe spinal canal compromise. After primary dorsal reduction and fixation, endoscopic anterior decompression was performed followed by anterior reconstruction using a distractible vertebral body replacement device (Synex) and an anterior fixation plate (MACS TL system).

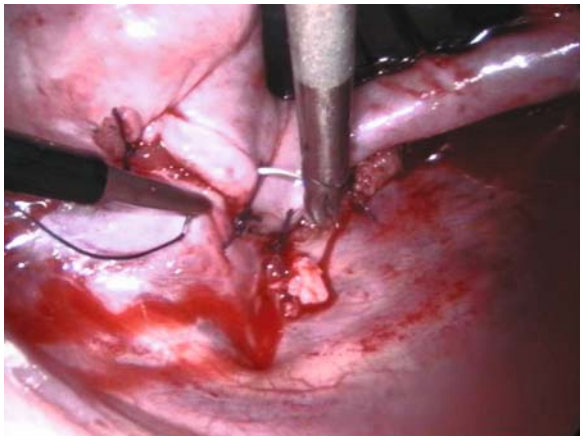


Fig. 23.13. Endoscopically-assisted suturing of the diaphragm

23.10 Postoperative Care

- Postoperative AP and lateral X-rays of the target area are taken. The patient is extubated immediately after the operation. In patients with chronic obstructive pulmonary disease, old patients, as well as in patients with cardiovascular disease, artificial ventilation might be necessary for the first 24 h after the operation.
- Low-dose low molecular weight heparin is given for thromboembolic prophylaxis.
- The patient stays in the intensive care unit for 24 h. The chest tubes can usually be removed on the first postoperative day.
- On the second postoperative day physiotherapy is started (1 h/day).
- From the third postoperative week, physiotherapy is intensified to 2 – 3 h daily.
- X-ray controls are performed on the second postoperative day, after 9 weeks, as well as after 6 and 12 months.
- The patient is allowed to return to work after 12 – 16 weeks.

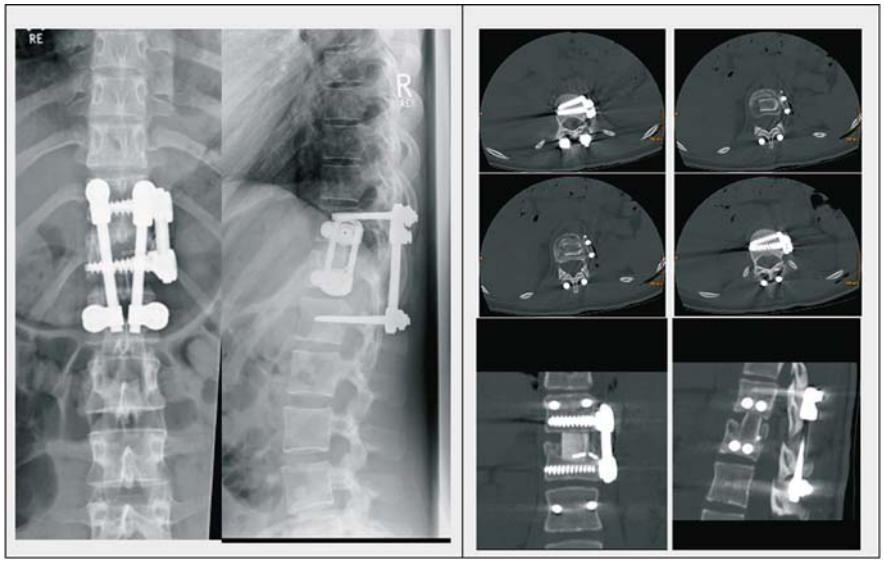


Fig. 23.14. Endoscopic monosegmental anterior reconstruction T11 – T12 with bone graft and MACS TL system

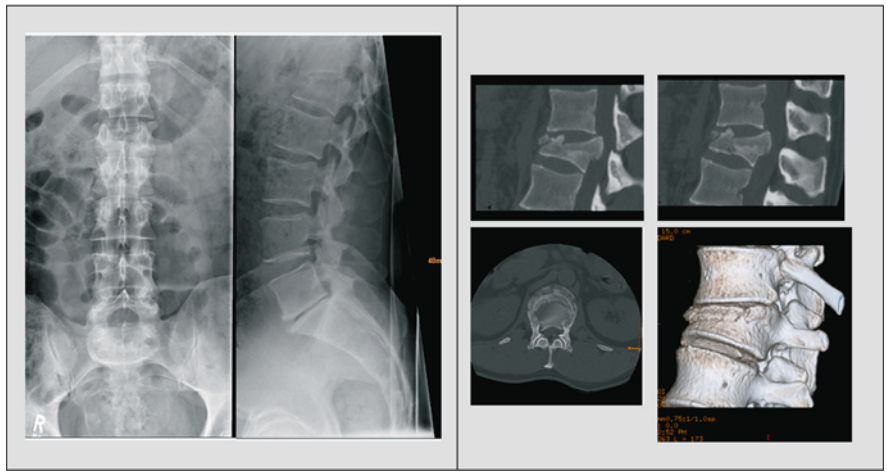


Fig. 23.15. Case example II. Compression fracture type A 3.3 with spinal canal compromise

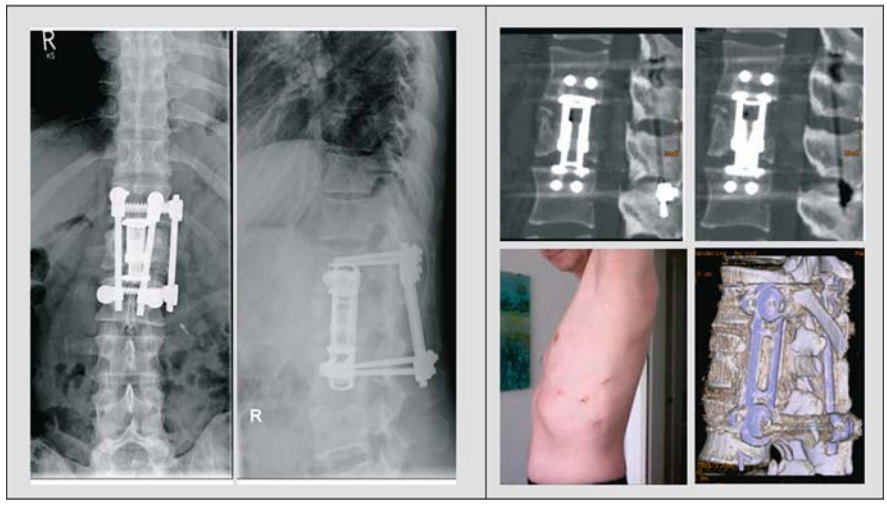


Fig. 23.16. Case example II. Primary dorsal reduction and fixation followed by endoscopic anterior decompression and reconstruction using Synex and MACS TL systems for bisegmental fusion

23.11 Complications, Hazards, and Pitfalls

23.11.1 Potential Intraoperative Complications

- Incorrect positioning of the patient, as well as incorrect positioning of the C-arm might result in malpositioning of the screws.
- Insufficient preparation of the segmental vessels can result in accidental injury, bleeding, and loss of visual control of the target area.
- Risk of damage to the nerve roots by uncontrolled monopolar coagulation.
- Risk of injury to the aorta and vena cava due to forceful use of sharp instruments.
- Accidental injury to the heart, lung, and vessels which may require open thoracotomy.
- Local injury to the lung parenchyma which may require suture or stapling.
- Opening of the peritoneum which requires an endoscopic suture.
- Dural tearing.
- Insufficient preparation of the graft bed which might lead to forceful impaction with risk of indirect injury to the dura and spinal nerves due to displacement of bone or disc fragment into the spinal canal or foramen.
- Insufficient reduction of the fractured vertebra.

23.11.2 Potential Postoperative Complications

- Intrathoracic hemorrhage requiring thoracoscopic revision procedure or thoracotomy
- Deep wound infection requiring open revision, debridement, removal of implant, and reosteosynthesis
- Recurrent pleural effusions
- Intrathoracic adhesions
- Implant failure

23.11.3 Own Complications

The following major intraoperative complications occurred: loosening of one locking nut, and one uncontrollable bleeding from cancellous bone. Both complications occurred during the first interventions and necessitated a change to an open approach. Another conversion to open thoracotomy was necessary in a patient with a lesion to the aortic wall which required sutures to control the bleeding. Thus, the overall conversion rate actually is 0.8 %.

An iatrogenic transient lesion of the L1 nerve root with sensory deficit and a transient compression of the thoracodorsalis nerve on the opposite side due to faulty positioning occurred. One deep wound infection at the approach site at L2 and one infected hematoma at the site of bone graft harvesting were seen. The overall rate of complications due to infections, pseudoarthrosis, and implant failure was 4.3 %, and 1.1 % due to the preparation and implantation of screws and implant. Complications due to the endoscopic approach, such as encapsulated pleural effusion, pneumothorax, and neuralgia of the intercostal nerve, occurred in 5.4 % of cases.

23.12 Conclusion and Critical Evaluations

Between May 1996 and May 2001, 371 patients with traumatic injuries of the thoracic and thoracolumbar spine underwent a minimally invasive thoracoscopic reconstruction, interpositional bone graft or cage, and anterior plate fixation (Fig. 23.17) [14]. The mean follow-up for our study group is 2.3 years, with at least 1-year X-ray follow-up in more than 85 % of patients. When the AO classification scheme is used, 61 % of the fractures were type A variants, 22 % were type B variants, and 17 % were highly unstable type C variants. As expected from the traumatic nature of the patients' injuries the majority (73 %) of the fractures were located within the region of the thoracolumbar junction (T11-L2) (Fig. 23.18). With stratification of our patients' motor and sensory function according to the classification scheme of Frankel et al. [9], 59 % of our patients were Frankel class E with no focal motor or sensory findings. Of the 41 % of patients who had deficits, 14 % were class D, with preservation of useful function distal to the injury; 4 % were class C, with no useful motor function distally; 4 % were class B, with no useful distal motor function but some sparing of sensory function; and 19 % were Frankel class A, with complete neurological injury. Overall, 15 % of patients demonstrated evidence of significant neurological compression at the time of admission as well as a neurological deficit, thus requiring anterior endoscopic decompression.

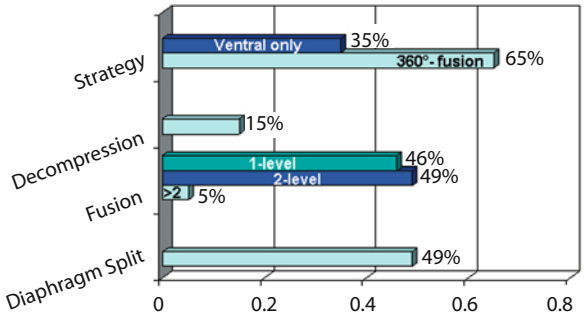


Fig. 23.17. Types of procedures performed ($n = 371$)

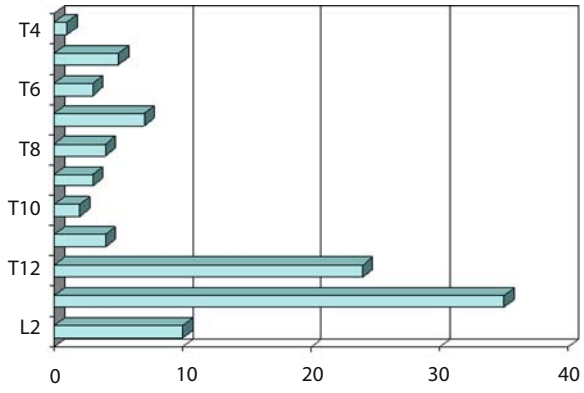


Fig. 23.18. Thoracoscopic operations on the thoracic and thoracolumbar spine ($n = 371$)

In 52 % of the surgical procedures for thoracolumbar pathologies, the diaphragm was incised and closed with staples or sutured under endoscopic control. No postoperative complications such as hernias or paresis of the diaphragm were recorded.

The duration of surgery became shorter over time. At the beginning it took 6 h, but the average operation time is now 2 – 3 h. Included in this time are all procedures such as monosegmental grafting, resection of the posterior fragment for decompression of the spinal canal, multisegmental surgery, as well as those performed at different levels. The shortest time for a monosegmental fusion T11/T12 was 70 min. Partial incision at the attachment and suture of the diaphragm increases the surgical time by 30 min and resection of the posterior rim by 60 – 90 min.

Based on our up-to-date experience with approximately 840 endoscopic procedures, the advantages of a minimally invasive procedure are as follows. There is marked reduction in postoperative pain and a prompt return to function and mobility of the patient. Our goal to reduce the morbidity associated with the approach could be reached. Routine experience with "open" spine and thoracic surgery is required to shorten the learning curve and to handle potential complications. We are confident that the development of implants and instruments adapted to the endoscopic procedure will

reduce the rate of complications and the duration of the operation even further.

The endoscopic approach has replaced open thoracotomy in the group of patients described. The impression that postoperative morbidity, as well as rehabilitation time, could be shortened by using to the endoscopic approach was proved in a clinical study comparing the results of 30 patients each following either open or endoscopic treatment. In the endoscopic group, the duration of application of analgesics was decreased by 31% and the overall dosage of applied analgesics was decreased by 42%. These results are supported by comparing our own results with those published by Faciszewski et al. [8]. In this multicenter study the complication rate of a total of 1,223 open anterior approaches to the thoracic and lumbar spine were reported. The postoperative rate of pleural effusion, intercostal neuralgia, and pneumothorax was 14% as compared to 5.4% in our own series. The infection rate in the study was 0.57% as compared to 0.53% in ours. Injury to major blood vessels was reported to be 0.08% which is less than in our study (one of 371 patients). However, we did not have any significant postoperative neurological deficits or lethal complications in the first 5 years, which were reported to be around 0.5% in Faciszewski et al.'s series. A deadly complication occurred due to the appliance of high frequency burr and, as a consequence, we no longer use rotating devices for endoscopic procedures. The goal to decrease intraoperative and postoperative morbidity has been achieved by the use of thoracoscopic techniques. However, complications such as pseudoarthrosis, donor site morbidity, or loosening of implants could not be influenced.

The biological and biomechanical drawbacks of vertebral body replacement with autogenous bone grafts have not yet been solved. Some of the complications also resulted from insufficient angular stability of the implants primarily used; since November 1999 improvements have been made using an anterior fixation system providing angular stability [4].

The level of safety of endoscopic surgery is reflected in lower complication rates and operation times which are at least comparable with the open procedure. The basic intention in introducing endoscopic techniques – to reduce access morbidity – could be fully realized. The complications are the expression of the dangers and limits of the procedure, the indication setting, and the high-risk environment of spinal surgery, which even the use of endoscopy cannot alter [3].

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A Minimally Invasive Open Approach for Reconstruction of the Anterior Column of the Thoracic and Lumbar Spine

24

B. Knowles, I. Freedman, G. Malham, T. Kossmann

24.1 Terminology

Minimally invasive open anterior column reconstruction of the spine describes a surgical technique that blends elements from both endoscopic and conventional open spine surgery. With the aid of specially designed surgical instruments the procedure is performed under direct vision through a small incision using an endoscopic set-up (Fig. 24.1).

24.2 Surgical Principle

The aim of the procedure is to restore anatomical alignment and integrity to unstable or destroyed segments of the anterior column of the thoracic and lumbar spine. An open minimally invasive surgical approach is used to minimise surgical trauma and to reduce perioperative and postoperative morbidity. The technique has been developed to combine attractive elements of both endoscopic and conventional open surgery. The procedure is based on the use of a table-fixed retractor system (SynFrame) and is performed with specially manufactured elongated surgical instruments that are operated from outside of the patient's body (Fig. 24.2).

A thoracoscope mounted to the retractor frame is used to illuminate the operating field and is attached to a video camera for monitoring and teaching purposes. Vertebral body reconstruction and augmentation with a variety of materials and spinal canal decompression is performed via an anterior (ventral) approach using a mini-thoracotomy or via a mini-retroperitoneal route. In our experience this procedure is associated with reduced blood loss, shorter hospital stay and less perioperative morbidity than conventional open spine surgery [6, 14, 15]. In contrast to endoscopic spine surgery this procedure does not require special anaesthetic procedures such as double-lung intubation. With an experienced and skilled surgeon operating times are equivalent to those for open procedures [19, 21, 22].

24.3 History

Since the 1970s, the management of thoracolumbar fractures has evolved from conservative management to operative intervention with decompression, reconstruction and internal fixation of affected segments.

The spinal column is situated dorsally behind the visceral cavities of the thorax and abdomen. A posterior approach for decompression and transpedicular



Fig. 24.1. Surgery is performed under direct vision through an open but minimally invasive approach



Fig. 24.2. Operating set-up. The SynFrame is mounted onto the operating table and the retractors and thoracoscope are fixed onto the ring

screw and rod stabilisation has been the standard of care for thoracolumbar fractures for some time [13]. However, 80–85% of axial forces on the spine are transmitted via the anterior vertebral column [8]. Hence, reconstruction of the axial load-bearing anterior spine has been shown to impart a biomechanical and clinical advantage to fracture outcome [9]. How to achieve satisfactory anterior fusion has been a topic of great debate as conventional open spine surgery is associated with significant surgical trauma and complication rates [4, 5, 7, 9, 10, 11, 14, 15, 22].

The thoracic spine (T4–10) has traditionally been accessed via a posterolateral thoracotomy. This involves a large 25-cm incision and is associated with a significant incidence of acute postoperative pain [5], chronic intercostal neuralgia and post-thoracotomy pain syndromes [4]. Conventional open spine surgery is also associated with a high incidence of other complications, such as wound infections, empyema, aortic laceration, pneumothorax, haemothorax, chylothorax, brachial plexus injury, Horner's syndrome and lung herniation [10, 11].

Similarly, open surgery in the form of a retroperitoneal thoracolumbophrenotomy has been the standard approach for fractures of the thoracolumbar region (T11-L3) [6]. This involves opening the thoracic cavity along a lower rib and incising the diaphragm to peel the peritoneal sac away from the lower thoracic spine down to the fourth lumbar vertebra. The operative approach is extensive and entails wide costophrenic detachment.

Capener described the first anterior approach to the lower lumbar spine in 1932 [3]. Unfortunately this open approach is also associated with profound morbidity [7, 19, 22].

As many of these complications were approach specific [7], less traumatic approaches for accessing the spine became desirable. Muscle-sparing thoracotomies have since been shown to reduce postoperative pain [9]. Since the early 1990s "minimally invasive techniques" that utilise endoscopic technology to reduce surgical soft tissue trauma have also emerged [20]. In 1993 video-assisted thoracoscopic surgery (VATS) techniques were applied to the treatment of thoracic spinal disorders. Similar endoscopic procedures were developed for the thoracolumbar junction and lumbar spine [12, 16, 17]. Endoscopic procedures have since demonstrated a significant reduction in postoperative pain, blood loss, recovery time and improved postoperative respiratory function. However, pure endoscopic thoracic and lumbar spine approaches have required invasive double-lumen tube intubation, increased anaesthetic monitoring and longer operative times. More significantly, complications are more difficult to manage and surgeons experience long "learning curves" before they feel familiar with the procedure.

In an effort to rectify the disadvantages of closed endoscopic approaches surgeons have begun to blend minimally invasive techniques with a limited open approach. Mayer pioneered the use of mini-thoracotomy and mini-retroperitoneal open approaches to access the thoracic, thoracolumbar and lumbar spine for the treatment of degenerative disorders [19, 21]. This chapter outlines our development of the treatment of fractures of the thoracic and lumbar spine by a minimally invasive open technique and gives an overview of our experience [14, 15].

24.4 Advantages

- No extensive preoperative anaesthetic work up, e.g. double-lung intubation, required.
- Small surgical incision, i.e. mini-intercostal and flank surgical approaches.
- Direct three-dimensional intraoperative view of spine using a stable easily adjusted retractor.
- Excellent direct illumination of the operative field by a thoracoscope.
- Direct view of the anterior spine allows safer mobilisation of blood vessels and nerves.
- Faster decompression of spinal canal.
- Easier reconstruction of the anterior spine column.
- Reduced blood loss and transfusion requirements.
- Reduced wound pain.
- Lower complication rates.
- Accelerated rehabilitation.
- Suitable for a range of pathology including traumatic fractures, pseudoarthroses and reconstruction of vertebrae destroyed by malignancy.

24.5 Disadvantages

- A "learning curve" is necessary but with experience operating times are equal.
- It is more difficult to manage intraoperative complications than with conventional open approaches but easier than with closed endoscopic surgery.
- Initial financial investment in mandatory equipment is required.

24.6 Indications

The anatomical location determines whether the minimally invasive procedure is performed via a right-sided mini-thoracotomy (T4-8; Fig. 24.3b), left-sided mini-thoracotomy (T9-L2; Fig. 24.3a), left-sided mini-retro-



Fig. 24.3. Male patients following left-sided (**a**) and right-sided (**b**) mini-thoracotomies for fractures of the 11th and 7th thoracic vertebrae, respectively

peritoneal approach (L3-4) or minimally invasive retroperitoneal access (L4-S1). Depending on the fracture type the overall management may include a preceding posterior stabilisation with or without decompression. The indications for a minimally invasive open approach to the anterior column of thoracic and lumbar spine fractures are as follows:

- T4-L5 unstable spine injuries as per Magerl classification [18]
- Neurological deficit
- Sagittal angulation of greater than 25°
- Axial compression of greater than 50 % of vertebral height
- Multiple fractures

24.7 Contraindications

Apart from contraindications to general anaesthesia there are no absolute contraindications for this approach. Individual consideration should, however, be made in patients with:

- Pleural empyema
- Previous thoracic/retroperitoneal surgery on the same side as access
- Severe coagulopathy
- Osteoporosis

24.8 Patient's Informed Consent

The patient is explained the aim and benefits of surgery and the expected postoperative course. The following approach-specific risks are outlined:

- Injury to spinal cord, spinal nerves, sympathetic plexus
- Lung contusion and/or pleural effusion necessitating an intercostal catheter for 24 – 48 h postoperatively
- Blood loss and possible transfusion-related risks
- Injury to thoracic or abdominal viscera including heart, spleen, kidney, ureter and bowel
- Postoperative pain
- Diaphragmatic herniation
- Postoperative deep venous thrombosis, pulmonary embolus and need for prophylactic treatment
- Superficial and deep wound infections
- Pneumonia
- Pseudoarthrosis
- Implant loosening/failure

24.9 Surgical Technique

24.9.1 Preoperative Planning

Comprehensive imaging of the spine, spinal cord and cauda equina enables the surgeon to anticipate the pathology at surgery. Plain films in anteroposterior and

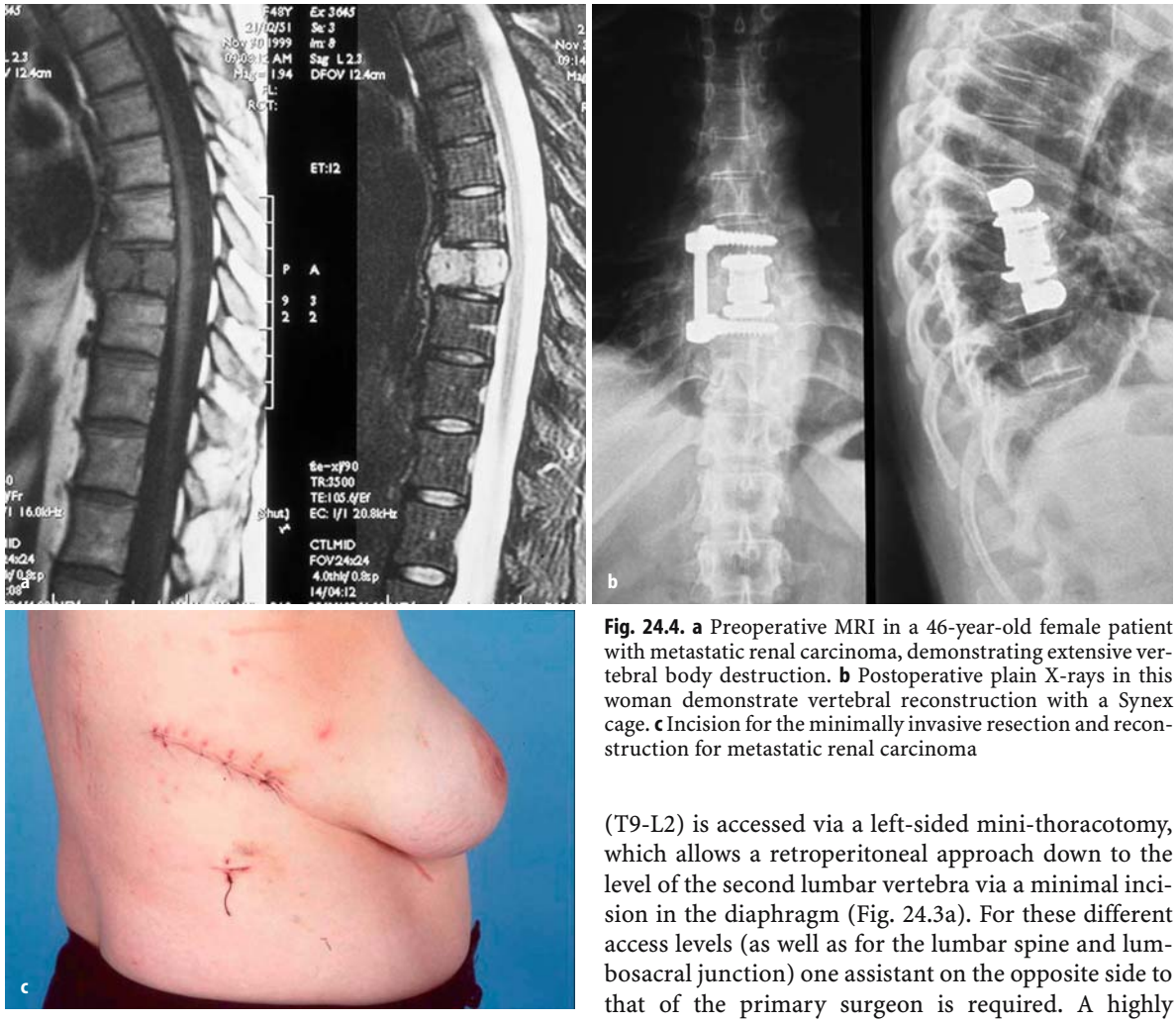


Fig. 24.4. a Preoperative MRI in a 46-year-old female patient with metastatic renal carcinoma, demonstrating extensive vertebral body destruction. **b** Postoperative plain X-rays in this woman demonstrate vertebral reconstruction with a Synex cage. **c** Incision for the minimally invasive resection and reconstruction for metastatic renal carcinoma

lateral positions are followed by computed tomography (CT) scanning in multiple planes, which is particularly useful for imaging bony structures. Magnetic resonance imaging (MRI) is useful in patients with neurological symptoms, in those unable to cooperate with clinical assessment and in patients with spinal canal compromise on CT scan (Fig. 24.4a).

The patient is positioned on the left (for upper thoracic intervention) or on the right side (for the thoracolumbar junction and lumbar spine), with the surgeon standing at the patient's back. The site for the surgical incision is selected according to the level of the affected vertebra [15].

24.9.2 Upper Thoracic Spine (T4-8) and the Thoracolumbar Junction (T9-L2)

Anterior reconstruction of the upper thoracic spine (T4-8) is performed via a right-sided mini-thoracotomy (Figs. 24.3b, 24.4c). The thoracolumbar junction (T9-L2) is accessed via a left-sided mini-thoracotomy, which allows a retroperitoneal approach down to the level of the second lumbar vertebra via a minimal incision in the diaphragm (Fig. 24.3a). For these different access levels (as well as for the lumbar spine and lumbosacral junction) one assistant on the opposite side to that of the primary surgeon is required. A highly trained scrub nurse may be capable of fulfilling this role. No intensive anaesthetic intervention such as double-lung intubation is needed. Induction prophylactic antibiotics and dexamethasone are administered routinely. In patients with neurological injury we give methylprednisolone as per the NASCI III protocol [1]. Controlled hypotension is maintained at a MAP of 75 – 80 mm Hg. The cellsaver is utilised.

Once the patient is correctly positioned the affected vertebra is localised with an image intensifier. A 6- to 8-cm incision (independent of location) is then made and underlying muscles are dissected bluntly. After opening the thoracic cavity the lung is identified and is then briefly disconnected from the ventilator so that it can be gently pushed aside to allow space for the surgery. The lung is protected with a moist surgical towel and ventilation to the lung is recommenced. The retractors are placed onto the table-fixed SynFrame (Stratec Medical, Switzerland) and adjusted according to the surgeon's requirements. The SynFrame is a stable, adjustable ring system fixed sterile by two adjustable arms onto the operating table (Fig. 24.2). The permanent sta-

bility of the operating field is a major advance and allows the surgeon to operate without further manipulations of the surgical field. A thoracoscope is inserted via a separate incision with an 11.5-mm-diameter trocar. This incision is later used for insertion of an intercostal catheter that remains in place for 24 – 48 h postoperatively. An endoscope is secured onto the frame to illuminate the operating field and is adjusted directly by the surgeon. As only the surgeon has a direct view of the operating field the endoscope is attached to a video screen so that nurses, assistants and trainees can observe the procedure. The vertebral reconstruction procedure can then commence.

24.9.3 Lumbar Spine (L3-4)

The lower lumbar spine (L3/4) is accessed via a left-sided minimally invasive pure lumbotomy. The affected vertebra is identified with the image intensifier and its projection is marked laterally on the flank. A 6- to 8-cm skin incision is then made and is followed by dissection of the three layers of the abdominal wall along their fibres until the retroperitoneal space is reached after penetrating the transversus abdominis fascia and muscle. The peritoneal sac is dissected off the fascia bluntly by a finger or a wet sponge mounted on a stick until the psoas muscle is reached. This potential space is kept open using retractors mounted on the SynFrame ring. Care should be taken not to damage the ureter, which can be gently pushed aside together with the peritoneum. The psoas muscle is mobilised in part to enable the surgeon to reach the lumbar vertebral bodies. Tilting of the table towards the surgeon can facilitate this. Muscular patients may require splitting of the psoas muscle along its fibres to reach the lateral aspect of the vertebral bodies. Attention must be paid to the lumbar plexus embedded deep within the psoas muscle and the iliohypogastric and ilioinguinal nerves crossing the surgical field.

24.9.4 Lumbosacral Junction (L5-S1)

The lumbosacral junction is accessed via a prone minimally invasive transperitoneal route. The abdomen is opened in the midline below the navel. The table is then tilted head down (Trendelenburg position) to allow the intestines to be pushed upwards. The peritoneum is incised on the left side of the aorta. It is advisable to isolate and secure the aorta and both iliac arteries. Access to the lumbosacral junction is then accomplished from the left side behind the anterior longitudinal ligament.

24.9.5 Reconstruction of the Anterior Column

After exposing the spine laterally, the level of the affected vertebra is identified with the image intensifier and the adjacent disc spaces are marked with K-wires. The location of the anterior longitudinal ligament and spinal canal can be calculated from the position of the K-wires. In most cases the overlying segmental vessels of the affected vertebra need to be clipped. The sympathetic chain is identified and where possible preserved. The abdominal aorta lies in front of the affected vertebra and directly anterior to the anterior longitudinal ligament. The ligament is not resected and serves as a safety marker for protecting the aorta and inferior vena cava on the lower aspect of the operating field. The vertebral discs are cut with a specially designed long-handled knife. After their removal the corresponding vertebral end plate is cleaned with specialised curettes (Synthes Spine USA). Care is taken not to penetrate the end plates. The vertebral body is then removed in part or completely using long osteotomes and rongeurs (Synthes Spine USA) and again special care is taken to preserve the anterior longitudinal ligament. For reconstruction of the void space, various materials such as autologous iliac crest bone grafts, allografts and cages (Synex; Stratec Medical Switzerland) filled with bone from the corporectomy have been used. Additional iliac crest harvesting or acrylic cement is occasionally used to fill the cage. In the last 3 years we have mainly utilised cages as they avoid problems of donor site morbidity (with autologous iliac crest bone graft harvest) and other autoimmune obstacles (with allografts).

24.10 Postoperative Care and Complications

The typical postoperative course for a patient is:

- Immediate extubation after operation.
- Low molecular weight heparin thromboembolic prophylaxis.
- Chest tube removed after 24 – 48 h.
- Mobilisation and physiotherapy to commence on the first postoperative day. Once the chest tube is removed the patient can commence rehabilitation.
- Anteroposterior and lateral X-rays of the operative site on the first postoperative day.
- CT assessment prior to the patient leaving hospital to check the exact location of the cage and for quality control purposes.
- Return to work after 6 – 12 weeks.

Potential complications of the procedure itself include:

- Poor patient positioning resulting in difficult access, longer operating time and potential inaccessibility.

- Segmental vascular injury causing bleeding which compromises the visual field.
- Damage to major thoracic or abdominal vessels may necessitate conversion to conventional thoracotomy and/or laparotomy.
- Injury to heart, lungs or abdominal viscera.
- Dural tear.
- Peritoneal tear.
- Displacement of bone or disc into spinal canal during corporectomy and/or grafting.
- Suboptimal fracture reduction.

Other potential postoperative complications are:

- Haemothorax or pneumothorax requiring thoracotomy.
- Infection of wound, body cavities or prosthesis that may require debridement and removal of implant.
- Implant failure or displacement.
- Ileus.
- Recurrent pleural effusions.

24.11 Results

We initially reported a series of 65 consecutive patients (28 women, 37 men) who were treated with minimally invasive open surgery to the anterior column between July 1999 and July 2000 [15]. Subsequently, by early 2004 we have gained additional experience with more than 200 minimally invasive operations on the thoracic and lumbar spine using minimally invasive open approaches. In 4 patients in our first series [15] surgery was performed for treatment of a pseudoarthrosis following previous intervention and in 6 patients for metastatic destruction of a single vertebra in the thoracic or lumbar spine (Fig. 24.4a). The remaining 55 patients had traumatic injuries. Of these, 30 patients had isolated spine injuries whereas 25 patients had additional (sometimes multiple) injuries to the head ($n = 10$), thorax ($n = 9$), pelvis ($n = 4$) and extremities ($n = 12$). Traumatic injuries to the spine were categorised according to Magerl's classification [18]. Thirty-four patients had type A, 14 had type B and 7 had type C fractures. There were 9 fractures of the thoracic spine (T4-10), 35 fractures involving the thoracolumbar junction (T11-L1) and 11 fractures of the lumbar spine (L2-4).

Out of the 65 patients, 29 received stabilisation with a posterior Universal Spine System (USS; Synthes, Switzerland) prior to the anterior spine surgery. In 8 patients a right-sided mini-thoracotomy was performed to access the midthoracic spine (T4-8), a left-sided mini-thoracotomy to reach the thoracolumbar junction (T9-L2) was used in 50 patients and a mini-retroperitoneal approach was used in 7 patients for lumbar spine intervention. Spinal clearance was performed in 11 patients via anterior mini-thoracotomy or retroperitoneal approaches. Autologous iliac crest bone was harvested in 11 patients, autologous spongiosa in 12 patients, femur allografts in 2 patients and iliac crest allografts in 2 patients. Expandable (Synex) cages were used for vertebral reconstruction in 38 patients. The cages were filled with spongiosa from the corporectomy and in 7 patients additional autologous spongiosa was harvested from the iliac crest.

The operating time (OT) from incision to closure was recorded. It must be emphasised that this time included the learning period of using this technique. The mean OT was 170 min (range 90 – 295 min) but this varied depending on the magnitude of the intervention. For a left-sided mini-thoracotomy ($n = 42$), the mean OT was 141 min. Addition of spinal clearance and iliac bone grafting saw the mean OT increase to 167 min. A right-sided mini-thoracotomy ($n = 7$) averaged 152 min. An additional 60 min were needed in cases that required spinal clearance and another 20 min were require for iliac crest bone graft harvesting. The mean OT was 165 min for the mini-retroperitoneal approach ($n = 10$) and 194 min when spinal clearance and iliac crest bone harvesting were required. With increased experienced our operating time has improved to approximately 120 – 140 min.

No patients required conversion to an open procedure and no complications related to the minimal access technique and neither visceral nor vascular injuries were observed. One patient with multiple metastases died intraoperatively due to an acute thromboembolic event. Four cases of mild postoperative ileus that settled with conservative management were noted. No patients developed intercostal neuralgia or post-thoracotomy pain syndromes. Most patients reported mild pain at the site of intervention but in all cases this resolved completely after several days. No postoperative wound infections or deep venous thrombosis were recorded. Patients with isolated spinal pathology were discharged from hospital after an average of 13 days (range 2 – 30 days). Patients with additional injuries stayed in hospital for an average of 20 days (range 2 – 86 days). The mean blood loss was 912 ml. The subgroup requiring spinal clearance ($n = 11$) had a greater mean blood loss of 1,716 ml (range 300 – 5,000 ml). This is less than in conventional open procedures and similar to endoscopic-based reconstructions of the anterior column [2]. Only 7 of the 65 patients required blood transfusions.

24.12 Critical Evaluations

Minimally invasive but open surgery for repair of the anterior thoracic and lumbar spine column has only re-

cently been described and as such there are few published reports of the technique. Nevertheless, our published series of 65 prospectively collected minimally invasive open procedures demonstrated a marked reduction in postoperative pain and a faster return to function for the patient compared to historical controls [15]. The minimally invasive techniques avoided the access-related morbidity associated with conventional open approaches in that postoperative pain, bleeding and surgical trauma were greatly reduced. There is also less inadvertent intraoperative organ injuries than has been reported with endoscopic approaches [12, 16]. This is largely due to the fact that the open, minimally invasive procedure enables the surgeon to directly visualise the operative field in three dimensions. This direct visualisation helps with vessel and nerve preparation, in performing a corporectomy and with spinal clearance. This view of the surgical field and the physical verification of events facilitated by open surgery is more familiar to surgeons not experienced with the magnified two-dimensional images in pure endoscopic procedures. The learning curve with the procedure is consequently rapid, and potentially serious complications and extended operation times are more easily avoided. Subsequently, we have performed more than 200 minimally invasive but open approaches for reconstruction of the anterior column of the thoracic and lumbar spine. The described approaches offer distinct advantages as compared to "pure" endoscopic or conventional open spine surgery and have become the standard method for anterior reconstruction of the thoracic and lumbar spine at our institution.

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25 Percutaneous Vertebroplasty in Osteoporotic Vertebral Fractures

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25.1 Terminology

The term vertebroplasty describes the internal augmentation of a fractured vertebra through the direct intraosseous injection of bone cement into the vertebral body in order to reduce pain and provide stability.

25.2 Surgical Principle

A large-caliber trocar needle is percutaneously inserted into the vertebral body via a transpedicular or an extrapedicular approach under fluoroscopic guidance. The bone cement (usually polymethylmethacrylate; PMMA) is injected slowly under image guidance and continuous monitoring of the vital parameters. Most procedures are performed with the use of fluoroscopic guidance; the use of computed tomography has also been described. Reduction of a kyphotic deformity is performed before the injection by manual traction and hyperlordotic positioning of the patient. The intervention can be performed under general anesthesia or conscious sedation and local anesthesia.

25.3 History

Vertebroplasty has become one of the fastest emerging techniques in spine surgery in the last 5 years. Deramond and Galibert, interventional radiologists at the university of Amiens, France, first performed the technique in 1984 as a treatment for an aggressive vertebral hemangioma of C2 and named it percutaneous vertebroplasty [11].

Later the indication was extended to the treatment of other osteolytic lesions with painful involvement of the spine [10], as well as to the treatment of osteoporotic vertebral fractures [20]. The first series in the United States was reported in 1997 [18]. In the late 1990s vertebroplasty was "reimported" to Europe, gained widespread popularity, and became the treatment of choice for fresh, painful osteoporotic vertebral compression fractures (VCFs).

25.4 Advantages

The reasons for the popularity of percutaneous vertebroplasty are its excellent results in pain relief, combined with a low morbidity of the procedure and the possibility of performing it in an outpatient setting. Vertebroplasty is also a low cost procedure, as no expensive implants or single-use devices are required.

But its major advantage is that it closes the gap between conservative therapy with bed rest, bracing, and analgesics, and "real" surgery with a multilevel instrumentation and stabilization. Vertebroplasty offers a treatment to a group of patients who, until then, only had very limited therapeutic alternatives [8].

25.5 Disadvantages

Due to the lack of alternative treatment options, percutaneous vertebroplasty has no major disadvantages. However, it is a technically demanding procedure, especially in severe osteoporotic cases and even more so in metastatic VCFs. Spine surgeons used to direct visual control might experience difficulties in relying on fluoroscopic guidance alone, and interventional radiologists might have more problems selecting the correct patients, handling stability issues, and identifying the limitations of the procedure.

25.6 Indications

Patient selection is the key to a successful outcome for most surgical interventions. The indication for percutaneous vertebroplasty in osteoporotic VCFs is usually based on:

- The presence of a VCF, which is not old or healed (a fresh or "chronic fresh" fracture should be shown by MRI; "chronic fresh" fractures are old, obviously not healing osteoporotic fractures which present the same MRI features as fresh fractures; see 25.6.1)
- The presence of pain corresponding to the level of the fracture, refractory to medical therapy
- The exclusion of contraindications

25.6.1 Fracture

The diagnosis of a VCF is made radiologically. Plain film radiographs of the thoracic or lumbar spine or the thoracolumbar junction in an anteroposterior (AP) and lateral view are required. Radiographs of the total spine are helpful for the identification of thoracic target level(s) in the presence of multiple fresh and old fractures; transition abnormalities at the lumbosacral and the thoracolumbar junction can be visualized more easily.

An MRI study of the part in question of the spine is extremely helpful in determining the age as well as the healing status of a fracture. The typical bone marrow edema (signal hypointensity on T1- and hyperintensity on T2-weighted images) pinpoints a recent or a non-healed fracture (pseudarthrosis) and is particularly obvious with fat saturation techniques (Fig. 25.1).

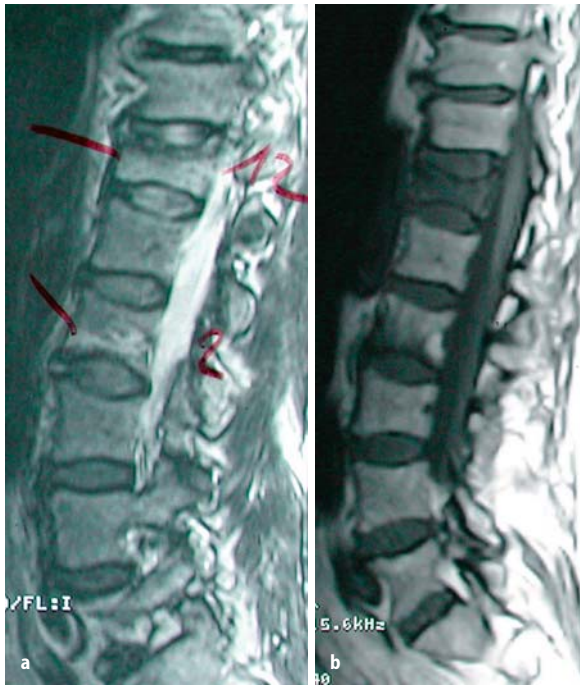


Fig. 25.1. T2-weighted (**a**) and T1-weighted (**b**) image of fresh vertebral compression fractures at T12 and L2: the edema is clearly visible

Fractures of metastatic and traumatic origin require additional computed tomography (CT) with sagittal reconstructed images, which allow the evaluation of osteolytic areas (perforation of the cortical wall, involvement of the pedicle) and the classification of the fracture type, respectively. A bone scan usually provides no additional information in patients with osteoporotic fractures.

As an exception to this we recommend the performance of percutaneous vertebroplasty in morphologically normal and non-fractured vertebrae, if both adjacent vertebral bodies are treated due to fractures and an osteoporosis has been diagnosed. This regimen follows biomechanical considerations: an osteoporotic vertebral fracture increases the risk of another fracture by 4 times and after a second fracture it is 12 times higher [23, 24]; furthermore vertebrae are at an increased risk of collapse if the adjacent vertebral bodies have been augmented [9, 30]. But the evidence is limited and, therefore, this so-called prophylactic augmentation is still a matter of discussion.

25.6.2 Pain

Most osteoporotic vertebral fractures occur due to minor traumas, are not very painful, and, therefore, if at all, are diagnosed months or years later by accident [19]. In the remainder, morbidity is significant and pain is severe and debilitating. For these patients the same therapeutic guideline should apply as for patients with other immobilizing fractures: to achieve the earliest possible mobilization in order to reduce the morbidity and to shorten the rehabilitation period. Despite the fact that there is a remission of pain in 85% of the patients within 2–12 weeks [19], we propose an early aggressive treatment in patients with debilitating pain.

Failure of a comprehensive conservative treatment with persistence of pain for months (chronic fractures, pseudarthrosis) is the classic indication for vertebroplasty. In rare cases an indication might be given in patients with less or even no pain if progressive subsidence of a fracture is observed.

25.7 Contraindications

In general percutaneous vertebroplasty has the same absolute contraindications as any other surgical intervention: systemic or local infections, bleeding disorders (e.g., oral anticoagulation), and anesthetic obstacles, which prohibit its performance under conscious sedation or general anesthesia.

Specific contraindications are unstable fractures, especially if they are accompanied by a compromise of the spinal canal or nerve roots due to a retropulsed

fragment, severe compression fractures affecting more than 70 % of the original vertebral body height, and an allergy to bone cement.

Technical aspects, such as a poor visualization and identification of the anatomical landmarks due to severe deformities, previous surgeries, or obesity, may prevent a safe and controlled performance of the procedure and, therefore, are also contraindications.

25.8 Patient's Informed Consent

Even if the risk of complications with percutaneous vertebroplasty is low, specific complications concerning the needle placement and the cement injection can occur.

While placing the needle every anatomical structure next to the pedicle and anterior of the vertebral body is in potential danger. These are the spinal cord, the nerve roots, the epidural venous plexus, the esophagus and the thyroid gland in the cervical spine, the lung in the thoracic spine, as well as the large paravertebral vessels.

During the injection of the PMMA, which is the most critical step of the procedure, "extravasations" can occur; this can lead to pulmonary emboli (PMMA if the viscosity is too low, fatty bone marrow, especially in multiple levels, if the viscosity of the PMMA is high) as well as to compressions of the spinal cord or nerve roots with a permanent or transient neurological deficit and/or neuropathic pain.

Other procedural complications include the risk of infection (despite the fact that no case in an osteoporotic fracture has been reported so far), rib fractures, and prolonged bleeding.

A comprehensive informed consent discusses the risk of:

- Lesions of the spinal cord and nerve roots with possible paraparesis, bladder and bowel dysfunction, radiculopathy with numbness and paresis, neuropathic pain, and transient neuritis
- Lesions of the lung (pneumothorax)
- Lesions of the paravertebral vessels with significant hemorrhage
- Pulmonary emboli
- Infection
- Fractures (ribs, pedicle)
- Death

Major complications occur in less than 1 % of patients treated for compression fractures secondary to osteoporosis [26]. The most critical factor is the experience of the surgeon. Reviewing the literature, almost all reported complications are due to wrong needle placement, bad visualization, and bad timing of the PMMA injection [4, 15, 21, 28, 29].

25.9 Surgical Technique

Percutaneous vertebroplasty is a surgical intervention and, therefore, a sterile environment is mandatory. The OR must be equipped with a radiolucent table and a good quality fluoroscope.

The following equipment is required:

- Large-caliber trocar needle, 11 gauge for the thoracic spine and 8 gauge for the lumbar spine, with a length of 10 – 15 cm. The larger the diameter of the needle, the lower is the required pressure to inject the same amount of PMMA with the same viscosity. A smaller needle would either require a higher injection pressure or a lower viscosity, both increasing the risk of potential complications. Two different shapes of the needle tip exist, a beveled, "Murphy needle" and a diamond-like needle; the advantage of the bevel is possibility of guiding the needle by simple rotation around its axis.
- Radiopaque PMMA cement. Several vertebroplasty products have now been developed, which have barium already added and have a longer time for application (e.g., Vertebroplastic; DePuy CMW, Blackpool, UK).
- Syringe (2 cc) or specially developed mixing and application device. The latter allows a safer and more controlled application of the cement.
- The use of contrast is not recommended regularly, as it has a different viscosity and flow pattern than PMMA and also complicates the assessment of the PMMA distribution within the vertebral body [13, 31].

Percutaneous vertebroplasty is performed with the patient under general anesthesia or local anesthesia and conscious sedation. The patient is positioned prone with cushions under chest and pelvis to obtain a hyperextension at the level to be treated. The affected vertebral bodies are identified with the image intensifier in AP and lateral views. An eventual height restoration and reduction of kyphosis is documented [27] (Fig. 25.2). A skin stab incision is made, the needle is inserted, and under fluoroscopic AP control guided into the pedicle. A lateral fluoroscopic control reveals the trajectory of the needle and the cephalic-caudal angle is corrected, if necessary. The needle is advanced using a surgical hammer, under AP control as long as the needle is in the pedicle, to avoid a penetration of the medial cortical wall, and then under lateral view until the tip of the needle reaches the anterior third of the vertebral body (Fig. 25.3).

This transpedicular approach is the standard approach for percutaneous vertebroplasty [12, 16, 18]. Usually a unipedicular approach will be sufficient and in vitro tests revealed no difference between a uni- and a bipedicular cement injection concerning biomechanical parameters [3], but in patients with large vertebral



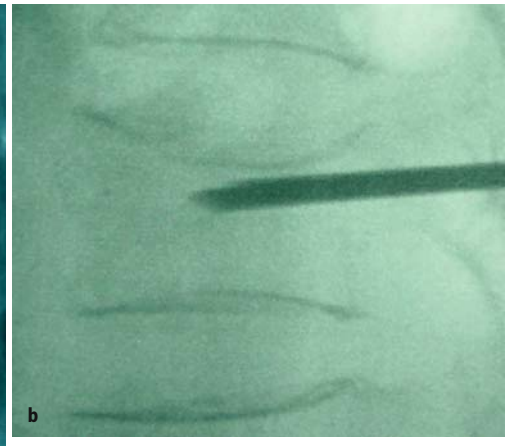
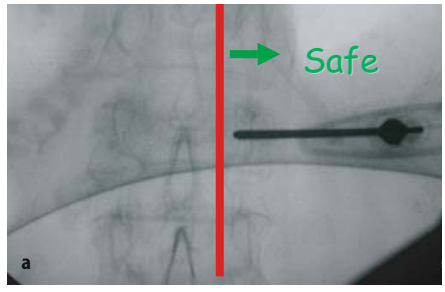


Fig. 25.2. Height restoration due to ligamentotaxis in a 3-week-old compression fracture at L2. **a** Lateral X-ray with the patient standing

b Lateral projection of the same vertebral body with the patient in a hyperextended position; this effect is not caused by the needle placement



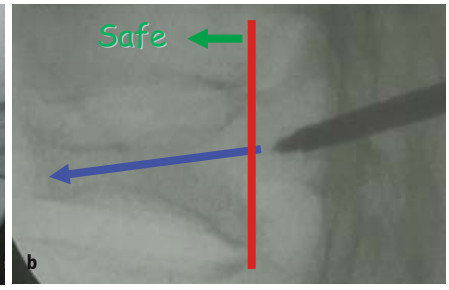


Fig. 25.3. Transpedicular approach. **a** While advancing the needle through the pedicle the AP projection is most important. As long as the needle tip is lateral of the medial cortical wall of the pedicle (*red line*), the spinal cord is not in danger. **b** After having entered the vertebral body and having safely passed the spinal cord (*red line*), the lateral projection is more important. The *blue line* indicates the optimal trajectory for this needle

bodies (especially at the lower lumbar spine) and in cases with a far lateral position of the needle tip in the AP view, a bipedicular approach may be necessary.

In patients with small pedicles, especially in the higher thoracic spine, an extrapedicular approach is preferable. The entry point of the needle is located at the craniolateral wall of the pedicle, allowing a more convergent placement of the needle. In the upper thoracic spine, fractures are highly suspicious for a metastatic origin and osteoporotic fractures are rare. A fluoroscopic identification of the pedicles T1 to T4 is difficult due to over imposition of the shoulder girdle. Therefore a combination of fluoroscopy and computed tomography might be helpful [12].

Alternatively the needle placement in these difficult cases can be performed under the guidance of a navigation system, if available. We have preliminary experience with the use of the VectorVision system (BrainLAB, Heimstetten, Germany), a fluoroscopically based computer navigation. A reference array is percutaneously fixed to the spinous process of the fractured vertebra (Fig. 25.4a). A disposable large-caliber needle is

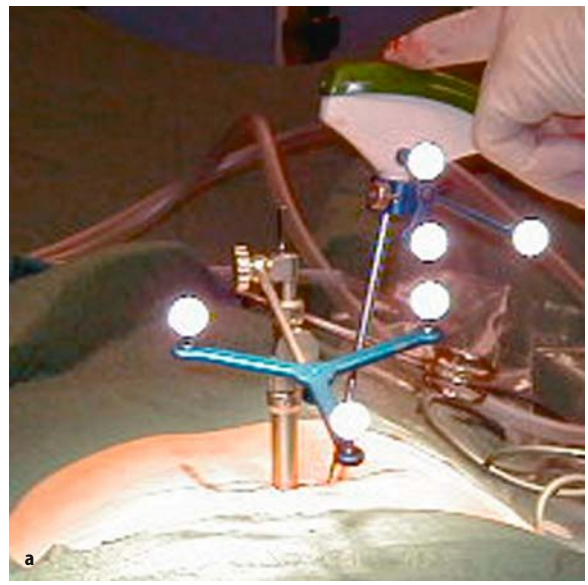


Fig. 25.4. a Minimal-invasive reference array (MIRA) in place, and positioning of the disposable needle mounted with a reference marker

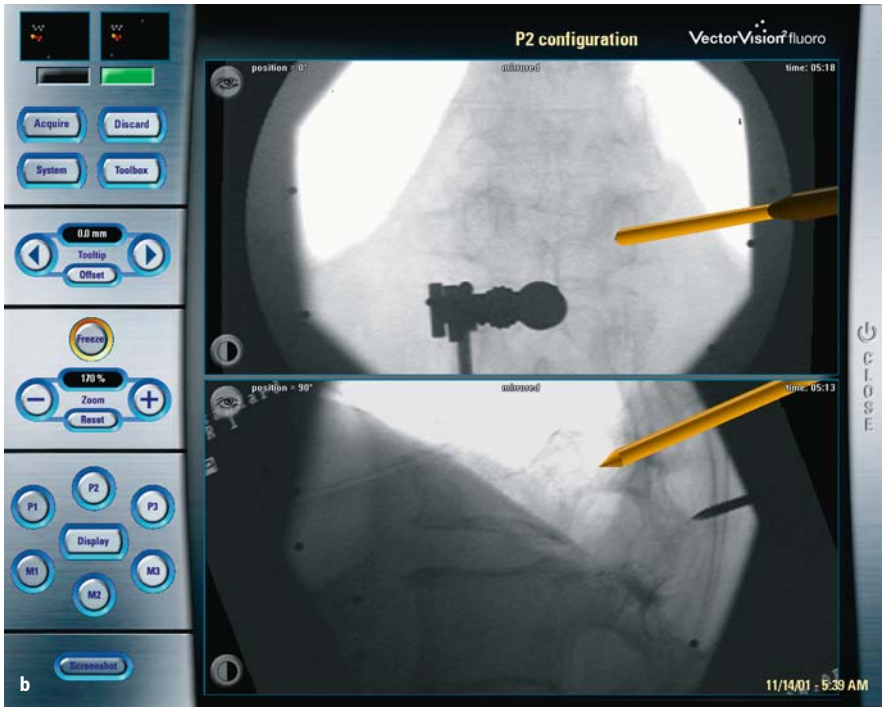


Fig. 25.4. (cont.) b Screenshot: navigation of the needle through the pedicle in the AP and lateral projection

armed with a reference marker and gauge-calibrated. Standardized fluoroscopy in an AP, lateral, and bull's-eye-oblique plane is obtained. Under navigation guidance the pedicles are probed in the usual transpedicular way (Hess and Mayer, unpublished data; Fig. 25.4b).

The injection of the cement is the next critical step of the procedure. The PMMA cement is prepared and injected according to the recommendations of the manufacturer. The injection must be carefully monitored in two planes, especially in the lateral view. The timing of the injection and the optimal viscosity are important parameters. The injection must be stopped immediately if a leak occurs. The injection is also terminated if the PMMA approaches the posterior cortical wall or if a sufficient amount of cement with a good distribution has been administered. A wide consensus exists in the literature that 2 – 4 cc in the thoracic spine and 4 – 6 cc in the lumbar spine can be considered as sufficient in terms of pain relief as well as restoration of strength and stiffness of the vertebral body [3, 22].

25.10 Postoperative Care and Complications

Percutaneous vertebroplasty can be performed as an outpatient procedure and the patients can be mobilized after about 2 hours. A thoracolumbosacral orthosis is not mandatory, but most patients who had conservative treatment before, will already have one. In these cases we suggest they continue to wear it for 1 – 2 weeks postoperatively.

Special emphasis must be put on the necessity to establish the diagnosis of osteoporosis and to initiate an adequate treatment in patients with a first fracture and to evaluate and modify the medical treatment in patients with a longer history of the disease.

As already mentioned above, the complication rate in patients with osteoporotic vertebral fractures is low. Extravertebral leakage of the PMMA into the epidural space and the paravertebral tissue occurs in up to 74% of the patients, if a close workup with a postoperative computed tomography is made [1]. Fortunately it remains clinically insignificant in most patients.

Complications such as a radicular neuritis respond in most cases favorably to symptomatic treatment with corticosteroids [2, 5]. Compromise of a nerve root and/or the spinal cord may require microsurgical decompression, depending on the severity of the neurological deficit [15, 21] (Fig. 25.5).

Pulmonary embolism may be treated symptomatically, but may also be fatal, despite an immediate and adequate intervention [4, 28, 29].

Complications in the postoperative period may be adjacent level fractures [9, 30] (Fig. 25.6) and a fracture of the augmented vertebral body itself [17] (Fig. 25.7).

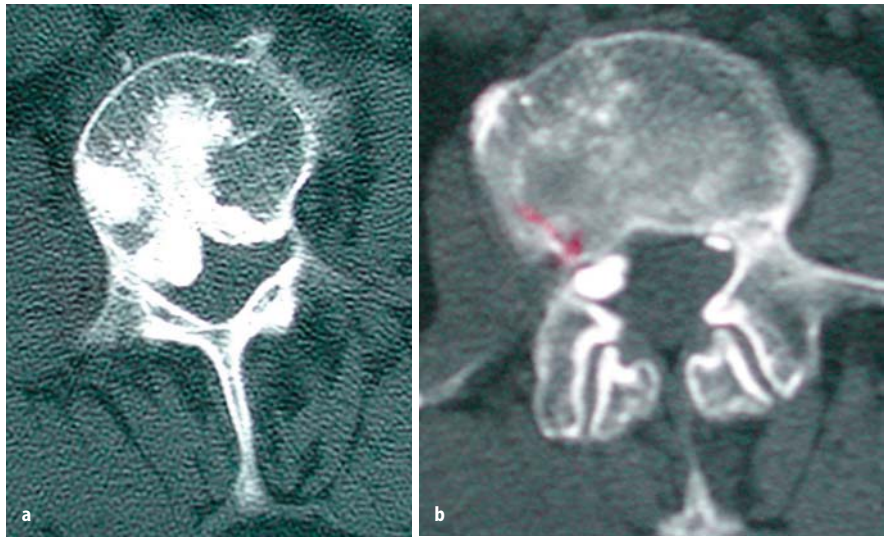
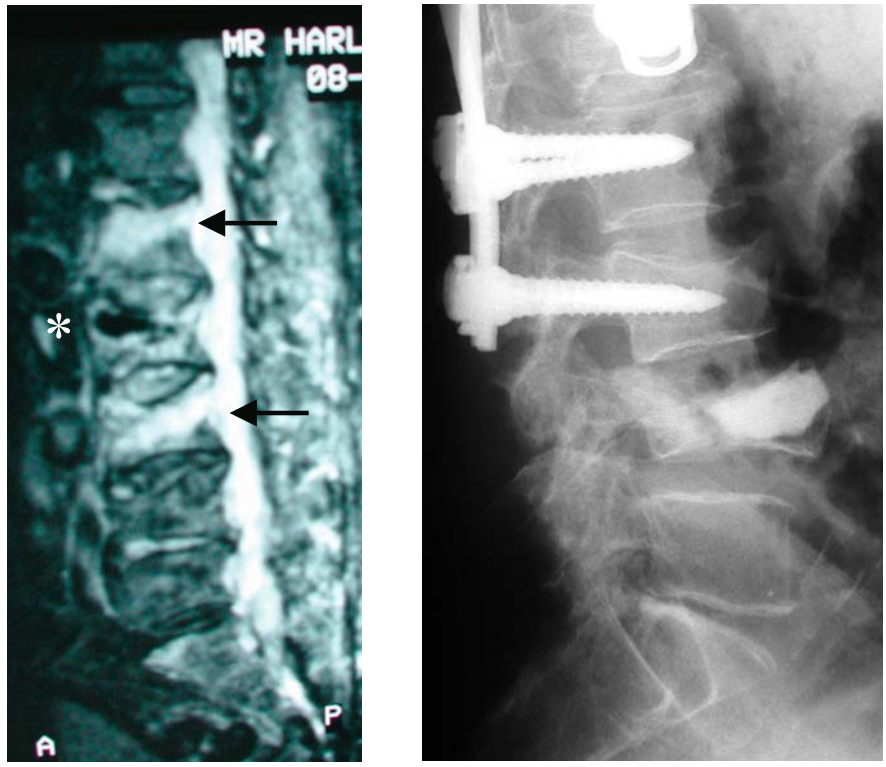


Fig. 25.5. A 65-year-old woman with acute vertebral compression fractures of T12 and L2. Postoperative CT scan, pinpointing the PMMA cement in the spinal canal and the right recess of L2/3. Microsurgical decompression after 5 days due to persistent neuropathic pain and paresis of hip flexion 3/5



▷
Fig. 25.6. An 82-year-old woman with adjacent vertebral compression fractures of L1 and L3, 2 months after percutaneous vertebroplasty of an osteoporotic VCF of L2. Sagittal fat saturated MRI, pinpointing the edema at L1 and L3 (*black arrows*) and the signal void resulting from the PMMA in L2 (*white asterisk*)

▷▷
Fig. 25.7. Lateral radiograph of a 74-year-old woman with a coronary split fracture of L4 at the bone-PMMA interface after a heavy fall on her back. Six months ago had augmentation of an osteoporotic compression fracture with good pain relief

25.11 Results

The PMMA cement augmentation of the vertebral body reportedly results in early postoperative pain relief and a decrease in medication use in a significant proportion of patients. To date only one randomized trial is available, published in abstract form only [7]. In this small study 31 patients with acute painful VCFs were randomized to undergo vertebroplasty or continued medical therapy. Medical therapy patients were permitted to cross over to vertebroplasty after completing 6 months follow-up. All vertebroplasty patients had significant improvement first or after a trial of medical therapy. The other published literature consists of a large number of case series of vertebroplasty in a variety of patient populations [1, 2, 6, 13, 16, 18, 25, 31, 32]. All of them consistently report early and marked pain relief in 80–90% of the patients, a significant reduction of pain medication, and an early return to the patients' ac-

tivities of daily living. Although long-term results are sparse, the effect of pain reduction is persistent for 4 – 5 years in patients with osteoporotic fractures [14].

25.12 Critical Evaluations

The clinical results of percutaneous vertebroplasty are overwhelming, but from a scientific standpoint long-term follow-up results of prospective controlled randomized clinical trials are still lacking. From a clinical point of view vertebroplasty has become safer with the development of special PMMA formulas and application devices. In the future the injection of PMMA cement might be replaced by the percutaneous instillation of osteoconductive and osteoinductive material or osteogenic growth factors, which would be a revolutionary step in the treatment of VCFs and especially those due to osteoporosis.

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26 Microsurgical Open Vertebroplasty and Kyphoplasty

B.M. Boszczyk, M. Bierschneider, B. Robert, H. Jaksche

26.1 Terminology

Vertebroplasty (VP) and kyphoplasty (KP) are percutaneous methods of injecting polymethylmethacrylate (PMMA) into fractured osteoporotic vertebral bodies with the aim of immediate stabilisation and pain relief. PMMA is injected at low viscosity directly into the cancellous bone in the VP technique [8]. KP differs from VP in that a contrast-filled, inflatable balloon is inserted into the vertebral body, allowing a degree of fracture reduction and leaving a cavity behind after withdrawal which is filled with high-viscosity PMMA [7].

26.2 Surgical Principle

The rationale behind applying spinal microsurgical principles to the vertebral augmentation techniques (VP and KP) is the advantage of achieving both neural decompression and vertebral stabilisation with minimal approach-related trauma. For selected indications this method enables a less invasive treatment of severe osteoporotic and neoplastic fracture types with neural compromise that are traditionally stabilised with open implant-related reconstruction [2].

VP or KP for traumatic fractures in non-osteoporotic vertebrae are not considered in this chapter.

26.3 History

The introduction of percutaneous augmentation techniques, VP in 1987 by Galibert et al. [6] and KP in 2000 by Wong et al. [18], has added highly effective procedures to the armament of the spinal surgeon faced with osteoporotic and neoplastic vertebral fractures. While several reviews have focused on the remarkable clinical success of the percutaneous application of these methods to uncomplicated fractures [1, 8, 9, 11], only the publication by Wenger and Markwalder [17] has dealt with the virtues of applying VP to more complex fractures in open surgery.

26.4 Advantages

Amongst the advantages of open surgical VP, as proposed by Wenger and Markwalder [17], are the decompression of compromised neural structures and the control over the spinal canal during the injection of the augmentation material. As the most commonly used augmentation material is still PMMA, which has the potential of inflicting thermal damage to neural structures besides mechanical compression once cured [10, 15, 16], the ability to immediately remove extruded PMMA from the spinal canal bears obvious advantages. The application of microsurgical principles to the technique of Wenger and Markwalder has led to the development of the microsurgical unilateral interlaminar approach for VP and KP [3–5], which minimises soft tissue trauma while maintaining the assets of spinal decompression and control during augmentation. Furthermore, as the interlaminar approach allows access to the vertebral bodies of both adjacent vertebrae, augmentation of neighbouring vertebrae can be performed through the same approach when required. The thoracolumbar junction and entire lumbar spine are accessible with this technique.

For the spinal surgeon accustomed to microsurgical procedures this method allows the expansion of VP and KP to more complex cases, involving neurological compression or severe posterior wall fragmentation, that are unsuitable for percutaneous treatment. No additional specialised instruments are needed for the approach as these are the same as for conventional microdiscectomy or decompression.

For carefully selected indications, microsurgical VP and KP fill the gap between percutaneous augmentation and open reconstruction with implants.

26.5 Disadvantages

Due to the narrowing of the spinal canal in the midthoracic spine, this technique is essentially limited to the thoracolumbar junction and lumbar spine. Above the thoracolumbar junction resection of the medial pedicle wall may be necessary to avoid exerting pressure on the spinal cord during intraspinal tool placement.

As proficiency in microsurgical decompression of the spinal canal without laminectomy and facetectomy is mandatory for this method, spinal surgeons unaccustomed to such techniques may need to accept a considerable learning curve. Furthermore, the surgeon must be able to deal with lesions of the dura and extruded PMMA through a very limited exposure of the spinal canal.

26.6 Indications

26.6.1 Considerations for Microsurgical Augmentation

Four conditions affecting the thoracolumbar and lumbar spine lead to the consideration of microsurgical VP or KP:

1. Osteoporotic vertebral fractures with symptomatic fragment-induced compression of neural structures
2. Osteolytic vertebral tumours with symptomatic or rapidly progressing neoplastic compression of neural structures
3. Osteoporotic vertebral fractures or osteolytic tumours with severe compromise of the posterior vertebral wall, judged to bear a high risk of epidural PMMA leakage
4. Osteoporotic vertebral fractures in the setting of preexisting symptomatic spinal stenosis requiring decompression

26.6.2 Type A Fractures

The character of the fracture and the quality of bone must be assessed during the preoperative evaluation. In osteoporotic vertebrae with rarefied trabecular structure, fractures tend to result in varying degrees of vertebral body collapse with possible retropulsion of the posterior wall into the spinal canal. In contrast to fractures in non-osteoporotic vertebrae, splitting or severe fragmentation occur less frequently. While mild vertebral collapse is ideal for percutaneous augmentation, the majority of osteoporotic fractures requiring microsurgical augmentation will be characterised by complete vertebral collapse or incomplete burst fracture types with varying degrees of neural encroachment. In the classification system by Magerl et al. [12] the fractures therefore suitable for augmentation are the A1.1 (endplate impression), A1.2 (wedge fracture), A1.3 (vertebral collapse) and A3.1 (incomplete burst fracture) types.

26.7 Contraindications

26.7.1 Thoracic Fractures

The microsurgical interlaminar approach has been used extensively at lumbar and thoracolumbar levels. However, only a small number of fractures of the midthoracic spine have been treated [5]. Here the space available between the spinal cord and the pedicle is the limiting factor and resection of the medial pedicle wall may be necessary to allow tool placement without danger of neural compression. Severe osteoporotic fractures of the upper thoracic spine (T1 – 4) are infrequent and have as yet not been treated with this microsurgical method.

26.7.2 Type B and C Fractures

These fracture types require additional posterior instrumentation in order to stabilise their inherent flexion and rotation instability characteristics.

26.7.3 Laminectomy

The extent of required decompression and vertebral body augmentation must be evaluated realistically with respect to the surgical goal that is achievable with this technique. When complete laminectomy becomes necessary, especially at the thoracolumbar levels, posterior instrumentation should be added. This is recommended as the resection of the posterior tension band leads to load transfer to the anterior column, where adjacent vertebral bodies weakened through osteoporosis or tumour metastasis may fail.

26.8 Patient's Informed Consent

Beside the general considerations for spinal surgery, the following points should be discussed:

1. Approach-related injury of the neural structures and dura with the possibility of neurological deterioration and cerebrospinal fluid fistula

2. Injury of abdominal or thoracic viscera and vessels through anterior vertebral perforation with VP or KP instruments
3. PMMA extrusion into the spinal canal with neurological compromise
4. PMMA leakage into the venous system with the potential of lethal pulmonary embolism or paradox cerebral embolism
5. Conversion to complete laminectomy and instrumentation if adequate decompression cannot be achieved microsurgically
6. Lowered fracture threshold of adjacent vertebrae in the presence of severe osteoporosis

26.9 Surgical Technique

26.9.1 Microsurgical Interlaminar Vertebroplasty and Kyphoplasty

The operation is performed under general anaesthesia. The patient is placed prone on a spine frame or cushions with legs extended. Osteoporotic patients must be treated very gently to avoid rib fractures. As lateral fluoroscopy will be needed for the vertebral augmentation after the decompression has been completed, the position of the C-arm should be taken into account during the initial positioning and draping of the patient. The vertebral body or bodies to be treated is/are localised with the C-arm. The level of the compressed neural structures and the morphology of the fracture dictates which interlaminar space is to be approached, i.e. cranial or caudal of the lamina of the affected vertebral body. When adjacent vertebrae are to be treated, the common interlaminar space is chosen as this will allow augmentation of both vertebral bodies through the same approach. A longitudinal midline skin incision is centred above the spinous processes of the targeted interlaminar space. In single or adjacent levels, an incision of 5 – 7 cm is usually sufficient. Subcutaneous dissection exposes the thoracolumbar fascia at its insertion to the spinous processes. The fascia is incised longitudinally, close to the spinous processes on the side with the predominating neurological symptoms or more severe disruption of the posterior wall. The paravertebral musculature is detached medially and gently retracted, exposing the interlaminar space. The spinal canal is opened by longitudinally dividing the ligamentum flavum and resecting the bony rims of the superior and inferior laminae using punches. As with any intraspinal procedure, care is taken not to injure the dura.

Decompression of the thecal sac and segmental nerve root is accomplished by piecemeal removal of ligamentum flavum, laminae and medial portion of the zygapophyseal joint. Decompression of the contralateral side is accomplished by "crossing over" the thecal sac as described in Chapter 44. Resection of the facet joint and laminae should be as sparing as possible. Once the lateral edge of the thecal sac is reached, it is gently undermined using a curved dissector and carefully mobilised medially (3 – 4 mm) to expose the lateral aspect of the posterior vertebral wall. The thecal sac may be retracted cranial or caudal to the segmental nerve root in accordance with the morphology of the fracture (Fig. 26.1a–c). It should be appreciated that, in contrast to non-traumatic spinal stenosis, the compression usually arises from anterior to the thecal sac due to posterior wall retropulsion. An attempt may be made to gently impact retropulsed bone in fresher fractures, however in severely osteoporotic bone the situation may be aggravated by further fissuring of the posterior wall, especially if the fracture is already partially consolidated. This is undesirable as any additional fissures will increase the risk of epidural cement leakage during augmentation.

The tip of a VP cannula or KP trocar may now be set on the posterior vertebral wall lateral to the thecal sac. The placement may be over or under the "shoulder" of the segmental nerve (Fig. 26.1b, c). This is done visually, verifying that the thecal sac is not violated. The angle of the instrument is adjusted in accordance with the lateral fluoroscopy view and is tapped into the vertebral body aiming for the anterior midline of the vertebral body. While the VP cannula is introduced into the anterior third of the vertebral body, the KP trocar is placed just beyond the posterior vertebral wall and a hand drill is advanced to create a channel for the placement of the kyphoplasty balloon. A biopsy may optionally be taken at this point. If VP is to be performed, contrast medium may optionally be injected in order to assess any leakage pathways from the vertebral body. Ideally, the vertebral body will fill as a cloud before the contrast medium dissipates. Very rapid paravertebral or epidural drainage should prompt the surgeon to either readjust the placement of the cannula (without reperforating the posterior vertebral wall) or inject the augmentation material very slowly under live fluoroscopy. For KP, the balloon is inflated gradually (Fig. 26.2a) until the desired effect of cavity formation and, as far as possible, fracture reduction is achieved. The balloon is withdrawn, leaving a cavity to be filled with PMMA.

For both techniques PMMA is injected in small portions (approximately 0.5 ml) into the vertebral body using frequent fluoroscopic control. KP allows PMMA to be introduced into the cavity at high viscosity (Fig. 26.2b) while the viscosity for VP must be lower in order to allow for trabecular distribution. The injection is discontinued once sufficient filling of the vertebral body has been achieved or leakage is detected. The epidural space may be inspected at any time during the procedure, allowing extruded PMMA to be removed

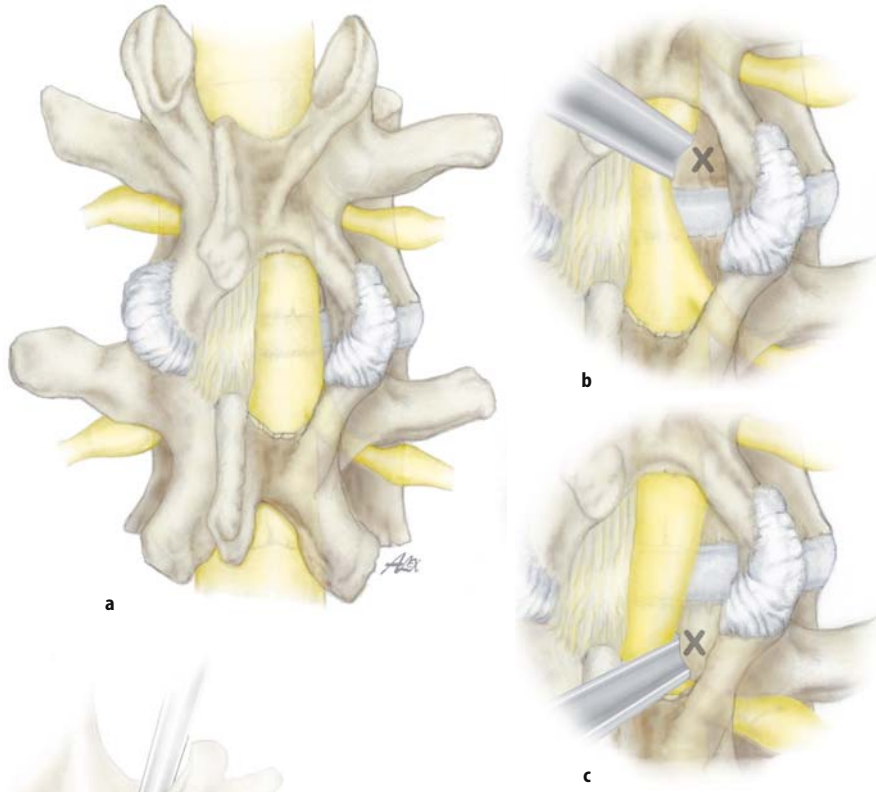


Fig. 26.1. a Illustration of the interlaminar fenestration, unilaterally exposing the thecal sac, thereby providing access for the decompression of the neural structures. **b** The entry point to the superior vertebral body (*X*) through the posterior wall is exposed by gentle retraction of the thecal sac. **c** The corresponding entry point to the inferior vertebral body (*X*) is reached by gently retracting the shoulder of the exiting nerve root

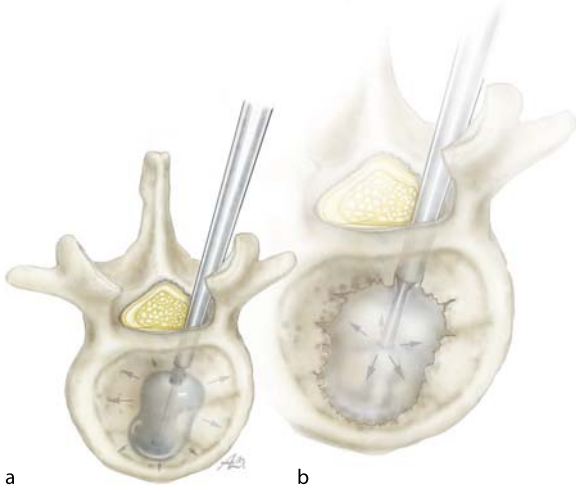


Fig. 26.2. a Illustration of a single kyphoplasty balloon placed convergently into the vertebral body through the interlaminar approach in an axial view. **b** After removal of the balloon the remaining cavity is cautiously filled with high-viscosity bone cement

before it is fully cured. After the augmentation has been completed, the instruments are withdrawn and the wound is closed in layers in the usual fashion after irrigation.

26.9.2 Considerations for Vertebral Tumours

The treatment of neoplastic lesions with this technique is more demanding than the treatment of osteoporotic fractures. Essentially, the decompression is performed in the same manner, although removal of tumour mass from under the thecal sac may be difficult. Bleeding from the vertebral body usually subsides after the injection of PMMA. Tool placement does not differ from osteoporotic fractures, however in kyphoplasty the balloon will expand predominantly into the region of the osteolysis. In cases with posterior wall infiltration (see also Fig. 26.3), careful attention must therefore be directed towards recognising any tendency of increased posterior wall retropulsion. During augmentation, PMMA will follow the path of least resistance in the osteolytic bone and leakage may occur unexpectedly. This is especially true for vertebrae that have received radiation, where parts of the cancellous bone may be filled with dense fibrous tissue.

26.9.3 Avoiding Complications During Augmentation

The single most important element in detecting leakage is the lateral fluoroscopy view. Often only a very fine trail of PMMA will initially be seen either posterior to the vertebral body, indicating epidural leakage, or anterior to the vertebral body, indicating venous embolism. The entire circumference of the vertebral body should therefore be visualised on the monitor. Saving an image before injection as reference is helpful in differentiating superimposed artefacts from real leakages. Injection should be interrupted immediately whenever



Fig. 26.3. a Sagittal T2-weighted MRI revealing osteolytic infiltration of the L5 vertebral body with extension to the spinal canal. **b** Axial T2-weighted MRI demonstrating the right-sided neoplastic neural compression. **c** Sagittal CT reconstruction at 7 month follow-up showing maintenance of vertebral body height. **d** Axial CT of L5 at 7 month follow-up showing the central PMMA placement and slender right-sided hemilaminectomy

leakage is suspected. As PMMA cures more quickly within the warm body environment, further injection may be attempted after 1 or 2 minutes. This will, however, only be possible with slow-curing cement and in kyphoplasty requires the withdrawal of the cement application cannula (not the working cannula) in order to maintain cement injectability. Extruded PMMA is usually easily removed from the epidural space as long as it is of a pasty consistency. PMMA usually does not adhere to the dura. Subligamentary deposits, however, may be impossible to remove. Although smaller deposits are unlikely to cause any neural damage, the spinal canal may be irrigated to dissipate heat during curing in such an event.

26.9.4 Vertebroplasty or Kyphoplasty

As review of the literature shows that pain relief and biomechanical stability resulting from both procedures are comparable [4], other factors need to be taken into account in the choice between these techniques. Fracture reduction and restoration of vertebral body height may be achieved through kyphoplasty, however severe loss of height and an older fracture age may limit these effects to a minimum [5]. The most valuable consistent effect achievable through kyphoplasty in this setting is the markedly reduced rate of leakage [5, 14] through the injection of high-viscosity PMMA into the preformed cavity, even in cases with significant posterior wall disruption.

26.10 Postoperative Care

Immediate postoperative care does not differ from that for isolated microsurgical decompression. As the vertebral body is stabilised as soon as the PMMA is fully cured (approximately 20 minutes), patients may be mobilised on the day of the procedure and do not routinely require bracing. As the surgical goal is accomplished with the decompression of the neural structures and stabilisation of the vertebral body, postoperative attention should be focused on the treatment of the primary disease leading to the fracture (osteoporosis or malignancy).

26.11 Hazards, Pitfalls and Complications

To date we have experienced no major complications with these methods. In a series published on our first 24 osteoporotic patients [5], there were two approach-related dural lacerations. These were sutured and sealed with fibrin glue without evidence of cerebrospinal fluid fistula at follow-up. The vertebral arch fractured in one patient during decompression without clinical consequence and one patient suffered perioperative rib fractures which healed during the follow-up period. Significant epidural leakage of PMMA requiring removal occurred in five patients. This was achieved before the exothermic curing phase. Minor subligamentary leakage was not removed. In total, the leakage in patients treated with VP amounted to 73 % while the respective rate for KP was 39 %. Here, leakage was defined as any breach of the vertebral cortical shell, regardless of magnitude, and was assessed from the postoperative computed tomography scan. In these complex fractures KP was found to provide a greater level of control over the injected PMMA than VP.

Significant prevertebral PMMA leakage occurred in a patient treated for metastasis of a bronchial carcinoma after the anterior cortex was inadvertently perforated with the VP trocar. The leakage, which collected close to the vertebral body, had no clinical effect. In another patient, treated for breast carcinoma metastasis, significant PMMA leakage occurred under the posterior longitudinal ligament during VP which could not be removed. Presumably as a consequence of radiation of the spine, the dura was strongly adherent to the surrounding structures and prevented adequate mobilisation for removal of the cement. The spinal canal was irrigated during curing of the cement and no neurological deficit was found postoperatively.

The overall complication rate for osteoporotic fractures with neurological deficits treated by conventional reconstructive surgery was found to be as high as 60 – 70 % in an investigation and review by Nguyen et al. [13]. Although very severe fractures with a high degree of fragmentation, or such requiring complete laminectomy, will continue to demand conventional surgical reconstruction, the reduced invasiveness and complication rate of the described microsurgical augmentation techniques justify considering these methods as a first-line approach whenever feasible.

26.12 Results and Conclusion

The results of the first 24 patients (21 women and 3 men; mean age 75.5 years; range 57 – 91 years) with a total of 34 severe osteoporotic vertebral fractures treated from 2000 to 2002 with microsurgical interlaminar VP or KP have been published in detail [5]. There were seven type A1.1 (see also Fig. 26.4), six type A1.2, ten type A1.3, one type A2.2 and ten type A3.1 fractures (see also Fig. 26.5).

Case example 1 (Fig. 26.3): This 67-year-old patient developed progressive low back pain and right-sided foot drop following osteolytic prostate cancer metastasis to the spine (Fig. 26.3a, b). Decompression of the L5 nerve root was performed through the L5/S1 interlaminar space. Impingement of the L5 nerve root at the shoulder made a slight hemilaminectomy necessary. Central augmentation by kyphoplasty in the load-bearing area was achieved (Fig. 26.3c, d). At 7 month follow-up the patient has only minor low back pain with resolving foot drop and is capable of extended hiking.

Case example 2 (Fig. 26.4): This 85-year-old patient presented with an acute onset of low back pain centred over L4 and pronounced neurogenic claudication with hypaesthesia of the L5 dermatomes bilaterally. Preoperative evaluation revealed a new mild endplate impression fracture of L4 (type A1.1) along with multisegmental spinal stenosis (Fig. 26.4a, b). Interlaminar decompression of L3/L4 and L4/L5 was performed from the left with “cross-over” decompression to the right. In order to treat the mild endplate impression fracture, PMMA was injected as vertebroplasty below the L4 superior endplate (Fig. 26.4c, d) via a vertebroplasty cannula introduced through the posterior wall of L4. Postoperatively, back pain had markedly subsided and the claudication improved.

Case example 3 [3](Fig. 26.5): This 79-year-old patient suffered an incomplete burst fracture of L1 (type A3.1) (Fig. 26.5a) after a fall and presented with severe back pain but without neurological deficit. Due to a recent history of septic knee endoprosthesis and pulmonary embolism, anterior reconstruction was declined. Percutaneous kyphoplasty was also declined due to the severe disruption of the posterior wall with increased risk of PMMA leakage or bone retropulsion.









d Postoperative lateral radiograph with evident PMMA filling below the superior endplate of L4

Fig. 26.4. a Preoperative sagittal CT-myelogram reconstruction revealing a mild superior endplate impression of L4 type A1.1. **b** Axial CT-myelogram demonstrating the predominantly left-sided spinal stenosis at L3/L4. **c** Postoperative AP radiograph showing the PMMA augmentation below the endplate of L4

An L1/L2 interlaminar approach (Fig. 26.5b) allowed the placement of the kyphoplasty balloon parallel to the inferior endplate (Fig. 26.5c), below the fractured portion of the posterior wall. Inflation of the balloon achieved a degree of height restoration (Fig. 26.5d) and allowed controlled filling of the vertebral body (Fig. 26.5e, f). Control over the spinal canal was maintained throughout the procedure. In the event of cement leakage, this could have been promptly removed. At 18 month follow-up the patient is free of thoracolumbar back pain despite moderate subsidence of the vertebral body (Fig. 26.5g).

These patients were followed postoperatively for an average of 9.5 months (range 1 – 31 months). During this period there was no progressive olisthesis or sign of instability attributable to the decompression. The majority of patients showed significant improvement of both back and leg pain (improvement of preoperative back and radicular pain was excellent in seven, good in ten, fair in five patients and poor in one patient). The patient with poor outcome had a symptomatic adjacent fracture at the time of follow-up. Neurological follow-up revealed an improvement in motor power in five of eight patients and an improvement of dysesthesia or numbness in five of eight patients with preoperative deficits. Radicular pain improved in all but one patient, who was found to have persistent nerve root impingement and has undergone an extended decompression since. With meticulous haemostasis, the average intraoperative blood loss in patients without bleeding disorders was below 100 ml, an amount comparable to solitary microsurgical spinal decompression. The actual augmentation procedure (i.e. in addition to the decompression) was found to add 10 – 40 minutes to the operation time, depending upon the complexity of the fracture and the use of VP or KP. Even with KP, an improvement of kyphosis of 10° or more was the exception in these severely injured vertebrae with a fracture age of at least 4 weeks and was only reached in two patients. In these severely osteoporotic patients a total of seven new fractures occurred during the follow-up period, only three of which were, however, adjacent to augmented vertebrae. Two of the adjacent fractures required augmentation.

Although clinical experience with the techniques described here is still limited, the two main components of microsurgical decompression and vertebral augmentation are each established methods. Combining microsurgical decompression with VP or KP allows the treatment of severe osteoporotic fractures associated with neurological deficits that are not sufficiently

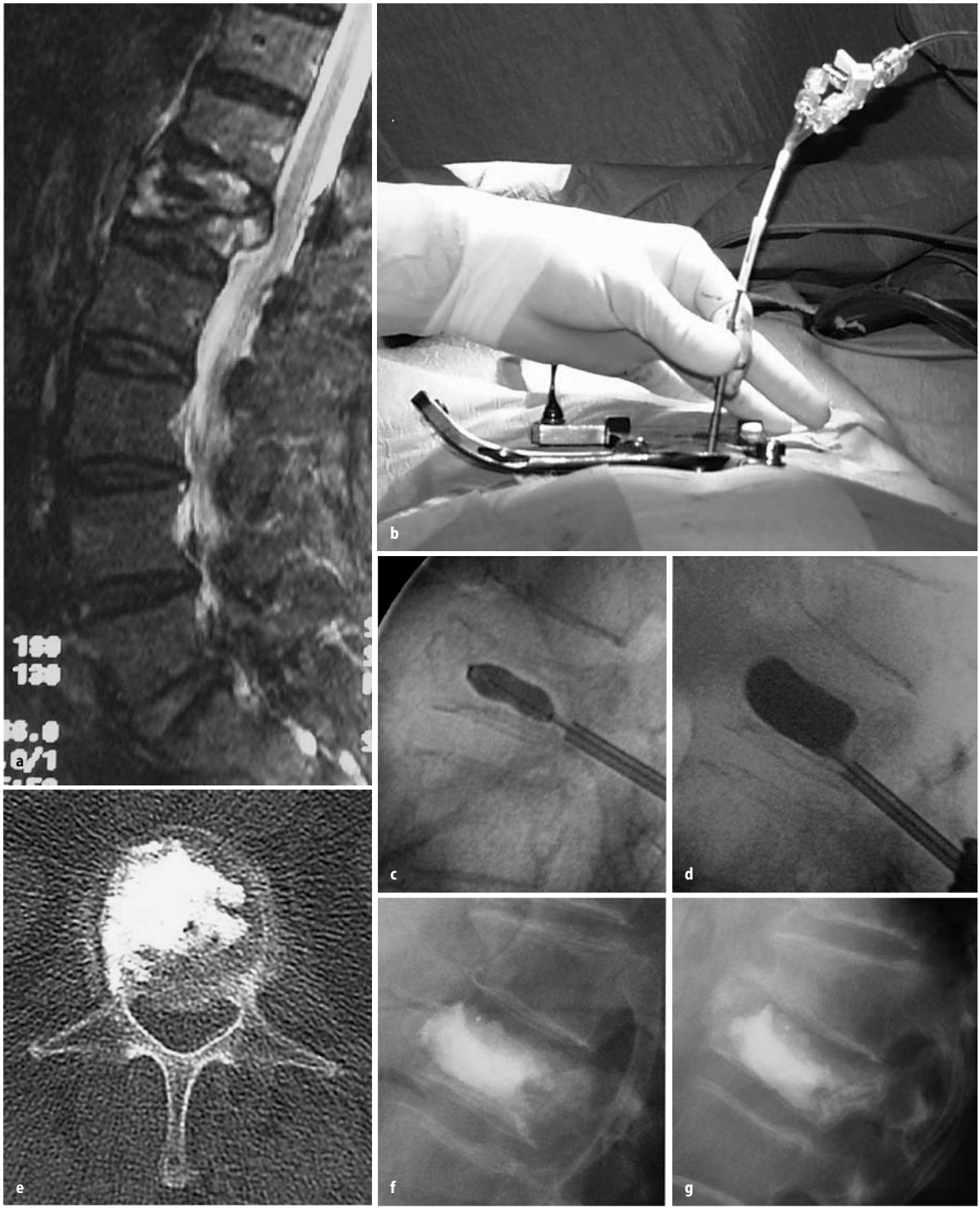


Fig. 26.5. a Sagittal T2-weighted MRI revealing an incomplete burst fracture of L1 type A3.1 with a large retropulsed fragment of the posterior wall. **b** Placement of a single kyphoplasty balloon via an L1/L2 interlaminar approach. **c** Placement of the kyphoplasty balloon parallel to the inferior endplate through the posterior wall after gently retracting the thecal sac. **d** Inflation of the kyphoplasty balloon and restoration of vertebral height. **e** Postoperative CT showing containment of PMMA within the vertebral body. **f** Lateral postoperative radiograph revealing superior endplate support by PMMA. **g** Lateral radiograph at 18 month follow-up revealing moderate subsidence of L1

treatable percutaneously. Furthermore, the risk of neural damage through uncontrolled epidural PMMA leakage in fractures with severe disruption of the posterior wall is reduced as direct control over the spinal canal is provided, allowing immediate removal of extruded cement. While these techniques are not suitable for severely unstable fractures, they do provide a less invasive alternative for many patients requiring decompression and stabilisation but not possessing suitable bone quality for instrumentation. Spinal surgeons accustomed to microsurgical procedures will easily adopt this method, expanding their options for VP and KP.

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Percutaneous Kyphoplasty in Traumatic Fractures 27

G. Maestretti, P. Otten

27.1 Terminology

- Kyphoplasty: This term describes a new method of percutaneous restoration of the shape of vertebral bodies with the aim of correction of a traumatic kyphotic deformity.
- IBT: Inflatable bone tamp.
- VAS: Visual analogue scale.
- CPC: Calcium phosphate cement.

27.2 Surgical Principle

27.2.1 Introduction

Ninety percent of all spinal fractures occur in the thoracolumbar region, and 66 % are compression fractures of type A (A1 35 %, A2 3.5 % A3 27.5 %). Type A fractures involve mainly the vertebral body: the posterior column is only insignificantly injured, if at all. The height of the vertebral body is reduced and the posterior ligamentous complex is intact. Translation into the sagittal plane does not occur. These type of injuries are caused typically by axial compression with or without flexion. The incidence of neurological injuries goes up to approximately 32 % in burst fractures (type A3) [13].

Although it is a very common fracture, there is no consensus as to a standardised treatment with various opinions regarding the most appropriate treatment for those fractures without neurological deficit and this remains a subject of controversy.

Internal fixation offers the possibility of immediate stability and correction of the deformity with the potential visual decompression of neurological structures when needed. With non-operative care, brace or body casts, the same possibility of stabilisation with less correction of the deformity is given [14, 17, 18]. Recent studies comparing long-term results in the treatment of burst fractures found the same results with lesser morbidity for non-operative treatments [21]. Failures after pedicle screw fixation and specifically after removal of instrumentation or after conservative management are possibly due to lesions of the disc and are later due to disc degeneration with decreased anterior column support.

Restoration of vertebral height and preservation of the endplate may prevent the secondary risk of kyphotic deformation and so decrease the risk of chronic pain. In this respect kyphoplasty is an improved technique for the reduction of fractures, for vertebral body height restoration and cement augmentation in the treatment of painful osteoporotic compression fractures with a decreased complication rate compared to vertebroplasty [8, 12].

New calcium phosphate cements which have a good resistance and stability under compression can now be used in association with kyphoplasty, and thus provide a new alternative treatment in non-pathological type A fractures. With this new, mini-invasive percutaneous technique we now have the potential to obtain clinical results comparable with the classic surgical treatment but with less surgical trauma to the patient [1, 19, 20].

27.2.2 Surgical Principle of Kyphoplasty

In the standard kyphoplasty procedure, an inflatable bone tamp (IBT) or balloon is used to restore the vertebral body height and correct the spinal deformities before cementation. The similarities of the technique to vertebroplasty are only in the use of a percutaneous intrabody cannula for the cement injection. However, it gives a number of potential advantages, such as a lower risk of cement extravasation, and can help towards a better restoration of the vertebral height.

A cannula is introduced into the vertebral body, through a trans- or extrapedicular approach, and is followed by the insertion of an inflatable balloon. The IBT is inflated, under permanent control of pressure and volume and a cavity is created inside the vertebral body. As the IBT is progressively increasing in volume, the superior endplate is elevated with restoration of the original vertebral body height.

Deflation and removal of the balloon leaves a cavity in the restored vertebral body. This cavity is filled with a very viscous cement, either with direct injection or, even better, with a prefilled 1.5-ml bone filler device under

low pressure. Filling is performed under continuous lateral fluoroscopic guidance. Higher cement viscosity, lower pressure injection and compacted bone around the cavity reduces the risk of cement extravasation. The procedure can be performed under general anaesthesia or under local anaesthetics with intravenous sedation.

The patient may be discharged from the hospital on the day of the procedure.

27.3 History

Kyphoplasty was developed independently of vertebroplasty in the 1980s, by an orthopaedic surgeon looking for a minimally invasive surgical procedure to address the pain and deformity of vertebral compression fractures (VCFs) following orthopaedic principles: anatomy restoration and solid fixation while minimising tissue disruption.

The first balloon kyphoplasty procedure for osteoporotic VCFs was performed by Dr M. Reiley in Berkeley, California, in 1998. The CE mark was obtained in February 2000.

The idea to use this technique to treat traumatic fractures in young patients appeared in three European groups independently of each other. The first kyphoplasty procedure with calcium phosphate cement was performed in Belgium by Prof. P. Vanderschot in July 2002. At the same time two other groups started with the same technique in Switzerland (G. Maestretti and P. Otten) and in Germany (H. Hillmeier).

The first advisory team meeting, regrouping the Kyphon trauma group, was held in Belgium in March 2003 to better define the indications and lay the foundations of a standard technique.

27.4 Advantages

The advantages of this minimally invasive technique are an almost immediate return to daily activities, disappearance of pain, minimal operative risks and good biomechanical stability of the fractured vertebra. Blood loss being minimal, this could be a first-choice technique in polytraumatised patients needing short-term spine stability, thus improving nursing in ICU without any risk of secondary lesions.

This technique enables normal mobilisation after 6 h, depending on residual pain, without a brace. Patients can be discharged from the hospital the same day as the operation. Compared to conservative management with braces, patients suffer less inconvenience and there is better reduction of the fracture and better control of pain under load. Compared to standard surgery, this technique offers a lower risk of morbidity allowing a quicker return to work and sport.

27.5 Disadvantages

This technique is an operation preferably performed under general anaesthesia although it is a minimally invasive technique and it necessitates extensive use of fluoroscopy. The technique uses the same approach as a kyphoplasty in osteoporotic fractures but the cement application is difficult. This is mainly due to a short crystallisation time, which makes it difficult to apply and necessitates a long learning curve. The initial cost is high, due to the price of IBTs, but we believe this cost is balanced out by a short hospitalisation time and a faster return to work.

27.6 Indications

The trauma group reached a consensus about the following indications:

- Traumatic fractures type A1, A3.1, A2 and A3.2 involving vertebral bodies from T5 to L5, without any neurological deficit, with at least 15° of deformity
- Traumatic fractures type A3.1, A3.2 in which the posterior fragment in the canal does not cause any neurological deficit
- Traumatic fractures type A2 and A3.2 only with a split less than 2 mm
- May be considered in fractures of type B associated with posterior instrumentation

27.7 Contraindications

Contraindications are given for high thoracic levels, cervical fractures, fractures of type A2 with a split larger than 2 mm and fractures of type A3.3 and type C. Pathological fractures should not be treated with this technique.

27.8 Surgical Technique

27.8.1 Kyphoplasty Technique

Compared with the standard kyphoplasty for osteoporotic fractures, there are some differences to consider in the treatment of traumatic fractures for young pa-

tients. First, the preoperative planning must include clinical examination, plain X-rays, a CT scan and sometimes an MRI to exclude type B fractures. This allows a better classification of the fracture and correct planning for the ideal trajectory of the cannulas. The planning ensures the best possible reduction of the fracture without increasing the risk of bone fragment displacement in the canal in type A3 fractures. An MRI examination is useful in defined cases, especially to exclude a type B fracture.

We recommend general anaesthesia in these procedures, to allow a possible switch to an open procedure in case of an unsatisfactory reduction. A radiolucent operating table is recommended and the patient is positioned in slight lordosis, so facilitating the reduction of the fracture and sometimes already reducing the fracture. A good fluoroscopic C-arm must be at hand and able to perform AP and lateral images.

After correct definition of the involved level, Jamshidi cannulas are placed under fluoroscopy either trans- or extrapedicularly, according to the preoperative CT planning. The choice of the trans- or extrapedicular method depends on the level and size of the pedicles. The cannula has to perforate the posterior cortical wall and penetrate a few millimetres into the vertebral body.

Guide pins are then introduced and X-rays must be taken, both in AP and lateral views, to ensure there is no perforation of the endplates and that the trajectory is parallel to the fractured endplate. Correct positioning of the guide pins (and then the IBT) depends on the trajectory and angulations of the fracture. A space of at least a few millimetres must be left under the superior endplate and the fracture line. Contact of the IBT and cement with the disc space must be avoided.

The working cannulas are introduced, foraging of the vertebral body is performed and two IBTs are placed (Fig. 27.1). The size of IBT must be chosen with regard to the vertebral body size, the amount of reduction needed and the type of fracture. For example, in an A3 fracture a 4-cc balloon is preferred and placed in the anterior third portion of the vertebra, minimising the risk of a posterior fragment displacement in the canal. Each IBT is connected to a syringe filled with radioopaque medium (Fig. 27.2). The syringe is also connected to a pressure transducer (giving pressure in atm

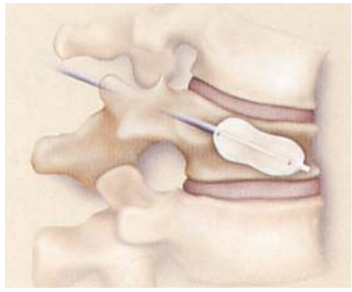


Fig. 27.2. Inflation of IBT

or psi). Simultaneous inflating of both IBTs is performed to 50 psi, and then the internal guide is removed. The IBTs are progressively inflated by 0.5-ml augmentation, under constant fluoroscopy with control of pressure and volume.

In cases of fractures in young patients, high pressures of 300 psi are quickly obtained with a low volume of IBT. In these cases you have to take time to let the pressure diminish while the balloons expand, with progressive displacement of trabeculae and correction of fracture. When the volume reaches 1.5 cc, an AP view is performed to further check the position of the IBTs. If the position is optimal, inflation is performed until a correct reduction is obtained. Operative time is proportional to the age, type of the fracture and deformity and it may take up to 1.5 h. Maximal pressure of 400 psi and total volume must not be exceeded as there is risk of rupturing the balloons.

When satisfied with the reduction, both IBTs are removed and the cavity is cemented. Calcibon is held in a fridge and mixed just before use, so as to delay the crystallisation time. Mixing is always performed by pouring the liquid first and then adding the powder, and it takes 60 seconds to obtain a viscous consistency. Cannulas, 1.5 cc in volume, are prefilled quickly, and the distal end is obtruded with bone wax to protect the cement from early contact with blood. Filling of the vertebral body starts in the anterior part and goes posteriorly, under constant fluoroscopy, paying special attention to the posterior fragment in type A3 fractures (Figs. 27.3, 27.4). This phase is short and takes a maximum of 3 min. Crystallisation is completed within a few minutes, cannulas are removed, a final fluoroscopy check is performed and the skin is sutured.

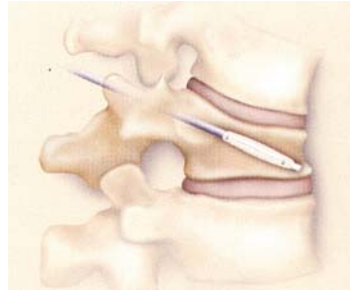


Fig. 27.1. Position of IBT in vertebral body

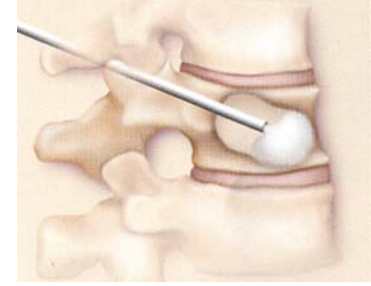


Fig. 27.3. Filling of the vertebral body starts anteriorly

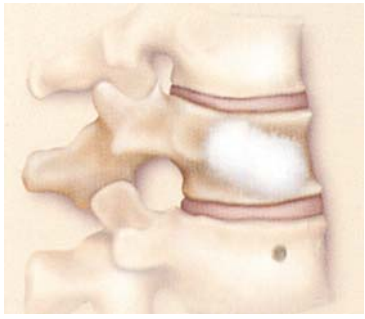


Fig. 27.4. Completed cementing of vertebral body

27.8.2 Calcium Phosphate Cements

Calcium phosphate cements (CPCs) consist of a powder containing one or more solid compounds of calcium and/or phosphate salts and a liquid that can be water or aqueous solution [3]. If the powder and the liquid are mixed in an appropriate ratio, they form a paste that at room or body temperature sets by entanglement of the crystals precipitated within the paste [2, 4]. The mass does not set for several minutes and is, depending on the liquid/powder ratio, injectable via a syringe [9, 10]. One of the most important characteristics of CPCs is that they are supposed to be osteoconductive and degradable [6, 7, 15, 16].

Although numerous reports on in vitro and in vivo investigation dealing with CPCs have been published, there are still some problems to overcome. These mainly involve the setting time, the compressive strength reached after setting and the degradation rate of the cement in vivo [5]. A relatively long time for the material to harden in situ was reported for Bone Source cement. Blood and tissue fluids, which come in contact with the cement shortly after initial placement, can significantly delay the final setting time of some cements. Alpha-BSM and Cementek harden after 20–40 min, which renders them impractical. Regarding strength, Norian SRS, Alpha-BSM and Cementek hardly develop a compressive strength that equals the maximum strength of trabecular bone [5]. Resorption of Bone Source is poorly documented.

A CPC that is mainly composed of alpha-tricalcium phosphate (alpha-$Ca_3(PO_4)_2$) and dicalcium ($CaHPO_4$) has also been developed and improved. This alpha-TCP cement was originally called Biocement D in 1998, but is now marketed under the name Calcibon. Animal studies were performed from August 1999 to May 2000, and use as a graft substitute in humans started in July 2000. The CE mark was obtained in December 2002. Mixed at a liquid to powder ratio of 0.35:1, it has a cohesion time of 1 min, an initial setting time of 2–3 min, a final setting time of 7.5 min at 37°C and a maximal compressive strength of 60 MPa reached at 3 days. The cement is composed of a cement powder that contains 61% alpha-TCP, 26% $CaHPO_4$, 10% $CaCO_3$ and 3% precipitated hydroxyapatite. The cement liquid is a 4% aqueous solution of Na_2HPO_4. The cement paste hardens as a CDHA trough hydrolysis of the alpha-TCP:

$$3\ Ca_3\ (PO_4)_2 + H_2O - CA_9\ (HPO_4)\ (PO_4)\ 5OH$$

To be injectable via a syringe, the liquid to powder ratio in Calcibon was set between 0.3:1 and 0.4:1. Cell culture studies using fibroblast and human bone marrow osteoprogenitors showed that the substance is not cytotoxic and stimulates differentiation of osteoblasts. Osteoclast response to the cement in tissue culture showed that the material was reabsorbed by the osteoclasts [11].

27.9 Postoperative Care

Depending on the residual pain, mobilisation can start as of the 6th postoperative hour. For 2 weeks we advise not to lift any load, and any physical effort is to be avoided.

Gentle decontracting massages are prescribed, with isometric muscular reinforcement. Standard advice for a good back posture is given by a physiotherapist. After 2 weeks, the patient may return to work and take part in sport. Delays are due to residual post-traumatic muscle contraction.

27.10 Results

27.10.1 Clinical Example

This young 25-year-old female, manual worker, fell at work from a height of 3 metres. She was admitted in emergency with acute low back pain, and an isolated L1 fracture (Fig. 27.5). VAS was initially at 9. CT scan confirmed a type A3.2 fracture with 22° of deformity (Figs. 27.6, 27.7). A Calcibon kyphoplasty was performed under general anaesthesia at day 2. Postoperative plain X-rays with the patient upright (Fig. 27.8) and a CT scan (Figs. 27.9, 27.10) at 24 h show the reduction of the fracture. The patient was discharged after 48 h, and resumed the work after 4 weeks, without any pain. At 1-year X-ray control shows a deformity of 6° (Fig. 27.11).

27.10.2 Clinical Results

From August 2002 to August 2003, 28 patients, with a mean age of 45 years, with 33 acute traumatic vertebral type A fractures were treated.

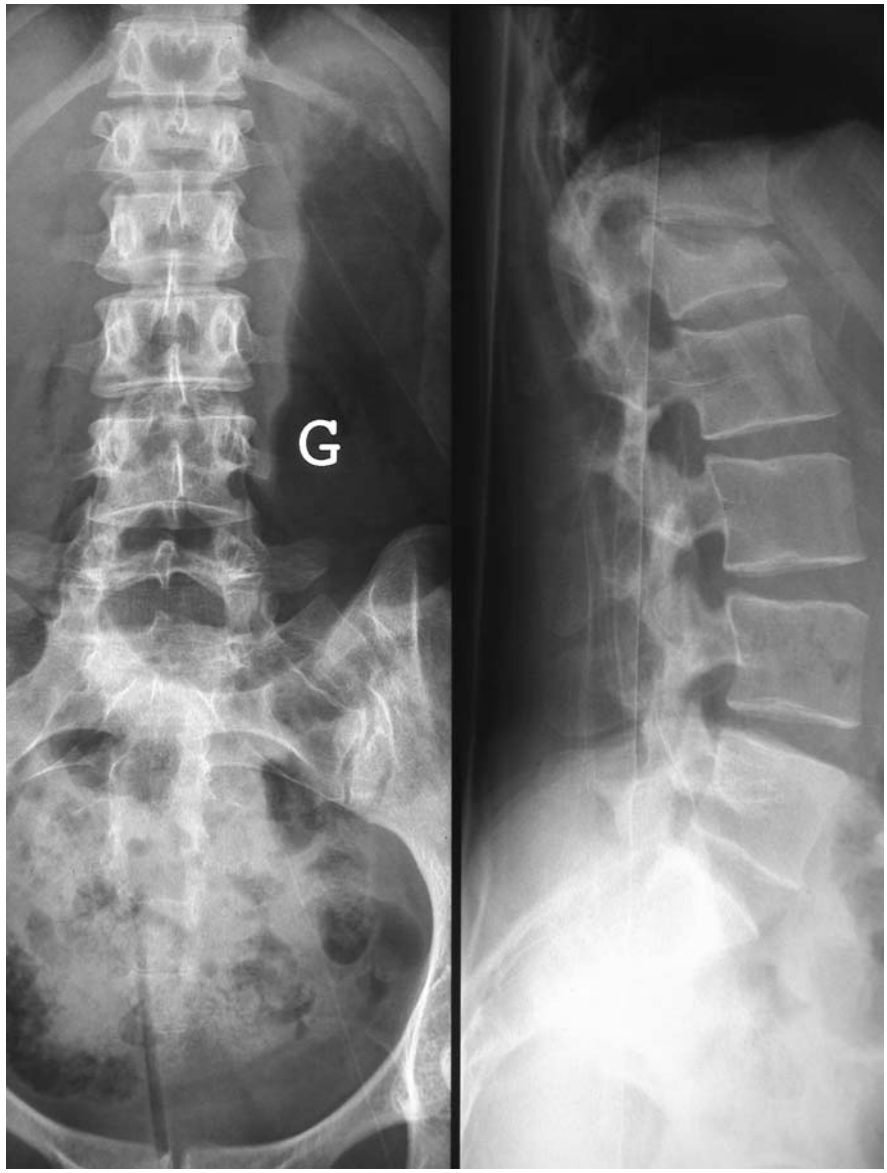


Fig. 27.5. Preoperative plain X-rays



▷
Fig. 27.6. Preoperative CT scan, axial



▷▷
Fig. 27.7. Preoperative CT scan, lateral



Fig. 27.8. Postoperative plain X-rays (standing)



Fig. 27.9. Postoperative CT scan, axial

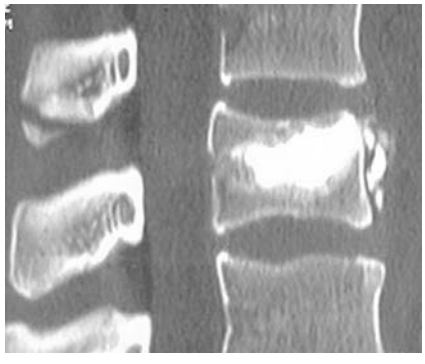


Fig. 27.10. Postoperative CT scan, lateral

All patients were evaluated with plain X-rays preoperatively and also after 24 h, 7 days, and 2, 6 and 12 months. A preoperative CT scan was always performed which was also done after 24 h and 1 year. Clinical examinations with VAS, Roland Morris disability score evaluations, are performed preoperatively, after 7 days, and after 2, 6 and 12 months. The operative procedures were performed in a general manner, under general anaesthesia. The type of fractures were 3 A1.1, 21 A1.2, 7 A3.1 and 2 A3.2. The mean surgery time was 60 min, the final pressure of the IBT was 233 psi and the mean volume of Calcibon injected was 6.8 ml.

The mean initial kyphosis was 17°, and reduction obtained preoperatively was to a mean of 5°. We noticed

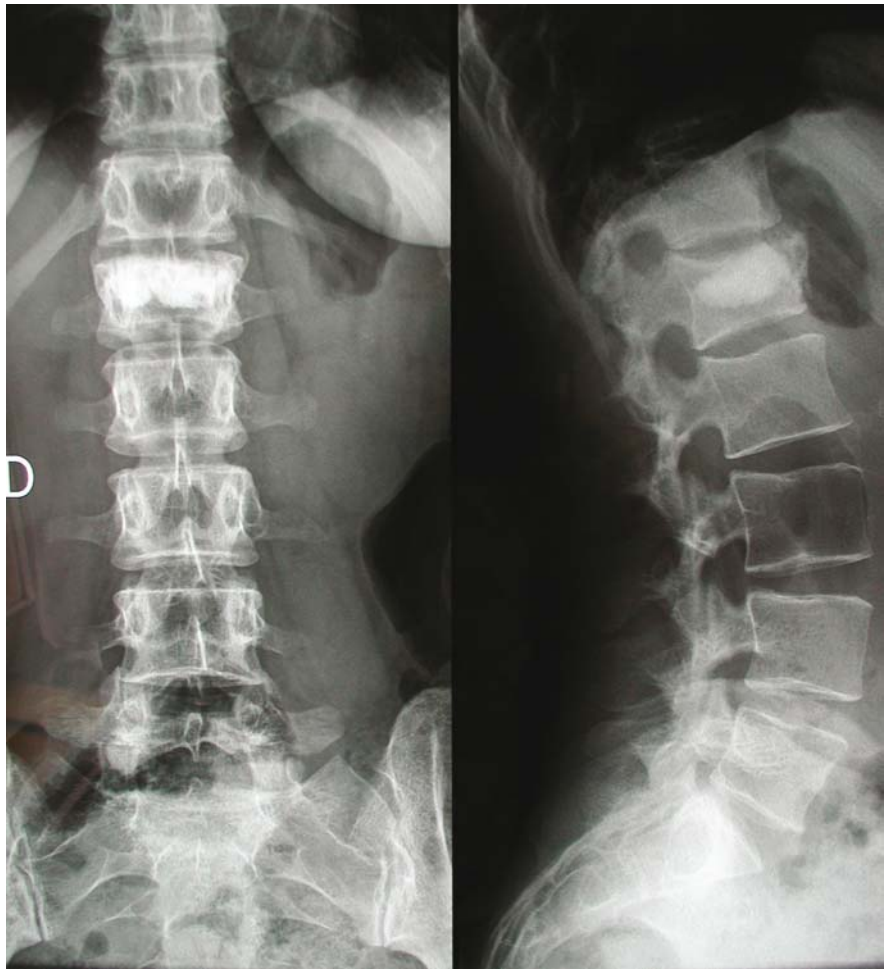


Fig. 27.11. X-rays at 1 year

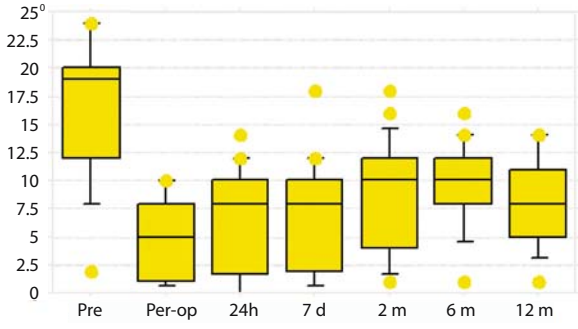


Fig. 27.12. Kyphosis angles in degrees

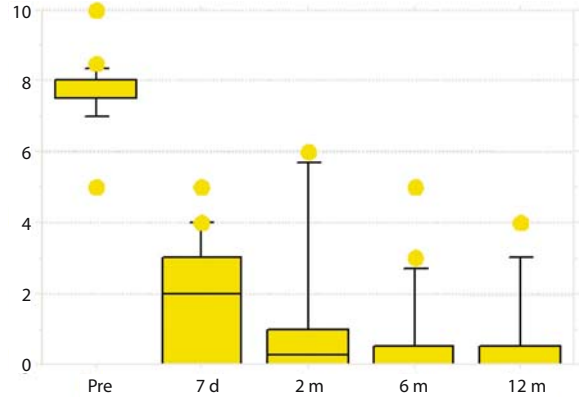


Fig. 27.13. Visual analogue scale

a gradual loss of correction from a mean of 6° at 24 h to a mean of 10° at the last follow-up (Fig. 27.12). The mean preoperative segmental kyphosis was 4°, perioperative correction was to –6°, 24 h after surgery it was –1° with a mean of 4° at the last follow-up. The height restoration (Beck index) was 0.70 preoperative, corrected to 0.90 perioperative, 0.87 24 h after surgery and 0.84 at the last follow-up without clinical significance. The VAS score demonstrated a decrease over time from a mean of 8.7 preoperative, to 3.1 at 7 days and 1 at the last follow-up (Fig. 27.13). Roland Morris disability scores demonstrated a similar improvement over time from a mean of 5 at 7 days to a mean of 2 at the last follow-up.

All patients with vertebral fractures as sole medical problems were discharged from the hospital within

48 h. All active patients returned to work within 3 months.

27.10.3 Complications

We noticed two anterior wall perforations by cannulas, six leakages in the disc space and one posteriorly in the spinal canal without any clinical significance. These leakages certainly occurred through fracture lines as we never noticed any leakage in veins or pulmonary embolism. No long-term complications were noticed.

27.11 Critical Evaluation

The standard treatment of thoracolumbar vertebral fractures type A is still debated. Conservative treatment does not restore the spine balance and due to the loss of anterior height this may lead to acceleration of disc degeneration and loss of anterior support.

Open surgical therapy with instrumentation carries definite risks, is destructive for muscles, but helps to restore the vertebral height, thus preventing the long-term chronic pain sometimes seen in posttraumatic kyphotic deformations. Kyphoplasty is a new technique in the treatment of osteoporotic fractures resistant to conservative therapy, and seems to be superior to vertebroplasty as the risk of complications, such as cement leakage and venous embolism, is less.

Our study demonstrates that kyphoplasty in the treatment of some thoracolumbar fractures compares well with the standard therapies. A rapid decrease in pain, early discharge from the hospital and the high rate of early return to normal daily activities and work is especially appealing. The tendency to lose the correction obtained after the operation justifies a long-term analysis. This long-term loss of correction has also been described with posterior instrumentation. Only long-term follow-up will tell if this technique can be used as a standard alternative therapy of acute thoracolumbar fractures, and determine which kinds of fracture should be treated this way.

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Lumbar Spine

Low Back Pain (Ch. 28) 249
Disc (Ch. 29 – 39) 260
Disc Reconstruction (Ch. 40 – 43) 364
Spinal Stenosis (Ch. 44) 397
Fusion (Ch. 45 – 48) 409
Dynamic Stabilization (Ch. 49 – 51) 459

Interventional and Semi-invasive Procedures for Low Back Pain and Disc Herniation

28

M.K. Schäufele

28.1 Terminology

Semi-invasive procedures for low back pain and disc herniations include a wide range of procedures. For the purpose of this chapter, the focus will be on spinal injection procedures, radiofrequency denervation procedures, and advanced interventional pain management procedures. The terminology of the different procedures is described in the corresponding sections.

28.2 Surgical Principle

Percutaneous spinal procedures are generally performed under fluoroscopic X-ray guidance, except for certain special procedures, such as vertebral biopsies, which may be performed under CT guidance. All these procedures can be performed on an outpatient basis. They can be safely done under local anesthesia and when necessary, under conscious sedation. A dedicated procedure suite is recommended with radiolucent procedure table, monitoring equipment, and a high quality C-arm. Percutaneous spinal injection procedures demand an excellent three-dimensional knowledge of the radiographic anatomy of the spine.

After the patient is positioned on the procedure table, the C-arm is positioned to identify the target tissue. The "universal lumbar view" (Fig. 28.1) allows identification of all target tissues. It is obtained by tilting the C-arm to accommodate for the lumbar lordosis, followed by rotating the C-arm into a 20 – 30° oblique view. Usually, a 22-gauge or 25-gauge spinal needle of various lengths is then inserted parallel to the X-ray beam ("tunnel view") and slowly advanced under frequent radiographic imaging with AP, oblique, and lateral C-arm projections. Once the target area is reached and after negative aspiration, a small amount of non-ionic contrast (such as Omnipaque 300) is injected. The injection of dye confirms appropriate positioning of the needle tip into the target tissue. Depending on the type of procedure, target tissues such as the nerve root sleeve, epidural space, or facet joint capsule can be identified. Dye injection also ensures that the needle is not placed inadvertently in the intravascular space. Next, a combination of a small amount of local anesthetic and, in the case of a therapeutic injection, a preservative-free steroid (such as Depo-Medrol or Celestone Soluspan) is injected. The needle is removed and the patient is observed for about 30 – 45 minutes in the recovery area. Significant side effects are rare and the majority of patients can resume normal activities the next day.



Fig. 28.1. Universal radiographic lumbar view ("Scottie dog view") allows target visualization for all lumbar spinal injections. *1* Transforaminal epidural, *2* interlaminar epidural, *3* intra-articular facet joint injection, *4* medial branch injection, *5* intradiscal access for discography and intradiscal procedures

For the purpose of this chapter, the most commonly performed interventional spine procedures are discussed, including epidural steroid injections, facet (zygapophyseal) joint injections, and radiofrequency neurotomies as well advanced interventional pain procedures, such as spinal cord stimulators and intrathecal drug delivery systems.

28.3 History

The first description of a caudal injection for patients with intractable sciatica was described in 1925 [14]. Robecchi first described injection of steroids into the spinal canal in 1952 [11]. The discovery of high levels of inflammatory cytokines in a herniated nucleus pulposus, such as phospholipase A2 by Saal in 1990, as well as other cytokines, contributed to the understanding of the significant inflammatory component that contributes to radicular pain [13]. Bogduk postulated that for "any structure to be deemed the cause of back pain, this structure should have been shown to be a source of pain in patients" [3]. This led to the development and use of precision injection techniques to selectively block pain transmission from potentially painful structures in the spine, such as the segmental spinal nerve roots, facet joints, and sacroiliac joints. In addition to the usefulness of these injection techniques for diagnostic purposes, additional injection of anti-inflammatory agents such as glucosteroids or application of radiofrequency energy for denervation procedures have expanded the therapeutic spectrum. Similar to advances in interventional cardiology, interventional spine procedures have become important diagnostic and therapeutic tools for spine specialists and stand in the treatment algorithm between the more traditional pharmaceutical therapies/physical medicine techniques and traditional open surgery. The advances in digital fluoroscopic imaging and mobile C-arm technology have greatly enhanced the ability to perform these procedures with maximum precision and safety for the patient.

28.4 Advantages

- Outpatient procedure
- Procedures are performed under local anesthesia or mild conscious sedation
- Patients can resume regular activities the following day
- Minimal side effects
- No skin incision
- No permanent structural alteration of the spinal canal or surrounding soft tissues
- Useful for diagnostic and therapeutic purposes

28.5 Disadvantages

- Therapeutic effects are often temporary
- Significant learning curve
- Multiple injections may be necessary to identify the pain generator

28.6 Indications

One has to differentiate between spinal injections for diagnostic purposes and spinal injections for therapeutic purposes. The pain generator is often unclear in patients with chronic spinal pain. The history and physical examination often cannot reliably identify the source of the patient's pain [8]. Furthermore, imaging studies such as X-ray, myelography, and MRI have a high rate of false-positive abnormalities that often do not correlate with the patient's pain [1]. Precision diagnostic injections are useful to determine the origin of a patient's pain. The double-block technique is recommended for diagnostic procedures to decrease the number of false-positive responses. First, a small amount of short-acting local anesthetic is injected into the target tissue (such as lidocaine 2 %). If the patient experiences at least 50 %, preferably 70 % of pain relief, the procedure is repeated with a second, longer-acting local anesthetic (such as Bupivacaine 0.5 %) to confirm the diagnosis.

In case of therapeutic spinal injections, the goal is to minimize the patient's pain through application of an anti-inflammatory medication, usually a steroid, at the site of pain and inflammation. Patients with acute or chronic radiculopathy may benefit from epidural steroid injections, whereas patients with facet-mediated pain may benefit from facet injections, medial branch injections, or radiofrequency neurotomies to denervate the painful facet joints. Chronic neuropathic pain syndromes may benefit from an implanted spinal cord stimulator, and patients with complex, intractable pain syndromes may benefit from intrathecal drug delivery systems.

28.7 Contraindications

- Bleeding diathesis and anticoagulant therapy, including platelet-inhibitors.
- Pregnancy.
- Bacterial infection.
- Allergy to non-ionic contrast dye or local anesthetics.
- Patients with diabetes mellitus need to monitor

their postinjection blood sugar if steroids are injected.
- Patients with artificial heart valves may require treatment with preoperative antibiotics.

28.8 Patient's Informed Consent

Patients may experience weakness or numbness after the injection consistent with the therapeutic duration of the local anesthetic that was injected. Therefore, patients should not drive until they have normal sensation and strength. If steroids were injected, patients may experience a steroid flush, irritability, and insomnia for a few days as well as stomach irritability. Injection site soreness usually subsides within a few days. Occasionally, a temporary increase in pain is noted. In case of interlaminar epidural steroid injections, the risk for a spinal headache exists in the inadvertent case of an intrathecal injection. In case of radiofrequency neurotomies, temporary neuralgias are not uncommon but usually subside within a few weeks. Significant side effects, such as epidural hematomas resulting in spinal cord injury, epidural abscesses, discitis, and intravascular injections resulting in permanent neurological deficits have been described but are extremely rare [5, 6, 9]. Implantable devices may pose the risk of infection, including epidural abscess and meningitis, lead and catheter migration, medication overdose, and hardware failure.

28.9 Surgical Technique

The requirements for interventional spine procedures include a sterile operating room or procedure room, monitoring equipment for blood pressure, pulse oximetry and EKG, high-quality digital C-arm fluoroscopy, sterile preparation, resuscitative equipment, needles, gowns, injectable agents, intravenous fluids, sedative agents, and trained personnel for preparation and monitoring of the patients.

28.9.1 Facet (Zygapophyseal) Joint Injections

Diagnostic injections of the facet ("Z") joint can be performed to test the hypothesis that the target joint is the source of the patient's pain [4]. These joints can be anesthetized either with intra-articular injections of local anesthetic or by anesthetizing the medial branches of the dorsal rami, the innervating branches to the target joint. Each joint is innervated by medial branches of the corresponding segmental nerve and the segmental nerve above. If the pain is not relieved, the joint cannot be considered the source of the pain. True positive responses are secured by performing controlled blocks, usually with comparative local anesthetic blocks: the same joint is anesthetized by using a local anesthetic of different duration.

Lumbar facet joints have been shown to be capable of being the source of low back pain with referred pain into the lower limb. History and physical examination findings are unreliable in determining facet joint pain [7]. Therefore, injection of these joints is necessary to prove or refute the diagnosis of facet-mediated pain. The facet joint is a true synovial lined joint allowing the spine to flex, extend, and rotate. The most common cause of facet joint disease is osteoarthritis. The sensory nerve endings entering the facet joint capsule become irritated by an inflammatory process resulting in a sensation of pain.

If facet joint injections are performed for therapeutic purposes, steroids are added to the injectate. For lumbar facet joint injections, the target joint is lined up through an oblique C-arm projection ("Scottie dog view"; Fig. 28.1). The C-arm is rotated to the contralateral side until the posterior facet joint line just becomes visible. Injection of the lower lumbar facet joints requires usually more rotation than the upper facet joints. In case of severely degenerated joints, visualization of the facet joint line may be difficult and may require rotation of the C-arm to the ipsilateral side to allow entry into the joint. Once the facet joint line is identified, a 22-gauge or 25-gauge needle is advanced into the joint. The joint is usually most accessible in the superior or inferior recess of the joint capsule. Once the needle has entered the joint, a distinct change in resistance is noted. Intra-articular placement is confirmed with injection of a small amount of non-ionic contrast, such as 0.2 cc Omnipaque 300 (Fig. 28.2a, b). Next, a small amount of local anesthetic such as 0.5 – 1 cc lidocaine 1 % or 2 %, or Bupivacaine 0.25 % or 0.5 % is injected. For therapeutic injections, a small amount of steroid such as 20 – 40 mg Depo-Medrol is added.

28.9.2 Medial Branch Injections

Each facet joint is innervated by two medial branches. In the case of the L4-5 facet joint, for example, the facet joint is innervated by the medial branches of the dorsal rami of L3 and L4. Therefore, successful treatment of the target facet joint with spinal injections requires an injection of the two supplying medial branches. For injection in the lumbar spine, the universal spine view (Fig. 28.1) is again used. The needle is placed in the groove where the transverse process joins the superior articular process. In the lateral view, the needle should remain posterior of the neuroforamen. A small amount

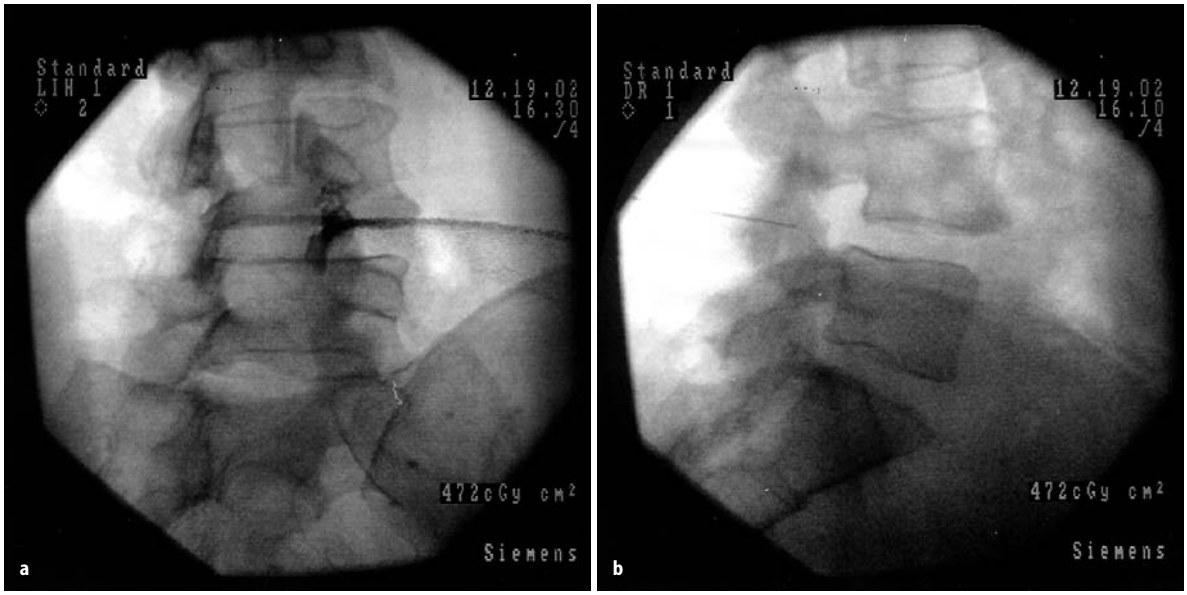


Fig. 28.2a, b. Right L4-5 intra-articular facet injections, AP and lateral

of local anesthetic such as 0.5 cc lidocaine 1 – 2 % or 0.5 cc Marcaine 0.25 – 0.5 % is injected. For therapeutic injections, a small amount of steroid such as 20 – 40 mg Depo-Medrol is added.

28.9.3 Medial Branch Radiofrequency Neurotomies ("Facet Denervation")

If a patient experiences 50 %, preferably 70 %, relief of pain from diagnostic intra-articular facet joint injections or medial branch injections, but without long-term relief, they can be considered for radiofrequency neurotomies with the goal to provide the patient with longer lasting pain relief. With proper technique, patients may have significant pain relief for approximately 6 – 12 months in the lumbar spine, or 1 – 2 years in the cervical spine. The needle placement is similar to the technique described for medial branch injections. Specialized electrodes and radiofrequency equipment is commercially available. Precise needle placement is necessary for a successful procedure (Fig. 28.3). Radiofrequency heating is usually performed at 70 – 80 °C between 60 and 90 seconds in one to three different locations in the target area. Prior to the lesioning, sensory testing is performed to assure proper placement of the

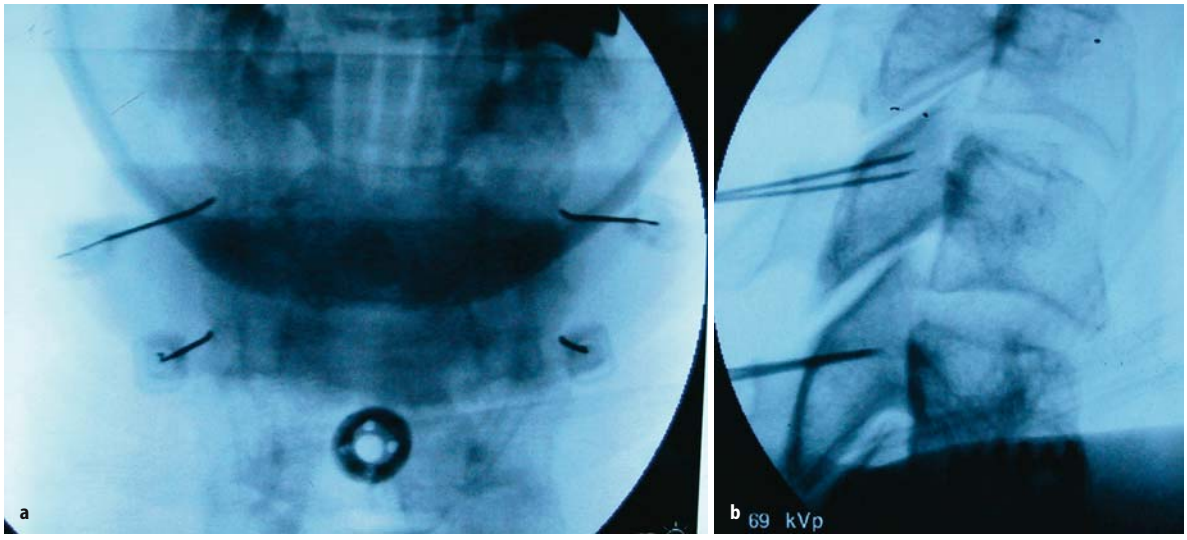


Fig. 28.3a, b. Bilateral C4, C5 medial branch radiofrequency neurotomy (denervation of the C4 – 5 cervical facet joint bilaterally), AP and lateral; the patient is s/p C5/6 ACDF

needle close to the medial branch. Motor testing is performed to assure that the needle tip is placed not too close to the segmental motor nerve.

28.9.4 Epidural Injections

Several different techniques have been described for epidural steroid injections. They include interlaminar epidural steroid injections, selective nerve root injection/transforaminal epidural steroid injections, and caudal epidural steroid injections.

28.9.4.1 Caudal Epidural Steroid Injection

Caudal epidural steroid injection is the least specific epidural steroid injection, but is also technically the easiest to perform. The patient is placed in the prone position. The caudal epidural space is approached via the sacral hiatus. The hiatus can usually be identified manually, but fluoroscopic placement assures placement into the spinal canal and not into the soft tissues. Usually a 22-gauge, 3.5-inch needle is placed through the sacral hiatus up to the S2 – 3 level. On the AP view, the needle tip should not extend significantly beyond the intersecting line between the sacroiliac joints. The needle should be positioned in the midline unless the patient complains about radicular symptoms only on one side. To confirm epidural flow, 1 – 2 cc of contrast dye, such as Omnpaque 300, is injected. Intravascular uptake is not uncommon and needs to be recognized. If this is the case, the needle needs to be repositioned. The thecal sac extends to the S2 level in adults and dural puncture is possible. Caudal epidural steroid injections usually require larger volumes of medication; an injection of 10 cc is necessary to reach the L4-5 level. Commonly, a combination of a lower concentration local anesthetic, such as lidocaine 1 % or Bupivacaine 0.25 %, 6 – 10 cc, and a steroid such as 80 – 120 mg Depo-Medrol is injected.

28.9.4.2 Interlaminar Epidural Steroid Injection

This approach is similar to the classic anesthesiologist's approach of the interlaminar space for epidural anesthesia. The patient is placed in the prone position. Using the universal view (Fig. 28.1), the interlaminar window on the affected side is identified. An interlaminar epidural steroid injection should not be performed on a patient with a previous spinal surgery at this level because the posterior epidural space may be altered and injection may result in an intrathecal injection, possibly resulting in spinal block and postpuncture headaches. The needle is advanced into the posterior epidural space, usually with the loss of resistance technique. A glass syringe is filled with air or sterile saline. The needle is slowly advanced through the ligamentum flavum. Once loss of resistance is noted, epidural placement is confirmed. Aspiration should be negative for CSF or blood. To confirm epidural placement, 1 or 2 cc of contrast dye is injected (Fig. 28.4). A combination of

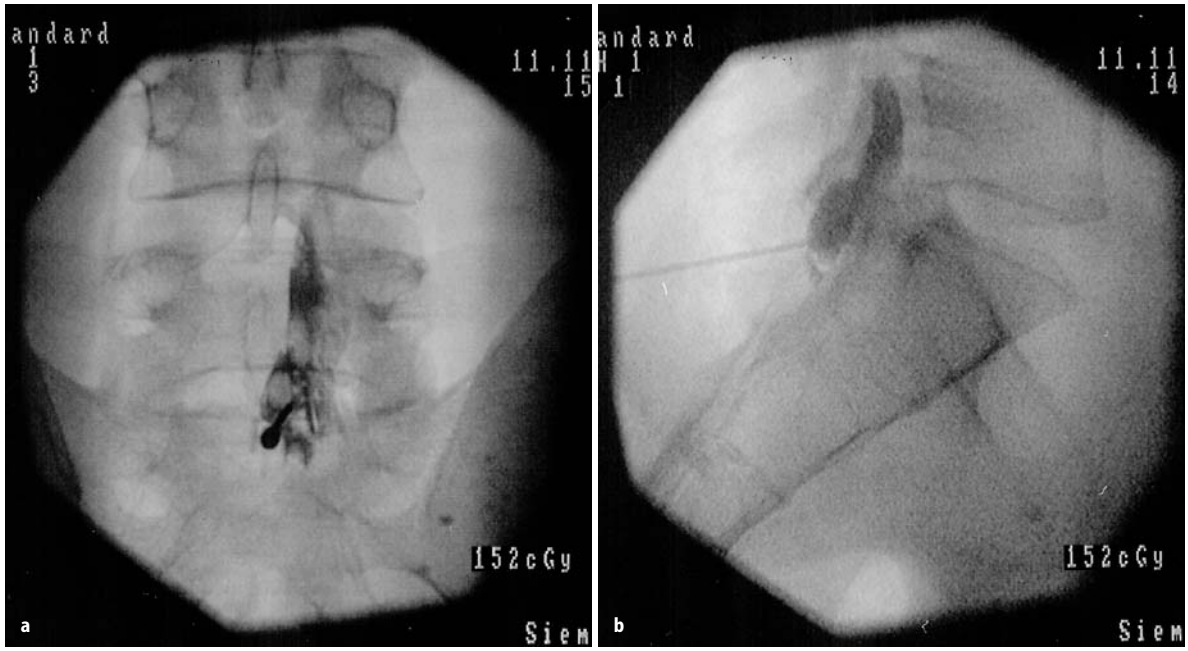


Fig. 28.4a, b. Lumbar interlaminar epidural steroid injection, AP and lateral. Note the contrast flow primarily in the dorsal epidural space

2 – 5 cc of local anesthetic such as lidocaine 1 % or Bupivacaine 0.25 % and steroid such as 40 – 80 mg Depo-Medrol is injected.

28.9.4.3 Selective Nerve Root Injection/Transforaminal Injection

With the transforaminal technique, the needle tip is placed superior to the nerve root and anterior into the epidural space. This technique allows specific blockade of one nerve root with a small amount of local anesthetic and can provide helpful diagnostic information about the source of a patient's pain, especially in patients with unclear history and physical findings and multilevel abnormalities on imaging studies. The patient is placed in the prone position on the fluoroscopy table. A small gauge (22-gauge or 25-gauge) spinal needle is inserted into the anterior and superior aspect of the corresponding neural foramen using the universal view (Fig. 28.1). One has to be careful with advancing the needle once the neural foramen is entered, to avoid nerve root injury. Once the needle is placed successfully in the anterior and superior aspect of the neural foramen and not more medial than the 6 o'clock position of the pedicle in the AP view, a small amount of contrast such as 0.5 – 1 cc Omnipaque is injected (Fig. 28.5). Next, a combination of 1 – 3 cc lidocaine 1 – 2 % or Bupivacaine 0.25 – 0.5 % with steroid is injected (40 – 80 mg Depo-Medrol or 6 – 12 mg Celestone Soluspan). For a selective nerve root injection, which serves primarily for diagnostic purposes by specifically blocking only one nerve root, the injection is stopped once the contrast has reached the medial wall of the pedicle to avoid spill into the epidural space. The amount of contrast injected is noted and the same amount of local anesthetic (usually of higher concentration) such as lidocaine 2 – 4 % or Marcaine 0.5 – 0.75 % is injected. The patient is observed after the procedure and appropriate and successful blockade of the segmental spinal nerve is confirmed with corresponding motor and sensory deficits. The patient's change in pain is recorded on a pain diagram.

28.9.5 Sacroiliac Joint Injection

The sacroiliac joint injection is best performed under fluoroscopic guidance with contrast enhancement. Rosenberg et al. [12] showed that intra-articular injection into the joint was achieved in only 22 % of patients with clinically guided sacroiliac joint injections. The purpose of sacroiliac joint injections is primarily diagnostic. Some patients can achieve prolonged relief with intra-articular steroid injections into the joint, but often the results are only temporary. Radiofrequency techniques to denervate the sacroiliac joint so far have not produced good reliable clinical outcomes. The patient is placed prone on the fluoroscopy table. From an AP position, the C-arm is slowly rotated until the anterior and the posterior joint lines separate. The needle tip should be placed into the lower aspect of the joint approximately 1 cm above its inferior joint line, where the joint is most accessible. A 22-gauge 3.5-inch spinal needle is advanced into the joint. Once the needle is in the joint, a change in resistance is noted. Intra-articular injection is confirmed with 0.5 – 1 cc of contrast dye

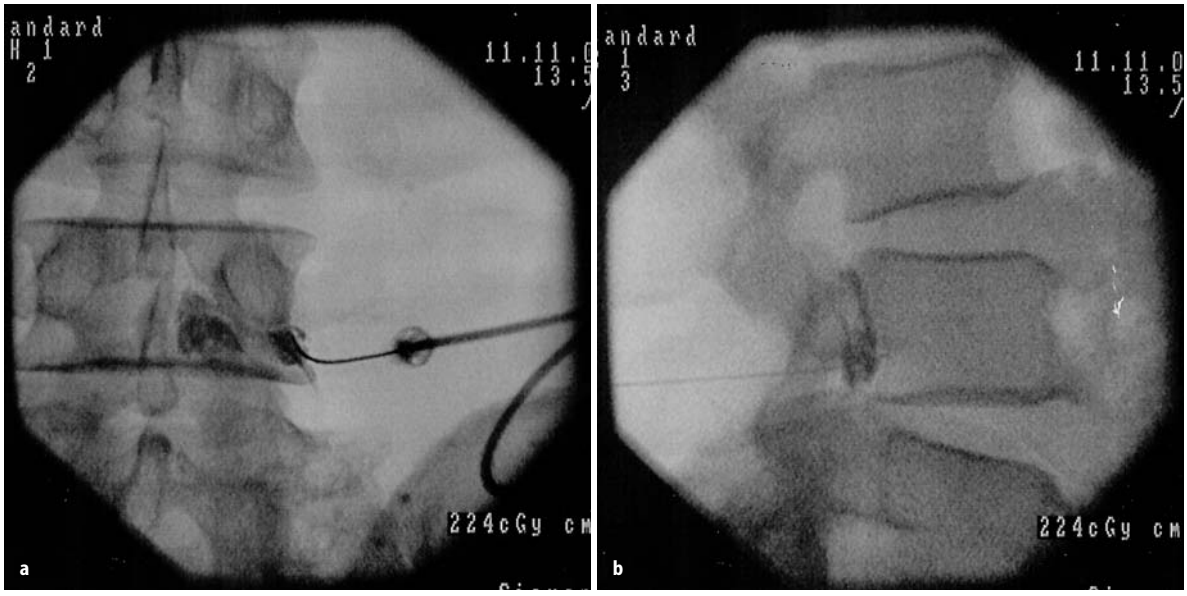


Fig. 28.5a, b. Lumbar transforaminal epidural steroid injection, AP and lateral. Note the contrast flow along the nerve root into the anterior epidural space

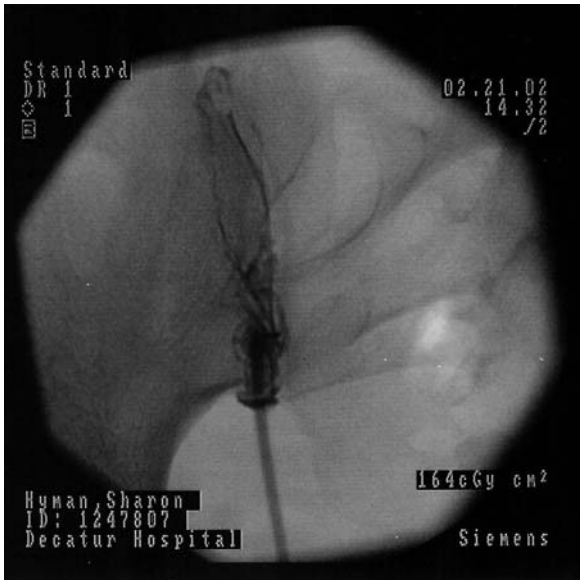


Fig. 28.6. Intra-articular sacroiliac injection with arthrogram, AP

(Fig. 28.6). AP and lateral images can be used to determine if capsular tears exists. A combination of 1–2 cc of local anesthetic such as lidocaine 1–2% or Bupivacaine 0.25–0.5% with or without steroids is then injected.

28.9.6 Discography

Discography is a diagnostic procedure to determine the source of a patient's low back pain. It is performed in patients in whom discogenic pain is suspected. Discography is the only functional test to determine if a patient's disc is painful. Contrast material is injected into the nucleus pulposus through a percutaneously placed needle. The most important assessment is the patient's pain response to the injection of non-ionic contrast into the nucleus. In addition, information about the disc morphology and imaging of possible fissures and tears into the annulus are obtained. This procedure is usually performed on patients who have primarily axial back pain and have not responded to non-surgical treatments. These patients are usually considered for intradiscal therapies or fusion surgeries. The patient is placed in an oblique position on the procedure table. The needles are usually placed opposite to the patient's painful side through a posterolateral approach, using the universal view for lumbosacral injections (Fig. 28.1). Intradiscal access is usually achieved by a double-needle technique using an 18-gauge introducer needle through which a 25-gauge needle is placed into the center of the disc. Alternatively, a 22-gauge 5- or 7-inch spinal needle can be placed directly into the disc by a single-needle technique. The needle is placed along the center of the X-ray beam into the inferior aspect of the disc to avoid injury of the nerve root. Needle position is confirmed in AP and lateral projections in the center of the disc. Non-ionic contrast dye is injected either manually or with manometry into the disc. A maximum of 3 cc of dye is injected into the disc and the pain response is recorded (VAS scale; Fig. 28.7). Injections with manometric measurements allow standardization of the pain responses. The International Spinal Injection Society recommends that patients with discs painful at 15 psi over opening pressure are considered to have a positive discogram, and patient's who have concordant pain between 15 and 50 psi over opening pressure are considered to have a probable painful disc at this level. The opening pressure is a measure of the internal disc pressure and refers to the initial appearance of dye in the disc with injection. Intradiscal placement of needles into one or two adjacent presumably normal discs is recommended to obtain a "normal control level." Discography is operator dependent and requires significant experience on the operator's part.

28.9.7 Epidural Adhesiolysis

The purpose of percutaneous epidural lysis of adhesions is to perform a mechanical and chemical lysis of adhesions in the epidural space, which may have formed after previous surgery or previous inflammatory processes with resulting scar formation in the epidural space. This can be accomplished through an epidural catheter or spinal endoscope. The patient is placed in the prone position. A special epidural catheter (Racz catheter) or spinal endoscope is placed into the epidural space, usually through a caudal approach. Non-ionic dye is injected to visualize scar formation indirectly by contrast filling defects. A spring-guided catheter is then placed directly into the scar formation. Attempts are made for mechanical disintegration of the scar. Chemical adhesiolysis is then attempted by injection of a combination of local anesthetic, hypertonic saline, and a steroid. Traditionally, this procedure has been performed as an inpatient procedure with serial injections over a 3-day period. Recently, this procedure is more commonly done as single injection as an outpatient procedure. With a spinal endoscope, the scar formation can be directly visualized and mechanically altered.

28.9.8 Implantable Therapies

Spinal cord stimulation systems and implantable intrathecal devices such as intrathecal opioid pumps are

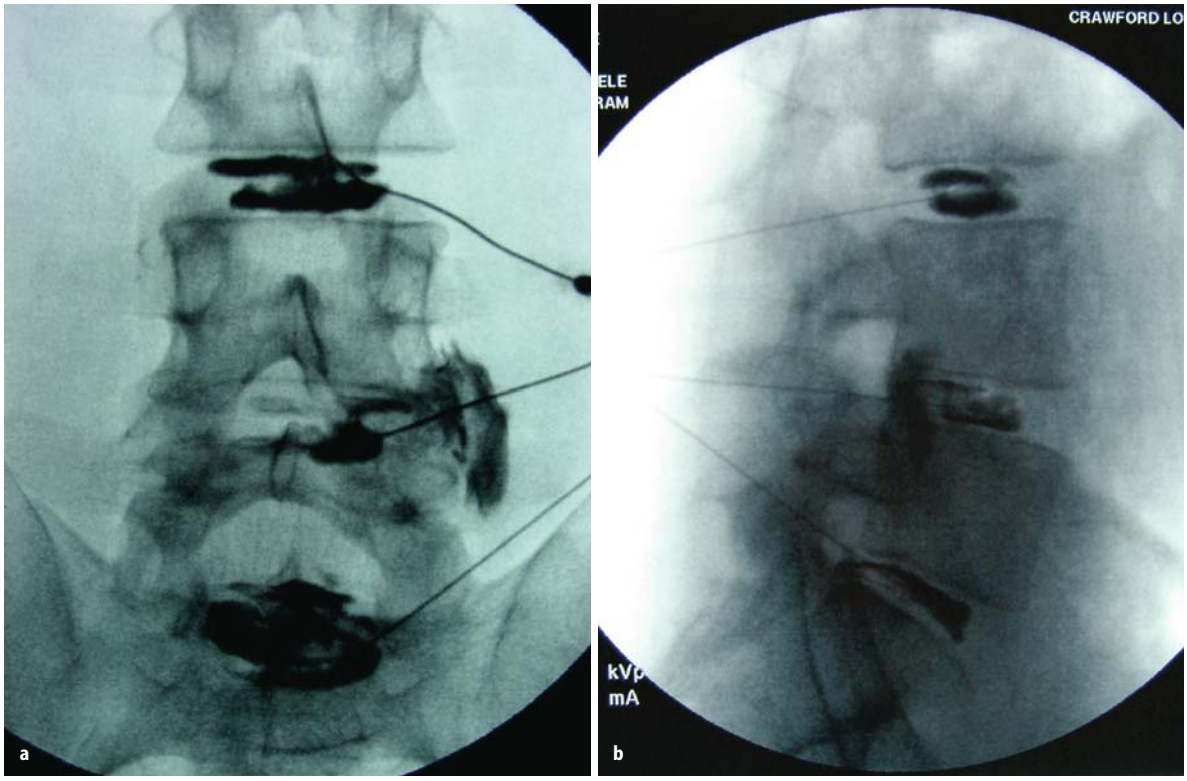


Fig. 28.7a, b. Lumbar discogram L3-4, L4-5, L5-S1. Note the large posterolateral annular tears with contrast extravasation at L4-5 and small annular tear at L5-S1; normal disc morphology of L3-4

considered advanced interventional pain management procedures and are appropriate treatment options for chronic pain syndromes that have not responded to other less invasive treatments. Spinal cord stimulations are primarily indicated for patients with chronic neuropathic pain such as chronic radicular pain and chronic regional pain syndromes. In the majority of cases, an epidural lead is placed as trial stimulation, usually in the thoracic spine for lower extremity pain syndromes. This lead is left with an external programmer for about a week to determine the effectiveness of the treatment. If the patient reports at least 50 % improvement of pain, a permanent system is implanted. Most of the currently used systems are fully implanted, similar to pacemakers (Fig. 28.8). They can be activated through telemetry by the patient or health care provider.

Intrathecal opioid pumps can be of great benefit for patients with difficult and severe chronic pain syndromes, especially in cancer pain. They are increasingly used for chronic benign pain syndromes that are not otherwise controllable. In most cases, the patient undergoes testing through a temporary intrathecal application (single-shot of temporary catheter) of opioids to determine the therapeutic effect. If this test provides significant pain relief, the system is then fully implanted. An intrathecal catheter is implanted and connected with a subcutaneous medication reservoir, similar in size to a hockey puck. This medication reservoir contains a pump. Usually, the reservoir is filled with morphine. Other pharmacologic agents, such as local anesthetics, can be used as well. The pumps require frequent refills, sometimes once a month.

28.10 Postoperative Care and Complications

Most patients are usually monitored for about 30 – 45 minutes after the procedure. In the case of epidural steroid injections, they should be specifically assessed for signs of spinal block, which would indicate intrathecal placement of the needle. The patient should not be discharged before motor and sensory deficits have resolved. Complications for all these procedures are rare and have been discussed in the section on patient's informed consent.

28.11 Results

The scientific evidence is summarized for each of the discussed procedures according to the classification



Fig. 28.8. Implanted spinal cord stimulator; patient is s/p L5-S1 fusion for spondylolisthesis with postoperative persistent back and leg pain. **a** a. p. view, **b** lateral view

Table 28.1. Designation of levels of evidence (ASIPP, adapted from Manchikanti 2000) [10]

Level I	**Conclusive:** Research-based evidence with multiple relevant and high quality scientific studies or consistent reviews of meta-analyses
Level II	**Strong:** Research-based evidence from at least one properly designed randomized, controlled trial of appropriate size (with at least 60 patients in the smallest group); or research-based evidence from multiple properly designed studies of smaller size; or at least one randomized
Level III	**Moderate:** Evidence from a well-designed small randomized trial or evidence from well-designed trials without randomization, or quasi randomized studies, single group, pre-post cohort, time series, or matched case-controlled studies or positive evidence from at least one meta-analysis
Level IV	**Limited:** Evidence from well-designed non-experimental studies from more than one center or research group
Level V	**Indeterminate:** Opinions of respected authorities, based on clinical evidence, descriptive studies, or reports of expert committees

published by the American Society for Interventional Pain Physicians (Table 28.1).

28.11.1 Diagnostic Facet Joint Injection

The validity, specificity, and sensitivity of facet joint injections are considered strong in the diagnosis of facet joint pain.

28.11.2 Therapeutic Intra-articular Facet Joint Injections

There is strong evidence of short-term relief and limited evidence of long-term relief for chronic neck and low back pain.

28.11.3 Therapeutic Medial Branch Injections

There is some strong evidence of short-term relief and moderate evidence of long-term relief of pain of facet joint origin.

28.11.4 Medial Branch Neurotomies

There is strong evidence of short-term relief and moderate evidence of long-term relief of chronic spinal pain of facet joint origin.

28.11.5 Caudal Epidural Steroid Injections

There is strong evidence for short-term relief and moderate evidence for long-term relief.

28.11.6 Interlaminar Epidural Steroid Injections

There is moderate evidence of short-term relief and limited evidence for long-term relief.

28.11.7 Diagnostic Transforaminal Epidural Steroid Injections

The current evidence provides moderate evidence of transforaminal epidural steroid injections in the preoperative evaluation of patients with negative or inconclusive imaging studies, but with clinical findings of nerve root irritation.

28.11.8 Therapeutic Transforaminal Epidural Steroid Injections

There is strong evidence for short-term and long-term relief.

28.11.9 Sacroiliac Joint Injections

The evidence of specificity and validity of sacroiliac joint diagnostic injections is moderate.

28.11.10 Epidural Adhesiolysis

There is moderate evidence for short-term and long-term relief with repeat interventions.

28.11.11 Discography

The evidence for lumbar discography is strong for discogenic pain provided lumbar discography is performed based on the history, physical examination, imaging data, and analysis of other precision diagnostic techniques.

28.11.12 Spinal Cord Stimulation

The evidence for spinal cord stimulation and proper selective population of neuropathic pain is moderate for long-term relief.

28.11.13 Implantable Intrathecal Drug Delivery Systems

There is moderate evidence indicating the long-term effectiveness of intrathecal infusion systems.

28.12 Critical Evaluation

Semi-invasive and interventional procedures for the treatment of painful spinal disorders have become increasingly popular since the 1990s. This is due not only to the better understanding of the pathophysiology of spinal pain and the ability to specifically identify and target painful structures with percutaneous procedures, but also because of advances in imaging technology. Similar to developments in other areas of medicine, there is an increasing demand for less invasive, outpatient procedures to alleviate a patient's pain. While many of these procedures allow a patient to return to full function with minimal downtime, future research needs to improve on implementation of randomized controlled trials to determine useful from useless procedures, and to improve on the therapeutic effects of injectable pharmaceutical agents and the delivery methods. Several international societies work on the standardization of these procedures, but much work in this area remains to be done [2]. If the appropriate research studies continue to support the effectiveness of interventional spinal procedures, their importance as intermediate therapy between traditional non-surgical and surgical treatment for spinal disorders will likely increase.

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29 Intradiscal Electrothermal Therapy

J. Saal

29.1 Terminology

IDET = Intradiscal Electrothermal Therapy.

29.2 Surgical Principle

Intradiscal electrothermal therapy (IDET) is a procedure for the treatment of discogenic low back pain. A specially designed catheter system (SpineCATH) is introduced into the posterior part of the disc space via a posterolateral percutaneous approach. The posterior parts of the disc space are heated up to a tissue temperature of about 75° C to achieve contraction of the collagen fibers in the posterior annulus fibrosus. A "stabilization" of the posterior annulus fibrosus is assumed.

29.3 History

The treatment of chronic discogenic low back pain presents the most difficult challenge to the spine specialist. Non-operative measures are frequently unable to reduce pain and improve function in this patient subgroup [4, 43]. Interbody fusion for these patients has yielded mixed and often poor results [3, 41, 45, 47]. An alternative therapy to address this problem is therefore desirable. The SpineCATH system to perform IDET was developed to address this difficult clinical dilemma.

29.4 Pathophysiology of Internal Disc Derangement

The natural history of the degenerating disc includes loss of nuclear hydrostatic pressure, which leads to buckling of the annular lamellae. This phenomenon leads to increased focal segment mobility and increased shear stress to the annular wall. The process progresses to delamination and fissuring of the annular wall. Annular delamination has been shown to occur as a separate and distinct event from annular fissures [29]. Fissures can be radial or concentric. In addition, electron microscopy has demonstrated micro "fractures" of collagen fibrils with disc degeneration. The progressive degeneration of the disc, manifested by any of these morphologic changes, has been shown to alter disc mechanics [39]. Tearing and delamination of the annulus can cause chronic pain. Mechanoreceptors in the disc wall have been shown to discharge with disc mobilization [34]. Nociceptive tissue has been shown to be sensitized resulting in a decrease in their firing threshold after treatment with inflammatory enzymes and mediators [31, 32, 44].

A scenario for chronic discogenic pain is created when any combination of annular fissures, delamination, or microfractures of collagen fibrils lead to mechanical distortion of annular lamellae and subsequent sensitization of nociceptors that may have also been presensitized by phospholipase A2 [12], nitrous oxide [22, 24], interleukin 1 [24], and metalloproteinase enzyme activity [24], or other chemical mediators. Afferent stimuli create substance P release and nociception. Repetitive stimulation of the DRG (Dorsal root ganglion) has been shown to create prolonged neural activity from the dorsal horn receptor fields [8, 10, 31, 42]. As the patient continues to load the disc, the neuronal activity continues. Clinically, the disrupted disc will often cause referral pain into the buttocks and leg due to DRG stimulation, CNS processing, or from direct chemical irritation of the nerve roots.

29.5 Thermal Impact Upon Tissue

Innervation of the intervertebral disc has been well documented by researchers since the 1930s. More recently Bogduk's work illustrated the sources of lumbar disc innervation [2]. Coppes et al. found nociceptive properties in nerves of the outer annular wall. In fact, they observed nerve fibers "deeper than the outer third of the annulus fibrosus" [6]. Freemont et al. also discovered significant neovascularization with neural expression of substance P, and linked that growth to disc de-

generation and back pain. They identified nerve fibers as deep as the inner third of the annulus fibrosus and into the nucleus pulposus in several disc samples [6].

Letcher and Goldring established that irreversible nerve blocks due to neural thermocoagulation occur at 45° C in the brain [26], and Cosman et al. [7] used radiofrequency (RF) lesioning to produce 45° C isotherms for neural tissue lesioning. The intradiscal temperatures generated by the SpineCATH (48 – 75° C) are in the range necessary to create thermocoagulation of neural tissue in the target zone accessed [35, 40].

Collagen contraction, or shrinkage, has been well documented in the use of non-ablative laser energy on joint capsular tissue and more recently in RF application in the glenohumeral joint capsule [11, 18]. Research has shown that there is a direct correlation between the amount of heat and duration of the heating applied to tissue and the resulting collagen contraction [15 – 17, 27, 30].

The breaking apart of the heat-sensitive bonds of the collagen fibrils causes tissue shrinkage. The framework of the intervertebral disc is composed primarily of types I and II collagen, which have a similar molecular structure. The tensile strength of these collagen fibers is derived from the extended conformation of the triple helix molecule, which is crosslinked with hydrogen bonds. A portion of these bonds is heat sensitive, breaking apart when exposed to a range of temperatures over time. The disruption of these stabilizing hydrogen bonds releases the molecular strands, which collapse. This collapse, like the release of a spring held taut, results in a new contracted state called the denatured or random coil conformation of the collagen fiber.

The optimal temperature for collagen contraction is reported to be 65° C. Sixty degrees (60°) C is the lowest practical temperature at which heat sensitive hydrogen bonds will start to break. As the temperature increases, more bonds break. It is unclear whether there is a additional shrinkage effect over 75° C.

Kleinstueck et al. attempted to study intradiscal temperature dispersion from the SpineCATH [25]. They placed the device in the nucleus rather than in the annulus and were able to measure temperatures of greater than 42° C (temperature sufficient to thermocoagulate unmyelinated nerve fibers) at distances greater than 10 mm from the probe. However, their use of previously frozen cadaveric discs, and the placement of the heating element in the nuclear cavity rather than in the annulus as is done in clinical practice may have limited the peak temperatures. Freeman et al. presented temperature maps in vivo on sheep demonstrating higher peak temperatures [13]. They found temperatures of greater than 65° C adjacent to the catheter. In a recent report Shah et al. found microscopic evidence of acute collagen modulation in cadaveric discs heated with a SpineCATH [40].

Recently Barensde et al. reported on a randomized clinical trial (RCT) evaluating the efficacy of an RF probe placed into the center of the nucleus and then heated [1]. The treated group fared no better than placebo. Houpt et al. [20] has previously demonstrated the inability of temperature dispersion for an RF device to raise intradiscal and annular temperatures. For these reasons the IDET technology (i.e., SpineCATH) does not use RF as a heating element but rather utilizes a thermal resistive coil (TRC) which produces conductive heat. Additionally, contrary to the RF device studied by Barendse [1], the IDET device is deployed into the annulus and is not deployed in the center of the nucleus [35, 37].

29.6 Patient Selection for IDET

The following 12 criteria represent the author's criteria for IDET candidacy. The key elements were tested as part of the Pauza RCT [33].

1. Severe, function limiting, chronic low back pain for more than 6 months.
2. Failure to adequately improve with a comprehensively applied aggressive non-operative treatment program consisting of stabilization exercise training, back education, activity modification, and when appropriate, fluoroscopically guided selective epidural cortisone injections and in some circumstances facet injections.
3. A duration of 3 months for the non-operative care program is recommended.
4. Normal neurologic examination.
5. Negative straight leg raise (SLR) – no reproduction of "true sciatica."
6. MRI that does not demonstrate neural compressive disease (Fig. 29.1a, b).
7. Preservation of disc height at the symptomatic level (< 30 % disc space collapse).
8. No measurable segmental instability.
9. No lytic or degenerative spondylolisthesis.
10. Discogram that demonstrates an annular fissure and reproduces concordant pain at one or more levels at an injection volume of < 2.0 cc (low pressure < 50 psi) with a documented negative control level (1ig. 29.1c).
11. No irreversible psychosocial barriers to recovery.
12. Motivated to improve with realistic expectations of outcome.

In summary, IDET is intended for psychologically stable and motivated patients with chronic function-limiting low back pain with a documented discogenic source of pain who have failed to improve with an aggressive exercise-based rehabilitation program. Dis-

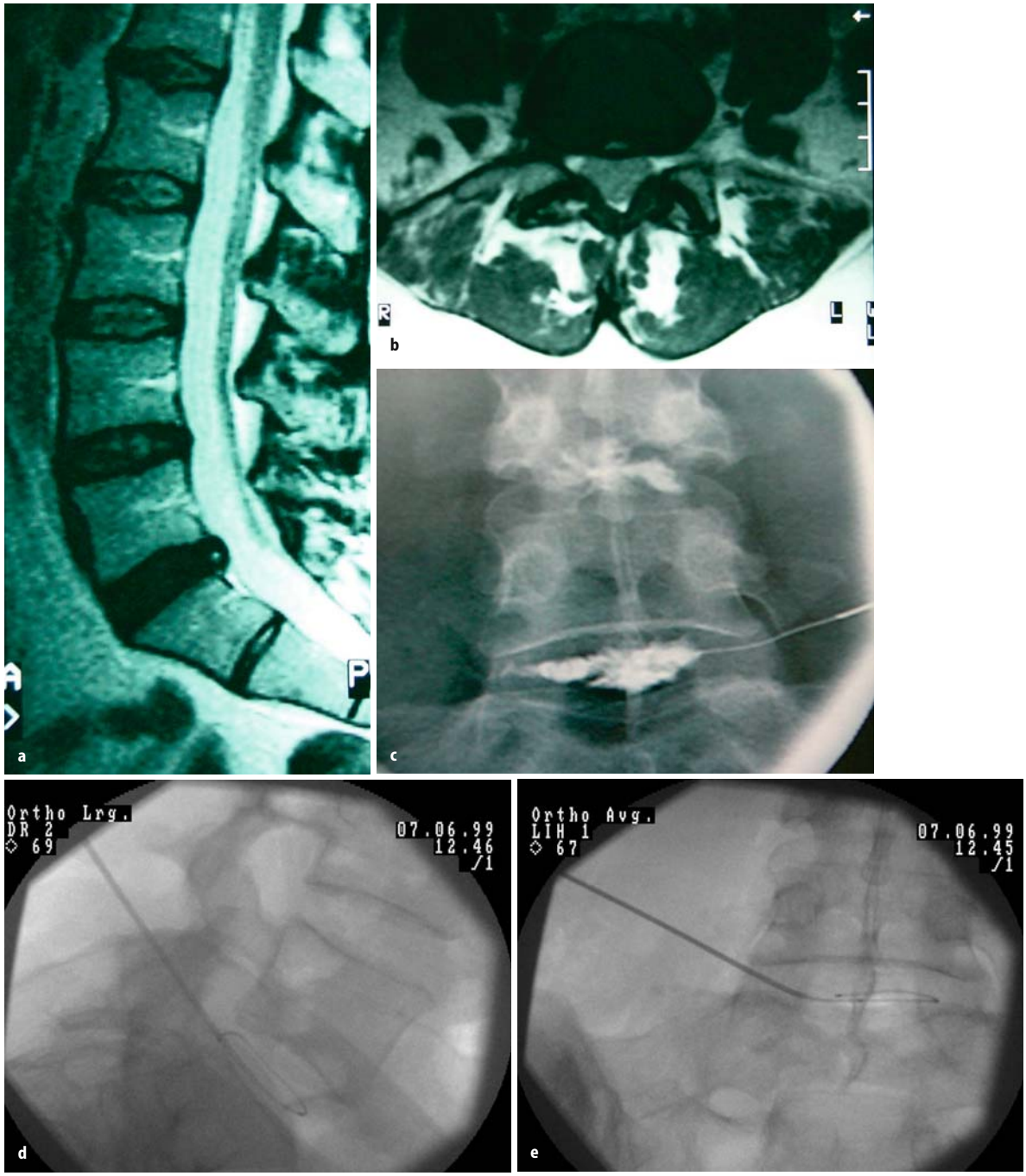


Fig. 29.1. a Clinical history: 45-year-old female with disabling low back pain for 2 years. Sagittal magnetic resonance imaging (MRI) scan, L5-S1 disc protrusion. **b** L5-S1 axial MRI disc protrusion. **c** Low volume discogram with moderately severe concordant pain reproduction. **d** Lateral radiograph L5-S1, SpineCATH navigated to the posterior annular wall. **e** Anteroposterior radiograph, L5-S1, SpineCATH navigated to the posterior annular wall

cography criteria for low volume concordant (or low pressure) pain provocation attempts to separate appropriate patients with focal annular lesions who will experience pain reproduction at low volumes from patients who are questionable candidates with global annular degeneration who will often experience pain reproduction only at larger volumes of injectate, i.e., >2 cc volumes (and higher injection pressures >50 psi). In addition, the effectiveness of IDET on the previously operated segment is an open question.

29.7 Surgical Technique

Local anesthesia and conscious monitored sedation is applied to the patient in an outpatient surgical or radiologic setting. A 17-gauge procedure needle is introduced into the symptomatic disc under multiplane fluoroscopic guidance. The SpineCATH (Smith and Nephew) is introduced through the procedure needle and navigated to the offending portion of the annulus (Fig. 29.1d, e) Care must be undertaken to avoid catheter kinking which may lead to catheter breakage. Treatment may be achieved with unilateral catheter deployment but roughly 40 % of the time bilateral deployment is necessary to cover the entire posterior annular wall. The Smith and Nephew autotemperature heat generator controls the catheter heat delivery system. Typically a maximum catheter temperature of 90° C is attained (corresponding to tissue temperature of approximately 75° C directly adjacent to the catheter). There are occasions when the temperature profile must be modified to a maximum temperature of 82 – 89° C to achieve patient comfort. The patient must be alert enough to be observed for the development of radicular pain during the procedure. If this occurs the catheter is repositioned or removed. Most patients will experience their typical back pain and referral leg pain during the procedure. However, this must be differentiated from radicular pain especially if the patient experiences it early in the heating cycle (i.e., catheter temperature 65 – 90° C). If this occurs, it is usually indicative of an extremely attenuated posterolateral annulus or a catheter that is extradiscal. It is the author's preference to inject 2 – 5 mg cefazolin into the disc after treatment and removal of the SpineCATH.

29.8 Postoperative Care

Experience has taught us to proceed slowly in the postoperative period. The following represents our current postoperative guidelines given to our patients:

- Plan to rest for 7 – 14 days after your IDET in a comfortable position (i.e., lying down or reclining), limit sitting or walking to 10 – 20 minutes at a time.
- Return to work advisory.
- Sedentary work: you may return in roughly 2 weeks, however you may still be sore after your IDET. Be aware of sitting restrictions listed below.
- For other job types, the decision will be made by your physician.
- Driving: none for the first 14 days, then limit your driving to 20 – 30 minutes for the first 6 weeks after your IDET. Make sure your vehicle has good lumbar support. You may need a pillow to help maintain your lumbar lordosis (normal low back curve).
- As a passenger, recline the seat and try to limit driving times to less than 45 minutes for the first 6 weeks. It is okay to recline and be driven home the day of your procedure or lie down in the back seat.
- Sitting: limit to 20 – 30 minutes at any one time for the first 6 weeks, in a chair with good support. Avoid sitting on soft couches or chairs. Use a pillow or towel to maintain your lumbar curve when sitting. Standing and walking about as breaks between sitting periods or short periods of lying down are helpful.
- Lifting: limit 5 – 10 lbs for the first 6 weeks.
- No bending or twisting of the low back.
- Housework: no bending or twisting for the first 6 weeks.
- No chiropractic, manipulation, massage (unless otherwise instructed), inversion traction, or traction for the first 12 weeks.

29.9 Postoperative Exercises

- Walk daily beginning at the end of the first week for approximately 20 minutes. Increase to 20 minutes twice per day. If back or leg symptoms increase at any point, reduce the duration of walking.
- Gentle leg stretches (hamstring, piriformis) with your back flat on the floor (lumbar neutral).
- Abdominal brace exercises can be begun at 2 – 3 weeks in lumbar neutral.
- Swimming can begin at 6 weeks, but avoid excessive kicking, advise using a pool buoy to support the legs.
- Formal physical therapy will usually begin at 6 – 8 weeks postoperatively, to begin training in a dynamic stabilization program.
- No treadmill or a stairmaster use for the first 6 weeks unless otherwise instructed.
- A lumbar corset with steel stays (or its equivalent) is prescribed for the first 6 – 8 weeks, to be used for all upright activities.

The most important principle appears to be allowing time for a healing reaction, and delaying aggressive exercise training for at least 3 months postprocedure. This time frame correlates with the timetable of collagen remodeling and has been observed to be the point at which patients experience a substantial reduction in their preprocedure pain.

Patients should be able to return to office work by 2 – 4 weeks and light lifting duties at 6 weeks postprocedure, although return to heavy work usually requires

5 – 6 months. The appropriate timing of return to work and postoperative management requires further study.

29.10 Results

The first published series of IDET-treated patients reported the 6-month (range 6 – 9 months, mean 7 months) outcome results for 25 patients with chronic low back pain of documented discogenic origin with mean duration of preoperative symptoms of 58.5 months who failed to adequately improve with a comprehensively applied non-operative care program who elected IDET instead of chronic pain management or spinal fusion [37]. The results demonstrated a statistically significant improvement in functional outcome as measured by VAS, SF-36 scores, sitting tolerance times, and narcotic analgesic medication. Sixty-two (62) patients who were treated with IDET and followed for a minimum of 1 year (mean 16 months, range 12 – 23 months) postprocedure demonstrated outcome evaluation scores that did not statistically vary from the 6-month group. The mean group change for the SF-36 bodily pain was 17 and physical function was 20. These scores are consistent with significant clinical improvement [37].

A 2-year follow-up study noted continued improvement in SF-36 scores and sitting tolerance times [38]. Similar findings were noted in a prospective cohort study by Shah et al. [40].

Karasek and Bogduk [23] reported on the 1-year outcome of IDET treated patients (35) and compared them to a control group of patients (17) similarly diagnosed but denied insurance authorization for IDET. The researchers used a 50 % reduction of VAS scores as an indicator of success. On this basis, 60 % were considered successes. Additionally, they noted that 23 % of the patients had total relief of symptoms. They reported that only one patient in the control group improved and the remainder continued to have similar pain intensity.

Derby et al. [9] reported that 62.5 % of IDET-treated patients had a favorable outcome based upon the Roland Morris scale, VAS, NASS outcome instrument, and a general activity scale. If patients had preserved disc height and had not undergone previous surgery at the index level the success rate was 76 %.

Wetzel et al. presented the 2-year results of a multicenter prospective cohort study and found statistically significant improvement in pain reduction and physical function in their study group [46].

Pauza and co-workers completed a sham-controlled blinded RCT of IDET [33]. Their data demonstrated a statistically significant difference improvement in pain scores in the IDET-treated group versus the placebo-sham group. This study answers the question that IDET is superior to placebo. The study found that 50 % of the IDET-treated group had at least a 50 % reduction in pain. Additionally, 22 % of the patients experienced a total cure. Clinically achievable success rates are best judged by the results of the aforementioned case control trials [9, 23, 33, 36 – 38, 46].

The data regarding IDET should be put in contrast to studies of spine fusion in the same patient population. A recent RCT demonstrated pain improvement of only 30 % in 60 % of cases [14]. Another arm of the same spine fusion RCT did not demonstrate a statistical difference in outcome between any of the fusion techniques [14]. This means that regardless of which screw, plate, cage, or graph that was used the results were the same. Brox et al. reported the results of an RCT that compared fusion surgery with physical and cognitive therapy, and found no statistical difference between the groups at 1 year follow-up [3]. Disappointingly, despite these findings the rates of spinal fusion have risen by as much as 35 % in some states while associated costs have risen by 300 %. Unfortunately, more fusions are being performed with more complex and expensive instrumentation despite the lack of evidence to support its use.

Arguably, if IDET can even help 50 % of the patients with severe disabling back pain with a documented discogenic source avoid spinal fusion, a tremendous contribution to patient care has been accomplished. However, attempts to overextend the indications for the procedure to the general population of patients with degenerative disc disease will yield poor outcomes and would be a disservice to patient care.

29.11 Complications

The potential complications from IDET can be divided into early stage and late stage. The early-stage complications can be nerve injury (needle-related and/or thermal), infection, bleeding, and burns. Complications from five specialty spine centers that regularly perform IDET were surveyed [28]. The researchers sent each a questionnaire requesting a report of all patients that had sufferedcomplications from IDET. They surveyed 1,675 consecutive IDET cases performed at the five centers between July 1997 and February 2001. The results were as follows:

- Six cases of transient nerve injury that resolved. Five cases were felt to be due to needle placement and one thermal.
- One disc space infection in an immunosuppressed gentleman with carcinomatosis on chemotherapy.
- No cases of catheter breakage.
- No cases of severe pain that required hospitalization.

- Five cases of post-IDET disc herniation, three at treated levels where a new documented injury occurred and two at adjacent levels.

As part of the same report the researchers reviewed the medical device reports (MDRs) on SpineCATH reported to the FDA. During a period of time that over 35,000 catheters were used, they found 21 cases of catheter breakage. Two were removed percutaneously and one excised at time of disc excision. The 18 cases where a small piece of catheter remained in the disc were not associated with any patient morbidity. Late-stage complications due to IDET might include rapid or accelerated disc space collapse at a treated level, or avascular necrosis due to endplate injury. Ho et al. reported at NASS on follow-up MRI scans 1 and 2 years post-IDET [19]. This report did not find any evidence of endplate injury or acceleration of the normal degenerative process.

There has been one report of cauda equina injury due to IDET [21]. This case involved a patient who was overly sedated, and whose catheter position prior to heating was not checked in the lateral plane. This case resulted in an extra-discal catheter deployment in a non-responsive patient who suffered a thermal neurologic injury.

A recent report noted obesity to be a negative predictor for IDET [5]. In this same cohort study the authors attempted to tabulate their complication rate. They considered any increase in postprocedure discomfort as a complication. They reported eight patients with symptoms. Six out eight of these patients resolved their postprocedure symptoms and went on to positive outcomes. Two patients had no pain relief with IDET, and it is unclear whether any persisting new symptoms related to the IDET were present. If we assume that two patients had new persisting symptoms related to IDET the complication rate would be 2/79 (2.4%). There were no cases of persisting neurologic injury, disc space collapse, or infection reported. Therefore, it is safe to assume that the risk profile of IDET is low, especially when the procedural protocols are observed.

29.12 Conclusion

The cost, morbidity, and observed degree of effectiveness make IDET an attractive alternative to spinal fusion, for a specifically diagnosed subset of patients with lumbar discogenic pain. However, keep in mind that the technology was designed to be used only for a specific group of patients, by specialists skilled in performing intradiscal techniques who individually or within a team context also possess the ability to accurately diagnose and effectively manage patients with complex spinal disorders.

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Microtherapy in Low Back Pain

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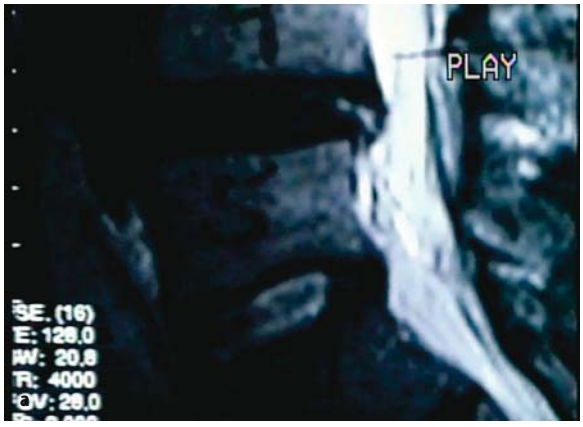
A. T. Yeung, C. A. Yeung

30.1 Terminology

Experimental in vivo stimulation of the annulus fibrosus of an intervertebral disc produced back pain, and the term "discogenic pain" was coined [1] to establish the association between annulus stimulation and the subjective pain perception. Histologically the end organ neural sensors are located in the outer layers of the annulus, epiannular surface, and the juxta endplate region [2–4]. Nucleus pulposus and its metabolic byproducts are known contact irritants to the nerve tissues and are known to reduce their membrane excitation threshold [5–10]. There is no direct contact between the neural end sensors and the intradiscal irritants in an intact disc.

Annular defects are demonstrated in degenerative discs in postmortem studies [11] and in in vivo discographic examinations [12–15] (Fig. 30.1). It is hypothesized that the degenerative process, trauma, and possibly metabolic changes lead to fissuring of the annulus fibrosus and defects in the endplates which bring the neural end sensors into chronic contact with the intradiscal irritants. Under these conditions, irritants have unimpeded entry into the sensory fields through annular fissures/tears/clefts. Defects in the annulus create an inflammatory response and ingrowth of granulation tissue [14], new vessels, and new nerve endings (Figs. 30.2, 30.3). Chronic exposure of the neural end sensors to the irritant in the annular defects is hypothesized to be the local pain sensitization pathway that leads to chronic lumbar discogenic pain (CLDP).

Chronic lumbar discogenic pain is a difficult condition to treat, as its pathogenesis is multifactorial and



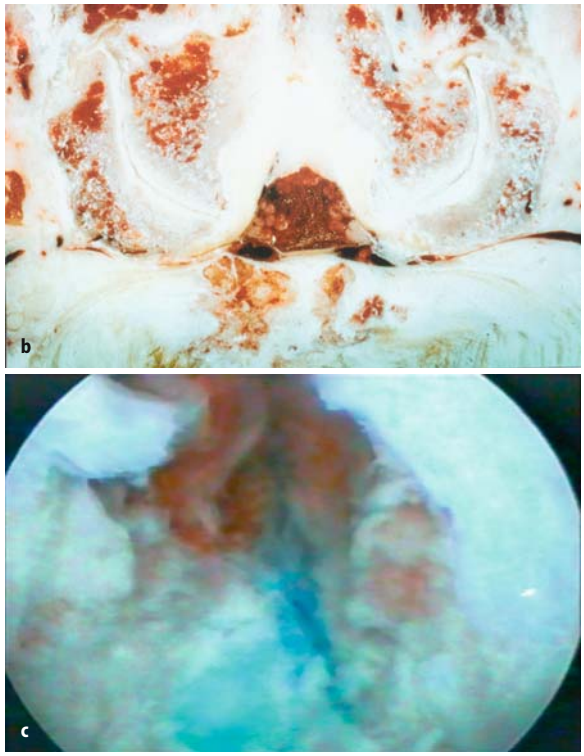


Fig. 30.1. a Lateral MRI of a patient with chronic lumbar discogenic pain (CLDP). MRI demonstrates large L4-5 high intensity zone (HIZ) representing an annular tear associated with a small disc protrusion. **b** A cadaveric axial section at L4-5 showing clumps of reddish tissue representing inflammatory granulation tissue. This tissue is the pathoanatomy represented by the HIZ seen on MRI. This granulation tissue fills annular ruptures and carries blood vessels and nociceptive pain fibers. Courtesy of W. Rauschning. **c** Endoscopic view of annular tear after Selective Endoscopic Discectomy (SED). Endoscopic view of the annular tear. The degenerative nucleus pulposus has been removed, revealing the annular tear and granulation tissue adjacent to the tear

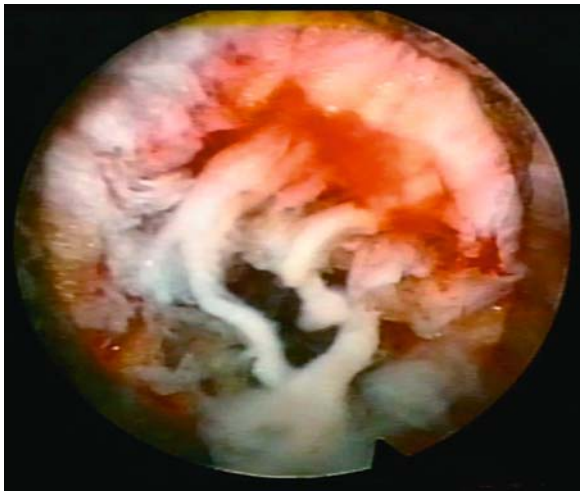


Fig. 30.2. Neoneurogenesis. Minute nerve filaments of non-myelinated nerves are sometimes visualized when there is a thick inflammatory membrane

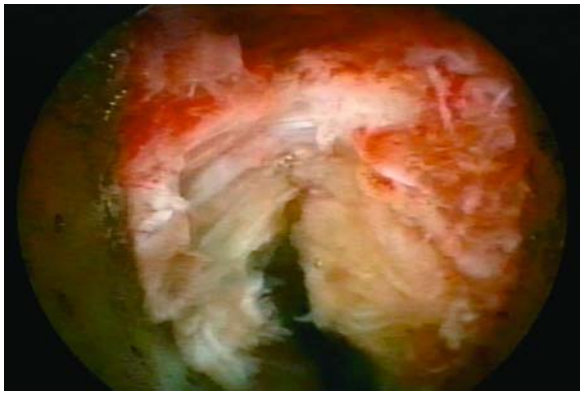


Fig. 30.3. Radial annular tear to the outer annular fibers. Inflammatory granulation tissue is seen in and around annular fissures

only partially understood. Non-operative therapeutic regimens often fail to achieve sufficient pain relief. Injection therapies with epidural steroids are good at relieving radiculitis, but are less successful at helping low back pain. Surgical options vary greatly, ranging from minimally invasive treatments such as intradiscal electrothermal therapy to 360° fusion.

Despite initial studies that seem promising for IDET, long-term results are lacking and patient selection is critical. The morbidity associated with the fusion technique, while better accepted and more thoroughly studied, is significant when considering only 65 – 80 % of patients obtain satisfactory clinical results [16 – 20] and the morbidity of the procedure often creates more problems when the procedure fails. Posterolateral Selective Endoscopic Discectomy (SED) and radiofrequency (RF) thermal annuloplasty is a minimally invasive treatment option for CLDP. This procedure, developed by the senior author, was investigated in 1997 and approved by the IRB at St. Luke's Medical Center, Phoenix, Arizona [21, 22].

30.2 Surgical Principle

The senior author's early experience with laser disc decompression (LDD) and early studies on his use of the KTP laser and RF as an adjunct in arthroscopic removal of contained disc herniations concluded that 65 % of the surgical patients also obtained relief of their back pain [23, 24]. Kambin's arthroscopic microdiscectomy instruments and technique allowed for visualization of the disc and annulus. This influenced the evolution of SED to include thermal modulation of disc, the inflammatory membrane, and granulation tissue surrounding the annular defect in disc herniations. Targeted thermal energy on these annular defects has demonstrated shrinkage of annular defects and ablation of inflammatory tissue in the disc. Yeung coined and trademarked the terms Selective Endoscopic Discectomy and Intraoperative Evocative Chromo-discography, using indigo carmine dye mixed with the non-ionic radio-opaque radiographic agent Isovue 300 in every endoscopic discectomy procedure. The dye has an affinity for the acidic degenerative nucleus pulposus, and helped target the disc tissue to be removed. The procedure was approved by an IRB protocol investigating the use of a flexible temperature-controlled probe in the course of endoscopic foraminal surgery for the full spectrum of discogenic pain and disc herniations.

The treatment rationale for SED and RF thermal annuloplasty is similar to the rationale for intradiscal electrothermal therapy (IDET). IDET utilizes electrothermal energy delivered to the annulus through a thermal resistive wire heated to 90° C for about 15 minutes. The electrothermal energy theoretically ablates the sensitized nerve endings in the outer annulus and annular tears making them less painful. It is also theorized to shrink the collagen fibers and thus help seal the annular tears. IDET is limited, however, because it is a fluoroscopically guided, but "blind" procedure. Ideal wire placement is at the nucleus/annulus junction or within the annular wall, but cannot be completely verified based on fluoroscopy. There is also uncertainty if the heat will actually reach the targeted fissures and associated nerve endings in each clinical case. Additionally, the physician cannot see when or if the electrothermal energy is achieving the desired tissue modulation to shrink the tear. The arbitrary length of annular heating may be inadequate to achieve the desired tissue effect or worse, may be too long, creating tissue destruction, necrotic degeneration, and pain sensitization.

Selective Endoscopic Discectomy and RF thermal annuloplasty is a fully visualized and targeted applica-

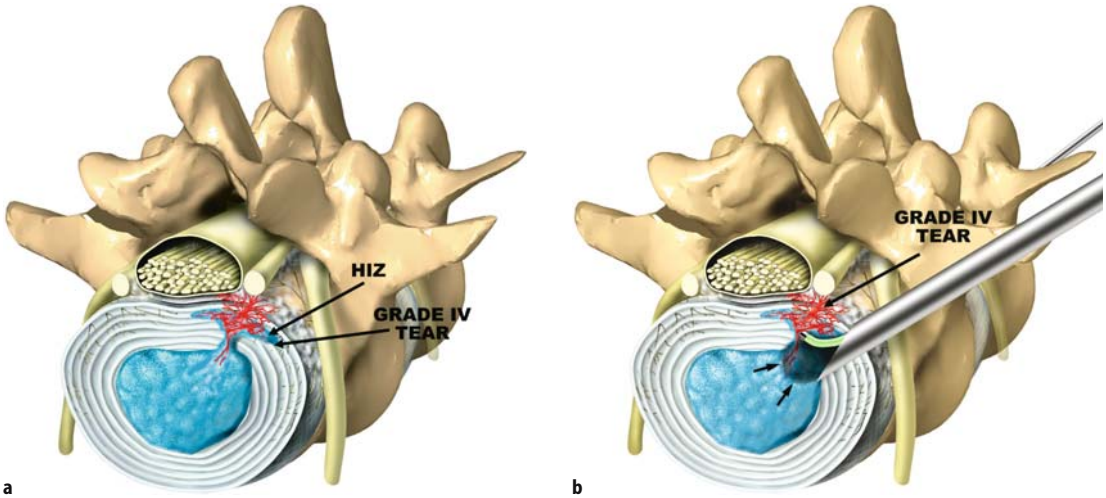


Fig. 30.4. a Illustration of a typical one quadrant grade IV annular tear. Chromo-discography stains the nucleus pulposus and the tract of the radial tear light blue. If there is communication with the blood supply in the outer annulus, an inflammatory response develops, but if the tear does not reach the vascular portion of the annulus, the annular collagen may just be torn, but there is no inflammation. **b** Illustration of SED and radiofrequency (RF) thermal annuloplasty. The *black arrows* denote the working cavity created by the selective discectomy. The flexible RF probe is shown ablating the granulation tissue within the annular tear. The position of the cannula and instruments in the posterolateral approach is optimally 25 – 35° in the coronal plane to allow access to the posterior portion of the disc

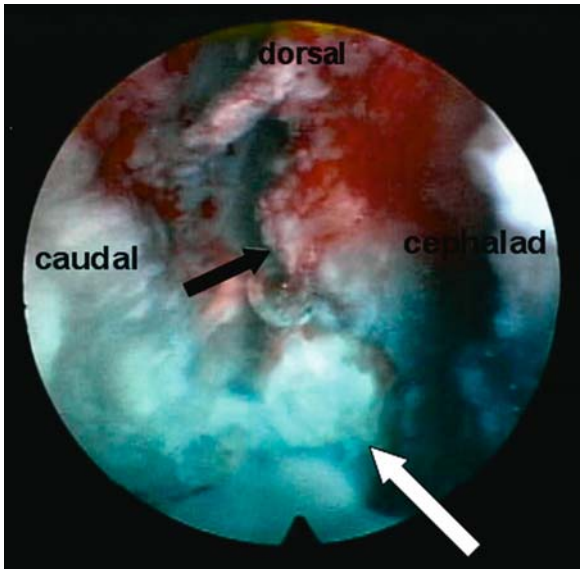


Fig. 30.5. Large posterior annular defect viewed through the 70° endoscope. The edges of the defect have inflamed granulation tissue (*black arrow*). There is also blue-stained degenerated nucleus pulposus within the defect (*white arrow*). This interposed nuclear tissue can prevent the tear from healing. All of this will be targeted with the bipolar RF probe

tion of electrothermal energy [25, 26] (Fig. 30.4). An endoscope is placed into the disc through the posterolateral transforaminal portal. Under direct visualization, the degenerative nucleus pulposus is removed and the disc cavity subsequently inspected. Disc tissue and granulation tissue is often identified in the layers of the annulus. The disc and granulation tissue is removed and ablated with a combination of mechanical instruments, Ho:YAG side-firing laser, and a bipolar flexible RF probe [26]. This not only removes the painful irritant, but also creates an environment to allow the tear to heal as the edges can now reapproximate and the intradiscal pressure is reduced (Fig. 30.5). The annular defects are endoscopically observed to contract and shrink after RF treatment. The granulation tissue and associated inflammatory membrane often seen in sensitized discs is completely ablated. This visual confirmation guides the extent of treatment. The RF electrode heating process is also hypothesized to ablate the sensitized neural sensory endings that have grown into the fissures [27, 28]. The continuous saline irrigation during the endoscopic procedure flushes out the toxic metabolites within the disc. It also prevents the accumulation of any by-products of the thermal treatment which can be neural irritants. Only scant carbonization of the tissues is observed.

30.3 History

Kambin, Hijikata, Mayer, De Antoni, Pimenta, and Leu are leaders in minimally invasive endoscopic spine procedures in their respective continents. In spite of their efforts and their experience with minimally invasive spine surgery, the techniques have been slow to gain acceptance because of the high learning curve and, in some cases, the lack of good visualization when compared with minimally invasive approaches using the

microscope. When the endoscope gained more acceptance, the approach most accepted has still been the traditional transcanal approach utilizing smaller incisions and tubular retractors. The decade of the late 1990s, however, brought increasing acceptance of endoscopic techniques and the foraminal and far lateral retroperitoneal approach as an alternative approach that spares the important dorsal muscle column implicated in Failed Back Surgery Syndrome.

Lumbar posterolateral intradiscal nuclectomy for the purpose of indirect nerve root decompression was first independently attempted by Hijikata [29] and Kambin [30] in 1973. Forst and Hausmann [31] used an arthroscope to view the intradiscal space in 1983.

In 1989 Schreiber [32] injected indigo carmine, a blue color vital dye, for intradiscal differential staining. Indigo carmine (10–20%) selectively stains the more acidic and fragmented degenerated nucleus pulposus, as demonstrated by direct visualization. The staining helps the surgeon locate and selectively remove or ablate this blue-stained degenerative tissue interposed within annular fissures. Although acute lumbar disc herniation has reliable correlating clinical symptomatology and imaging studies, CLDP has no generally agreed upon criteria in either area.

In two separate prospective randomized studies, Mayer [33] and Hermantin [34] showed equal or better satisfaction with posterolateral endoscopic discectomy versus posterior transcanal discectomy in treating herniated nucleus pulposus (HNP), non-extruded and sequestered lumbar disc herniations amenable for percutaneous decompression.

Yeung described SED for extruded herniated nucleus pulposus [25, 35] and consistently documented a decrease in low back pain (LBP) in addition to the resolution of sciatica. After achieving clinical success in relieving LBP, Yeung began treating discogenic LBP with RF thermal annuloplasty with encouraging results [21].

Abnormal patterns of intradiscal radiologic contrast images were first reported by Lindblom [36] in 1941 in a postmortem injection study. Patterns of abnormalities in discographic images have been classified [15, 37, 38]. Hirsch [39] introduced the concept of provocation saline disc injection to identify painful/symptomatic discs when patients experienced a subjective painful response to disc pressurization. Other investigators have studied provocation discography [11, 40–44], with mixed conclusions regarding the reliability of this test for clinical use. Due to the conflicting literature, provocative discography remains controversial, but is the only practical provocative test to identify a painful disc (discogenic pain). It is commonly used to confirm that a disc is a pain generator, and thus a suitable target for treatment by fusion, disc arthroplasty, or other minimally invasive intradiscal procedures including SED and RF thermal annuloplasty [13] (Fig. 30.6).

30.4 Advantages

The advantages of SED and RF thermal annuloplasty lie in the minimally invasive nature of the treatment compared to fusion. The surgical approach relies on tissue dilation rather than cutting. The posterolateral transforaminal approach spares the important dorsal muscle column. It is a motion-sparing treatment that retains

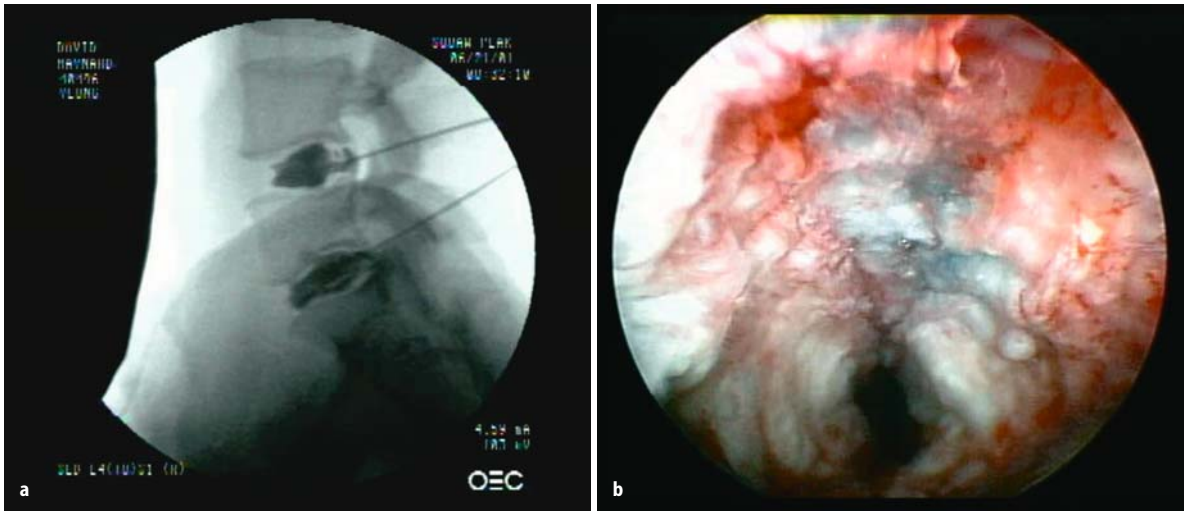


Fig. 30.6. a Lateral discogram at L4-5 and L5-S1. The discogram at L4-5 outlines a symptomatic grade IV radial tear. At L5-S1, a degenerative pattern is identified, but the disc is asymptomatic. **b** Endoscopic view of L4-5 radial tear. The annulus is still mostly intact, but inflammatory tissue is seen in the area. The blue stain is from the indigo carmine dye that stains the radial tear and the interpositional disc tissue in the tear, keeping it from healing

the native biomechanical relationship of the spine. Importantly, it does not burn any bridges for other more invasive surgical treatment options such as fusion or disc arthroplasty if the patient fails to achieve satisfactory pain reduction.

While more invasive than IDET, the advantages of direct endoscopic visualization allow targeted application of the RF probe, visual confirmation of collagen shrinkage/modulation, removal/ablation of nucleus pulposus and granulation tissue interposed within the annular tears, and evacuation of the toxic intradiscal metabolites and thermal byproducts via the continuous saline irrigation.

30.5 Disadvantages

The high learning curve transitioning from direct to endoscopic visualization has discouraged some surgeons from adopting a new surgical skill. Learning spinal foraminal anatomy and the recommended use of local rather than general anesthesia has limited the surgeon's surgical experience. There are currently few academic centers who have adopted endoscopic spine surgery as an integral part of the training curriculum, and interest has been restricted to surgeons willing to take time out to learn a new technique.

30.6 Indications

Patients with CLDP who have failed non-surgical treatment and who have no contraindications with foraminal access to the lumbar spine are candidates for this procedure. Nevertheless, while this is a minimally invasive operation, it has surgical risks, and is normally considered for patients who have few alternatives or after full disclosure of the risk/benefit ratio. Most surgical candidates are considered after extensive non-operative treatments including physical therapy, steroid injections, and pain management.

Discography will help the surgeon identify painful discs that may be amenable to treatment. Concordant pain during the discogram is important in identifying the disc as a pain generator, but the pattern of the pathoanatomy is also important. A single quadrant radial annular tear will be more amenable to treatment versus a circumferential annular tear. Equally important, discography can identify those patients that are pain sensitive and would not do well with any treatment. These patients have severe pain with simple needle insertion into the skin and/or lack a negative control level, feeling pain at discs normal on MRI and with normal discogram patterns.

Patients who meet the selection criteria for IDET or nucleoplasty would be candidates for SED and RF thermal annuloplasty.

30.7 Contraindications

Contraindications are considered to be relative. Severe lumbar degeneration has other causes of chronic back pain that may be predominantly from the facet or sacroiliac joint. Psychological and medical–legal factors need to be weighed against the potential benefits of any surgical procedure. Anatomic considerations for accessing the disc, severe instability, and stenosis are factors that will affect good results. Patients who are better candidates for a traditional stabilizing procedure should consider the likelihood of surgical success with traditional fusion when compared the microtherapy. The greatest risks are in patients who have chronic pain that defies any treatment and have severe disabling pain poorly explained by the pathoanatomy. When these patients have skipped lesions or multiple levels of discogenic pain or disc protrusions, there is no other viable surgical alternative. While most of these patients improve, and are grateful for any relief they can get, there is a small group of patients who may be unrealistic about the efficacy of the procedure or who react out of proportion to their pathoanatomy. Patients who cannot withstand the pain of needle insertion in the process of discography, for instance, may do poorly and may actually claim that the procedure, no matter how well it goes, made them worse. Postoperatively, especially in multiple level discogenic pain, after an initial period of improvement, disc subsidence causing foraminal stenosis or recurrent or subsequent disc herniation may occur. This may not be discovered until the recurrent symptoms become severe enough that a follow up MRI is performed. The patient may later elect to undergo a fusion or surgical procedure with another surgeon without further improvement. These patients are high risks for the surgeon if the medical–legal situation in his/her community is in crisis and if the procedure is not uniformly accepted by his/her peers who do not do the procedure. Partially, for this reason, the surgeon should do his/her own evocative discography and make the decision with respect to surgery. His/her experience with discography and its role in patient selection will be appreciated greater as he/she develops experience in the technique and in patient selection. His/her experience will then help with providing a more complete informed consent.

30.8 Patient's Informed Consent

Standard informed consent is obtained by informing the patients of their options for treatment, including no treatment or pain management only. The efficacy of the endoscopic technique should be discussed in the context of other surgical treatments available, including fusion. The surgeon's experience and his review of the literature should be discussed with the patient.

In addition to the standard risks of traditional posterior lumbar disc surgery, the surgeon should discuss the possibility of exiting nerve root dysesthesia. Since the surgical approach is adjacent to the dorsal root ganglion of the exiting nerve root, this may become irritated and result in dysesthetic pain along the exiting nerve root dermatome. This is usually in a different distribution to the patient's preoperative radiculitis since the traversing nerve root is typically affected, unless the patient has a foraminal herniation. We point this out because the patient may be concerned about a new area of symptoms. The patient can be reassured that the vast majority of exiting nerve root dysesthesia is temporary and has about a 5 – 15 % incidence [25, 35]. In traditional posterior transcanal discectomy traversing nerve root dysesthesia occurs, but is not considered an issue since the symptoms are in the same distribution as the preoperative radiculitis and it too is temporary. It is also difficult to differentiate the preoperative irritation to the traversing nerve root versus that caused by or aggravated by the surgical manipulation. Most patients are told that the nerve is recovering or "waking up" and it takes some time for it to become less irritated. A prospective study comparing a group of 100 consecutive patients undergoing selective endoscopic discectomy with a matched surgical group without neuromonitoring revealed no difference in dysesthesia or complication rate. While continuous EMG warned the surgeon of the proximity of surgical instruments to the exiting nerve, the use of local dilute anesthetic was equally safe in avoiding neuropraxia [45, 46]

Peers unfamiliar with electrothermal microtherapy may be inappropriately critical of the procedure because of lack of understanding of this emerging technology.

30.9 Surgical Technique

The patient is placed prone on the radiolucent hyperkyphotic frame (Kambin frame; US Surgical) with the arms away from the side of the body. Care is taken to line up the patient with the C-arm to ensure a perfect posterior-anterior (PA) and lateral view on the fluoroscopy. The spinous processes should be centered between the pedicles on the PA view and the endplates parallel on the lateral view. The surgical level must be centered to avoid parallax error. Anesthesia consists of local 0.5 % lidocaine infiltration, supplemented by Versed and fentanyl for conscious sedation.

30.9.1 Needle Placement

Accurate instrument placement is essential. This begins by directing an 18-gauge spinal needle into the posterior third of the disc via the posterolateral approach under fluoroscopic guidance. The needle entry point is approximately 12 cm lateral to the midline and parallel to the disc endplates on the lateral fluoroscopic view. The needle trajectory is typically 25 – 35° in relation to the coronal plane. Yeung has described a step-by-step protocol for optimal needle placement that takes into account the patient's individual anatomy [25, 35].

30.9.2 Evocative Chromo-discography

A confirmatory contrast discography is performed at this time. The following contrast mixture is used: 9 cc Isovue 300 with 1 cc indigo carmine dye. This combination of contrast ratio gives readily visible radio-opacity on the discography images, and intraoperative light blue chromatization of the pathologic nucleus and annular fissures which help guide the targeted fragmentectomy (Fig. 30.7).



Fig. 30.7. Evocative Chromo-discography. Discography is an integral part of microtherapy. Here, discography at L5-S1 identifies grade V tears causing concordant back pain and radicular pain in the L5 as well as the S1 dermatome. The contrast dye leaks out of the large grade V tears and outlines the exiting L5 and traversing S1 nerve

30.9.3 Instrument Placement

Insert a long thin guide wire through the 18-gauge needle channel. Advance the guide wire tip 1–2 cm deep into the annulus and then remove the needle. Slide the bluntly tapered tissue dilating obturator over the guide wire until the tip of the obturator is firmly engaged against the annulus. An eccentric parallel channel in the obturator allows for application of 0.5% lidocaine circumferentially around the guide wire into the annulus. This dilute solution is enough to anesthetize the annulus, but not the spinal nerves. Hold the obturator firmly against the annulus and remove the guide wire. Infiltrate the full thickness of the annulus through the obturator's center channel using 0.5% lidocaine.

The next step is the through-and-through fenestration of the annulus by advancing the bluntly tapered obturator with a mallet. Annular fenestration is the most painful step of the entire procedure. Advise the anesthesiologist to heighten the sedation level just prior to annular fenestration. Advance the obturator tip deep into the annulus and confirm on the C-arm views. Now slide the beveled access cannula over the obturator toward the disc. Advance the cannula until the beveled tip is deep into the annulus. Remove the obturator and insert the endoscope to get a view of the disc nucleus and annulus. The degenerated nucleus is preferentially stained blue from the indigo carmine while the annular fibers remain unstained allowing for selective discectomy.

Selective Endoscopic Discectomy is performed using the Yeung Endoscopic Spine Surgery system (YESS; Richard Wolf Surgical Instruments, Vernon Hills, IL) in order to selectively remove the nucleus pulposus in contact with and interposed within the annular tears. This is accomplished utilizing endoscopic pituitary rongeurs, larger hinged pituitary rongeurs, a suction-irrigation shaver, and a Ho:YAG side-firing laser. This creates the intradiscal working space, removes any nuclear tissue interposed in the annular tears, and allows visualization of the inner annular fibers.

The thermal annuloplasty portion of the procedure uses a bipolar RF electrode (Ellman Trigger-flex probe; Ellman International, Hewitt, NY). Under direct visualization the flexible Ellman RF probe ablates ingrown granulation tissue [14, 27, 28, 47, 48] and nerve endings already in the annular defects, and shrinks the annular openings (Fig. 30.8). Visualized tissue reaction to the RF modulation guides treatment length (Fig. 30.9). At the conclusion of the procedure, the annular fenestration is modulated by thermally shrinking the annular fibers. A foraminal injection of 40 mg triamcinolone or Depomedrol helps decrease the incidence of postoperative dysesthesia.

30.10 Postoperative Care and Complications

The patient is allowed to ambulate as tolerated, but twisting, lifting, stretching, and physical therapy is usually avoided for 3–6 weeks to allow the annular fibers to heal. The patient is given instructions on isometric lumbar stabilization exercises. Relief of back pain is immediate in 50% and gradual in the other 40%. About 10% may perceive worsening of their symptoms, especially if they experience postoperative dysesthesia.

As with arthroscopic knee surgery, the risks of serious complications or injury are low, about 1–3% in the author's experience. The usual risks of infection, nerve injury, dural tears, bleeding, and scar formation are always present as with any surgery. Transient dysesthesia, the most common postoperative complaint, occurs about 5–15% of the time and is almost always transient. Its cause is still incompletely understood and may

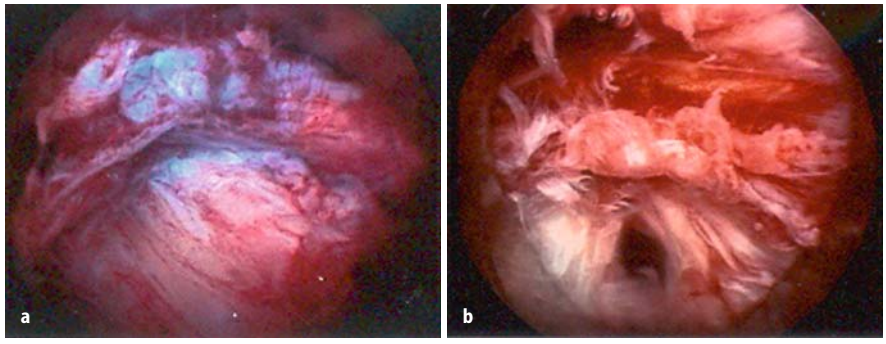


Fig. 30.8. a Inflammatory membrane. The grade V annular tear, stained blue by Evocative Chromo-discography, is surrounded by inflammation. Chemical irritation is the likely cause. **b** Blood in the foramen may look like inflammation. Bleeding in the epidural space can also look like inflammation and may be mistaken for an inflammatory membrane, but the condition of the surrounding tissue, as in this view of the fenestrated annulus, demonstrates relative healthy annular collagen. The annulus is bluntly dilated by the endoscopic obturator and cannula used to perform selective discectomy and thermal annuloplasty from the "inside" of the disc for a contained central disc herniation causing predominant back pain. Avoiding thermal annuloplasty of the outer annulus may help decrease the dysesthesia that can occur with ablation of the inflammatory membrane in the outer annulus and epidural space. Visualized thermal modulation of the annulus will contract the loose tissue. Central disc protrusions respond well to SED and thermal annuloplasty

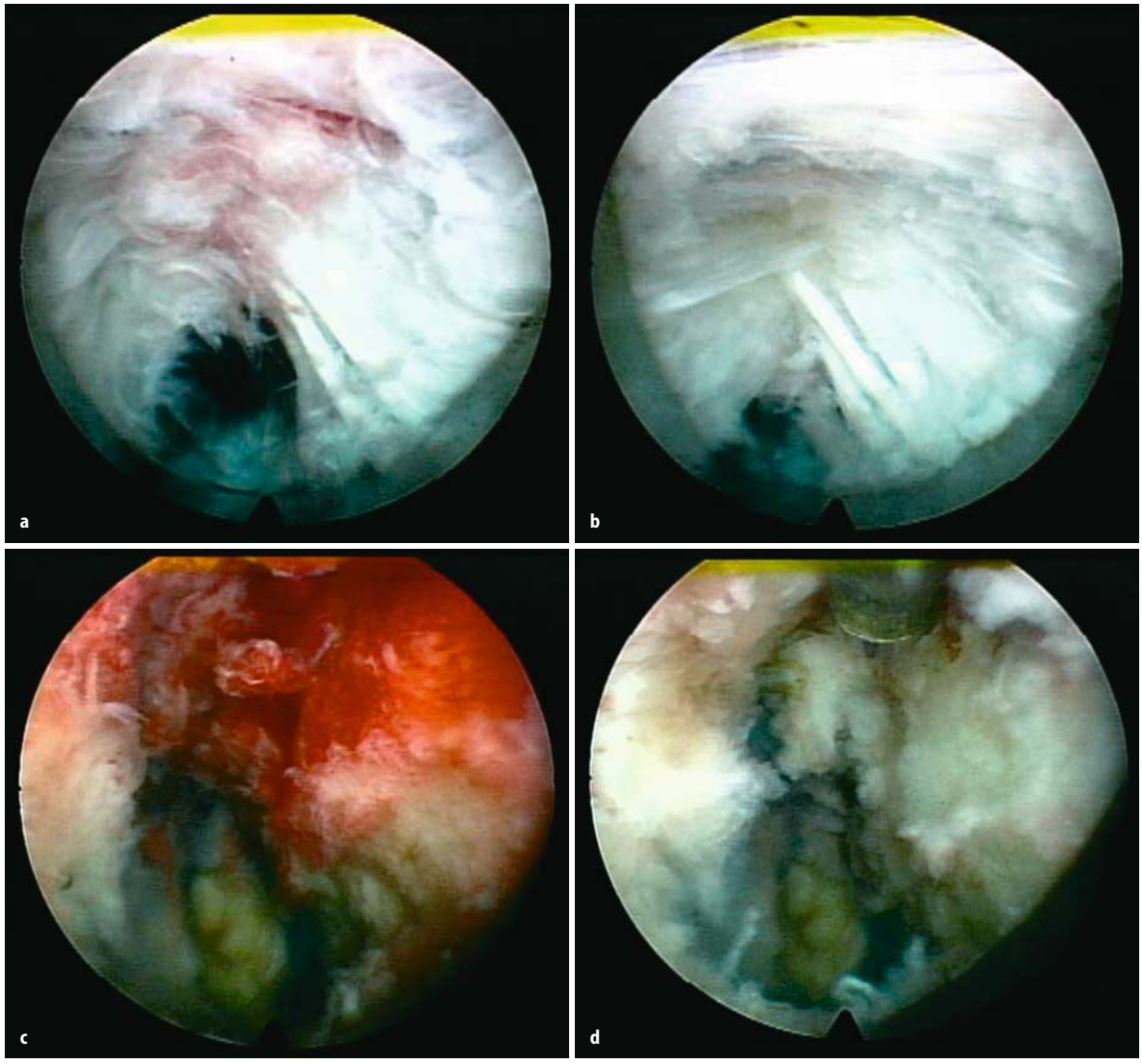


Fig. 30.9. a Granulation tissue in a recent annular tear associated with a bulging disc. **b** Granulation tissue is completely ablated and removed after visualized RF thermal treatment. The length of RF thermal treatment is determined by visual confirmation of ablated granulation tissue and shrinkage of the annular collagen. All interposed granulation has been removed. **c** Inflammatory membrane and granulation tissue in an annular tear. **d** After RF thermal treatment, the inflammatory membrane is ablated

be related to nerve recovery, operating adjacent to the dorsal root ganglion of the exiting nerve, or a small hematoma adjacent to the ganglion of the exiting nerve, as it can occur days or even weeks after surgery. Transient dysesthesia can occur even in cases where no adverse events were detected with continuous EMG and SEP neuromonitoring [45, 46]. Thus it cannot be completely avoided. The symptoms are like a variant of complex regional pain syndrome (CRPS), but less severe, and without the skin changes that accompany CRPS. Dysesthesia is readily treated by transforaminal epidural blocks, lumbar sympathetic blocks, and the use of Neurontin titrated up to 1,800 – 3,200 mg/day or Zonegran up to 400 mg/day if needed.

Avoidance of complications is enhanced by the ability to clearly visualize normal and pathoanatomy, the use of local anesthesia and conscious sedation rather than general or spinal anesthesia, and the use of a standardized needle placement protocol. The entire procedure is usually accomplished with the patient remaining comfortable during the entire procedure and should be done without the patient feeling severe pain except when expected, such as during evocative discography, annular fenestration, or when instruments are manipulated past the exiting nerve. Local anesthesia using 0.5 % lidocaine allows generous use of this dilute anesthetic for pain control and still allows the patient to feel pain when the nerve root is manipulated. Continu-

ous EMG and SEP can also help monitor and prevent nerve irritation. This usually correlates well with the patient's intraoperative feedback.

30.11 Results

A retrospective review of 113 consecutive surgical cases treating CLDP performed by one surgeon (A.T.Y.) was carried out between January 1997 and December 1999 [21]. There was a minimum 2-year follow-up. Selection criteria included failure of 6 months of non-surgical treatment in patients with chronic back pain without sciatica from lumbar disc herniation. Diagnoses included internal disc disruption, annular tear with high intensity zone, and degenerative disc disease. The subjects had surgery at only one or two disc levels.

Two outcome measures were used for clinical assessment: a surgeon-based modified MacNab method and a patient-based questionnaire. The results of this endoscopic procedure were each graded excellent, good, fair, and poor for the modified MacNab and the questionnaire methods. A mandatory poor result was given to any patient who had repeat spine surgery at the same level, had indicated dissatisfaction with the surgical result on the questionnaire response, or who felt the same or worse after the surgery.

Using the surgeon's assessment data, 83 patients (73.5%) were in the satisfactory outcome group. This group of patients included excellent, good, and fair categories. Excellent outcome was reported in 17 patients (15%); good in 32 patients (28.3%); and fair in 34 patients (30.1%). Thirty patients (26.5%) were determined to have poor results. The specific reasons were as follows: 12 patients were not improved after the endoscopic surgery, 8 patients had subsequent lumbar fusion; 7 patients had repeat lumbar endoscopic surgery; and 3 patients had lumbar laminectomy. Twelve patients in the poor category elected to have no further back surgery. Of the 18 patients who had secondary back surgery, 10 reported improvement after the subsequent operation. The satisfied group of patients would select the lumbar endoscopic surgery again in the future given the knowledge gained from their endoscopic experience.

Out of the 83 patients that returned the questionnaire, 64 (77.1%) reported satisfactory results with 14 (16.9%) rated excellent, 24 (28.9%) rated good, 26 (31.3%) rated fair, and 19 (22.9%) rated poor. The response rate to the questionnaire was only 73%, but the distribution of the patient grading was very similar to the surgeon-based assessment. In fact the questionnaire respondents have a higher percentage in the excellent group 16.9% (14/83) versus 15% (17/113) and lower percentage in the poor group 22.8% (19/83) versus 26.5% (30/113).

Perioperative adverse events from this study were low and included three cases of dysesthesia and one case of thrombophlebitis.

30.12 Critical Evaluations

Posterolateral transforaminal SED and RF thermal annuloplasty is a minimal access visualized surgical procedure. This chapter focuses on the role of annular defects as the first portal leading to pain sensitization. The authors' hypothesis on chronic pain sensitization is based on the following established findings. Nucleus pulposus (proteoglycan) and its metabolic by-products are known to be contact irritants to neural tissues [7–10]. End neural sensors, in a normal disc, are found in outer layers of the annulus fibrosus and juxta endplate zone [3, 4, 49]. These end sensors normally are shielded from direct contact with irritants by intact inner layers of annulus and cartilaginous endplates. Defects which develop in the inner annular layers or cartilaginous endplates potentially expose the end sensors to chronic direct contact with the proteoglycan. The chronic contact triggers a repair process in the annular defects resulting in ingrowth of new vessels [14], new nerve endings, and granulation tissue into the defects. The migrated cellular elements in the defects are in constant anatomic contact with the proteoglycan of the nucleus pulposus. Chronic direct contact between the irritants and end sensors is hypothesized to be the local process that initiates the back pain sensitization cascade. The interposed nuclear tissue may also prevent the annular tears from healing properly.

The treatment rationale for SED and RF thermal annuloplasty is based on the removal/ablation of the nucleus pulposus and granulation tissue interposed within the annular tears. The RF electrode heating process is also hypothesized to ablate the sensitized neural sensory endings that have grown into the fissures. The continuous saline irrigation during the endoscopic procedure flushes out the toxic metabolites within the disc. It also prevents the accumulation of any by-products of the thermal treatment.

This procedure thus has many theoretical advantages over some of the other percutaneous intradiscal procedures such as IDET and nucleoplasty (Coblation). IDET and Coblation rely solely on fluoroscopic guidance and are thus blind procedures. They are not designed to remove the interposed tissue within the annular tears or remove any by-products of their energy treatment.

Recent investigations on fusion outcome, with interbody implants, showed successful fusion rates, up to 98%, but the rate of clinical improvement ranged from 65% to 85% [16–20]. While our results fall within this

same range, comparison of results by the different surgical methods from the available literature data is not feasible because of the lack of uniformity in the important issues concerning this condition. Consensus is lacking in the definition of the condition, in patient selection criteria, in procedural details of provocation discography, as well as in the selection of outcome instruments. The available surgical options vary greatly in their invasiveness and in their hypothesized treatment mechanism [16–20, 48, 50–54]. A better understanding of the local intradiscal process that leads to pain sensitization is especially important, because all established operative procedures attempt to achieve one or more of the following: nucleus removal; changing the biomechanical properties of the interspace; and ablating annular neural sensors.

The authors believe, in the absence of a better objective diagnostic test, that evocative discography provides a gross estimation of the presence or absence of discogenic pain [13, 37, 40, 41, 55] and localizes the painful level(s). Surgeon-performed preoperative provocation (Evocative Discography) has patient selection advantages because the overall pain response in unsedated CLDP patients can be compared with the patient's overall reaction to needle insertion. The patient's behavior during the procedure provides additional clinical information that helps the surgeons with patient selection.

The authors emphasize that the posterolateral transforaminal SED technique has a steep learning curve and is equipment intensive. The technique was originally developed for nerve root decompression secondary to lumbar disc herniation and focal lumbar stenosis [25, 33–35, 56–58]. Mastery in spine endoscopy developed for the original purposes has enabled the authors to expand its capabilities, including paying attention to the annular fissures. As spinal endoscopy continues to evolve, other spinal pathology can be addressed by using the transforaminal endoscopic method. The roles of annular defects, and the cellular and molecular interactions within the defects are worthy of further investigation. Intradiscal endoscopy has established a window into intradiscal pathology.

30.13 Conclusions

Posterolateral transforaminal SED and RF thermal annuloplasty were used to interrupt the purported annular defect pain sensitization process, thought to be necessary in the genesis of CLDP. Lack of clinical benefit from the subject procedure did not degrade any subsequent surgical or non-surgical treatment options.

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31 Principles of Microsurgical Discectomy in Lumbar Disc Herniations

H.M. Mayer

31.1 Terminology

The term "microsurgical discectomy" describes the removal of herniated parts of lumbar intervertebral discs through a posterior approach with the help of a surgical microscope and microsurgical instruments. It implies the application of the general principles of microsurgery as well as the approach to the anatomical target area through a limited skin incision.

31.2 Surgical Principle

For herniated lumbar discs which are medial, paramedian (between midline and medial border of the pedicle), or intraforaminal (between medial and lateral border of the pedicle), the pathology is approached through a paramedian incision (5 mm from the spinous process on the symptomatic side). The dorsolumbar fascia is incised and the muscles are bluntly retracted from medial to lateral without dissecting any of the insertions. Thus, the interlaminar region (window) is approached. The yellow ligament is opened laterally and the nerve root is exposed and mobilized. The herniated part of the lumbar disc is removed and the rest of the nucleus pulposus can be removed from the intervertebral space in order to decrease the rate of recurrent herniations. The procedure is performed with the help of a surgical microscope using the microscope "from skin to skin" (see Chapter 3). In extraforaminal disc herniations, the skin incision is between 3 and 5 cm lateral to the midline. The dorsolumbar fascia is opened in a semicircular manner and the intertransverse space is approached via blunt transmuscular dissection. The intertransverse ligament and muscle are excised lateral to the facet joint, and the dorsal root ganglion is exposed. It is mobilized if necessary to expose the disc herniation which usually compresses the ganglion toward the lower borders of the pedicle. The disc herniation is removed. In the majority of cases, no attempts are made to remove disc material from the intervertebral space. The spinal canal is not opened (see Chapter 34).

31.3 History

The surgical treatment of lumbar disc herniations is characterized by several historical landmarks within the last 90 years. It was Oppenheim and Krause in 1909, Steinke in 1918, Adson in 1922, Stookey in 1922, and Dandy in 1929 who first described lumbar disc operations which were in fact misdiagnosed as "spinal tumors" or "chondromas" [1, 11, 40, 50, 52]. In 1934 Mixter and Barr defined disc tissue as the morphological correlate for low back pain and sciatica in their patients. Their historical paper about the treatment of "ruptured lumbar discs" by laminectomy marks the beginning of "disc surgery" which dominates spine surgery of today at least by numbers [35]. With the development of myelography and discography, the diagnosis and localization of lumbar disc herniations became easier in the following years [31]. The surgical approaches became less invasive so that hemilaminectomies were the standard surgical approach for the majority of disc herniations at the beginning of the 1970s.

Despite this progress, the clinical results of lumbar disc surgery remained moderate. In the majority of the patients the neurological symptoms as well as the radicular pain could be improved, however, due to persistent or even worse low back pain, the clinical success rate varied between 4% and 44% in publications of the 1970s and beginning of the 1980s [4–6, 18, 19, 27, 37, 43, 49] (Table 31.1).

The rising numbers of patients with so-called failed-back-surgery syndromes was an indicator for the contribution of the surgical technique to postoperative complaints. Indeed, most of the postoperative problems patients were facing were a result of traumatizing surgical approaches, lesions to nerve roots and bony structures, as well as wrong level explorations.

The application of microsurgical techniques to the treatment of lumbar disc herniations is due to the efforts of Yasargil, Williams, Wilson, Goald, and Caspar [7, 15, 20–22, 54, 63–67, 69].

Table 31.1. Results of "standard" non-microsurgical lumbar discectomy

Author	Patients (n)	Results(%) Satisfied	Not satisfied
Jochheim et al. (1961) [25]	188	84	16
Bushe et al. (1968) [6]	404	95	5
Biehl and Peters (1971) [5]	450	81.8	18.2
Oldenkott (1971) [37]	733	70	30
Biehl (1974) [4]	640	82.7	17.3
Vogt (1974) [56]	119	76.5	23.5
Salenius and Laurent (1977) [43]	886	56	44
Thomalske et al. (1977) [53]	1,000	93.2	6.8
Finneson (1978) [18]	296	67.6	32.4
Frenkel and Angehoefer (1978) [19]	124	96	4
Schramm et al. (1978) [47]	3,238	>80	
Berger (1979) [3]	1,101	87.7	12.3
Oldenkott (1979) [38]	760	89	11
Mayer and Reiche (1982) [32]	139	88	12

31.4 Advantages

The main advantages of microsurgical discectomy are

- No restrictions in indication
- Magnification and illumination of the surgical field
- Reduced skin incision
- Reduced damage to paravertebral muscles
- Reduced trauma to osseous structures
- Improved hemostasis due to meticulous preparation of epidural veins
- Gentle preparation of neurological tissues
- Decreased blood loss
- Less severe complications
- Homogenous clinical results
- Decreased operating room time
- Decreased postoperative morbidity
- Shorter hospitalization
- Outpatient procedure
- Positive didactic effects for the surgeon (preoperative planning) and for the assistant (can follow the operation)

31.5 Disadvantages

There are a few inherent disadvantages of microsurgery which also apply to lumbar disc operations:

- Small field of vision with the danger of creating indirect lesions to nerves of blood vessels
- Training (learning by doing) necessary for surgeons who are not educated in microsurgery

31.6 Indications

Microsurgery for the treatment of lumbar disc herniations is indicated in all kinds and forms of herniation:

- Medial, paramedian, intra- and extraforaminal herniations
- Subligamentous, epidural extrusions with and without free fragments
- Disc herniations of all kinds associated with lateral or central spinal stenosis
- Disc herniations associated with non-symptomatic segmental instability

31.7 Contraindications

There are no contraindications for lumbar microdiscectomy.

31.8 Surgical Technique, Postoperative Care, and Complications

See following chapters.

31.9 Results

The analysis of 11 retrospective clinical studies performed between 1977 and 1993 (n = 3,543 patients) reveals clinical success rates of microdiscectomy between 76% and 100% with a postoperative follow-up time of between 6 months and 5.5 years (Table 31.2). The major differences between microsurgical and macrosurgical

Author	Patients (n)	Results(%) Satisfied	Not satisfied
Yasargil (1977) [69]	100	100	0
Williams (1978) [63]	530	91	9
Goald (1978) [20]	147	96	4
Goald (1981) [22]	477	91	9
Ebeling and Reulen (1983) [14]	150	82	18
Hudgins (1983) [24]	157	91	9
Ebeling et al. (1986) [16]	485	91	9
Williams (1986) [64]	903	86	14
Ferrer et al. (1988) [17]	100	76	24
McCulloch (1989) [33]	257	84	16
Kotilainen et al. (1993) [29]	237	92	8

Table 31.2. Clinical success rates of microdiscectomy (range, 76 – 100 %) with a postoperative follow-up time of between 6 months and 5.5 years

Table 31.3. Microsurgical (*Mic*) versus standard macrosurgical (*Mac*) technique

Author	Patients	Stay in hospital (days)	Unfit for work (weeks)	Follow-up (years)	Good outcome (%)	Reoperations (%)
Wilson and Harbaugh (1981) [66]	Mic 100	1	4.8	2	–	2
	Mac 100	2.5	11.8	2	–	8
Kho and Steudel (1986) [28]	Mic 131	–	–	1 – 5	93	2.5
	Mac 136	–	–	1 – 5	93	0
Nyström (1987) [36]	Mic 56	5	8	3	89	–
	Mac 33	13.3	18.4	6.3	59	–
	Mac 31	14.5	15.6	6.4	68	–
Silvers (1988) [48]	Mic 270	3.7	10.6	–	98	5.1
	Mac 270	7.1	13.4	–	95	5.5
Probst (1989) [41]	Mic 150	–	–	1.5	95	4
	Mac 150	–	–	1.5	90	3.3
Kahanovitz et al. (1989) [26]	Mic 30	2	8	1.5	–	–
	Mac 34	7	7	1.5	–	–
Andrews and Lavyne (1990) [2]	Mic 112	2.8	5.5 – 9.9	1	97	4.5
	Mac 30	9	12.4	3.5	88	11.4
Caspar et al. (1991) [9]	Mic 299	–	16.4	–	93.5	5.7
	Mac 199	–	18.6	–	83.3	12.6

techniques are that the overall success rates are higher and that the results are more homogenous in patients undergoing a microdiscectomy (Table 31.3).

31.10 Critical Evaluation

Microsurgical and endoscopic techniques have revolutionized a great number of surgical specialties. The development of imaging techniques as well as of technical equipment has always had one common goal: to achieve the technical goal of a surgical procedure with less tissue trauma in a fast and efficient way. This should always result in better or at least comparable clinical results. All surgical specialties which have adopted microsurgical techniques since the 1970s have had this benefit for a vast number of surgical interventions. Although there is a still ongoing discussion about the benefit of microsurgical discectomy, the arguments against this technique are fading away.

It has been proved that microsurgical discectomy does not prolong the operation time. Microsurgery does not lead to a significantly higher number of wrong level explorations or missed disc fragments. Microsurgery can be used for all kinds of disc herniations without any anatomical, technical, or philosophical restrictions. Microdiscectomy has brought an enormous benefit in the treatment of extraforaminal disc herniations (see Chapter 34). The overall rate of complications is not increased, and the rate of severe intraoperative complications is decreased as compared to standard techniques [61].

Many arguments against microsurgery are superficial and biased. There is no need for prospective randomized studies to prove the benefits of the microsurgical philosophy as long as comparable clinical results can be achieved with less tissue trauma.

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The Microsurgical Interlaminar, Paramedian Approach

32

H.M. Mayer

32.1 Terminology

The microsurgical approach through the "interlaminar window" is synonymous with the terms "microdiscectomy" or "microsurgical discectomy," although from a semantic point of view these terms are misleading. The goal of the surgical procedure is not an entire "discectomy" (which would be impossible with this approach for anatomical reasons) but a removal of slipped disc material (nucleus, endplate, anulus fibrosis) from the spinal canal in order to decompress the neural structures.

32.2 Surgical Principle

The spinal canal is reached through a limited skin incision close to the midline (spinous process) on the symptomatic side. The surgical microscope can be used from "skin to skin." The paravertebral muscles are retracted without cutting any insertions at the spinous processes of the laminae. The interlaminar window is exposed as well as the medial third of the facet joint. The yellow ligament is fenestrated or lifted and the underlying nerve root is exposed from its origin to its entry into the foramen at the base of the pedicle of the vertebra caudal to the disc space. At the levels cranial to L5/S1 subarticular decompression as well as a limited laminotomy is necessary to expose the disc space. The nerve root is mobilized by microsurgical dissection and the herniated disc material is removed with rongeurs. The remaining loose parts of the nucleus pulposus are removed from the intervertebral space carefully avoiding damage to the endplate or anterior perforation of the disc space with the rongeurs. With the help of the microscope, retraction of the muscles as well as damage to the structures covering the spinal canal (facet joint, lamina, yellow ligament) is restricted to a minimum. Exposure of the nerve root can be performed with minimal manipulation. Epidural bleeding is restricted due to meticulous preparation and dissection of epidural veins and venous plexus. Epidural fat can be preserved to cover the nerve root at the end of the procedure in order to minimize the ongrowth of scar tissue. The anulus fibrosis can be closed by an inverting suture.

32.3 History

The historical aspects of microsurgical discectomy have been described in the previous chapter. However, from my personal point of view, two outstanding surgeons have to be mentioned in this respect: Wolfhart Caspar [2–4] and John A. McCulloch [8, 10]. Due to their continuous and never-ending efforts, microsurgery is now an essential part of the surgical technology applied in the treatment of spinal diseases.

32.4 Advantages

There is no doubt that it is primarily the technical advantages which characterize the use of a surgical microscope in lumbar disc surgery. General advantages have already been described in the previous chapter. Table 32.1 summarizes the specific advantages of the microsurgical approach to lumbar disc herniations as compared to the standard techniques.

Table 32.1. Technical data: standard and microdiscectomy

	Micro	Standard
Preoperative planning	+++++	++
Positioning	=	=
Skin incision	2–3.5 cm	4–7 cm
Exposed segments	1	2–3
Muscle insertions	Intact	Not intact
Segmental denervation	Rare	Always
Osteoclastic decompression	Rare	Always
Blood loss	< 50 cc	> 200 cc
Discectomy	=	=
Anulus suture	Possible	??
Wound drainage	No	Yes
Time for surgery	=	=

They can be summarized as follows:

- Small skin incision (2.5 – 3 cm)
- Exploration of only the target segment
- Preservation of muscle insertions
- Preservation of segmental innervation of the paravertebral muscles due to limited retraction
- Preservation of lamina and facet joint by only limited osteoclastic extension of the approach
- In selected cases (e.g., at L5/S1) preservation of the yellow ligament (see below)
- Preservation of epidural fat and epidural venous plexus
- Limited manipulation of the nerve root
- Safe dissection of epidural adhesions and/or scar tissue
- Safe decompression of the nerve root from its exit from the thecal sac to its entrance into the foramen.
- Safe removal of disc tissue and fragments from the spinal canal as well as from the intervertebral space
- Limited blood loss of less than 50 cc on the average
- Suture and reconstruction of anulus fibrosis and/or yellow ligament possible
- No wound drainage necessary in the majority of patients
- Optimal teaching to assistants due to unobstructed view of the surgical field
- OT times comparable/shorter than with standard techniques
- Surgery possible as outpatient procedure due to less tissue trauma
- Short rehabilitation period

32.5 Disadvantages

There are quite a few disadvantages arising from general differences between wide and limited surgical approaches.

32.5.1 Technical Disadvantages

The main characteristic of the microsurgical approach is the limited visualization of anatomical structures surrounding or lining the surgical target area. Simultaneous vision of the target area and its neighborhood is not possible. Thus, the risk of indirect lesions to structures outside the surgeon's visual field has to be realized. It is, therefore, important to "secure" the anatomical structures which have already been passed on the way to the target area (e.g., speculum to retract muscles). The technical disadvantage of adapting the focus is now solved by the new generation of surgical microscopes which have autofocus functions. Most of these new microscopes have a very comfortable depth of focus. Moreover, the individual setup for each surgeon can be programmed and easily adjusted through a touch screen (Fig. 32.1a–c). The field of vision can be enlarged by tilting the microscope thus creating a larger area of visualization.

32.5.2 General Considerations

The microsurgical approach implies several modifications concerning surgical planning, positioning of the patient, and intraoperative control of removal of disc herniation which might appear as disadvantages to surgeons not experienced with microsurgery. Since the surgical corridor to the target area in the spinal canal is very limited, the localization of the skin incision has to be determined very accurately (see below). Once the skin incision is placed, there is no way of altering the approach other than by enlarging the incision. The level of the disc space must be localized in its exact projection onto skin level so that an approach along the strictly vertical axis will be possible. This implies a positioning of the patient on the surgical table which places the surface of the back horizontally. Lumbar lordosis should be completely compensated. Please note, that one of the most common mistakes with microsurgical approaches in lumbar disc surgery is exploration of the wrong level. Microsurgical dissection within the spinal canal can be extremely difficult when epidural veins are congested. Compensated lumbar lordosis as well as low or no pressure on the abdomen will diminish this problem which is often faced by beginners.

32.6 Indications (see also Chapter 31)

There are no anatomical or technical limitations for the application of microsurgery for the treatment of lumbar disc herniations which are located between the midline and the entrance of the foramen (medial, paramedian, intraforaminal). In disc herniations extending to the lateral third of the foramen a combined approach (paramedian-interlaminar and extraforaminal (see Chapter 33) is recommended. It is indicated in all forms of disc herniations including associated pathology (e.g., lateral or central spinal stenosis). Its application is limited neither by the size or configuration of the herniated disc nor by the clinical urgency. Since microsurgical discectomy can be performed without prolonged operating times, it can be applied in all the various clinical situations.





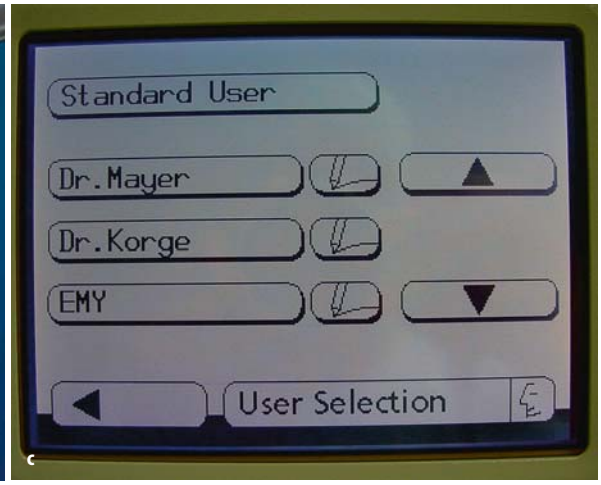


Fig. 32.1. a OPMI Vario NC 33 (Zeiss) draped for spinal surgery. **b** Touch screen function to adjust the individual setting for the surgeon. **c** Example of a user list on touch screen

32.7 Contraindications

There are no contraindications for the application of lumbar microdiscectomy through the paramedian approach except for combined intra- and extraforaminal localizations or mere extraforaminal herniations.

32.8 Patient's Informed Consent

The patient should be informed about the following approach-specific risks and hazards:

- Nerve root, cauda equina, and conus medullaris lesions with postoperative neurological deficits including bladder and bowel dysfunction
- Dural tears with menigocele and/or CSF fistulas
- Injury to retroperitoneal blood vessels (requiring emergency surgery) or to other structures in the abdominal cavity (e.g., ureter, peritoneum, bowel)
- Meningitis
- Spondylodiscitis with epidural abscess
- Epidural scarring with neurological deficits or permanent sciatica
- Segmental instability requiring stabilizing surgical procedures
- Chronic low back pain and radicular symptoms ("failed-back-surgery" syndrome)

32.9 Surgical Technique

The surgical technique differs significantly between the approach to a "virgin back" and the approach to an "operated back" in case of recurrent disc herniation. The technical modifications of the technique according to the underlying pathology in a previously operated back are described below.

32.9.1 Surgical Technique in a "Virgin" Back

32.9.1.1 Preoperative Planning

Preoperative planning is paramount in microsurgical disc operations.

- Plain X-rays in AP and lateral planes are necessary, as well as an MRI. The latter imaging technique has become standard in the diagnosis of lumbar disc herniations. In uncomplicated cases, a spinal CT scan can be enough for preoperative planning. There is no need for routine lumbar myelography or discography in most of the cases.
- Plain X-rays give an impression about the curvature of the lumbar spine, the disc height, the degree of spondylarthrosis as well as of the size and shape of the interlaminar window. The information is important because it predicts the necessity of bony enlargement of the interlaminar space. Watch the degree of lumbar lordosis!
- In patients with hyperlordosis especially at L5/S1 the risk of "slipping" into the wrong, supradjacent segment is high. In combination with the MRI, the thickness and shape of the yellow ligament can be evaluated before the operation. MRI not only gives a clear picture of the underlying disc pathology (e.g., size, shape, localization of disc herniation), it also shows the size and shape of the facet joint, the yellow ligament, the size of the lateral recess and the central volume of the spinal canal. It shows the amount and localization of epidural fat, the size and shape of the spinal nerve(s) involved in the pathology, as well as the amount of congestion within the epidural venous system.
- Lumbar disc herniation can be exactly classified so the surgeons knows whether they are dealing with a contained or non-contained disc, with subligamentous epidural extrusions, or with free disc fragments underneath or beyond the posterior longitudinal ligament. The localization of the herniation within the level of the disc space, cranial or caudal to the disc space can be determined as well as the origin and extension of the disc material.
- MRI should be as actual as possible (not older than a week) in order to correlate possible intraoperative findings with the preoperative picture.
- Note the extension of the disc herniation and be prepared to enlarge your approach in the direction of the disc herniation (e.g., extension of the laminotomy in fragments cranial to the disc space or extended subarticular decompression in herniations within the lateral recess).
- Carefully read the MRI to find out disc herniations which are located in the axilla of the nerve root. This pathology can be extremely difficult to treat if the surgeon tries to approach the disc herniations lateral from the nerve root (see below).
- In the treatment of recurrent herniations realize the amount of scar tissue and the amount of the remaining bony structures (lamina, facet joint). The bony structures are the only reliable landmarks during microsurgical dissection in recurrent disc herniations.
- Look for conjoined nerve roots! If you are not sure that a conjoined nerve root might be involved, perform an MRI myelography or a conventional myelography in order to be prepared to deal with this anatomical variation.

32.9.1.2 Positioning of the Patient

The patient is placed on a special operating table in the knee-chest position ("Mecca position"; Fig. 32.2). Positioning shows the following characteristics:

- Hip and knee joints are tilted 90° in order to ensure venous drainage from the lower extremities and thus diminish the risk of deep venous thrombosis.
- The patient is place on their knees and thighs as well as on their chest. Anterior thighs, knees, and chest must be protected against pressure sores by gel or soft cushion pads.

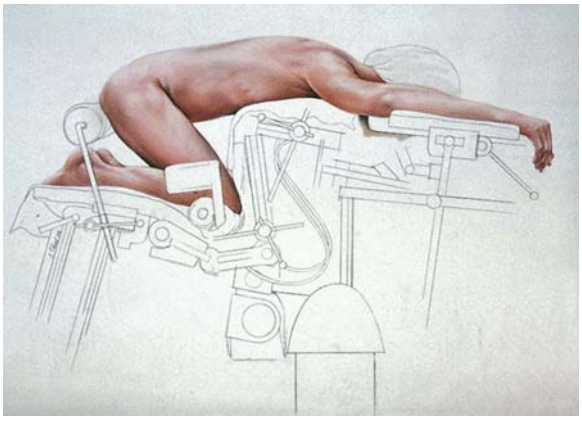


Fig. 32.2. Positioning of the patient (lateral view)

- The posterior part of the operating table can be tilted selectively in order to reduce or completely compensate lumbar lordosis. This not only leads to an enlargement of the spinal canal volume, it also "opens" the interlaminar space at least in patients with motion segments of unaltered flexibility.
- The arms are abducted 90° at the shoulder joint, and the forearm is flexed 90° at the elbow joint. Both arms are placed on arm holders which are padded with gel pads to avoid pressure especially on the ulnar nerve.
- Check for hyperabduction of the arms and for pressure on the axilla to prevent pressure lesions of the brachial plexus.
- In young patients, the head can be rotated up to 60 – 70° and placed on the gel pad. In old patients as well as in patients with concomitant degenerative disc disease of the cervical spine, rotation should be avoided. In these patients, the head is placed in a prone position with a gel pad under the forehead.
- Check the eyes, nose, and chin of the patient! Pressure on the eyes can result in postoperative blindness, and pressure on the nose or chin can result in pressure sores which do not heal very well and which might cause cosmetic problems for the patient.
- The abdomen of the patient should be free. In fact it should hang to avoid any pressure on it. Check that the cushion place under the thorax does not compress the hypogastric area.
- Tilt the table to adjust the surface of the back parallel to the surface of the floor.

32.9.1.3 Localization

A line for the skin incision is marked after localization of the disc space to be approached. After disinfection of the skin a needle is placed parallel to the spinous process at the presumed level of the disc space. The needle is inserted on the contralateral side in order to avoid subcutaneous or intramuscular hematoma which might aggravate microsurgical dissection on the approach side. Lateral fluoroscopy verifies the correct placement of the needle at the level of the disc space (Fig. 32.3).

- Note that the level of the disc space is marked with the needle, and the interlaminar space is slightly *below* this mark!
- The skin incision is placed so that the level of the disc space is in the middle third of the incision (Fig. 32.4). This means, that the surgeon has the option to expose not only the level of the disc space but also the spinal canal cranial or caudal to the disc space.
- The incision line can be adapted to the extension of the disc herniation (e.g., if there is an extension inferior to the disc space, then the skin incision may leave the disc space mark in its superior third). If there is a cranial sequestration, the skin incision can be moved slightly in the opposite direction.
- The skin incision is marked about 5 mm lateral to the midline.
- If two adjacent segments have to be approached, the length of the skin incision should be adapted.
- In the rare event, that two disc herniations are symptomatic at different levels not adjacent to each other (e.g., L5/S1 and L3/4) then two separate skin incisions are recommended.

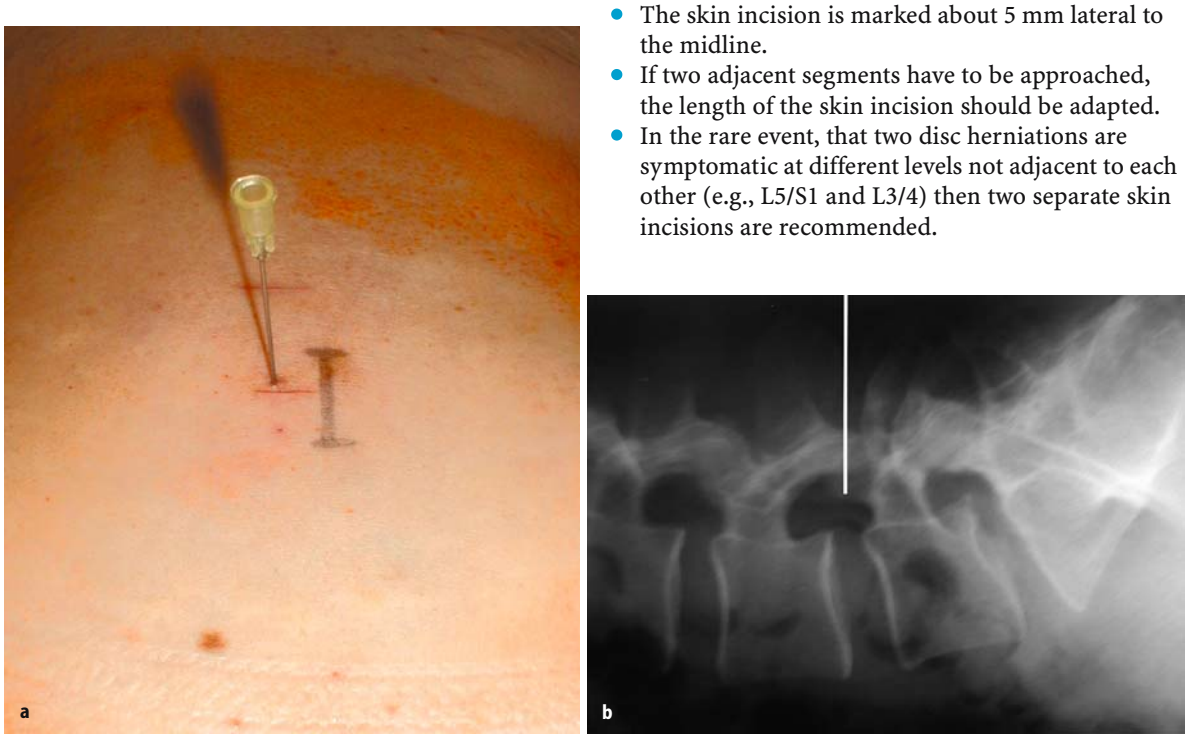


Fig. 32.3. a Localization of the disc space with a needle. **b** Lateral fluoroscopy showing the needle at the level of the disc space

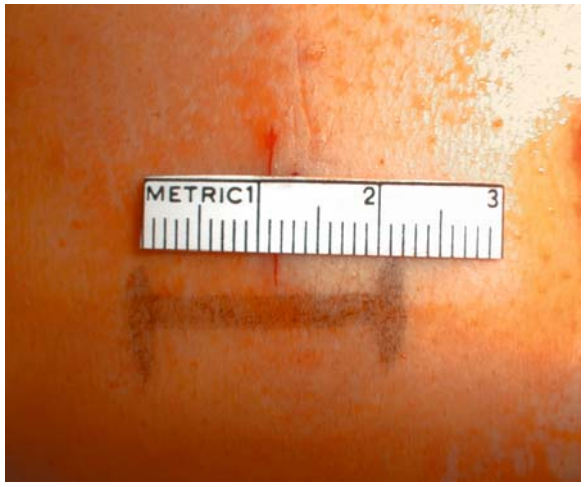


Fig. 32.4. Skin incision centered over the disc space

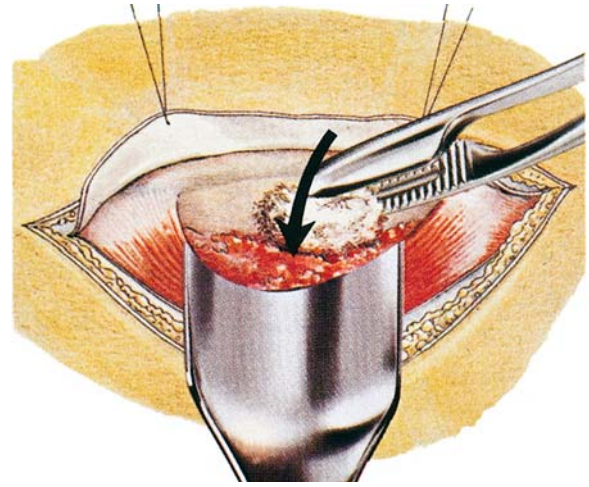


Fig. 32.6. Retraction of the paravertebral muscles (with permission of Aesculap)

32.9.1.4 Approach to Skin–Interlaminar Space

The author recommends the use of the surgical microscope from the skin incision. The skin is incised and the dorsolumbar fascia is exposed close to the midline. The spinous processes as well as the space in between are palpated.

- The superficial and deep layer of the fascia are cut about 5 mm from the midline and fascial splitting is completed in a semicircular manner ending on the adjacent spinous processes (Fig. 32.5). The medial part is gently lifted and can be temporarily secured by sutures.
- With the help of a blunt Langenbeck hook and bipolar coagulation, the superficial layer of the paravertebral muscle group is retracted from the interspinous ligament and the adjacent laminae (Fig. 32.6). Good illumination and magnification by the microscope helps to identify traversing veins which are coagulated and dissected.
- With peanut swabs, the interlaminar space is cleared from soft tissue and identified (Fig. 32.7).
- The insertions of the small rotators of the multifidus muscle group are sharply dissected from the lateral superior lamina and from the facet joint capsule (Fig. 32.8).
- A speculum which retracts the muscles from the interlaminar space is inserted, turned 90° toward the assistant and opened. Care has to be taken not to overstretch the skin!
- The lateral retractor is inserted to complete lateral retraction of the muscles (Fig. 32.9). Take care that the interlaminar window with the yellow ligament and the inferior part of the superior lamina are in the center of your vision field.

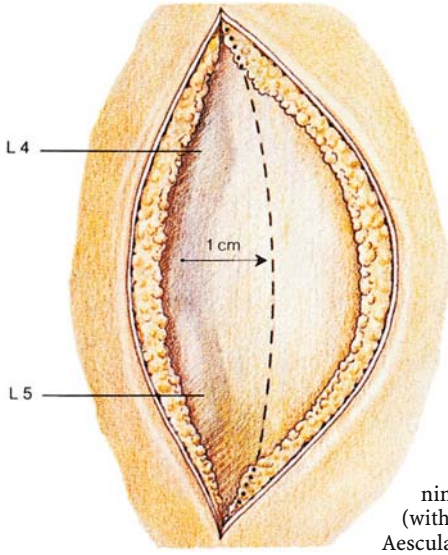


Fig. 32.5. Opening of the fascia (with permission of Aesculap, Tuttlingen)

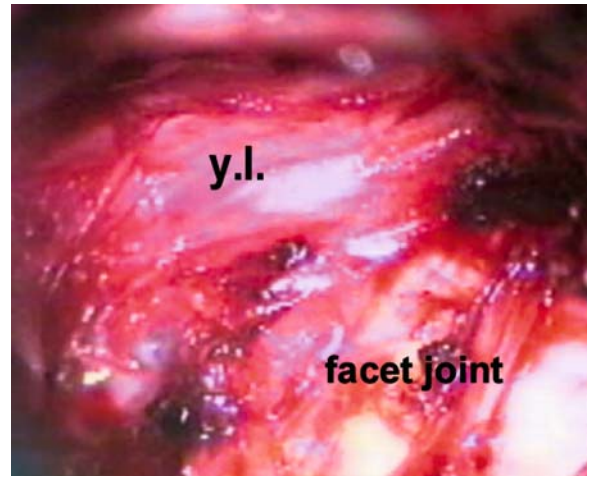


Fig. 32.7. Identification of the interlaminar window. *y.l.* Yellow ligament

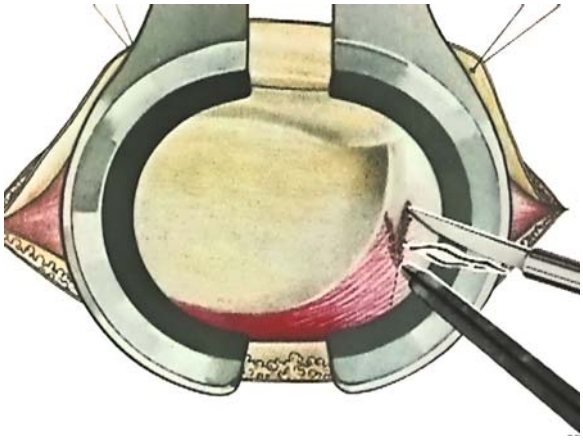


Fig. 32.8. Detachment of the rotators and insertion of the speculum (with permission of Aesculap)

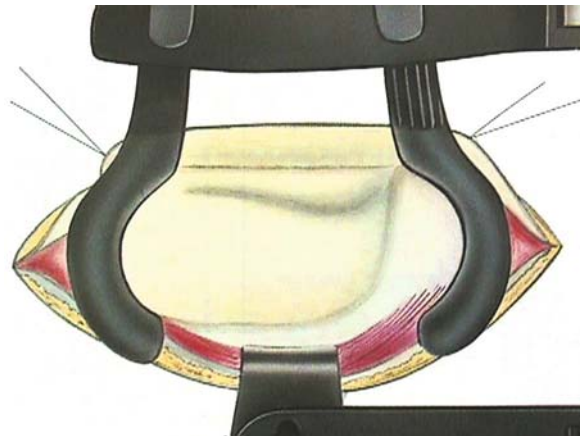


Fig. 32.9. Insertion of the lateral retractor (with permission of Aesculap)

32.9.1.5 Approach to the Spinal Canal

32.9.1.5.1 "Open-door" Flavectomy

The topography of the interlaminar space shows a great variability. At L5/S1 the yellow ligament sometimes reveals a nearly horizontal orientation thus facilitating the entrance into the spinal canal. It is at this level that an "open-door" technique is possible to enter the spinal canal. With a microsurgical scalpel, the yellow ligament can be detached from the laminae as well as from its attachments to the facet joint capsule whereas the medial part is left in place. Thus, the ligament can be elevated toward the midline without resection. At the end of the operation, the ligament is simply relocated and covers the spinal canal again.

32.9.1.5.2 "Conventional" Microsurgical Flavectomy and Decompression

In the majority of the cases the inferior lateral corner of the surgical field is first identified, and this is where the inferior border of the inferior facet is marked by the facet fat pad which leads the surgeon in between the layers of the yellow ligament. With a Kerrison rongeur, the fat pad can be entered and the inferior lateral part of the outer layer of the yellow ligament can be removed. This is the safest way to start entry into the spinal canal. The outer layer of the yellow ligament is resected and the inner layer is left in place. Resection is easy in most instances since the surgeon is still on the safe side (i.e., outside the spinal canal).

Once the thin internal layer of the yellow ligament is exposed, the spinal canal can be opened safely. Using a medium-size microdissector, the yellow ligament can be bluntly perforated moving the dissector in a craniocaudal direction applying only slight pressure (Fig. 32.10). As soon as the dissector enters the spinal canal, the surgeon feels a sudden loss of resistance at the tip of the instrument. This kind of preparation minimizes the risk of perforating the dura. The perforation of the yellow ligament is enlarged by a bigger blunt dissector which splits the yellow ligament fibers. With Kerrison rongeurs of different sizes, the lateral third of the yellow ligament is resected. Resection must be completed in the caudal direction down to the superior border of the inferior lamina. If there is hypertrophy of the yellow ligament, the lamina should at least be undercut or resected ("laminotomy") until the posterolateral circumference of the thecal sac is decompressed. The same is true for the cranial aspect of the interlaminar window. However in the majority of cases (even sometimes at L5/S 1), a few millimeters of the inferior border of the supradjacent lamina have to be resected as well. What has been described up to here is the easier part of the clockwise opening of the spinal canal (from 9 to 3 o'clock; Fig. 32.10). However, once this is achieved, the surgeon is on the safe side, since the dura can now be identified clearly under the epidural fat tissue. Avoid coagulation of the fat tissue since it can be used at the end of the operation for covering the neural structures.

32.9.1.6 Exposure of the Nerve Root

I recommend to start exposure of the nerve root at 6 o'clock. If the facet joint does not show any hypertrophy, resection can be continued from medial to lateral with the Kerrison rongeur carefully avoiding pressure on the theca. Thus, the medial part of the joint capsule is opened, and the medial parts of the inferior articular process of the supradjacent vertebra are resected. This

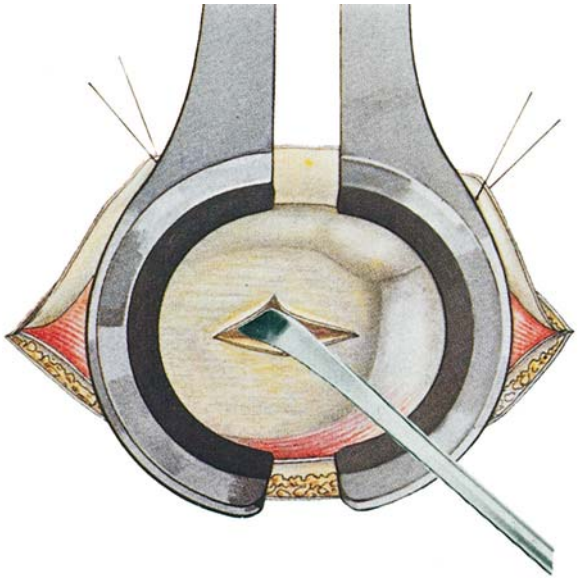


Fig. 32.10. Opening of the yellow ligament (9 – 3 o'clock) (with permission of Aesculap)

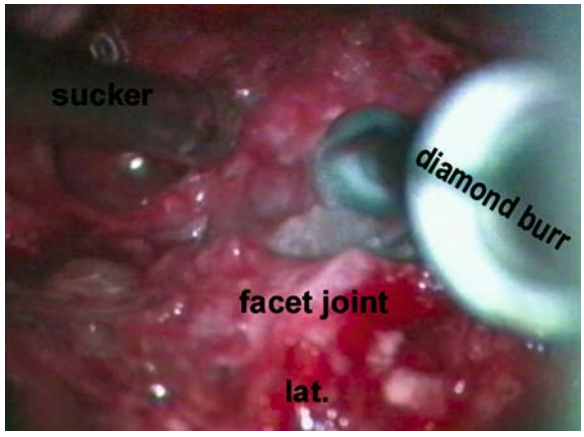


Fig. 32.11. Removal of medial part of the superior facet with high-speed burr

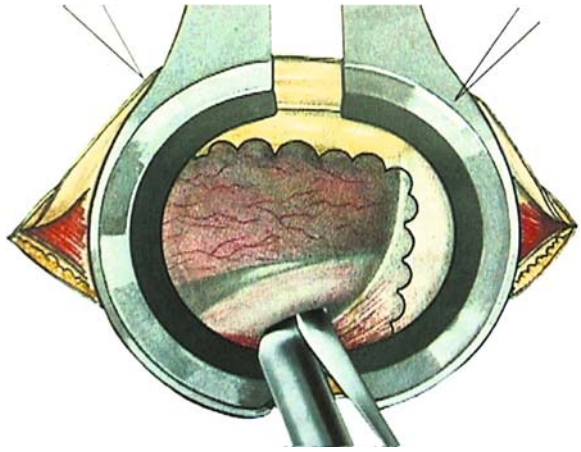


Fig. 32.12. Identification of lateral border of nerve root (with permission of Aesculap)

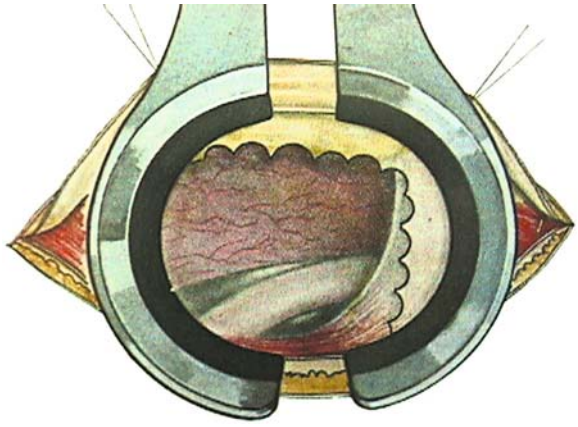


Fig. 32.13. Identification of the "axilla" of the nerve root (with permission of Aesculap)

part of the procedure can be accelerated with the use of high-speed drills (Fig. 32.11).

Once the medial edge of the superior articular process is identified, it is undercut until the lateral border of the traversing nerve root can be identified (Fig. 32.12). Now, topographic orientation is easy. With a blunt-tipped probe, the medial border of the inferior pedicle can be palpated. Once it is identified, exposure of the nerve root is completed until its entrance into the foramen caudal and lateral to the pedicle can be visualized. We feel that this is the safest way to start decompression, since the rongeurs are used parallel to the course of the nerve root. This minimizes the risk of dural tears. After this stage of the operation the "axilla" of the nerve root can be identified as well (Fig. 32.13). The other advantage is that the nerve can now be mobilized more easily during exposure of its cranial part ("shoulder").

Exposure is then continued along the lateral border of the nerve root until the superior border of the disc space can be identified. It is recommended to first expose just the shoulder of the nerve root. It then can be moved slightly toward the midline thus exposing the disc herniation. In most of the cases, the herniation is covered by a more or less vascularized epidural membrane. At L5/S1 it is a common finding that a layer of epidural fat covers the nerve root as well as the lateral aspect of the disc herniation. Care should be taken to avoid crude coagulation of these structures. However, congested epidural veins covering the disc herniation should be coagulated and dissected sharply to avoid tears and major bleeding during removal of the herniated disc tissue. (*Cave*: Before starting coagulation identify the veins! Coagulation of venous lacunae may result in severe bleeding. In these cases handle the veins carefully using small neuroswabs for covering and preparation.)

32.9.1.7 Exposure of the Herniated Disc

Once the nerve is gently mobilized it can be retracted slightly with a dissector toward the midline. Now the size and extent of the herniation can be identified (Fig. 32.14). If it is a "free" peridural fragment, it is gently mobilized and removed. Removal of disc material leads to a "release" of the spinal nerve and facilitates further decompression. We try to avoid using hooks which exert permanent pressure on the nerve. It is less traumatizing using the blunt tip of the surgical sucker to intermittently pushing the nerve away from the target area. Now, decompression can be completed in the craniolateral part with less risk of damage to the traversing nerve root (Fig. 32.15). The extent of cranial decompression depends on the topographic localization of the superior border of the disc space as well as on the cranial extension of the disc herniation. Intraforaminal herniations usually extend cranial and lateral to the disc space (see also Chapter 34). This affords a wider resection of caudal and lateral parts of the superior lamina. However, care should be taken not to resect the isthmus between the superior and inferior articular facet which might result in segmental instability. There is an increasing risk for destruction of the isthmic region if the decompression is extended more then 10 mm into the superior lamina (Fig. 32.16).

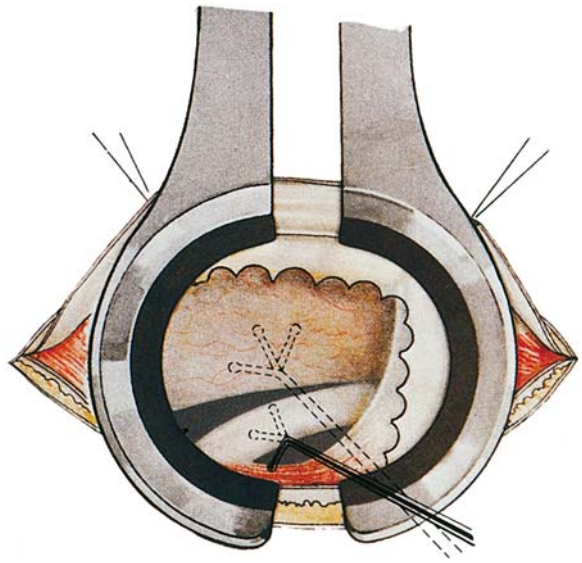


Fig. 32.15. Completion of subarticular decompression

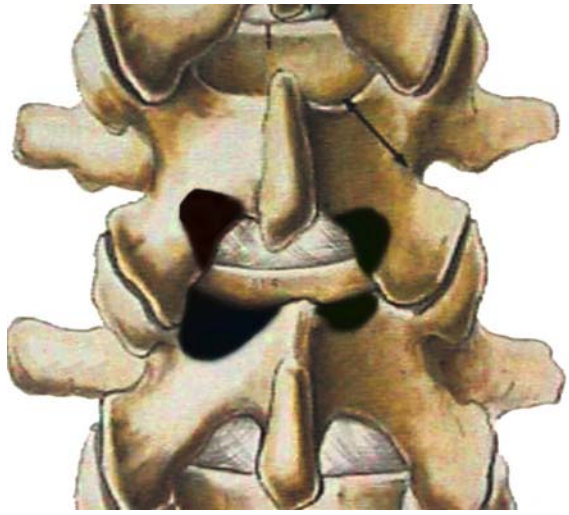
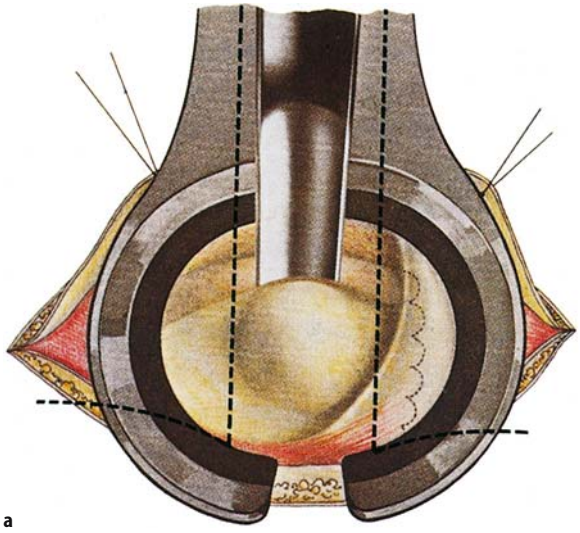


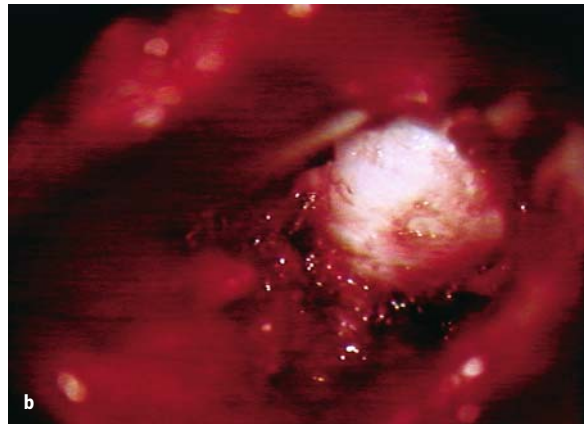
Fig. 32.16. Extent of decompression (watch the isthmus!)

32.9.1.8 Removal of the Herniated Disc

Removal of the disc material is achieved in different ways depending on the size, configuration, and extent of the disc herniation.



a



b

Fig. 32.14. a Exposure of the disc herniation (with permission of Aesculap). **b** Exposure of the disc herniation intraoperative view

32.9.1.8.1
Disc Protrusions ("Contained" Disc Herniations)

This type of herniation is the domain of percutaneous discectomy procedures (see Chapters 35, 37). According to the indication criteria generally accepted, it is rarely seen in "open" surgical exposures. However, since the disc herniation is not perforated, it should be a surgical principle to limit opening of the disc space to a minimum. In these cases, the posterior longitudinal ligament as well as the anulus fibrosus are opened with one incision parallel to the disc space. Thus a slit is created which is enough to perform intradiscal decompression. Removal of nucleus pulposus is started with the smallest rongeur (1.5 mm) and continued with the medium-sized (2.5 mm) straight and angulated forms. At the end of removal of the herniated and loose parts of the nucleus pulposus, the slit can be closed with one resorbable inverting suture.

32.9.1.8.2
"Perforated" Herniations (Extrusions)

In theses types of herniations, the outer limits of the anulus fibrosus and/or the posterior longitudinal ligament are ruptured ("non-contained" disc herniations). After removal of the perforated part of the herniation, the disc space is opened extending the incision from the perforation to the posterolateral circumference. Here again, the anulus can be sutured if technically possible.

32.9.1.8.3
"Epidural Fragments"

Usually, the fragments are removed first. In most of the cases, there is still continuity between the fragment and the perforation in the posterior anulus. We prefer removal of the nucleus pulposus in these cases to decreases the risk of recurrent herniation. Sometimes, especially in older herniations, the fragment is dislocated from the perforation which might be closed or covered with scar tissue in the meantime. We believe that, in these patients, removal of the fragment might be sufficient.

32.9.2
Surgical Technique in Recurrent Disc Herniation

32.9.2.1
Preoperative Planning

The principles of preoperative planning are basically the same for first and second or third operations in the same motion segment. However, additional considerations have to be made before starting the operation:

- Preoperative X-ray films should be "read" carefully to find out the amount and configuration of bone removal (e.g., hemilaminectomy, partial facetectomy) in order to be prepared for the bony landmarks during the approach to the motion segment.
- A preoperative MRI should include examination with and without gadolinium in order to be able to evaluate the size of the "true" recurrent herniation within the epidural scar tissue. There is always epidural scar tissue accompanying or covering the recurrent disc herniation. MRI can show edema of the spinal nerve distal to the compression/adhesion. Take care to exclude a "new" disc herniation at another (adjacent) level. Carefully evaluate the lateral recess region and determine the necessity and amount of bony decompression.
- Look for scar tissue along the approach track to the spinal canal. In patients not operated on using a microsurgical technique, there is usually significant scar tissue in the paravertebral muscles covering the interlaminar space.
- Look for pseudomeningocele! Sometimes, there is no information available from the first operation. You can never be sure that the dura has remained intact.
- Look for Modic I changes in the adjacent vertebral bodies! If a recurrent disc herniation is associated with Modic I findings, and if the patient has low back pain contributing significantly to his complaints (> 50 %), we would prefer to combine microsurgical rediscectomy with segmental stabilization (instrumented fusion).
- Spinal CT scan is not routinely used in recurrent herniations because it does not give information additional to MRI. However, the configuration of the facet joints as well as the osseous borders of the central spinal canal and the lateral recess can be evaluated.
- We do not see hard indication for lumbar myelography or discography in recurrent herniations.

32.9.2.2
Positioning of the Patient

See Section 32.9.1.2.

32.9.2.3
Localization

Do not rely on the scar in the back. Even if the first operation was a microsurgical procedure, the localization of the scar may be superior or inferior to the disc space. The reason for this is that you do not know how the patient was positioned during the first operation. For example, if, for the first operation, the lumbar spine was in less kyphosis than during the recurrent operation,

the scar will localize inferior to the approach track. So we strongly recommend localization as described above.

32.9.2.4 Approach to Skin–Interlaminar Space

The approach from skin to fascia is the easiest part of the operation. Sometimes you will find non-resorbable sutures of the fascia. *Beware*: Non-resorbable sutures are sometimes used to prevent late CSF fistulas in case of dural tears. So be prepared during dissection of the scar tissue close to the interlaminar window.

- The fascia is cut as describe above.
- In case of scar tissue within the paravertebral muscles, this scar tissue is retracted by subperiosteal dissection with a sharp Cobb-type elevator. I recommend to start retraction on the hemilamina above or below the interlaminar space depending on the amount of laminotomy which has been performed at the first operation.
- Thus, first the hemilaminae bordering the interlaminar space are exposed. These are the most reliable landmarks.
- Dissection is continued laterally using different types of elevators, dissectors, and rongeurs to identify and expose the facet joint (or the remains of it).
- Then the speculum is inserted as described above.

32.9.2.5 Approach to the Spinal Canal and Exposure of the Nerve Root

The approach to the spinal canal is the most difficult and hazardous part of this operation. First, the scar tissue covering the interlaminar space is "thinned-out" layer by layer down to the level of the laminae. Do not go deeper than the laminar level to avoid dural laceration (Fig. 32.17)! The scar which covers the posterior and medial parts of the spinal canal is not responsible for the clinical symptoms!

- Entry into the spinal canal is performed from the superior border of the interlaminar space. Using a high-speed burr, the caudal border of the supradjacent lamina is identified. A diamond drill is used to thin out the inferior part of the lamina. Thus, the interface between bone and scar tissue (or remnants of yellow ligament) can be exposed. With a blunt-tipped dissector, the scar tissue is dissected from the inner surface of the lamina, and an entrance for a small (2 mm) Kerrison rongeur is created. Stepwise resection of the inferior parts of the lamina will then expose "healthy" dura superior to the target area (Fig. 32.18).

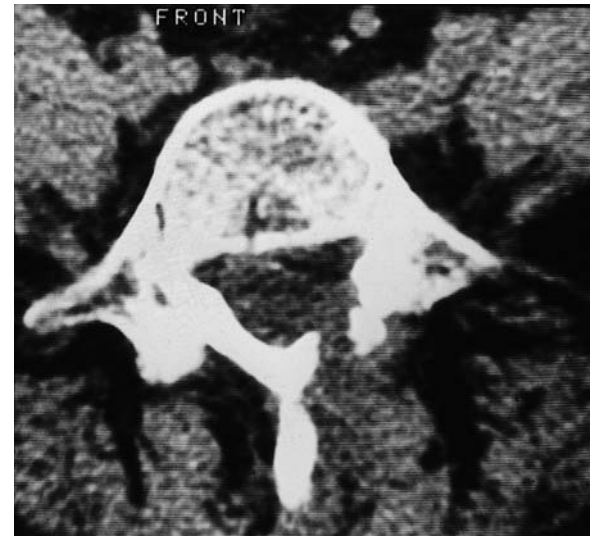


Fig. 32.17. Dissection of scar tissue down to the level of the lamina. Do not go deeper than the lamina



Fig. 32.18. Resection of inferior parts of lamina to expose "healthy" dura. *s.t.* Scar tissue, *d* dura, *l* lamina

- If bony resection is completed from 3 to 6 o'clock within the surgical field, the superior part of the lateral recess can be entered staying lateral to the shoulder of the nerve root (Fig. 32.19). The key for safe dissection is always the orientation to bony structures and the dissection of the fibrotic tissue from the inner surface of the osseous structures bordering the spinal canal.
- Dissection is continued along the shoulder of the nerve thus decompressing the lateral recess. This can be achieved with only slight manipulation as long as removal of scar from the nerve root sleeve is not attempted.
- The inferior borderline for safe dissection is the pedicle. The spinal nerve can be gently dissected from the medial border of the pedicle and decompressed. Usually the epidural scar tissue ends caudal to the pedicle at the entrance into the foramen.

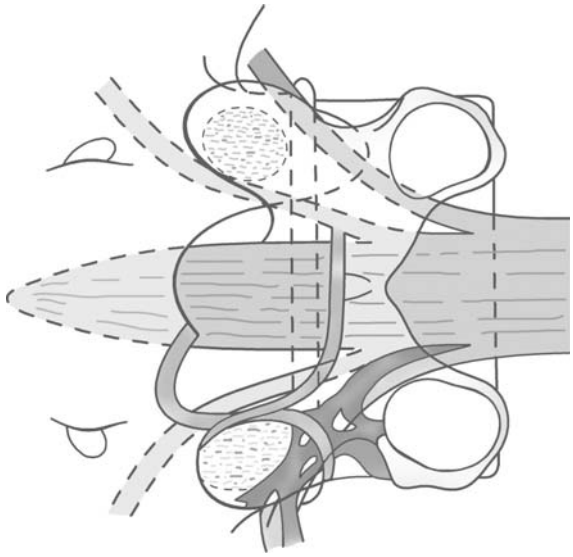


Fig. 32.19. Decompression along the superior lateral border of the lateral recess

- The spinal nerve is now exposed and decompressed from its root sleeve exit to its entrance into the foramen. However, it might still be covered with scar tissue. We do not recommend performing external neurolysis in the posterior and lateral circumference of the nerve.

32.9.2.6 Removal of the Herniated Disc

- The next step is mobilization of the nerve from the posterior aspect of the disc space. In most cases, there is significant scar tissue which strongly adheres the spinal nerve and the thecal sac to the "floor" of the spinal canal. Dissection is continued carefully with angulated, blunt microdissectors to separate the neural structures from the underlying scar and/or disc herniation. In true recurrent herniations, it is safer to leave a thin layer consisting of scar tissue and the remains of the posterior longitudinal ligament and anulus fibrosis between the theca and the herniation. This means that the scar tissue is opened lateral to the shoulder of the nerve and the recurrent herniation is entered directly with a blunt microdissector. The herniation thus can be mobilized and removed from underneath the fibrous layer adherent to the dura. In the majority of cases, the recurrent herniation contains endplate material [1].

32.9.3 Hemostasis

At the end of nucleus pulposus removal, meticulous hemostasis must be achieved. Please avoid leaving Gelfoam or other types of hemostatic agents in the spinal canal. If there is epidural bleeding or oozing of blood, try to tamponade the veins temporarily with Gelfoam or Surgicel, irrigate with cold saline solution, and wait. Be patient, since most epidural bleedings will stop after a couple of minutes. Then carefully remove the hemostatic agents. Very often, the fragile epidural veins adhere to the Gelfoam or Surgicel. The result is recurrent bleeding while removing the hemostatic agents. This can be avoided by removal of the Gelfoam or Surgicel pieces under continuous irrigation which mollifies the adherences. In case of severe bleeding from the central venous plexus (Batson) gel- or powder-type hemostatic agents can be used (e.g., FloSeal; Baxter Healthcare, Fremont, CA, USA, or Arista; Medafor, Bad Wiessee, Germany) can be used.

32.9.4 Closure of the Anulus

In subanular disc herniations, the anulus should be opened in a way which allows resuturing of the anular flaps. If there has already been a perforated disc herniation, the rest of the anulus can be adapted and closed with one or two microsurgical inverting sutures. Usually a 5 – 0 non-resorbable suture with a TF-4 small radius needle can be used (Fig. 32.20). This can be achieved in about 20 – 50 % of all patients. Although there is now proof that suturing the anulus prevents early recurrences, the author believes that readapting the ends of the anulus fibrosus can promote and support the low healing potential of this structure.

If there is enough epidural fat tissue, it is mobilized with microsurgical dissection and used to cover the spinal nerve in order to diminish the risk for adherent epidural fibrosis. Two neuroswabs are placed into the spinal canal during closure of the fascia with resorbable sutures. This avoids blood from the paravertebral muscles dripping into the spinal canal during closure. Before the last suture is closed, the swabs are removed.

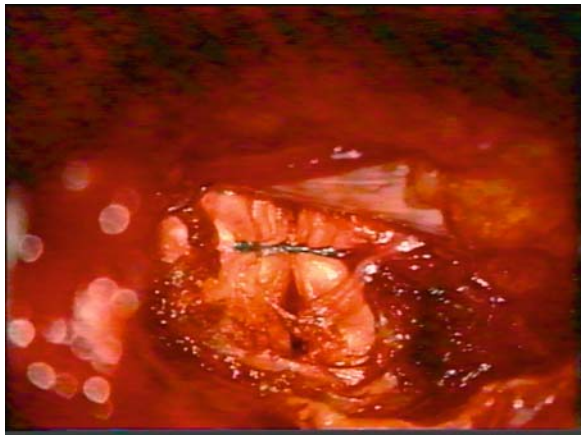


Fig. 32.20. Inverting suture of the anulus fibrosus after discectomy (L4-5 right side). Note the traversing L5 nerve root

One of the subcutaneous resorbable sutures is fixed to the superior fascial layer to avoid subcutaneous seroma formation. The skin is closed with a monofilament resorbable intracutaneous suture.

32.10 Postoperative Care

The patient is allowed to mobilize 6 hours after the operation. From the first postoperative day isometric exercises are performed. However, we recommend to restrict postoperative physiotherapy to a minimum in the first 2 – 3 weeks following the operation. Patients are instructed to mobilize themselves ad libitum, i.e., they are allowed to carry out all activities which do not cause or worsen low back pain and/or sciatica. Thus, the postoperative course is determined by the patients themselves. Postoperative hospitalization ranges between 1 and 8 days depending on the individual case. From the medicolegal point of view, the procedure can be performed on an outpatient basis. However, in our own experience we can not recommend it since control of early postoperative complications as well as postoperative pain management within the first 24 hours can best be performed within the hospital.

32.11 Complications

Overall complications of microsurgical discectomy range between 1.5 % and 15.8 % in the literature with an average of 7.8 % [6, 7, 12 – 14]. There are significantly less severe intraoperative complications as compared to non-microsurgical discectomies [15]. The same is true for the rate of postoperative spondylodiscitis which averages 0.8 % (versus 2.8 % for macrosurgery) in a study published in 1986 [5].

The most important as well as the most frequent complications are listed below [9, 15]:

- Urinary retention (5 %)
- Perineural fibrosis (3 %)
- Superficial wound infection (2 %)
- Dural tears (1 %)
- Deep venous thrombosis (1 %)
- Postoperative segmental instability (1 %)
- Disc space infection (< 1 %)
- Missed pathology (< 1 %)
- Root injury (< 1 %)
- Lesions due to positioning (< 1 %)
- Cauda equina syndrome (< 0.1 %)
- Retroperitoneal blood vessel injury (< 0.1 %)
- Epidural hemorrhage (< 1 %)

32.12 Critical Evaluation

The most frequently used arguments against microsurgery are aimed at the technical aspects. It is often stated that microdiscectomy requires longer OT times as compared to conventional surgery. This is true, but only for surgeons not trained in microsurgery and at the beginning of their learning curve [11]. Wrong level exploration as well as the rate of early recurrences (which can be an indicator for "missed" fragments in the spinal canal) do not show a significantly different rate as compared to non-microsurgical techniques. There are no technical or clinical limitations for the use of the microscope in lumbar disc herniation. This is also true for the treatment of disc herniations which are associated with other types of pathology such as lateral recess of central spinal canal stenosis [9]. There is no evidence from the literature that the frequency of complications is higher in microsurgical discectomy. However, it has been proved that the number of severe intraoperative complications was significantly higher when no microscope was used [15] (see above).

There is of course no direct relationship between the clinical long-term result and the surgical technique. This fact erroneously leads to the statement that the microsurgical technique is simply "not necessary." However, this is in contradiction to the basic philosophy of all surgical specialties which commits us to achieve a good clinical and technical result with the least iatrogenic trauma.

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The Translaminar Approach

33

L. Papavero

33.1 Terminology

The anatomical unit of the lumbar spine is a vertebral body and the disc below. According to McCulloch [2] we can imagine a three-storied anatomical house: the first storey is the disc level, the second storey is the foraminal level, and the third storey is the pedicle level. Without any exception the second storey, i.e., between the upper rim of the disc space and the lower border of the cephalic pedicle, is covered by the lamina (Fig. 33.1).

33.2 Surgical Principle

If we compare a disc fragment extruded underneath the lamina of the second storey to a fish on the bottom of a frozen lake, there are two methods to get it hooked.

The first one is to cross the surface with an icebreaker and to start to angle … This is similar to the standard interlaminar exposure with flavectomy and partial resection of the facet joint and/or of the lamina which allows for targeting a cranially extruded disc herniation. However, the potential consequences of extensive resection of bone and yellow ligament are segmental instability and more or less extensive scar tissue. After surgery both can result in increased axial-loading back pain.

The second option would be to cut a small hole in the frozen surface exactly targeted on the fish and to cast the line. If the disc fragment is extruded cephalad into the spinal canal or especially into the root canal encroaching the exiting root, the translaminar approach (TLA) sparing partial facet joint resection and conventional flavectomy corresponds to this latter method of fishing.

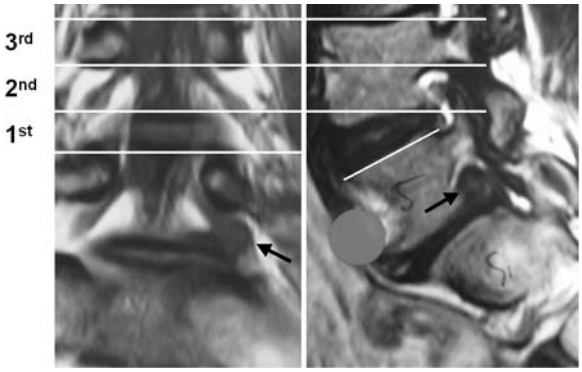


Fig. 33.1. Lumbar disc herniations (LDHs) which extrude cephalad into the second storey are the best indication for the translaminar approach. An example at the L5/S1 level is shown (*black arrows*)

33.3 History

There are only a few papers dealing with the topic of the TLA. Di Lorenzo et al. [1] proposed the approach in 1998. The comments of the reviewer were quite skeptical: the (suspected) technical difficulty of the procedure, the (assumed) inability to clear the disc space, and the risk of early or late fracture of the pars interarticularis were seen as important limitations of the technique. In 2002, Soldner et al. [3] published their positive experience with 30 patients. Although this time the description of the surgical technique was appreciated by the reviewers, the issue of long-term stability was questioned thoroughly.

33.4 Advantages

- Facet joint and yellow ligament are mostly preserved
- Bypassing of the scar tissue when dealing with a cephalad recurrent herniation in a case operated previously via an interlaminar route (Fig. 33.2)
- Integrity of the yellow ligament when dealing with a first-storey recurrent disc herniation in a case previously approached via the TLA

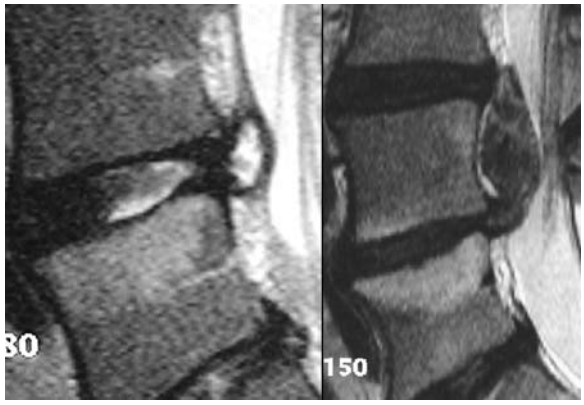


Fig. 33.2. *Left* First-storey LDH successfully approached via a microsurgical interlaminar approach L4/L5. *Right* Three years later a huge recurrent herniation was completely removed via a TLA to L4

33.5 Disadvantages

- MRI desirable for surgical planning
- Keyhole target area requires microsurgical skills
- Bayoneted microinstruments (optional)

33.6 Indications

The best indication for the TLA is a second-storey extruded disc fragment, ideally when it pushes the exiting root upward against the lower border of the pedicle (Fig. 33.3). Some huge and caudally dislocated, so called "mid-vertebral body" fragments can also be approached (Fig. 33.4). When previous disc surgery has been performed via an interlaminar access, then a second-storey recurrence may be treated with TLA.

33.7 Contraindications

Severe spinal canal stenosis is a contraindication for TLA because of the lack of an adequate lamina. The same holds true for malformations, such as spina bifida.

In the case of a foraminal disc herniation, the bulk of the fragment should be between two lines marking the medial and lateral borders of the superior facet. Disc material located more laterally should be approached through a paraspinal approach.

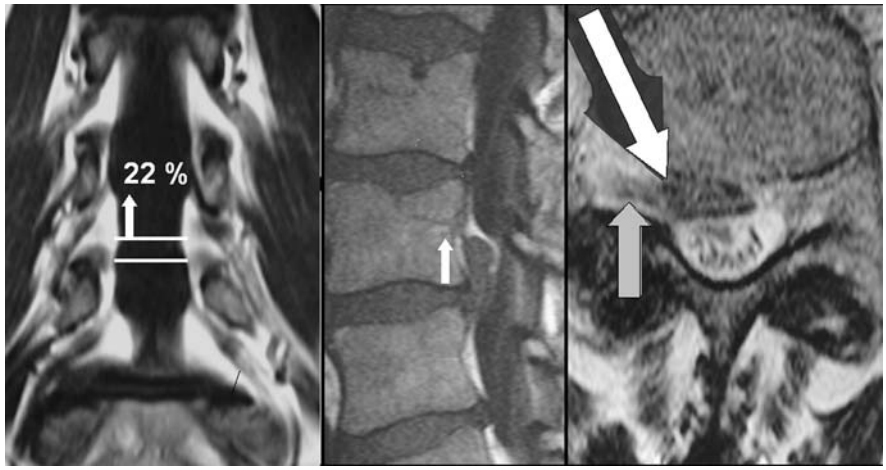


Fig. 33.3. *Left* About 22 % of LDHs migrate cranially encroaching the exiting root. *Center* Sagittal T1-weighted image shows at the L4/L5 level a "typical" disc fragment suitable for the TLA. *Right* Axial T2-weighted slice: the intraforaminal compression of the exiting root L4 (*gray arrow*) by the extruded disc fragment (*white arrow*) is evident

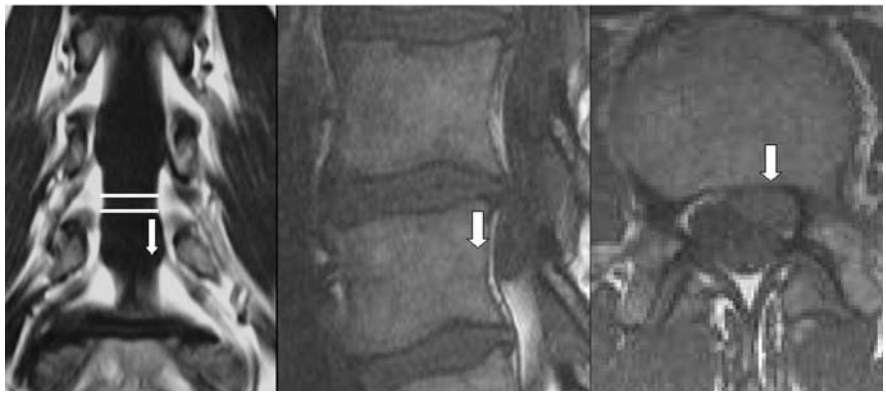


Fig. 33.4. *Left* Caudally extruded disc fragments (*white arrows*), so called third-storey LDHs, can also be approached via the TLA. *Center* Sagittal T1-weighted image shows an exemplary finding. *Right* Axial T1-weighted slice confirms the encroachment of the L5 root. Remark: the MRI axial slice shows the cross-section of the pedicle in the third-storey LDH where does it not in the second storey!

33.8 Patient's Informed Consent

The patient should be informed that in case of necessity the TLA could be widened to a laminotomy with partial facet joint resection corresponding to the conventional interlaminar approach. There are no specific complications related to the TLA.

33.9 Surgical Technique

When planning the TLA, the following anatomical details should be kept in mind: the width and the overlapping of the lamina in relation to the disc space increase in the caudal-cephalic direction, whereas the width of the isthmus decreases. This means that the translaminar hole will be more medially and more oval-shaped in the cranial direction (Fig. 33.5).

33.9.1 Anesthesia

The same anesthetic set-up as for any other surgery of lumbar disc herniation would be appropriate.

33.9.2 Positioning

It is up to the surgeon to choose between genupectoral, kneeling, or prone frame-supported position. Anatomical remark: the lumbar laminae are oblique in the sagittal plane, i.e., they "dive" in the caudal-cephalic direction. Attention should be paid to compensate for this fact, at least partially, by tilting the operating room table in a "head upwards" direction. The advantages of a horizontal target lamina are twofold: the placement of the retractor blade and the drilling of the hole become easier (Fig. 33.6).

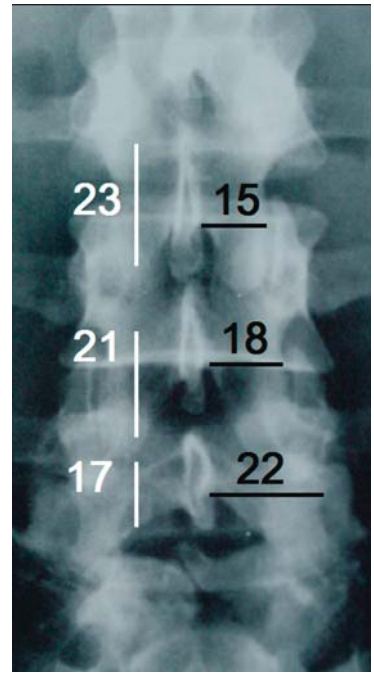


Fig. 33.5. The height of the lamina and its overlapping onto the disc space increases (*white numbers* in mm) in the caudal-cephalic direction whereas the width of the isthmus decreases (*black numbers*)

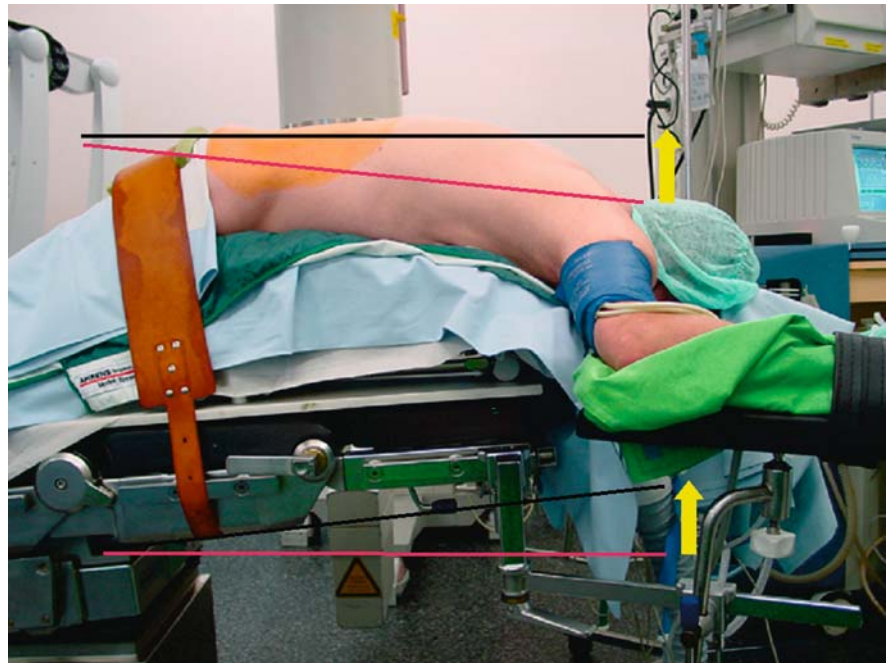


Fig. 33.6. Care should be taken to reduce the natural oblique inclination of the laminae in the caudal-cephalic direction (*red line*) by tilting the table "head-upwards" in order to get an approximately horizontal "laminar plane" (*black line*)

33.9.3 Radiographic Labeling

Since the surgical corridor to the target area is limited, the location of the skin incision has to be determined very accurately. Two skin marks are recommended in lateral fluoroscopy:

1. The equator or the upper border of the disc space
2. The upper rim of the extruded disc fragment as shown by the MRI or as calculated on the axial CT scans

The distance between the two marks is usually up to 12 mm. Care should be taken to insert the needle exactly perpendicular to the horizontal spine. Once the surface of the lamina has been approached, looking at the twin skin drawings will enable the hole to be drilled exactly centered on the region of interest (Fig. 33.7).

33.9.4 Approach

The skin incision should be about 15 mm off the midline and centered on the twin marks. Provided the radiographic labeling is correct, a strictly vertical approach will lead to the lamina.

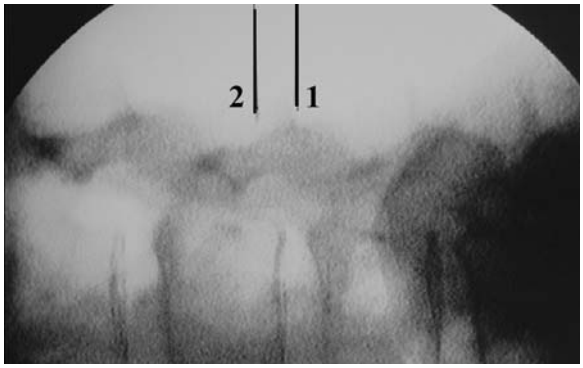


Fig. 33.7. The fluoroscopic marking of the disc space (*1*) and of the cephalad extruded disc fragment (*2*) should be drawn on the skin. Once the lamina has been exposed the skin marks should be projected onto the lamina itself

Two options are given:

1. The subperiosteal route along the lateral surface of the spinous process requiring the incision of some of the tendinous insertions of the multifidus muscle. A Caspar- or Williams-type retractor is then inserted.
2. The transmuscular route by bluntly splitting the multifidus muscle with the index finger. A tubular retractor (15 mm diameter) is inserted and fixed with a holder arm.

Irrespective of the kind of speculum used, the lateral border of the lamina should be visible underneath the retractor valve. At the beginning of the learning curve it is useful to duplicate the skin marks onto the lamina prior to insert the retractor.

33.9.5 Microscopic Decompression

At this point the lamina should have been tilted parallel to the floor, so that the cutting burr can be held more easily perpendicular to the lamina. With slow circular movements a round (L5) or oval-shaped (L4 and cephalad) hole of about 10 mm in diameter is made. Three layers, "white" (= outer cortical bone), "red" (= spongy bone), and "white" (= inner cortical bone), will be drilled off. For the sake of safety the inner cortical bone should be drilled with a diamond burr (Fig. 33.8). Remarks:

1. At least 3 mm of the lateral border should be spared in order to avoid a fracture of the pars interarticularis (Fig. 33.9).
2. Usually the translaminar hole is located just cephalad to the cranial insertion of the yellow ligament. So, after removal of the thin shell of inner cortical bone with small punches epidural fat will appear.

The epidural exploration starts with the up and down dissection of the fat along the lateral border of the thecal sac. That should be continued cephalad up to the axilla of the exiting root. Usually at this stage extruded or

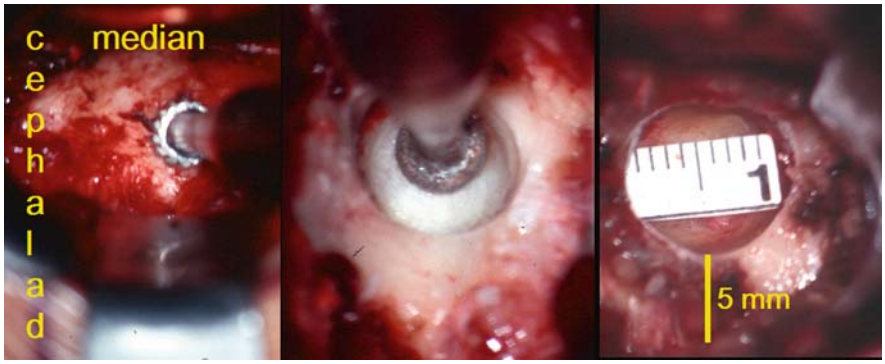


Fig. 33.8. *Left* The outer cortical and the spongy bone can be drilled off with the cutting burr. *Center* The inner cortical bone is removed with the diamond burr. *Right* Usually a 10-mm-diameter hole provides an adequate exposure of the lateral thecal sac and of the axilla of the exiting root. In our series at least 3 mm of the border of the pars interarticularis was spared. No fracture of this bony structure occurred

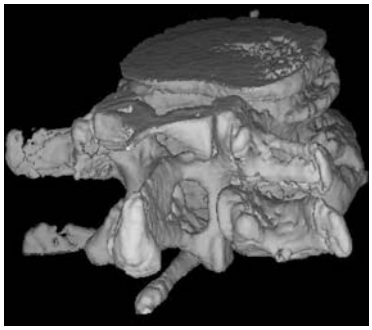


Fig. 33.9. The three-dimensional CT shows how the shape of the hole becomes more oval at the L2 lamina compared with the more caudal L5 (Fig. 33.8)

subligamentous disc fragment(s) can be mobilized. After decompression the root slips caudally into the visible field (Fig. 33.10). The root canal is probed with a double-angled hook.

If an extensive annular perforation is detected the disc space should be cleared. In our experience that was required in only 20% of cases. The rate of recurrence was 4%.

33.9.6 Wound Closure

The wound closure is quite straightforward. Gelfoam soaked with long-acting steroid to fill in the hole is optional, but should be avoided if the disc space has been cleared.

33.10 Postoperative Care and Complications

The patient can be mobilized the day of surgery. In the series of the first 30 patients, plain X-ray films were performed routinely 6 and 12 months after surgery in order to reveal segmental instability caused by a fracture of the pars interarticularis. The findings were negative without exception. Nowadays radiological investigations are only performed in symptomatic patients.

Based on our experience with 63 patients treated by the TLA the following complications have been listed:

1. Wrong level surgery (2): This occurred at the beginning of the learning curve and was corrected intraoperatively. After introduction of the "twin marks" labeling access to the wrong level was no longer a problem. Tilting of the operating room table in order to direct the lamina absolutely parallel to the floor further minimizes this risk.
2. Dura tears (4): The particularly thin axillary dura should be handled very carefully during dissection of adherent disc fragments. Due to the narrow access gluing a patch on durotomy is the best working solution.
3. Enlarging the hole to conventional laminotomy (4): Although not exactly a complication, this change of strategy becomes necessary whenever a significant annular perforation is detected on the caudal half of the disc space, especially at the L5/S1 level.
4. Recurrent disc herniation (2): The low incidence is more than acceptable, considering that in only 20% of the patients the disc space has been cleared.

33.11 Results

Sixty-three patients (37 men, mean age 54 years) mostly presenting an exiting root syndrome underwent the TLA. The lamina at L4 (27) and L3 (19) was frequently involved. At surgery extruded (61%) and subligamen-

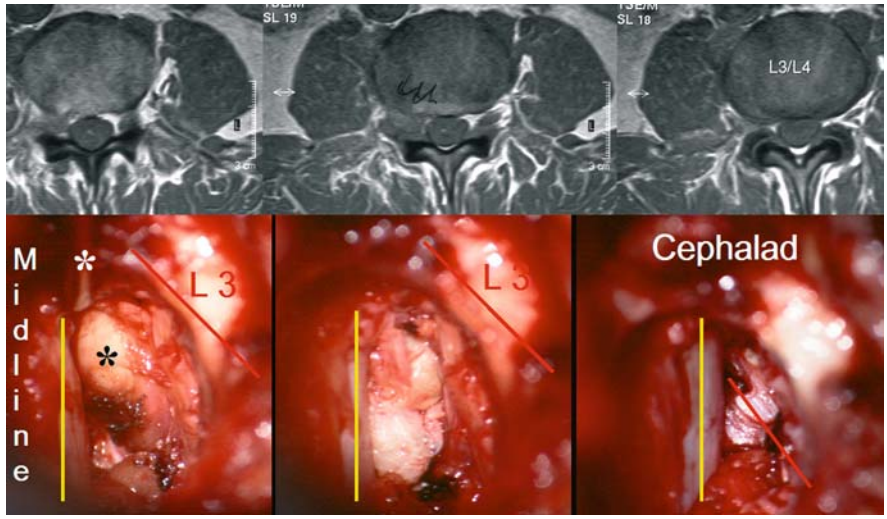


Fig. 33.10. *Top* T1-weighted axial images show a second-storey disc fragment migrated cephalad and impinging severely the root L3 into the canal. *Bottom left* The dissector (*white asterisk*) moves along the lateral border of the thecal sac (*yellow*) and uncovers the huge fragment (*black asterisk*) which is located in the axilla of the root L3 and pushes it cranially against the pedicle. *Bottom center* The "capsule" has been opened. *Bottom right* After removal of the herniated disc material the root L3 relaxes back in its normal location

tous (39%) disc fragments were found. In 4 cases the translaminar hole was enlarged to a laminotomy and in 12 patients the disc space was cleared.

An independent observer performed follow-up examinations at 1 and 6 weeks, 3, 6, and 12 months, and once yearly thereafter (mean follow-up 22 months). The outcome was excellent (complete relief of symptoms) in 59%, good (mild discomfort not requiring medications) in 33%, fair (better than preoperative, but functional limitations requiring medication or bracing) in 6%, and poor (no better than preoperative) in 2%.

The unsatisfactory results were related to the postoperative persisting back pain, as in patients complaining about a facet joint syndrome. In these cases the MRI showed a black disc with a significant spontaneous or postsurgical reduction of the height of the intervertebral space. Facet block injection relieved the symptoms in most of the patients.

33.11.1 Special Case 1

A 65-year-old woman underwent an instrumented fusion at L4/L5 in 1999 because of severe load-depending back pain. The postoperative course was satisfactory until 3 years later. A sudden right-sided L3 syndrome with motor deficits prompted an MRI which showed a second-storey disc herniation at L3/L4. The TLA allowed for removal of the fragment skipping the scar tissue. Recovery was excellent, and 6 months after surgery plain X-Ray films showed a partial bony closure of the translaminar hole (Fig. 33.11).

33.11.2 Special Case 2

A 70-year-old man became unable to walk because of a severe weakness of the right thigh. The roots L3 and L4 were both affected. The sagittal MRI image showed a combined impingement of these roots due to simultaneous second-storey lumbar disc herniations L3/L4 and L4/L5. After removal of the extruded disc fragments via a two-level TLA the patient recovered partially and could walk with the help of a cane (Fig. 33.12).

33.11.3 Special Case 3

In a 72-year-old man affected by Parkinson disease the muscular dysbalance and the scoliotic deformity required the preservation of the right facet joint L2/L3. The huge cranially extruded disc fragment causing a severe palsy of the iliopsoas muscle was removed via a TLA (Fig. 33.13).

33.12 Critical Evaluations

Is it useful to perform a TLA if a cephalad migrated disc fragment encroaching the exiting root can be approached via the conventional microsurgical interlaminar route? In this context we could also ask if microsurgery in itself is necessary at all, taking the point that a satisfactory decompression of the root can also be obtained by conventional disc surgery. It is the author's firm belief that the combination of correct indication for (micro)surgery along with the least access trauma leads to rewarding clinical results. It is important to notice that less invasive surgical techniques are characterized by a more "straightforward" approach to the target area, bypassing the exposition of anatomical structures merely seen as landmarks. The transmuscular insertion of pedicle screws gives an idea of this philosophy.

The TLA fulfils both requirements and can be recommended as the route of choice for the specific sub-

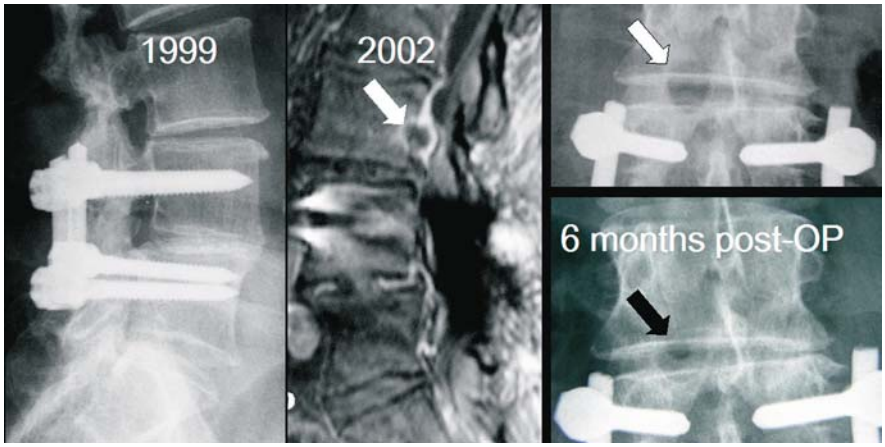


Fig. 33.11. *Left* The plain film shows a regular instrumented fusion. *Center* The sagittal MRI picture shows a second-storey LDH L3/L4 (*white arrow*) impinging the exiting root L3. *Top right* TLA hole after surgery (*white arrow*). *Bottom right* Partial concentric bony closure of the hole (*black arrow*)

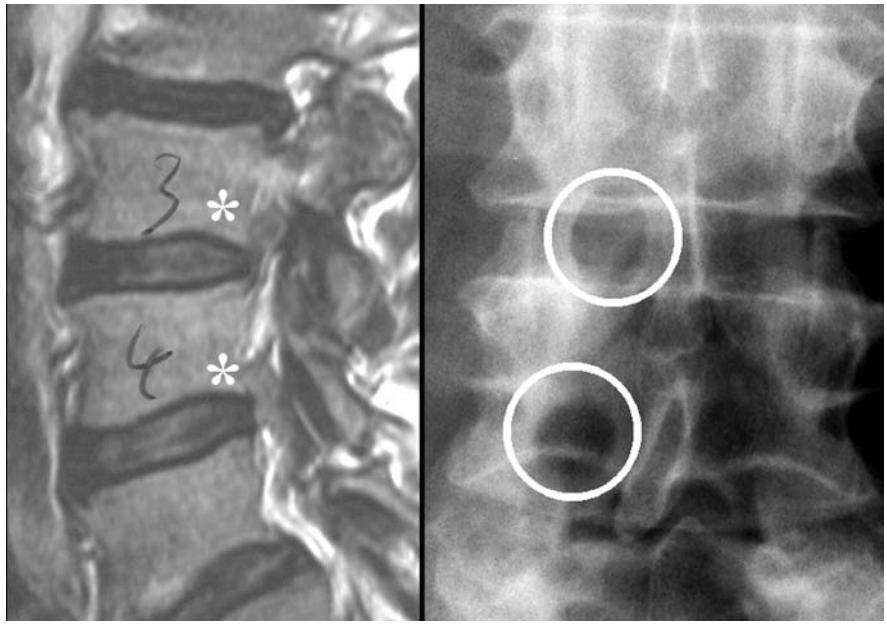


Fig. 33.12. *Left* T1-weighted sagittal image shows adjacent second-storey LDHs. *Right* Plain film after surgery

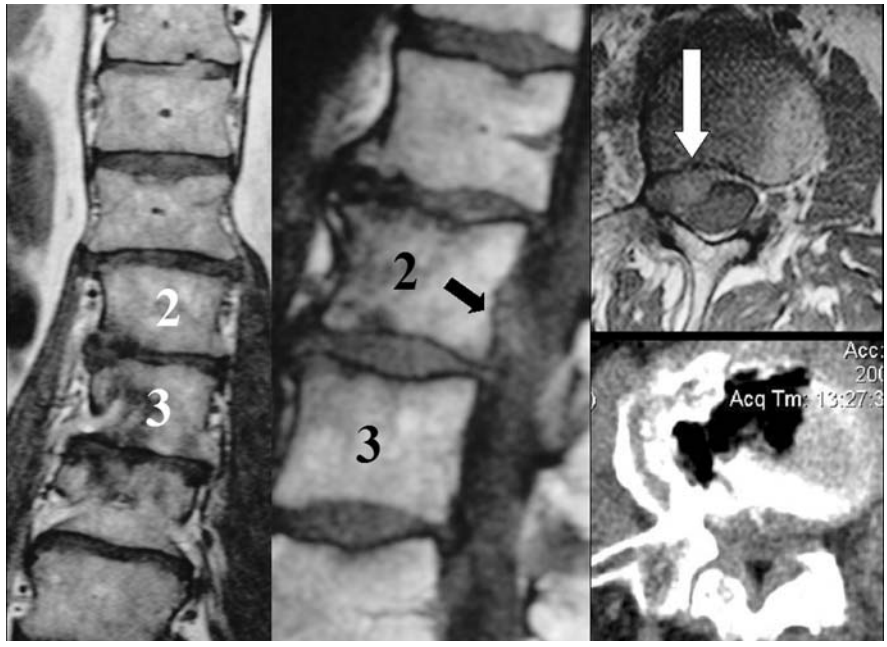


Fig. 33.13. *Left* Coronal T1-weighted image depicting the kyphotic angulation L2/L3 and the severe degeneration of the disc. *Center* The same finding on lateral slice. *Top right* Axial T1-weighted image showing the root impingement. *Bottom right* After surgery CT confirms that the facet joint L2/L3 has been spared also on the right side

group of cranially extruded disc fragments. However, keyhole surgery should not be an end in itself, therefore switch to conventional laminotomy whenever problems should arise!

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34 The Lateral, Extraforaminal Approach

L. Papavero

34.1 Terminology

Various terms have been proposed to define an anatomical subgroup of lumbar disc herniations. Definitions such as extreme lateral [11, 22, 28, 30, 31], far lateral [10, 13, 14, 20, 35], extraforaminal [17, 21, 27], and extracanalicular [33] are used synonymously. Equally, different nomenclatures such as far out zone, extracanalicular zone, extraforaminal zone, hidden area [19], and lateral interpedicular compartment [30] define the paraspinal area where these herniations occur.

To put it simply, we assume that the lumbar roots leave the spinal canal through a bony tunnel which looks like an alphorn (Fig. 34.1a). The rostral circumference is delineated by the pedicle and the dorsal by the pars interarticularis of the superior vertebra. The narrow medial entrance corresponds to the lateral recess. The wide oval-shaped exit is the intervertebral (or neural) foramen. The alphorn becomes longer and increasingly horizontal from the upper to the lower lumbar vertebrae [37] (Fig. 34.1b).

For the purposes of this chapter extraforaminal disc herniations (EFDHs) are defined as those ruptured lat-

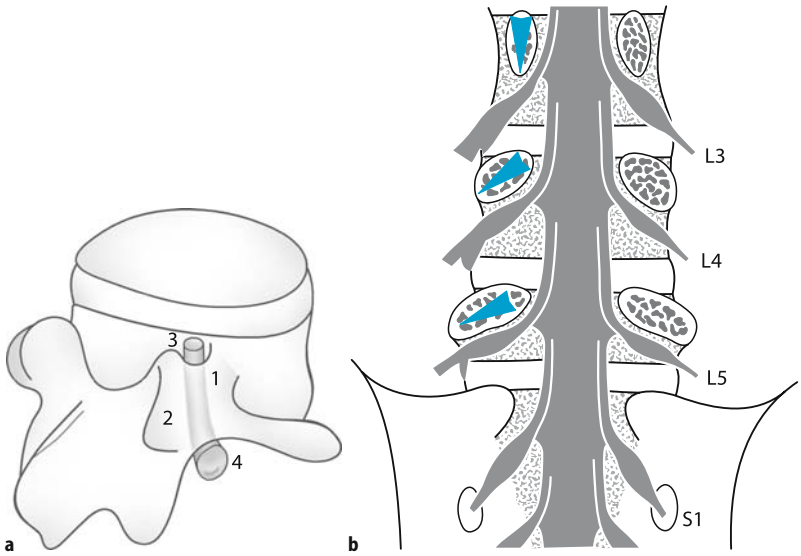


Fig. 34.1. a *1* Pedicle, *2* pars interarticularis, *3* lateral recess, *4* extraforaminal area (from [37]) **b** The horizontal width of the pedicles increases in the caudal direction and their orientation becomes more horizontal (*arrowheads*). An extraforaminal disc herniation always encroaches the nerve which exits at the same level

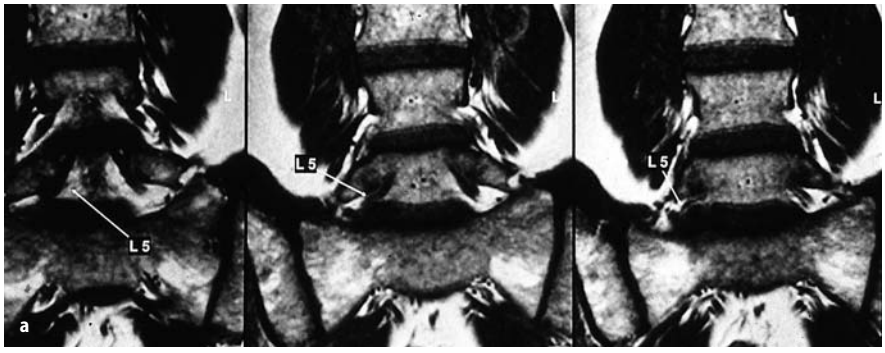


Fig. 34.2. Magnetic resonance imaging (MRI) shows a right-sided extraforaminal disc herniation (EFDH) at L5/S1, where the coronal slice shows how the EFDH encroaches the nerve (**a**), and the axial slice confirms that the location of the disc herniation is lateral from the pedicle (**b**; *asterisk*)

eral to the pedicle and compressing the nerve which exits at the same level, for example, an L5/S1 EFDH causes an L5 root compression (Fig. 34.2a, b).

The microsurgical muscle-splitting approach is indicated whenever the disc prolapse is completely out of the intervertebral foramen or at least two thirds lateral to the pedicle.

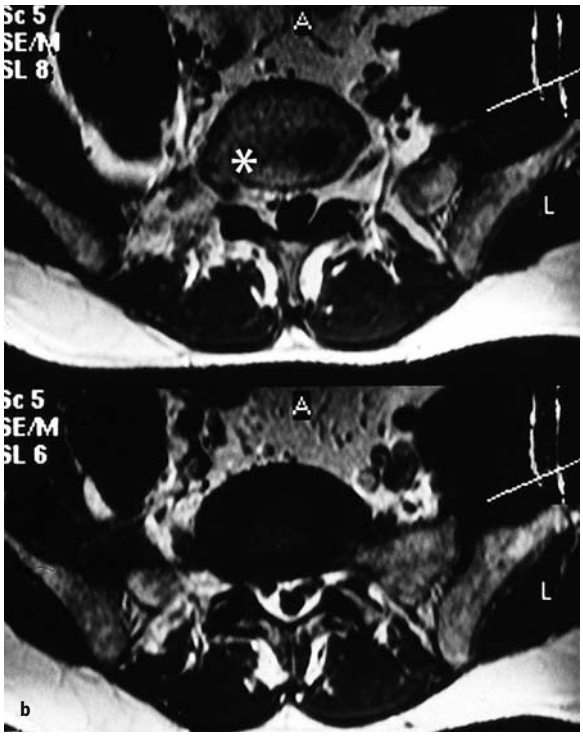


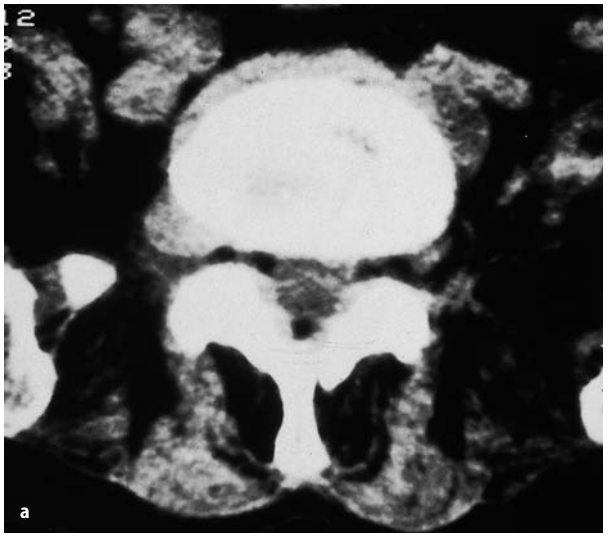
Fig. 34.2 b (contin.)

34.2 Surgical Principle

Most EFDHs are disc fragments extruded cephalad to the interspace of origin [15, 24, 30]. The aim of a minimal traumatizing surgical approach is to remove selectively the compressing lesion with preservation of the functional anatomy, i.e., of the facet joint.

In order to achieve this goal, the combined use of several tools has proved helpful.

1. CT or MRI provide a precise localization of the EFDH (Fig. 34.3a–c). However, it has been reported



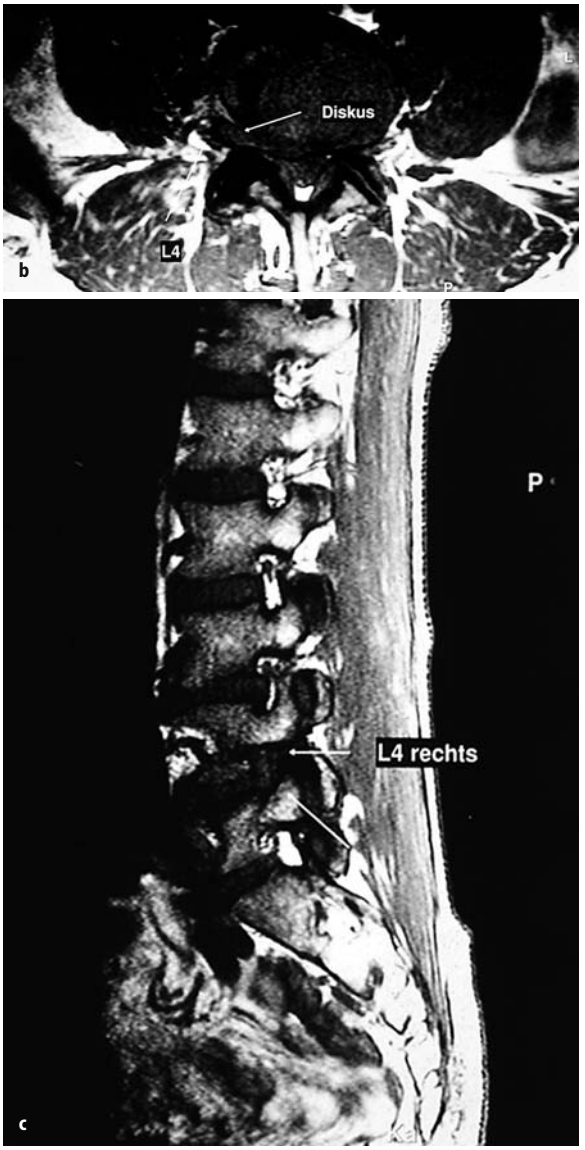


Fig. 34.3. a Axial computed tomography of L5/S1 showing EFDH on the right side. The left L5 root crosses the extraforaminal fat. **b** MRI showing a right-sided EFDH of L4/L5. The comparison of both extraforaminal areas on the axial scan shows a displacement of the paraspinal fat on the right side. Furthermore, the cleavage plane between the multifidus and the longissimus muscle (L4) is evident. It provides a straightforward approach to the target area. **c** Sagittal scan. The complete displacement of the periradicular (L4 right) fat leads to the "dark" appearance of the foramen

that nearly one third of EFDHs are overlooked on CT/MRI [24]. This rate of misdiagnosis has been confirmed by our experience. The failure to detect EFDH leads to suboptimal surgical procedures with poor postoperative results. Therefore, an accurate radiological diagnosis is the first step in planning the paraspinal microsurgical approach. These findings should be looked for carefully [24]:

(a) Disc material lateral to the neural foramen or in continuity with the lateral disc margin (Fig. 34.3b).
(b) Displacement of paraspinal fat. Split the axial scan in half and compare both extraforaminal areas (Fig. 34.3b). Also compare the lateral sagittal scans left and right looking for a "dark" neural foramen (Fig. 34.3c)
(c) Add an investigation of the L2/L3 level, if the lower discs appear normal on CT, as 46% of EFDHs occur at the L2/L3 and L3/L4 levels!

2. An accurate preoperative X-ray labeling of EFDH, as described below, allows a straightforward muscle-splitting approach to the target area, without the necessity of locating any bony landmark from the beginning of the procedure (Fig. 34.4).
3. The use of the microscope offers the advantages of a powerful coaxial illumination along with a comfortable magnification and, most importantly, a three-dimensional visualization at a distance of only 20 mm, instead of the natural interocular distance of 64 mm. This requirement becomes essential when we have to reach the EFDH at 7 – 9 cm surgical depth via a skin incision of 4 cm.
4. Instruments specially designed for lumbar microdiscectomy make the careful dissection of the small vascular and neural structures from the extruded fragment easier.

34.3 History

In 1944 Lindblom [18] described disc herniations outside the spinal canal in a cadaver study, but the clinical relevance of this finding was not suspected at that time. Echols and Rehfeldt in 1949 recognized EFDH as a source of failed lumbar discectomy [7]. Scaglietti and Fineschi reported in 1962 a series of 24 EFDHs operated on between 1957 and 1960 [34]. Interestingly, it was the negative surgical exploration of the assumed herniated disc as well as of the adjacent discs cranially and caudally that led the authors to resect the facet joint and to dissect the extraforaminal part of the nerve root. The location of EFDHs was described carefully and their role in the 5% incidence of "negative" intraoperative findings in lumbar disc surgery was well understood. As characteristic features of this subgroup of lumbar herniations they stated the fact that the diagnosis of EFDH can never be made preoperatively (which held true at that time!) and that EFDH can never cause an S1 radiculopathy (which still holds true!).

In 1971 Macnab also reported two cases of L5 root compression due to an EFDH L5/S1 discovered after a failed exploration at L4/L5 [19]. The ball started rolling. In 1974, Abdullah and coworkers clearly correlated the clinical picture of a mostly upper lumbar root syndrome with the discographic finding of an "extreme lateral" disc herniation [1]. The clinical and imaging identity of EFDH was recognized, but a surgical route specifically tailored for this herniation outside the vertebral canal was still lacking. Operative techniques for EFDH (Fig. 34.5) consisted usually in an interlaminar approach extended laterally via a subtotal [1, 2, 8, 10, 16, 17, 19, 28] or total [1, 3, 16, 19, 28] facetectomy. Later on, the paramuscular approach using a midline skin incision long enough

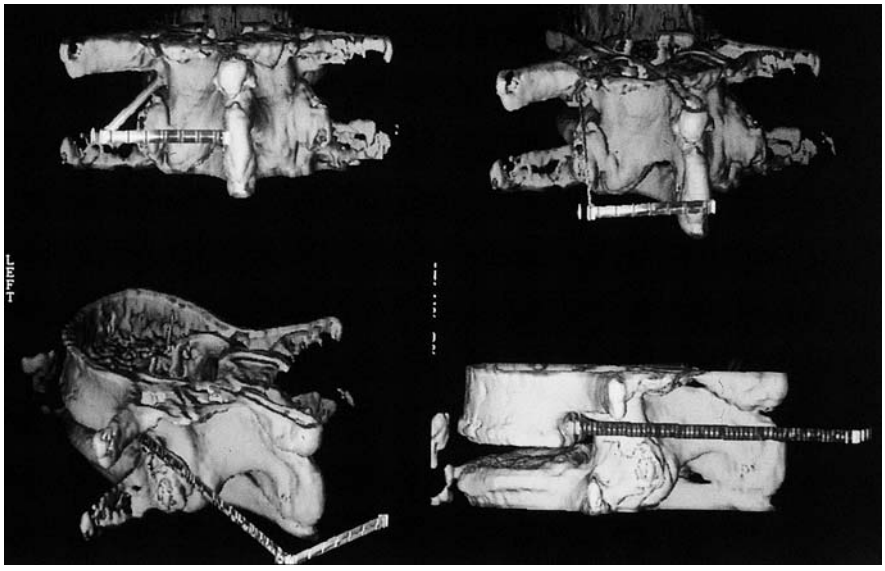


Fig. 34.4. Three-dimensional computed tomography showing the spatial relationship between spinous process (midline), paramedian skin incision, and the muscle-splitting approach leading to the extraforaminal target area

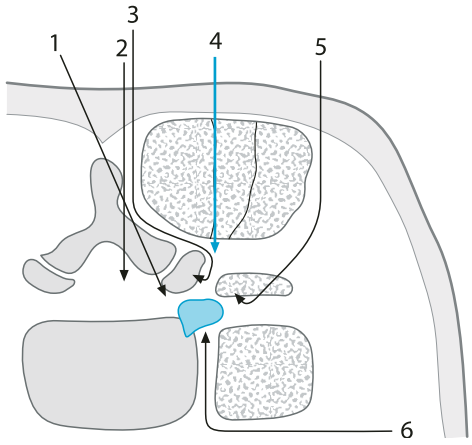


Fig. 34.5. The various surgical routes to the EFDH can be classified into three groups, intraspinal approaches (*1*, *2*), paraspinal approaches (*3*–*5*), and the retroperitoneal approach (*6*)

to allow a retraction of the paraspinal muscles lateral to the facet joint [14, 15, 35, 36] was reported. The minimal amount of bony resection needed to reach the extraforaminal compartment and the familiar surgical anatomy were advocated as advantages of this procedure.

The paraspinal muscle-splitting approach was originally used for lumbar ganglionectomy in chronic pain syndromes [25] and for posterolateral fusions [38]. The modifications for the microsurgical approach to the EFDH will be presented here.

The retroperitoneal route to EFDH [7] in our view represents a surgical overtreatment of a benign disease.

Developments in spinal endoscopy allow for percutaneous removal of EFDH with a working channel technique [29]. Further studies are still required to assess the clinical value of this method [4, 32].

34.4 Advantages

- Straightforward approach to the herniation
- Excellent exposure of the extraforaminal compartment
- Microscopic dissection of the nerve and its vessels from the disc fragment
- Bony resection usually limited to hypertrophied facets and to the L5/S1 level
- Minimal soft tissue traumatization

34.5 Disadvantages

- Accurate preoperative X-ray labeling is necessary
- Skills in microsurgery are essential
- The learning curve, especially at the L5/S1 level

34.6 Indications

Extraforaminal disc herniations located at least two thirds lateral to the pedicle.

34.7 Contraindications

Foraminal disc herniations located more than two thirds inside the (intervertebral) root canal.

34.8 Patient's Informed Consent

Most of the complications of this procedure do not differ from those of the more common intraspinal microdiscectomy.

The possibility of postoperative burning neuropathic pain mimicking roughly the radicular distribution of the decompressed nerve should be mentioned. This usually resolves within several days, but in rare cases may persist for up to 6 months. This is probably caused by the sensitivity of the ganglion entrapped in the canal during the dissection of the nerve from the extruded disc fragment.

The facet distress syndrome consisting of low back pain with pseudoradicular irradiation burdens the patients more often following an L5/S1 procedure. At this level, adequate bone removal to expose the far lateral compartment requires generous drilling of the facet joint.

The recurrence rate for EFDH reported in the literature is about 5 % [9, 15]. Unsatisfactory relief of radicular pain can occur in 20 % of the cases [9].

34.9 Surgical Technique

The key points of the procedure are described in following sections.

34.9.1 Anesthesia

General endotracheal anesthesia is recommended. The reasons are not only safe control of the patients airways and hemodynamics, but also the possibility of prolonging operation time, if difficulties should arise, without any discomfort for the patient and the surgeon. As single-shot prophylaxis against infection, 1 g cephazoline is administered intravenously 20 min before the skin incision.

34.9.2 Positioning

A genupectoral, kneeling, or prone frame-supported position is left to the surgeon's preference. The freely hanging abdomen reduces venous congestion and "opens up" the intertransverse space, allowing for a better approach to the external rim of the root canal.

34.9.3 Radiographic Labeling of the Disc Herniation (e.g., L3/L4 on the Left Side)

The use of a C-arm can be recommended in order to save time.

34.9.3.1 Lateral View

Marking is performed on the side contralateral to the intended skin incision (Fig. 34.6) to prevent both CSF flow and hematomas on the surgical track. Insert a spinal needle one finger's breadth lateral to the spinous process, perpendicularly to the skin and projecting toward the lower rim of the affected disc space. Draw a horizontal line at this level (Fig. 34.6 *A*). Now switch the C-arm into the AP view. A blunt K-wire is placed on the same side of the intended skin incision as shown in Fig. 34.6 (*bottom*) and the following lines are drawn:

1. Two horizontal lines
   (a) The lower border of the affected disc space (this line should be identical with the previous marking in the lateral view; Fig. 34.6 *A*)
   (b) The lower border of the transverse process above the affected disc (Fig. 34.6 *B*)
2. Two vertical lines
   (a) The midline (row of the spinous processes; Fig. 34.6 *C*)
   (b) A line about 4 cm off to the midline, marking the lateral boundary of the pedicle above and below the affected disc (Fig. 34.6 *D*)

The distance between the two horizontal lines (AB) is the skin incision and will be 3–4 cm in length and about 4 cm paramedian (Fig. 34.7a).

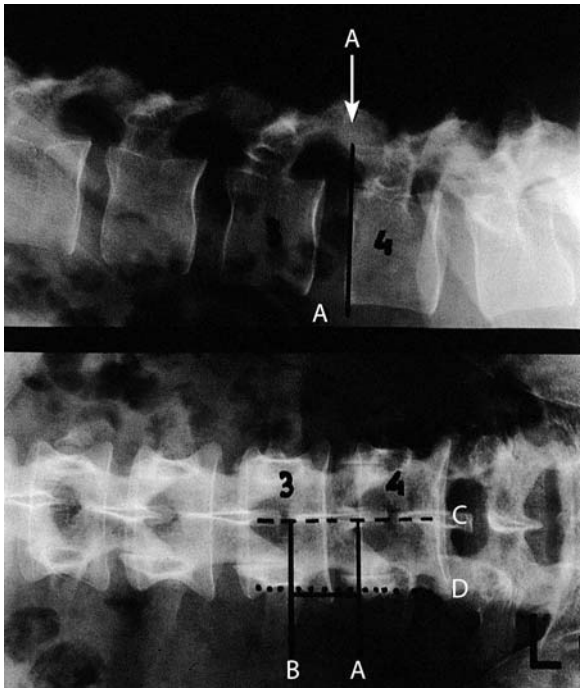


Fig. 34.6. Preoperative radiographic labeling of an extraforaminal disc herniation L3/L4 on the left side. *Top* Lateral fluoroscopic view. *Bottom* AP view with the patient already positioned

34.9.4 Soft Tissue Dissection

Extraforaminal disc herniation surgery at L3/L4 on the left is shown in Fig. 34.7. The second cut is through the subcutaneous tissue and the posterior layer of the thoracolumbar fascia (Fig. 34.7b). After longitudinal incision of the erector spinae aponeurosis, the musculature is dissected bluntly using the index finger along the cleavage plane between the multifidus and the longissimus muscle (Fig. 34.7c). If this fibrous separation cannot be palpated, the muscle is split downward to the lateral tips of the transverse processes. The medial third of the transverse processes is now exposed. A modified Caspar lumbar speculum-retractor system (Fig. 34.7d) is then introduced. The appropriate length of the speculum is selected so that the tips rest firmly on the transverse processes, thereby exposing the upper and the lower border of the situs.

The longer lateral blade of the retractor holds the longissimus thoracis muscle aside. The shorter medial self-locking blade rests on the dorsal aspect of the facet joint and effectively retracts the multifidus muscle thus enabling the inspection of the extraforaminal compartment. The lower half of the upper transverse process and the upper half of the lower one are exposed. The lateral surface of the pars interarticularis represents the medial border of the surgical exposure. The tips of the transverse processes are the lateral boundary (Fig. 34.7e). An intraoperative lateral radiographic check at this point of the procedure is essential. By introducing this step we were able to cut down our rate of wrong level exploration to zero. At the L5/S1 level the fluoroscopic control provides additional information of how much bone has to be removed from the ala in order to approach the outer foramen.

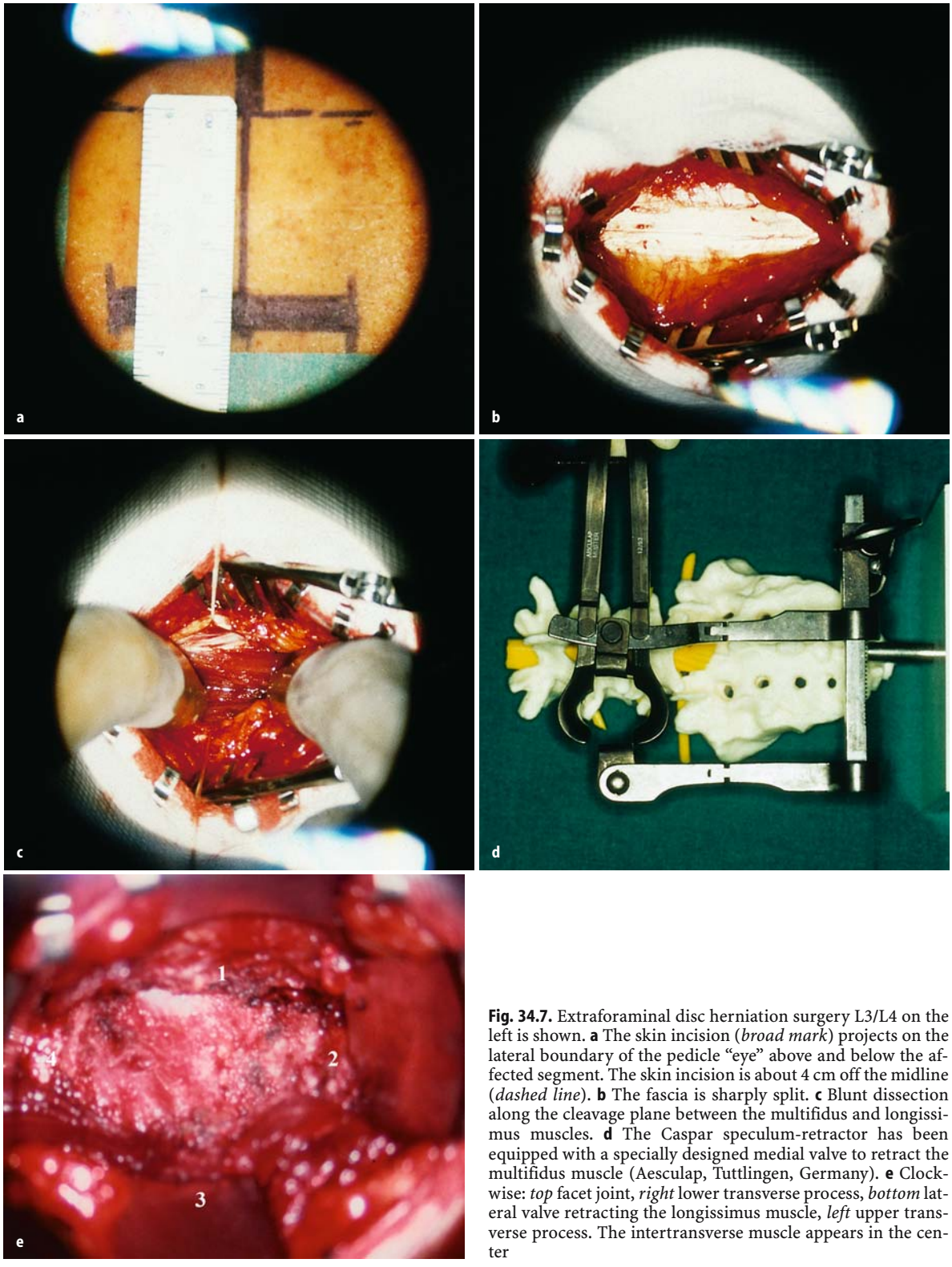


Fig. 34.7. Extraforaminal disc herniation surgery L3/L4 on the left is shown. **a** The skin incision (*broad mark*) projects on the lateral boundary of the pedicle "eye" above and below the affected segment. The skin incision is about 4 cm off the midline (*dashed line*). **b** The fascia is sharply split. **c** Blunt dissection along the cleavage plane between the multifidus and longissimus muscles. **d** The Caspar speculum-retractor has been equipped with a specially designed medial valve to retract the multifidus muscle (Aesculap, Tuttlingen, Germany). **e** Clockwise: *top* facet joint, *right* lower transverse process, *bottom* lateral valve retracting the longissimus muscle, *left* upper transverse process. The intertransverse muscle appears in the center

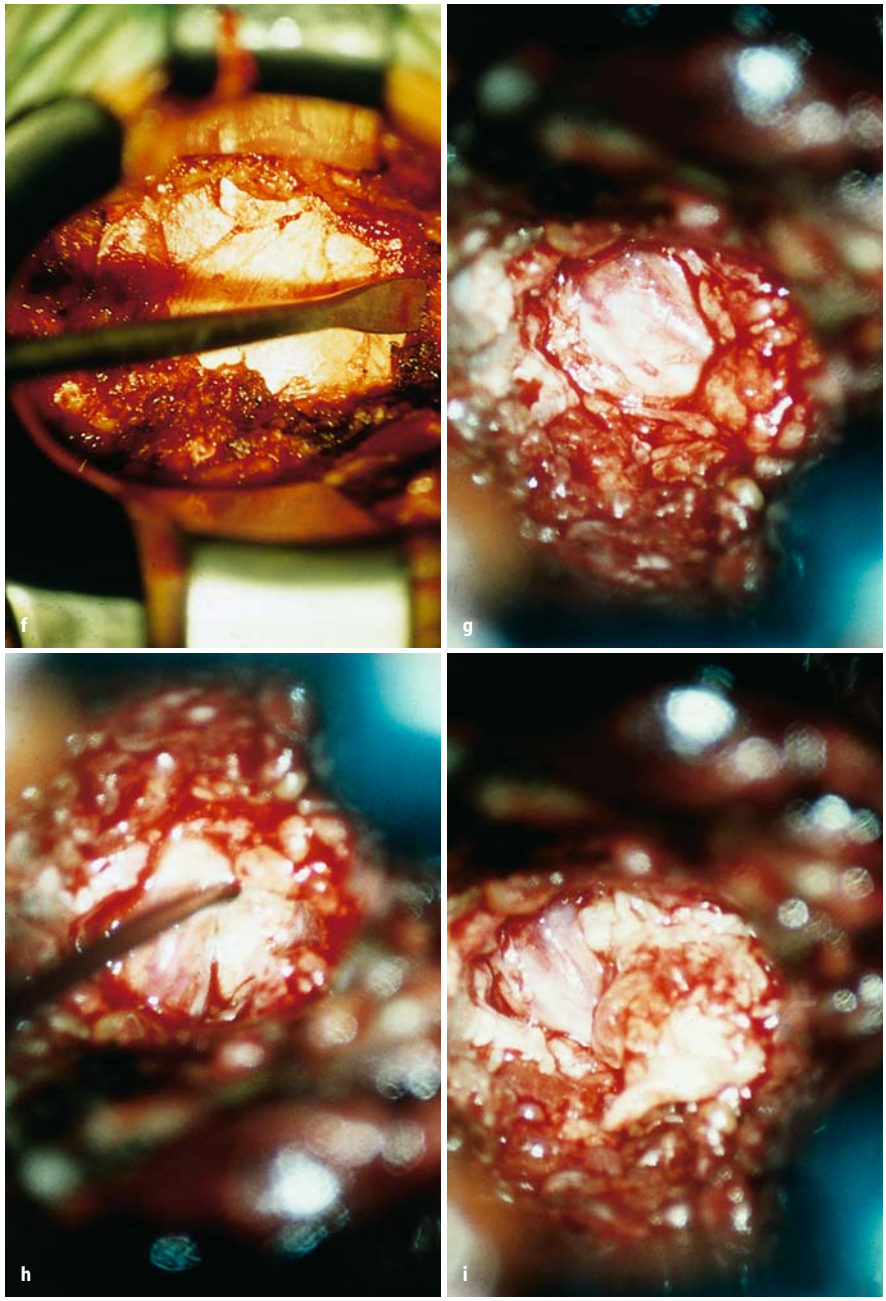


Fig. 34.7. (cont.) f After its incision, the intertransverse membrane or ligament is dissected. **g** Following the incision of the intertransverse membrane, the nerve L3 looks severely stretched (**h**) by an extruded disc fragment lying underneath. **i** Removal of the huge disc herniation

34.9.5 Microscopic Decompression

The use of the microscope and of bipolar coagulation is optional to this point of the procedure, but imperative when proceeding. Tilting the operating room table by 15 – 20° away from the surgeon is another key point because this gives a better view of the area lateral of the pedicle (Fig. 34.8).

Drilling off bone is not usually necessary, except in the case of an extremely hypertrophied facet joint or at the L5/S1 level. An arcuate cautery line on the cranial-lateral part of the joint capsule labels the amount of bone to be resected. After sharp incision and removal of some of the capsule, bone is burred with a long and angled drill-handpiece. Diamond dust-coated burrs are recommended for bone removal in proximity to the dorsal ganglion. The medial half of the intertransverse muscle is incised and pushed laterally, thereby exposing the intertransverse membrane, also called the "intertransverse ligament" (Fig. 34.7f). After incision, the fat surrounding the nerve appears.

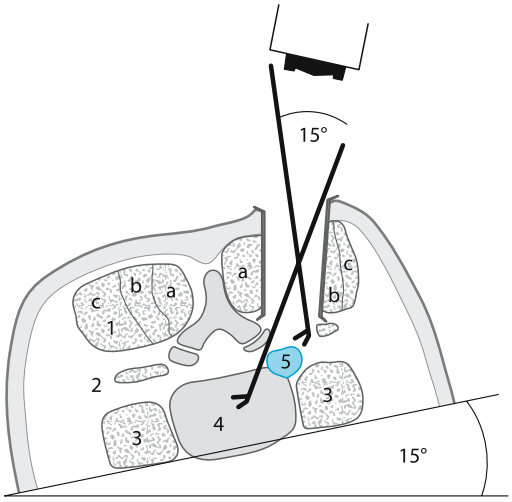


Fig. 34.8. The combined tilting of the microscope and of the operating room table facilitates the overview of the extraforaminal area, mostly avoiding any bony removal from the facet joint. *1* M. sacrospinalis, *a* m. multifidus, *b* m. longissimus, *c* m. iliocostalis, *2* m. intervertebralis, *3* m. psoas major, *4* intervertebral disc, *5* disc herniation

Because of the close proximity of the nerve, the accompanying vessels, and the herniation (Fig. 7g, h), the sucker should also be used as a nerve retractor.

However, beware of an excessive retraction of the dorsal ganglion in order to minimize the incidence of postoperative burning dysesthesias!

Branches of the lumbar artery should be dissected carefully and spared whenever possible. The accompanying veins can be cauterized if they hinder the access to the disc fragment.

Typically, we find the nerve and the ganglion pushed laterally and cranially by the mostly free disc fragment. As a rule, removal of the fragment alone is sufficient (Fig. 34.7i). If an extensive perforation of the anulus is evident, we recommend additionally clearing the disc space. Due to the preservation of the facet joint and of the ligamentous elements, a surgically induced instability is most unlikely. After probing the root canal with a double-angled blunt hook for residual fragments, the nerve may be covered with Gelfoam soaked with crystalline steroid.

34.9.6 Wound Closure

Placing a drain is optional and in our experience seldom necessary. The musculature requires no suturing, and the fascia and the aponeurosis are closed by absorbable stitches.

34.9.7 Special Considerations for the L5/S1 Level

Because of the particular anatomical relationship between disc space, transverse process L5, and ala, the microsurgical muscle-splitting approach at the lumbosacral level should be practiced only by a surgeon who is familiar with the technique. Repeated intraoperative fluoroscopic checks may also be necessary. If difficulties should arise, switching to the conventional "macro-approach" should be considered.

34.10 Postoperative Care

Ambulation to the toilet is permitted the evening of surgery and physical therapy from the following day. The duration of hospitalization in Germany ranges from 3 to 7 days, depending on the financing modalities of the hospital. Wearing a brace is not necessary. The patients return to work usually 6 weeks following surgery (Fig. 34.9a, b).

34.11 Complications

Data on complications following the muscle-splitting approach are still lacking in the literature.

In our early series of 30 patients, the wrong level was initially explored in three procedures and of these, two patients required revision surgery. After introducing the intraoperative radiographic check, no revision surgery had to be performed in the following series of 156 patients. In about one quarter of the L5/S1 approaches, the fluoroscopic control of a probe in position confirmed the interspace L4/L5. The source of error may sometimes be due to the palpable "adhesion" of the transverse process L5 to the ala, so that the transverse process L4 is misinterpreted as the most caudal one.

In the unfortunate case shown in Fig. 34.10, the intraforaminal disc herniation L4/L5 (Fig. 34.10 *left*) was an erroneous indication for the muscle-splitting approach. Not only was the wrong level, L3/L4, exposed, but also a subcutaneous abscess developed (Fig. 34.10 *right*). After successful drainage, the disc herniation was removed 8 weeks later via an interlaminar route.

Two patients developed a spondylodiscitis which resolved under bed rest and antibiotic therapy.

Spinal instability occurred in one patient resulting from an overly extensive resection of the L3/L4 facet joint at the beginning of our learning curve. The postoperative low back pain was resistant to conservative treatment, but resolved after interbody fusion and transpedicular screw fixation.

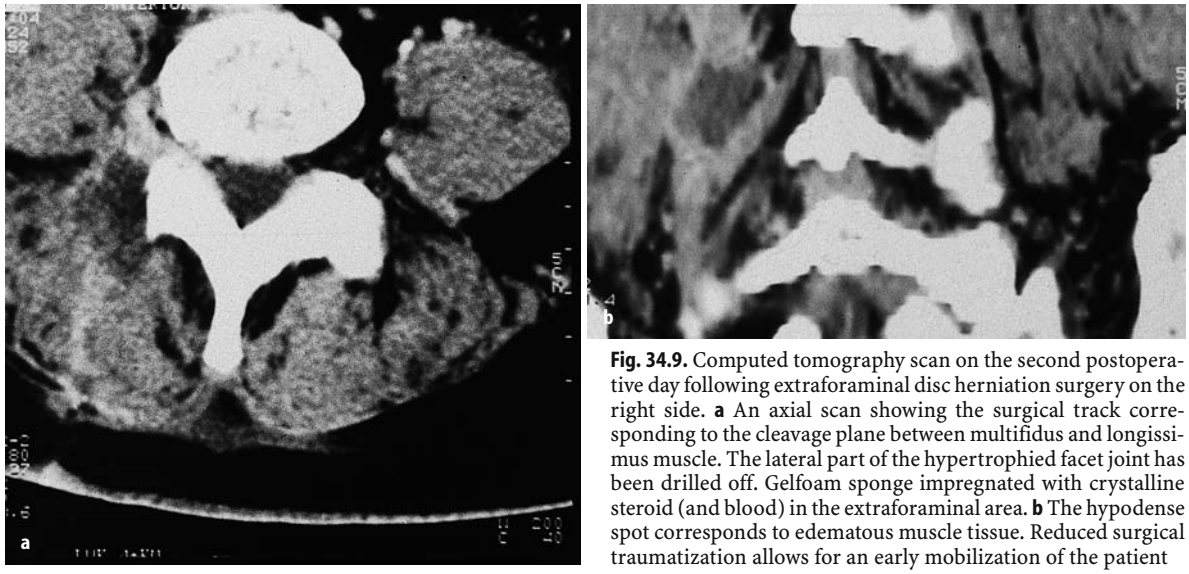


Fig. 34.9. Computed tomography scan on the second postoperative day following extraforaminal disc herniation surgery on the right side. **a** An axial scan showing the surgical track corresponding to the cleavage plane between multifidus and longissimus muscle. The lateral part of the hypertrophied facet joint has been drilled off. Gelfoam sponge impregnated with crystalline steroid (and blood) in the extraforaminal area. **b** The hypodense spot corresponds to edematous muscle tissue. Reduced surgical traumatization allows for an early mobilization of the patient

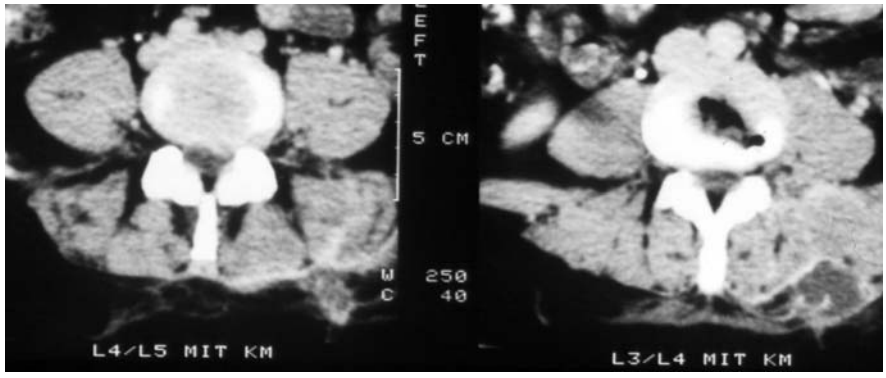


Fig. 34.10. Intraforaminal disc herniation L4/L5 on the left side (*left*). Because intraoperative fluoroscopic control of the approached segment was not carried out, the wrong level L3/L4 was explored. Additionally, a subcutaneous abscess developed (*right*)

Four patients required surgery for true recurrent herniation. Relapses always occurred in the first postoperative year and were not correlated with clearing the disc space at the first operation. We felt that dissecting the scars in the extraforaminal compartment was more demanding than in the spinal canal. Here, the medial surface of the pedicle facilitates the identification of the root.

34.12 Results

Although a comparison of the results in the literature (Table 34.1) is hampered by the different lengths and the various modalities of the follow-up, there is some consensus concerning the outcome data. Speaking in general terms, the outcome is rated as excellent if all preoperative symptoms are relieved and the patient is able to carry on with daily occupations without impairment. A minimal persistence of symptoms which do not interfere significantly with patient's work is defined as a good result. If only some of the preoperative symptoms resolve and the patient's physical activities are significantly limited, the clinical status has to be defined as fair. Obviously, a poor condition is given when symptoms and signs are unchanged or worse than before treatment. As a rule of thumb, we can expect that half of the patients will enjoy an excellent result and one third a good result, whereas one tenth will have to accept a fair outcome and the rest (7%) will be disappointed after surgery (Table 34.1).

Table 34.1. Outcomes in EFDHs treated with the muscle-splitting approach

Author and year	Number of cases	Outcome (%)			
		Excellent	Good	Fair	Poor
Darden et al. (1995) [5]	25	48	32	12	8
Epstein (1995) [8]	58	44	35	21	
O'Hara and Marshall (1997) [23]	20	60	30	–	10
Papavero (1997) [26]	113	41	35	20	4
Porchet et al. (1999) [30]	202	31	42	20	7

Some results can be reported on our updated series of 214 patients operated on between 1990 and 2002; 198 patients were available for an average of 30 months follow-up. All patients underwent several examinations and filled in the Finneson–Cooper questionnaire for self-evaluation of their lumbar disc surgery [12]. Excellent and good results were achieved in 36% and 40%, respectively, of the patients. The incidence of fair and poor results of 20% and 4%, respectively, did not change in comparison with patients operated on up to 1997.

The neurological examinations comparing pre- with the postoperative deficits showed that the incidence of sensory deficits decreased from 77% to 35% and the incidence of weakness from 78% to 31%. The preoperative reflex pattern was altered in 65% of patients and normalized only in 8% after surgery. In the majority of the cases, however, the residual deficits were mild and did not impair the daily activity of the patients.

Finally, it has to be mentioned that in this series only 13% of the patients complained about a postoperative facet distress syndrome versus 33% (out of 38 cases) operated on previously in our department for EFDH via laminotomy and partial facet resection (Fig. 34.11).

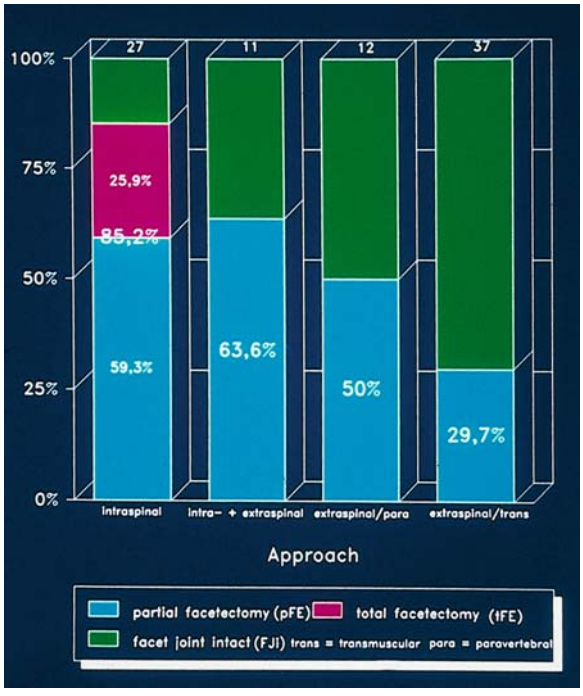


Fig. 34.11. The microsurgical paraspinal approach, usually at the L5/S1 level, requires the removal of the lateral part of the facet joint and therefore these patients complain more often of postsurgical load-dependent back pain

34.13 Critical Evaluation

Extraforaminal disc herniation should be considered in the differential diagnosis of the elderly (mostly male) patient suffering from an upper lumbar root syndrome. EFDHs can be identified on both MRI and CT if slices are performed from L2 through S1. A careful examination of the neural foramina and the extraforaminal areas is recommended routinely, but becomes imperative when no intraspinal finding congruent with the symptomatology can be detected.

Several surgical approaches to EFDHs have been proposed. As in other fields of modern spinal surgery, the location of pathology more than the familiarity of the surgeon with a particular route should determine the surgical approach. The paraspinal muscle-splitting approach is indicated whenever two thirds of the disc herniation is lateral to the pedicle and no additional pathology, such as spinal stenosis or an associated intraspinal disc herniation, have to be treated. Techniques requiring facet removal carry a theoretical risk of spinal instability. The incidence of this sequela has been reported to be only about 4% [9]. However, the analysis of the fair results in our series indicates a group of patients without gross postsurgical radiological abnormalities suffering postoperatively from load-dependent back pain and responding favorably to facet blocks. The majority of them underwent generous facet joint drilling at the L5/S1 level!

Therefore, in the case of pure EFDH with no need of access to the spinal canal, we recommend the muscle-splitting approach as the most direct and the less traumatizing surgical route. It is well worth becoming familiar with the intertransverse anatomy and this is facilitated by the microsurgical technique.

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Transforaminal Endoscopic Discectomy 35

J. Krugluger

35.1 Terminology

Minimally invasive surgery has conquered all fields of surgery. In particular, orthopedic surgery has contributed much to the development of instruments and techniques necessary for minimizing surgical approaches. However, the advances in minimally invasive joint surgery have yet not been seen in spinal surgery.

There are various diagnoses of spinal disorders that would profit from minimally invasive surgery. The most common pathology addressed in spinal surgery is degenerative disc disease. The area of conventional disc surgery has already peaked. Due to patients' postoperative complaints, generalized under the term "postlaminectomy syndrome," the indications for conventional macroscopic disc surgery have been questioned in recent years.

Parallel to this increase and decrease of conventional disc surgery, the idea of the minimally invasive approach has grown. The use of the microscope enabled conventional surgeons to minimize their skin incision combined with more accurate surgery in the spinal canal. However, in standard or microdiscectomy, open surgery is carried out and scarring occurs. The role of the scar as a source of postoperative pain is not yet explained. But avoiding the translaminar approach with bone removal, postoperative scarring due to hematoma, and all the possible complications is the goal of less invasive approaches.

The posterolateral approach was addressed soon as a possible alternative to conventional surgery. The anatomy of the spine coming from a posterolateral aspect allows very differentiated access to nearly all relevant structures that need to be dealt with in disc surgery. Of all the different possible posterolateral approaches, one is called the transforaminal approach. The name already includes how the access way proceeds. The usual posterolateral approach is directed to the center of the disc. The transforaminal approach has been developed to address the more posterior parts of the disc including to some extent the anterior part of the spinal canal. This is where most of the disc pathologies are located. Moreover lateral portions of the disc, difficult to deal with in standard and microdiscectomy, can easily be reached.

Therefore, the transforaminal approach seems ideal for about 80% of all disc lesions. Instruments have been developed with a diameter so small that foramina of normal height can easily host the nerve root, the fiberglass optic, and the instruments.

This technique allows access to the epidural space from the lumbar disc as far cephalad as the middle of the vertebral body or approximately 2–3 mm caudally. The foraminal approach is routinely accessible from T10 to L4-5. L5-S1 can be accessed with special techniques that include foraminoplasty of the lateral facet.

35.2 Surgical Principle

The basis of the transforaminal approach is the anatomy of the posterolateral aspect of the spine. The upper border of the foramen is the pedicle of the upper vertebra. The ventral aspect of the foramen includes the posterior wall of the upper vertebra, the disc, and a small part of the posterior wall of the lower vertebra. The lower border is the pedicle of the lower vertebra and the posterior wall is the facet joint. The foramen has an outer plane according to the lateral border of the pedicles, the center of the foramen is the space between the pedicles, and the inner plane is virtually the line connecting the inner border of the pedicles. The foramen has an upper half, where the nerve root exits the spinal canal, and a lower half where the disc is located.

The way the root leaves the dura is first called the exiting zone, which is still located within the spinal canal. This is followed by the zone where the root penetrates the foraminal space, the root then forms the ganglion, and further on joins the lumbar plexus in the lumbar fossa.

The lower half of the foramen is normally filled with fatty tissue. Small veins coming from the paravertebral plexus cross the foramen to join the epidural veins. The lumbar segmental arteries usually do not cross the foraminal working area. In the case of a disc lesion this lower part is filled with disc tissue or protruded annu-

lus material. The whole space at the foramen is, in normal anatomy, a non-preformed endoscopic space. Temporary virtual space has to be created by fluid to gain visualization. The fluid escapes partially into the spinal canal or into the lumbar fossa along the fascia of the psoas muscle. Sufficient fluid and pressure has to be maintained during surgery to allow permanent good visualization.

35.3 History

Invasive approaches to the spinal canal for diagnostic purposes were first described in the early 1930s [15]. The instrumentation used, however, was quite large and there was considerable associated morbidity. Ottolenghi [14] described both diagnostic and therapeutic techniques. Hult [5] in 1951 described posterolateral fenestration via a small retroperitoneal approach, with good results in 73 % of cases. This is about the result we can reach with current minimally invasive surgery techniques such as chemonucleolysis or percutaneous discectomy. In 1956 Craig [2] described the use of a posterolateral approach with an excellent description of this approach to all levels of the thoracic and lumbar spine, which is still used as the standard uniportal approach for many procedures. In the same year Feffer [3] described the injection of hydrocortisone into the disc space for the treatment of disc pathology. Smith suggested the enzymatic absorption of the nucleus pulposus by means of chymodiactin in 1963 [16]. It was definitely the first alternative to surgical discectomy. After the Federal Food and Drug Administration (FDA) approved the use of chymopapain it gained widespread use not only in the USA. Several years after chymopapain reached the height of its popularity, another alternative to surgical discectomy emerged [6]. The first report on percutaneous discectomy is credited to Hijikata [4] in 1975. Kambin and Gellmann [7] described similar techniques in 1983. The development of appropriate instrumentation and the description of a safe "triangular working zone" by Kambin were the basis for all further progress (Fig. 35.1). Onik and Helms [13] described in 1985 the use of a small automated aspiration probe for central nucleus decompression. The ease and safety of this procedure was striking and minimally invasive disc surgery was no longer limited to some specially trained surgeons. Early results with up to 90 % reported success rate could not be followed in subsequent reports of randomized controlled studies [6].

The next step was the introduction of discoscopy by a Swiss group of orthopedic surgeons [10]. It was performed as a biportal posterolateral approach to intradiscal pathology. The procedure required triangulation in the disc with direct, simultaneous visual observation

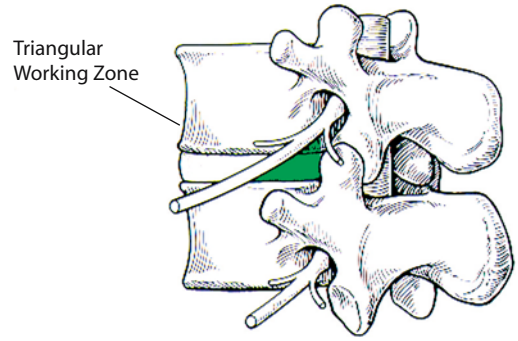


Fig. 35.1. Triangular working zone

during removal of nucleus material. Angled lenses enhanced the range of visualization in the confined spaces. Discoscopy combined with manual decompression was superior to other automated techniques. Visual control of instrument placement and decompression enhanced safety and accuracy of the procedure. In 1987 Choy et al. [1] described the use of lasers in percutaneous disc surgery. The first operation was performed in Graz (Austria) by Choy himself. But the initial high interest in laser surgery has declined, due to a combination of expensive technical equipment and moderate clinical results.

The description of the transforaminal approach represented a further advance in disc surgery. The aim is to reach the epidural space at the appropriate level of the disc lesion by introducing a rigid endoscope through the small foramen. The triangular working zone defined by Kambin is helpful for the orientation but the primary goal of surgery is not the fenestration of the annulus. The first steps of foraminal exploration were done during discoscopy-assisted intradiscal decompression. During removal of the instruments the surgeons had the chance to visualize the foramen. More and more the idea took place not only to inspect the foraminal space while retracting the instruments, but also to enter it for therapeutic reasons. Matthews and Stoll [11] started to use the foraminal access for decompressive disc surgery.

Despite the fact that the technique involves transgressing the epidural space, subsequent local fibrosis was rare. Further investigations involved instrument developments. Steerable tips of the rigid endoscopes allowed even better exploration of the spinal canal. The small epidural veins were, in the beginning of endoscopic spine surgery, sometimes the reason to abandon the procedure when bleeding started. Use of bipolar cauterization and radiofrequency techniques are very helpful in coping with these problems nowadays, although most of the surgeons use simple fluid pressure to control venous bleeding.

The manual decompression of the disc was done with small forceps that fit into the working channel.

This limitation and sometimes time consuming procedure if larger herniations had to be removed was overcome by using automated resectors.

The conjoined use of all technical abilities in endoscopic spine surgery allowed the development of a secure and controlled technique of disc surgery.

35.4 Advantages

Minimally invasive transforaminal approach allows very gentle and smooth access in one-level disc surgery. The insertion of a guide wire and dilatators minimize muscle damage dramatically. Moreover the segmental muscle of the erector spine is not touched at all. Postoperative muscle strength stabilizing and moving the spine is the same as preoperatively. Immediate trunk-stabilizing muscle training can be performed after the surgery. Pain arising from detached muscle and tendon fibers is not limiting activity of the patient.

The posterolateral approach does not cause fibrosis along the simply muscle-dilating approach. Generally none of the endoscopic surgical procedures are prone to postoperative complications due to fibrosis. This benefit of other endoscopic surgical techniques was reinforced by the results after transforaminal exploration of the spinal canal. Only very few reports on scar formation are available and scar formation is hardly ever given as a reason for failed surgery in minimally invasive disc decompression.

The facet joints are protected during endoscopic transforaminal surgery. The working cannula is located just beneath the joint and the instruments cannot hit the joint if the cannula is crossing the foramen. But even in those cases where selected foraminal decompression is done by removing the outer parts of the facet first and expanding gently toward the spinal canal, only the bony stenosis due to hypertrophy of the lower zygapophyseal joint is decompressed. The posterior part of the joint where the muscle are inserted is never touched [8].

Posterolateral decompressive disc surgery with all its different techniques of tissue ablation, such as manually, laser, radiofrequency, etc., had as their basic rational the "jelly donut theory". Removal of a portion of the disc centrally should allow the nuclear jelly-like material of the herniation to ooze back into the newly created space. Many disappointing results defeated the whole theory [6].

The visual control of tissue ablation not only ensures that the right structure is ablated, but also ensures that the amount of ablated tissue is just sufficient to relieve the nerve root. The ability to reach the herniated tissue via the transforaminal approach overcomes the drawbacks emerging from indirect intradiscal decompression.

Last but not least endoscopic stab wound incisions are much less painful than conventional surgical incisions. Postoperative pain management is therefore much easier than in conventional surgery. Whereas conventional disc surgery usually requires general anesthesia, the transforaminal approach can mostly be carried out with local anesthesia, therefore the endoscopic transforaminal approach is a suitable outpatients procedure.

35.5 Disadvantages

Limitations of endoscopic disc surgery mainly arise from localization of the herniated nucleus pulposus. Intraforaminal disc herniations are easily addressed with endoscopic procedures. Some experience is required to treat lateral disc herniations. Orientation in the non-preformed space is more difficult if the standard landmarks such as the facet joint, the exiting nerve root, and the disc are missing.

If self-confident orientation at the triangular working zone its gained, even mediolateral disc herniations are no limitation. The working cannula can be advanced under the facet joint, and the instruments can be advanced to the midline of the spinal canal, sometimes even further. But do not forget, as the foramen is entered, the movement of the instruments becomes more and more limited. Only disc herniations limited to the level of the disc space can be decompressed sufficiently. If the herniation is turned cranially or caudally in the spinal canal, the transforaminal approach is not an adequate surgical technique [9].

Extremely large herniations compressing the cauda equina should not be addressed by endoscopic surgery, as one cannot be sure to remove all the tissue.

Technical limitations are obviously the size of the instruments. In the monoportal approach only a working channel of about 3 mm is available if simultaneous visual control of decompression is mandatory. The instruments available nowadays with an automated shaver are better than manual forceps, but compared to arthroscopic surgery the instruments are very limited. The quality of fiberglass optical systems lack the quality of instruments known from arthroscopic surgery.

Primary access to place the guide wire and dilatators has to be done under fluoroscopic control. The exposure to X-rays is mandatory to identify landmarks and repeatedly verify optimum needle and/or guide wire placement that distinguishes the appropriate working zone within a spinal segment. To minimize radiation exposure during surgery, principles of radiation safety have to be obeyed. The surgeon and surgical team should wear protective lead shielding and keep maximum possible distance during imaging. A well-colli-

mated machine with strict quality control monitoring must be used. Image memory mode is superior to live imaging with total exposure time markedly reduced.

The procedure itself is mainly performed at disc levels L2-5. At level L5-S1 it is often impossible to gain adequate access as to allow controlled disc removal. For this level alternative approaches such as the transiliac approach are suggested. But even at the upper level the procedure is quite demanding. All surgeons report on learning curves [9]. Foraminal stenosis is sometimes limiting the access to the disc spaces and the herniated tissue.

35.6 Indications

The major indication for transforaminal disc surgery are intraforaminal herniated nucleus pulposus. The herniated tissue should not extend markedly caudally or cranially. If the disc herniation is located more medially it can sometimes be reached by endoscopic means too, but it has to be more or less at the level of the disc.

Mediolateral herniations are a second step in training for transforaminal disc surgery. The working cannula has to be passed underneath the facet joint to reach the disc material, but mediolateral herniations quickly join the standard repertoire of the surgeon.

35.7 Contraindications

As in other minimally invasive surgery it is very important to take into account the patient's overall conditions if surgery is indicated. Social situation, workers' compensation, and psychological disorders are some of the points that have to be considered.

In addition to the standard contraindications of disc surgery. anatomical aspects must be obeyed. The segment L5-S1 is difficult to access via the lateral approach. The iliac crest may be an obstacle in entering the foramen L5-S1. If in lateral X-ray the iliac crest extends proximally of the disc L4-5 it is difficult to enter the foramen L5-S1 and have sufficient room to move the instruments. Other surgical techniques should be considered. The L5-S1 disc is sometimes protected by an enlarged transverse process. This anatomical variation can easily be detected before surgery and represents an absolute contraindication for this type of surgery. The same is true for a large transverse process with nearthrosis to the sacrum and/or iliac bone.

The height of the foramen should be normal if we decide to use the transforaminal approach. To some extent percutaneous widening of the recessus has been done already. Doing this we have to keep in mind that the time of the surgery grows rapidly, and this type of surgery is only for experienced surgeons with adequate equipment. Simultaneous treatment of disc herniation and lateral recess stenosis is not a standard indication for the transforaminal approach.

The localization of the herniation can be a contraindication. Cranially or caudally herniated fragments cannot be reached by the transforaminal approach. The more medial the herniation is located, the more the range of movement of the instruments is limited. Herniations occupying more than 50 % of the spinal canal are a contraindication for this type of surgery.

Experience of the surgeon is necessary to judge from preoperative imaging techniques if the patient's anatomical condition is suited for endoscopic surgery. There is no standard answer we can suggest. Every herniation has to be rated individually including the type of herniation, experience of the surgeon, and equipment available.

35.8 Surgical Technique

The surgery needs the standard sterile conditions of an operating theater. Perioperative antibiotic prophylaxis is suggested but not mandatory. The type of anesthesia depends on the preference of the patient, the experience of the surgeon, and the type of hospitalization. Local anesthesia is suggested in the beginning to identify root contact early and it is preferred for the outpatient's procedure too. If we do the procedure with local anesthesia, some sedation of the patient is used. Regional and neuroleptanalgesia are suggested as well. General anesthesia is probably more comfortable for the surgeon and the patient too.

We position the patient on a spine frame and watch that the stomach is free. The epidural veins are not filled in this position, and lordosis is reduced during surgery.

The entry point for the skin incision must be more lateral than in standard intradiscal techniques. About 10 – 16 cm lateral to the midline are suggested for the foraminal approach depending on the height of the patient (Fig. 35.2). The approach is above the iliac crest at the level of the disc space. The whole procedure has to be performed under fluoroscopic control to avoid misdirecting the instruments in the retroperitoneal or intraperitoneal space.

The skin is infiltrated with local anesthetic, the supposed working canal is infiltrated, and we may put some local anesthetic around the facet joint and the outer annulus. The infiltration of the root has to be avoided, as controlled surgery relying on root reaction in case of contact would otherwise not be possible. A stab wound incision is usually sufficient. The guide



Fig. 35.2. Position of the entry point: above the iliac crest, 10 – 16 cm lateral the midline



Fig. 35.3. Instrument position in the lower foramen

wire is directed toward the caudal part of the foramen under lateral fluoroscopic control (Fig. 35.3). Elastic resistance indicates the ideal position entering the outer annulus. We suggest checking the position of the guide wire with anterior-posterior (AP) fluoroscopy too. The wire should reach the medial interpedicular line in AP view.

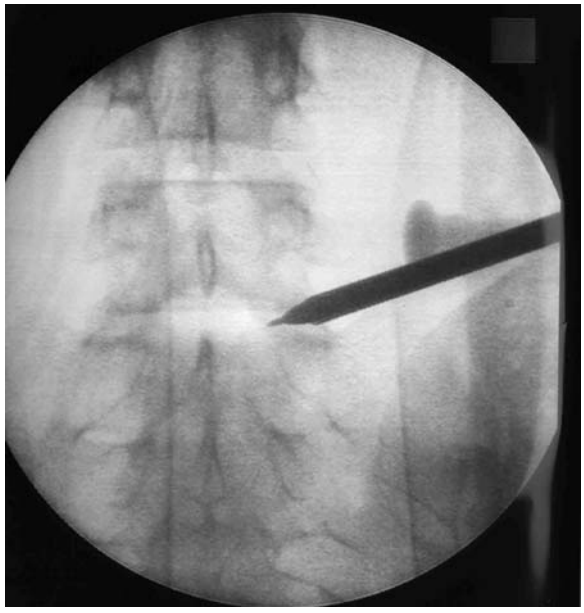


Fig. 35.4. "Bullet sign"

The dilatators are entered with slight rotating movements watching not to protrude the guide wire further into the disc. If the position of the dilatators is just at the tip of the guide wire the working cannula is advanced over the dilatators with gentle rotating movements. The ideal instrument position is described as the bullet sign: the guide wire tip, the dilatators just behind it, and the working cannula at the end of the shaft of the dilatators (Fig. 35.4). The position of the instruments is documented fluoroscopically, and then the dilator is removed. The guide wire may be left as guidance for the endoscope. As the endoscope is inserted, the wire is removed [17]. Cold Ringer's solution is used for irrigation.

First of all the visible structures have to be identified. The endoscope is partially advanced and retracted until the triangular working zone is clearly identified with all its surrounding elements: facet joint, exiting root, and disc. The orientation is sometimes difficult if the intraforaminal herniation prohibits the visualization of the foramen. Nevertheless the facet joint and the localization of the root should be identified first before decompression of the disc material is started. If the anatomical structures are identified, secure ablation of the protruded disc material can be started by the method of choice: manually, laser, radiofrequency, or automated instrumentation. Interfering bleedings from epidural veins are rare if suprarenin is used with the irrigation. If it happens, bipolar cautery or radiofrequency is helpful.

The decompression of herniated material has to liberate the exiting nerve root as well as the traversing root. Sufficient decompression of the traversing root

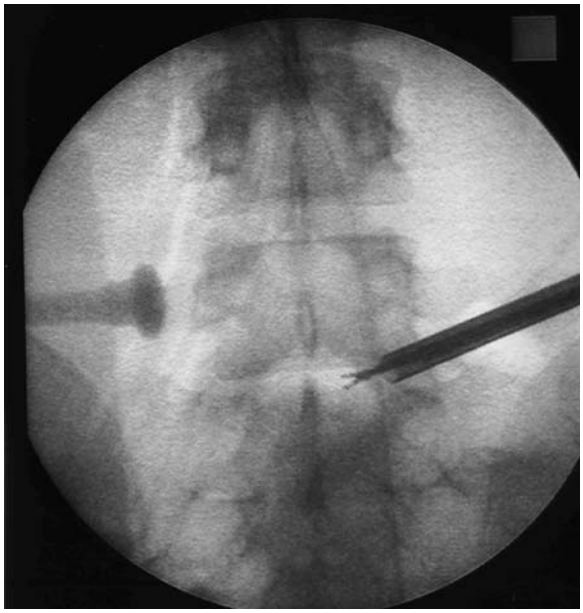


Fig. 35.5. Treatment of medial herniations

sometimes demands entering the spinal canal via the foraminal approach (Fig. 35.5). The working cannula is passed underneath the facet joint, but it should never be advanced more than the medial interpedicular line to avoid dura lesions with the sharp rim of the cannula. One has to keep in mind that the range of movement of the instruments is quite limited once the foramen is entered with the working cannula. The direction of the cannula for reaching dislocated fragments must be explored meticulously before advancing the working cannula.

After removal of disc material the exiting root and traversing root are checked with a hook for residual disc material.

35.9 Postoperative Treatment

After surgery the patient is discharged either the same day in the evening or the day following surgery. Bed rest is suggested for a maximum of 24 hours. Muscle-balancing physiotherapy and medical training therapy is started immediately. Neural mobilization exercises, if available, can reduce postoperative root irritation pain. Residual pain is treated with standard painkillers. No permanent pain medication is suggested.

Return to work depends on social factors, working situation, and type of work. Sitting occupations and work without lifting will be possible within the first 2 weeks. Heavy lifting will need at least 6 weeks rehabilitation. Sport activity may be started according to progress in medical training therapy.

35.10 Complications

The complication rate of transforaminal surgery is low in general. The main reported complications are transient. The approach itself has some inherent dangers. Lesions of the retroperitoneal structures and even lesions of the bowels have been reported. Careful preoperative evaluation of MRI or CT scan may indicate far posteriorly dislocated parts of bowels. The positioning of the patient on a frame to avoid pressure on the abdomen minimizes the risk of bowel injury.

The facet joint, its capsule, and the posterior branch of the nerve root are the posterior border of the working triangle. According to their position they are endangered by instrument manipulation. Definite complications of these structures are very seldom reported.

The cranial border of the working triangle is the exiting nerve root. Lesions of the exiting root or its ganglion are usually transient. Paraesthesia or some motor weakness may occur. They subside spontaneously within the first weeks postoperatively. Neural mobilization techniques may support full recovery.

Bleeding from epidural veins may be disturbing during the operation but usually stop and do not represent a postoperative problem. Lesions of the dura may cause leakage of some CSF, which usually subsides soon after surgery but may cause a temporary headache postoperatively.

The infection rate was 0% in primary endoscopic operations. There was one postoperative wound infection following open revision surgery. Mechanical complications such as fracture of instruments sometimes occur. No severe complications due to instrument failure have been reported. All instrumentations available are very safe and easy to use nowadays.

35.11 Critical Evaluation

The results of the transforaminal approach for disc surgery have to be rated very carefully. Early reports were very enthusiastic. The concept of transforaminal discectomy has now been expanded to utilize a variety of instruments to ablate the disc material in a more efficient manner than the early instruments could. The clinical data, however, vary a lot. The clinical efficacy of these methods is not yet established, and there is a lack of validation compared with other techniques. There is a remarkable learning curve for each surgeon even with sound experience in spine surgery and/or arthroscopic surgery. Orientation in the non-preformed paravertebral space is challenging. A minimum of 20 operations has to be done together with an experienced surgeon till secure approach and instrument handling is

reached. That is the reason why the results reported needs differential analysis. Reports of small series are prone to having learning curve bias and are not representative for the overall success of the method. In large series usually the learning curve for indication has already been overcome and the learning curve of the surgical technique has also been surmounted. Generally in publications of larger series an overall of rate of 80–90% good or excellent results of surgery are reported [11, 17]. This compares favorably with the results of microdiscectomy [12]. Nevertheless we have to keep in mind that this surgical technique is suitable for only a very limited type of disc herniation.

When using it in the narrow indication range, it yields good pain relief and functional recovery for the patients. When expanding to other indications, the results deteriorate dramatically. The transforaminal approach can be used successfully in disc surgery if anatomical considerations and indications are obeyed. The major advantage of the transforaminal approach is the minimal tissue trama necessary to remove herniated disc fragments. Indications are disc herniations located in the foramen, lateral to the foramen, or just medial of the foramen.

Sparing the nucleus pulposus by just removing the herniated part of the disc is controversial. On the one hand younger patients benefit from nucleus pulposus residuals in the disc, and not loosing disc height postoperatively. On the other hand reherniation rate is reported to be higher in endoscopic surgery than in microdiscectomy.

Postoperative recovery and the option to perform the procedure as an outpatient procedure are additional advantages of this type of minimally invasive disc surgery. Cost effectiveness is a major point to consider in surgery nowadays. It is probably one of the strongest arguments for transforaminal disc surgery.

Limitations concern the anatomical situation. The foramen height as limiting factor may be overcome by foraminoplasty, but foraminoplasty is a surgical technique in itself; it is not a procedure for routine transforaminal disc surgery and additional equipment is needed. The localization of the herniation limits the surgical indication too. Free fragments, sequestered caudally or cranially are absolute contraindications as well as herniations filling more than 50% of the epidural space. Depending on the experience of the surgeon the indications may be extended. But we have to know before surgery very exactly the position of the herniation and the estimated range of movement of the instruments. The overall exclusion rate for anatomical reasons is about 30% of patients with disc herniations.

When starting to do transforaminal disc surgery the learning curve must be considered as well as the necessity of keeping up the standard of surgical skill. This means that a certain number of procedures have to be done. Therefore it is obvious that the procedure is limited to surgeons regularly performing disc surgery. Some of all the herniations done during a period of time may be ablated by the transforaminal approach. The procedure is not suitable for occasional disc surgery.

The limitations of instruments and visualization will be overcome soon. Any instrumentation we use now is somewhat old-fashioned after 6 month.

Transforaminal disc surgery is a fascinating procedure. It is an additional tool for spine surgeons with very good results and great benefit for the patients, but sound training of the surgeon and observance of indications and limitations are advisable.

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36 Microscopically Assisted Percutaneous Technique as a Minimally Invasive Approach to the Posterior Spine

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36.1 Terminology

The approach introduced here, the "microscopically assisted percutaneous technique" (MAPN = microscopically assisted percutaneous nucleotomy), is applicable to all regions of the posterior spine. MAPN describes an atraumatic percutaneous transmuscular exposure of the interlaminar window. Muscle trauma related to the approach is reduced to the minimum by the so called "transmuscular dilatation" (see Sections 36.2 and 36.9).

36.2 Surgical Principle

The aim of this technique is the minimising of the approach trauma especially in paraspinal muscles. The technique of transmuscular dilatation allows gentle spreading of the fascia and the fibres of the paraspinal muscles. Detachment of muscles from the spinous process, the lamina and the facet joint can be avoided. The target area is exposed through a working tube through which lumbar disc herniations can be removed with the help of a surgical microscope.

36.3 History

The incidence of lumbar disc herniation in Germany is about 4.5% and from 100,000 inhabitants 87 will be subjected to surgical treatment [18, 22]. These figures illustrate the need for an operative modality that offers the patient the maximum safety and at the same time is associated with minimal trauma related to the approach. This ultimately should result in earlier rehabilitation of the patients.

The open lumbar discectomy was gradually replaced in the 1970s by the microdiscectomy techniques introduced by Yasargil [26] and Caspar [1]. The latter is still considered the "gold standard" for the operative treatment of lumbar disc herniation due to the relatively minimal trauma related to the (mini-open) approach and the excellent illumination and visualisation provided by the surgical microscope. In inexperienced hands, the disadvantage of this technique, however, is the dissection of the short segmental paraspinal muscles (multifidi) from their bony attachments, which can result in scarring as well as segmental denervation. In association with a postoperative height loss of the intervertebral space the motion segment can destabilise [23].

As an attempt to further minimise the trauma related to the approach, Hijikata [16] in 1975 described the method of percutaneous discectomy. The indications for this technique as well as for the automated discectomy described by Onik [21, 22] are very limited. Automated percutaneous lumbar discectomy (APLD) [21, 22] is obsolete due to the lack of proven efficacy. Percutaneous endoscopic intradiscal discectomy has never become an international standard procedure due to the restricted indication just for contained disc herniations.

The introduction of endoscopically assisted procedures by Destandeau [7] and Foley [5, 9] is considered a further advance in the armamentarium of minimally invasive lumbar disc surgery. The main disadvantage of this method, however, is the lack of three-dimensional vision.

Our concept is based upon minimising the surgical trauma related to the approach by splitting of the paravertebral muscles combined with use of the operative microscope which offers the surgeon three-dimensional vision. Accordingly, this approach can be generally applied for all types of lumbar disc herniations and for decompressive procedures in all areas of the posterior spine (see Section 36.6) [12, 13].

36.4 Advantages

1. Less surgical trauma to the muscles.
2. Three-dimensional visualisation of operative field.
3. Reduced bleeding from the approach area.
4. Good possibilities for inclination of the working channel in sagittal and transversal planes.

5. The approach can be extended in every instance, if needed, to enable the surgeon to do a standard microdiscectomy or even an open discectomy.
6. The procedure can also be performed under local anaesthesia.
7. Excellent cosmetic outcome.

36.5 Disadvantages

It is a demanding technique, which requires experience in microsurgical techniques. The learning curve may be long.

36.6 Indications

The technique is applied mainly for access to lumbar disc herniations. All kinds of lumbar disc herniations which require a standard midline approach can be managed by this technique [13]. Above that additional indications for the approach technique proposed here include: lateral (intraforaminal) disc prolapse [3, 14] and central and/or lateral stenosis in the lumbar spine as well as the thoracic and cervical spine [4, 12, 15]. An overview of indications is shown in Fig. 36.1.

36.7 Contraindications

Segmental stability is a prerequisite for successful application of the MAPN technique in posterior decompressions of the spine. Accordingly, the presence of segmental instability in functional studies constitutes a contraindication for this technique. In addition, the technique is not applicable for anterior stenosis caused by anteriorly located lesions. The presence of facet joint arthrosis with massive hypertrophy is considered a relative contraindication.

36.8 Patient's Informed Consent

As for other operations, the patient should be informed about the possible general and local complications. In addition, the possibility of conversion to traditional microdiscectomy should be pointed out.

36.9 Surgical Technique

36.9.1 Paramedian Approach

The approach is done with the patient in the prone or in the knee-chest position. The lateral decubitus position can be an alternative in certain cases (as in old polymorbid patients) where the procedure is done under local anaesthesia.

After skin disinfection and draping, the space between the two laminae at the desired level is determined and documented by the image intensifier. A stab incision of 15 mm length, about 2.5 cm paramedian, is made and two soft tissue dilators are applied in sequence. This allows gentle spreading of the fascia and the fibres of the paraspinal muscles to the extent that allows the introduction of the working channel (Figs. 36.2 – 36.4). These steps are performed under C-arm guidance, to prevent approaching the wrong level. The working channel has blunt threads on its outer surface which enables it to pass tightly through the paraspinal muscles while spreading them apart. The working channels (Medicon, Tuttlingen, Germany) are available in three different lengths (45, 55 and 65 mm) and two

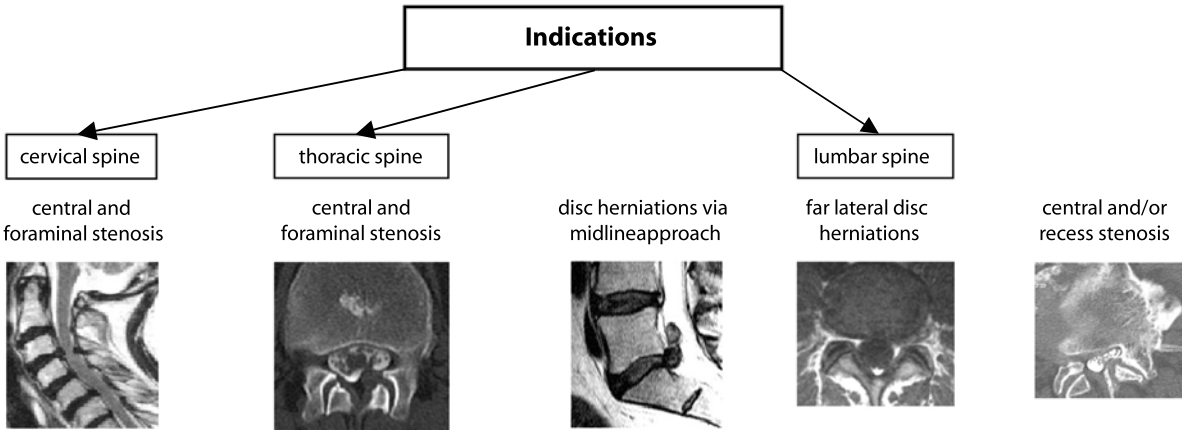


Fig. 36.1. Overview of indications for the microscopically assisted percutaneous approach in the posterior spine



Fig. 36.2. Intraoperative X-ray control with first dilator in place at level L5/S1

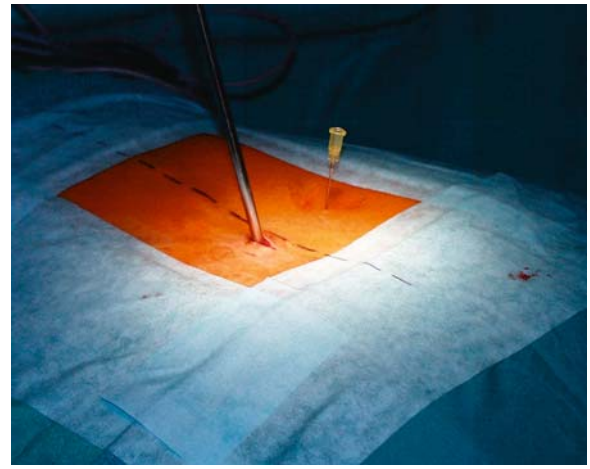


Fig. 36.3. First dilator in situ, spinal needle contralaterally for marking of the level

outer diameters (11 and 14 mm). A handle on the working channel allows angulating movements, providing optimum direction of vision and access. In all posterior spine regions a good anatomical landmark is the inferior edge of the laminar arch. The angle of the working tube to the midline is about 10°. All further steps of the operation are executed through this channel.

The interlaminar space is exposed under vision of the operative microscope. The opening to the ligamentum flavum varies from simple splitting for removal of free sequestrated disc fragments to partial flavectomy in cases with hypertrophy of the ligamentum flavum causing canal stenosis. The possibility of tilting the working channel in the sagittal and transversal planes permits elimination of stenosis of the lateral recess of the ipsilateral as well of the contralateral side (crossover technique). Generally speaking, the type and extent of surgical decompression varies according to the surgical indication and the intraoperative findings. The procedure entails removal of the free disc fragments in cases with sequestrated prolapse (Fig. 36.5), nucleotomy when loose disc fragments are present in the intervertebral disc, radiculolysis for periradicular fibrosis, decompression of the lateral recess in cases with lateral stenosis flavectomy for ligamentum flavum hypertrophy and osseous decompression for central stenosis. In addition, through this approach it is possible to access intradural lesions, and thus we resort to this approach in cases needing diagnostic or therapeutic myeloscopy.

The principles of the technique are more or less the same in all spinal regions when midline approaches are needed. However, there are differences in the patient's

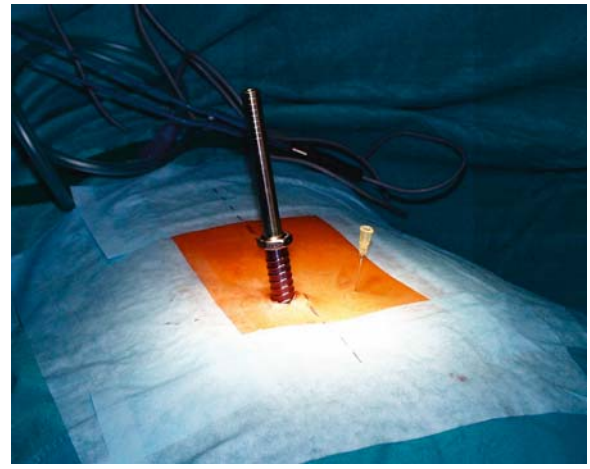


Fig. 36.4. Insertion of the working channel

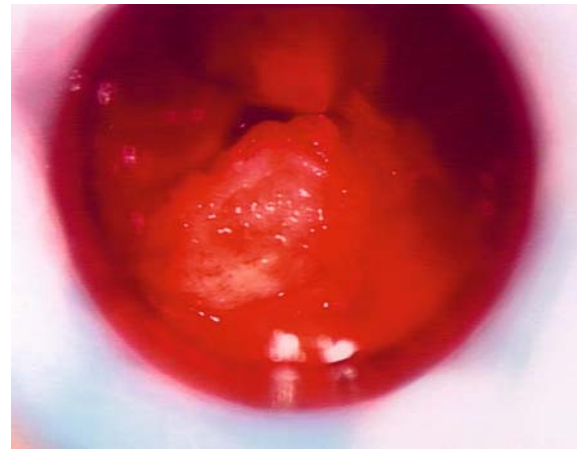


Fig. 36.5. View through operative microscope, the disc herniation is being mobilised

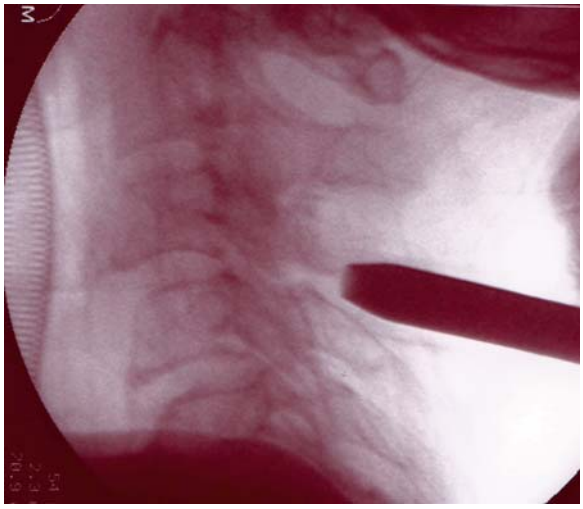


Fig. 36.6. Intraoperative X-ray control with second dilator in situ at level C3/4

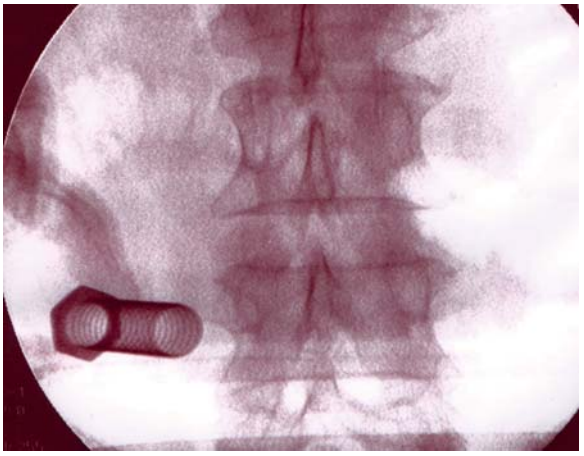


Fig. 36.8. Working channel placement in X-ray control (AP view) for transforaminal approach at level L3/4

position. In the lumbar region, we prefer the knee-chest position. The lateral decubitus with the thighs flexed is resorted to when the operation is done under local anaesthesia. The standard prone position is used for lesions in the posterior thoracic spine. The same is applied to approaches of the cervical spine but an inclined neck facilitates the decompression (Fig. 36.6).

36.9.2 Transforaminal Approach

The approach is ideal for intraforaminal and extraforaminal disc herniations (Fig. 36.7) as well as for foraminal stenosis. The angle between the lateral part of isthmus region and the lower border of transverse process is marked under fluoroscopic control in the anterior-posterior view. The stab incision is done usually about 5 – 6 cm away from the midline. Two dilators are applied in sequence to allow insertion of the working channel. The latter should be inclined 10° towards the midline. After correct positioning of the working channel (Fig. 36.8), the next steps are done using illumination and visualisation of the operating microscope. Dissectors and probes are used to search for the nerve root in the extraforaminal region (lateral to the pars interarticularis). Usually the nerve root can be identified caudad to the inferior border of the transverse process and, sometimes, resection of a small part of the intertransverse ligament may be necessary. After cranial mobilisation of the nerve root and the accompanying branch of the segmental lumbar artery (*cave*!!), the herniated disc can be exposed and removed. In case of partial intraforaminal disc herniation, trimming of the yellow ligament will be necessary.

After removal of the herniated part of the nucleus, the nerve root is probed all around by using blunt



Fig. 36.7. Intraforaminal disc herniation at level L3/4 left side in transversal (**a**) and sagittal (**b**) MRI scan

hooks of different lengths. In case of neural foramen stenosis as a result of facet joint hypertrophy, careful undercutting can be done from this lateral position without damaging the facet joints. A difficulty with this technique can arise at the level of L5/S1, due to high iliac wings.

36.10 Postoperative Care and Complications

In general, mobilisation of the patients is started 4 hours after surgery. A postoperative spinal support is not required. In our first series of 43 patients with lumbar disc herniation treated using the aforementioned technique we found an incidence of intraoperative dural injury of 9 %. Recurrent disc herniation was evident in 4.5 % (1 year follow up) [13].

In a study including 38 patients suffering from spinal canal stenosis the incidence of dural injury was 5 % and reoperation was necessary in 8 % of them due to residual stenosis and one epidural hematoma [12, 15].

The lateral approach for foraminal and extraforaminal pathology was completely safe and recurrent disc herniation was encountered in two cases (7 %). Both were successfully reoperated on using the same technique [14].

No complications were encountered in the series done for cervical spine posterior decompressions [4].

In summary dural violations, recurrent disc herniations and residual stenosis are the main complications in the learning curve of this technique

36.11 Results

36.11.1 Results in Lumbar Disc Herniations via the Paramedian Approach

In the period between May 1998 and May 2003, 485 patients with lumbar disc herniations were operated on using this technique (Fig. 36.9). The first consecutive 43 cases done in the period between May and September 1998 were evaluated and the results were compared with those of the traditional microdiscectomy (Table 36.1) [13]. The male to female ratio was 3:2. The mean age was 54 years (range 22 – 77 years). The affected level was L4-5 in 21 patients, L5-S1 in another 21, and L2-3 in the remaining patient. The patients were

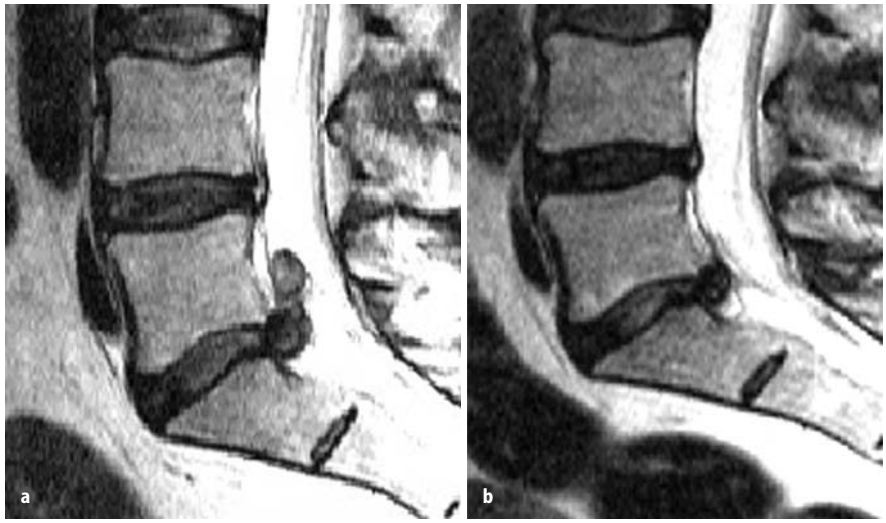


Fig. 36.9. MRI scan with sequestrated disc herniation (**a**) in level L5/S1 and postoperative situation after discectomy using the microscopically assisted percutaneous technique (**b**)

Table 36.1. Comparison between results of microdiscectomy and microscopically assisted percutaneous technique in lumbar disc herniation

Parameter	Microscopically assisted percutaneous technique	Microsurgical discectomy	References
Operative time	69 min	60 min	[11]
Revisions	4.3 %	4 – 9 %	[6, 10, 17, 19, 26]
Clinical results (good and excellent outcome)	80 % (3 months postoperative) 75 % (1 year postoperative)	80 – 90 % (6 – 66 months postoperative)	[10, 11, 17, 19, 26]
Postoperative hospital stay	4 days	4 days	[25]
Return to work	100 % in 8 weeks	?	

examined 3 months after the operation at the outpatient clinic and a questionnaire was done 1 year after the surgery. The subjective perception of pain using the visual analogue scale (VAS) [2], the neurological deficits, the need for analgesics and the ability to return to work were analysed. The operative time and the blood loss in this series were compared with those encountered in 86 microdiscectomies done by the same surgeons 1 year before the introduction of the microscopically assisted percutaneous technique.

The mean operative time in the cases treated by the microscopic percutaneous assisted technique was 69 minutes, which is slightly longer than that reported for conventional microdiscectomy (63 minutes). The mean blood loss with the MAPN technique was 30 ml in comparison with 90 ml in the standard microdiscectomy. Apart from dural injuries in four cases, no other intraoperative complications were encountered in the microscopically assisted percutaneous technique.

Early recurrent disc herniations necessitating surgical reintervention was encountered on two (4.5%) occasions. The early postoperative follow up 3 months after the operation showed that 50% of the patients were free from any symptoms, 30% had minimal symptoms (<2 in VAS), 18% had pain resembling sciatica but was tolerable, while the remaining 2% (one patient) had persistent symptoms without evidence of recurrent herniation. Apart from those without a job, all employed patients returned to their work within 4–8 weeks after surgery. Eighty percent of the patients reported that they no longer need any analgesics. The motor function improved from an average 3/5 preoperatively to an average of 4/5 (according to Janda).

It was possible to contact 32 out of the 43 patients and ask them about their medical condition with reference to the local symptoms. Of those, 75% gave values between 0 and 2 while the remaining 25% gave values between 2 and 5 VAS because of sciatic pain.

A randomised prospective study is presently being conducted in cooperation with the department of orthopaedics in Otto-von-Guericke-University Magdeburg. The main aim is to study the effect of minimising the approach on the extent of muscle injury and local epidural fibrosis depending upon MRI done at regular intervals after surgery. The control group comprises cases treated by conventional microdiscectomy.

36.11.2 Results in Lumbar Intraforaminal Disc Herniations via the Transforaminal Approach

A prospective study includes 27 patients treated in the period between February 1999 and October 2002 [14]. The mean age was 59.4 years and 53% were women. The average operative time was 43 minutes and the mean blood loss was 40 ml. The VAS and Oswestry Disability Index (ODI) [8] improved significantly (Table 36.2) after a mean follow up of 10 months (4–24 months). Recurrent disc herniations were encountered on two occasions, 2 and 6 months after primary surgery, and were successfully treated by the same technique.

Table 36.2. Results of transforaminal approach. (*VAS leg* Visual analogue scale leg pain, *VAS back* visual analogue scale back pain, *ODI* Oswestry Disability Index)

Study parameters	Preoperative	Postoperative	Significance
VAS leg	7.2 (SD 1.15)	3 (SD 1.78)	$P<0.001$
VAS back	6.1 (SD 1.75)	4.1 (SD 2.1)	$P<0.001$
ODI	29.3 (SD 4.9)	11.5 (SD 8.2)	$P<0.001$

36.11.3 Results of the Treatment of Lumbar Canal Stenosis

Thirty eight patients (13 women and 25 men) with symptomatic lumbar stenosis were treated during the period between November 1998 and December 2001 utilising the aforementioned approach [12, 15] The mean age of the patients at the time of surgery was 73.2 years. The number of segments to be decompressed was 56. The mean operative time for each segment was 74 minutes, while the mean blood loss measured 32 ml. The mean follow up was 32 months (18–55 months). The VAS for leg and back pain and the Oxford Claudication Score (OCS) [20] had improved significantly (Table 36.3). Dural tears were encountered on two occasions (5%). Three patients (8%) needed to be revised using open technique, one due to epidural bleeding causing symptoms and the other two because of residual stenosis. Because of advanced comorbidity in two patients, the operation had to be done under local anaesthesia.

36.11.4 Results of Surgical Treatment of Cervical Radiculopathy

Thirteen patients suffering from cervical radiculopathy (4 patients) and myelopathy (9 patients) were operated according to this technique during the period October 1998 to October 2001 [4]. The patients were strictly selected according to the offending pathology. Nine pa-

Table 36.3. Results of operative treatment of lumbar canal stenosis. (*VAS leg* Visual analogue scale leg pain, *VAS back* visual analogue scale back pain, *OCS* Oxford Claudication Score)

Study parameters	Preoperative	Postoperative	Significance
VAS leg	6.8 (SD 1.2)	3.1 (SD 1.9)	$P<0.001$
VAS back	7 (SD 1.2)	4 (SD 2.1)	$P<0.001$
OCS	29.4 (SD 5.2)	14.1 (SD 7)	$P<0.001$

Table 36.4. Results of treatment of cervical radiculopathy and myelopathy. (*VAS neck* Visual analogue scale neck pain, *VAS arm* visual analogue scale arm pain, *NDI* Neck Disability Index)

Patient number	Age (years)	Sex	Neurological deficits (preoperative)	Imaging findings	Level	Operative time (min)	NDI (preoperative)	NDI (postoperative)	VAS neck (preoperative)	VAS arm (preoperative)	VAS neck (postoperative)	VAS arm (postoperative)	Neurological deficits (postoperative)	Follow up period (months)
1	65	Male	Sensory C8	Bony foraminal stenosis	C7/T1	60	65	10	7	8	3	2	Complete recovery	42
2	51	Male	Sensory + motor C8	Bony foraminal stenosis	C7/T1	70	70	50	6	8	5	6	Improved	36
3	76	Female	Myelopathy	Central stenosis (ligamentum flavum hypertrophy)	C3-6	90	70	40	8	8	2	3	Improved	25
4	80	Male	Myelopathy	Central stenosis (ligamentum flavum hypertrophy)	C5/6	85	55	20	8	7	4	1	Improved	19
5	43	Male	Sensory C8	Bony foraminal stenosis	C7/T1	45	65	0	6	7	2	1	Complete recovery	16
6	69	Female	Myelopathy	Central stenosis (ligamentum flavum hypertrophy)	C2/3	50	65	25	9	7	6	4	Improved	14
7	76	Male	Myelopathy	Central stenosis (ligamentum flavum hypertrophy)	C3/4	45	80	45	5	5	5	4	Improved	12
8	52	Female	Myelopathy	Central stenosis (ligamentum flavum hypertrophy)	C5/6	105	70	45	8	6	6	4	Improved	11
9	72	Female	Myelopathy	Central stenosis (ligamentum flavum hypertrophy)	C5/6	65	60	0	3	5	1	1	Complete recovery	12
10	73	Male	Myelopathy	Central stenosis (ligamentum flavum hypertrophy)	C3-5	110	75	–	9	6	–	–	–	Died 9 months postoperative
11	57	Female	Myelopathy	Central stenosis (ligamentum flavum hypertrophy)	C3/4	60	60	20	5	7	1	3	Improved	9
12	55	Female	Sensory + motor C7	Intraforaminal disc prolapse	C6/7	80	60	5	6	8	2	2	Complete recovery	7
13	75	Male	Myelopathy	Central stenosis (ligamentum flavum hypertrophy)	C3/4	45	65	30	7	7	3	5	Improved	5



Fig. 36.10. MRI scan with posterior stenosis at level C3/4 preoperative (**a**) and after microscopically assisted percutaneous decompression (**b**)



Fig. 36.11. Cosmetic outcome 3 months postoperative after decompression at level C6/7

tients (7 monosegmental, 1 bisegmental and 1 trisegmental pathology) suffered from cervical myelopathy resulting from hypertrophied ligamentum flavum (Fig. 36.10). The other 4 patients presented with monoradicular symptoms due to either bony foraminal stenosis or intraforaminal disc prolapse. The mean follow up period was 17 months (1 patient died after 9 months postoperatively due to unrelated causes). Patients were evaluated using a modified version of the Oswestry Index, called the Neck Disability Index (NDI) [24], and the VAS for neck and arm pain. The average operation time per segment was 61 minutes. The mean NDI improved from 13.2 (preoperatively) to 4.8 (postoperatively). The VAS for arm pain and for neck pain also showed marked postoperative improvement (Table 36.4). Complete recovery of the preoperative neurological deficit was found in 4 patients while the remaining 8 patients showed improvement of the neurological symptoms during the follow up period. There were no intraoperative or postoperative complications and no reoperations (Fig. 36.11).

36.12 Critical Evaluations

Surgery for lumbar disc herniations represent the main indication for the use of the so-called microscopically assisted percutaneous technique. After a decisive learning curve, the procedure offers substantial advantages which makes it an alternative to the standard microsurgical procedures. Certainly a smaller skin incision is not the cause for a better clinical result therefore subsequent studies need to be done to evaluate the potential advantages as well the limitations of the procedure introduced here. We believe that this minimally invasive approach is a good alternative, especially to the open techniques, in the treatment of lumbar canal stenosis where polymorbidity is a considerable problem. In our series, the mean age of the patients was 73.2 years. The patients are characterised by an increased surgical risk because of the commonly associated diseases. The minimal trauma related to the approach and the early mobilisation of the patients are advantages of this approach.

Finally we must understand that the presented studies includes a small number of patients with a limited follow up.

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Arthroscopic and Endoscopic Spine Surgery via a Posterolateral Approach

37

P. Kambin

37.1 Terminology

The term of arthroscopic microdiscectomy was introduced in the early 1990s when a small caliber glass arthroscope became available and arthroscopic appearance of the anatomical and neural structures of the posterolateral annulus and the spinal canal were described [19, 22, 25, 27]. The term arthroscopic discectomy maybe used when an intradiscal access to the disc herniation is being attempted. However, when a transforaminal or translaminar approach is being used, the term of endoscopic discectomy maybe appropriate.

37.2 Surgical Principle

The key word for arthroscopic or endoscopic spine surgery is visualization. A satisfactory visualization of the neurovascular structures requires proper positioning of the instruments in the posterolateral annulus adjacent to the spinal canal at the onset of the operative procedure. This concept is in contrast with the nuclear debulking procedure where the nuclear tissue is mechanically resected [12, 14, 15, 47, 50, 55], chemically lysed [67], or vaporized via a laser light [1, 4, 6, 21, 23]. Similar to open discectomy, arthroscopic or endoscopic disc surgery is geared toward the resection of herniated disc fragments and decompression of the nerve roots.

37.3 History

The direct access to the spinal canal via a laminectomy or laminotomy is the oldest, and still an acceptable method of reaching and evacuating the offending herniated disc material from the spinal canal.

Mixter and Barr [53] are credited with the direct midline approach to the content of the spinal canal for the retrieval of herniated lumbar discs. The literature suggests that other investigators, including Bucy [2], Dandy [7], Elsberg [8], Goldthwaite [10], Putti [60], and others also performed laminectomies for the treatment of low back pain and sciatica in the early twentieth century.

Although the early outcome of laminotomy and discectomy is usually satisfactory, the incidence of complications [61, 68] and interoperative insult to the myoligamentous structures and facet joints combined with the development of epidural and perineural fibrosis and chronic neural edema [54, 57] has led many investigators to introduce an alternative of intervertebral disc decompression without the need of entrance into the spinal canal.

Hult [18] in 1956 used the anterior retroperitoneal approach. The concept of chemonucleolysis was introduced by Smith et al. [67] in 1963. In the early and mid 1970s, mechanical nuclear decompression was utilized [15, 39]. Schreiber and co-workers [66] introduced the noble concept of biportal access to the intervertebral disc for visualization and removal of nuclear tissue. Automated nucleotomy was introduced in the mid 1980s [55]. In recent years, various laser lights have been used for intradiscal nuclear vaporization [1, 4, 6].

The posterolateral approach to the vertebral bodies for tissue biopsy was introduced by Valls et al. [69] and Craig [5] in the late 1940s and 1950s. A similar approach was subsequently utilized for discography and nuclear debulking procedures.

The knowledge of the anatomical and arthroscopic appearance of the periannular structures [25, 27] combined with the radiographic landmark of a safe zone [19, 25] on the dorsolateral corner of the annulus have been instrumental in the recent developmental advancement in the field of minimally invasive lumbar surgery via a posterolateral approach.

The knowledge of dimensions of a triangular working zone [19, 35, 52] has permitted the placement of an oval cannula [30, 32, 33] (5×8 and 5×10 mm I.D.) in the dorsolateral zone of the annulus for disc resection [27, 33, 41, 44, 64] and arthroscopic anterior column stabilization [26, 29, 34, 40, 48, 65]. Further lateralization of the skin entry point has permitted entrance to the nerve root foramen for decompression of the lateral recess [36], inspection of the content of the spinal canal [28, 32, 33, 41], and intracanalicular surgery [71].

Our experience with the posteromedial endoscopic interlaminar approach to the spinal canal and lateral recess dates back to 1991 [20, 24, 31, 33]. In recent years, a modified version of the technology has been introduced by other investigators [9].

37.4 Advantages

It is not the intention of this author to minimize the important role of open laminotomy in management of spinal disorders. However, the shortcomings and complications associated with open laminotomy and discectomy have been described [61]. Arthroscopic microdiscectomy is a minimally invasive operative procedure and emphasizes the avoidance and manipulation of contents of the spinal canal when feasible.

This approach provides the following long-term benefits:

- It protects the epidural and neural venous systems and prevents venous stasis and chronic neural edema [17, 54, 57, 58]. In addition, it minimizes perineural and epidural scar formation.
- The later technique does not disturb the fine dural and neural ligamentous structures and minimizes the tethering of the nerve roots. The use of a cannula reduces the incidence of injury and denervation of the paraspinal muscles, which is seen following undue traction during open surgery [62, 70]. In addition it prevents the incidence of postoperative instability and spondylolisthesis due to excess bone removal [38, 46].
- In a contained herniated disc, intradiscal surgery minimizes the incidence of recurrent herniation by protection of partially intact posterior annular fibers and the posterior longitudinal ligament.

37.5 Disadvantages

The limitations of the posterolateral approach include the difficulties associated with the retrieval of migrated sequestrated disc fragments and access to L5-S1 intervertebral discs in the presence of an elevated iliac crest which is prevalent in the male sex. The ongoing research in the field of minimally invasive surgery may facilitate the arthroscopic access and decompression of the nerve roots in the latter group of patients.

37.6 Indications and Contraindications

Proper patient selection is the key to successful arthroscopic microdiscectomy.

There is no clinical evidence in the literature which demonstrates that a simple disc resection, whether performed via an open technique or posterolaterally, is beneficial in the management of back pain without associated radiculopathy.

An open laminotomy or laminectomy should be performed when intracanalicular compression is deemed related to a benign or malignant lesion.

Individuals with cauda equina syndrome will require an open posteromedial approach for decompression, laminotomy, and resection of the offending nuclear and/or annular tissue.

A high incidence of dural tears following re-exploration of the spinal canal for extraction of a reherniated fragment mandates meticulous resection of epidural fibrous tissue and repair of the dural tear via a laminotomy procedure. Elderly individuals with signs and symptoms of root compression, presenting with correlative imaging evidence of a global bulging disc and hypertrophy of the ligamentum flavum are most likely suffering from spinal stenosis and are best treated via an open procedure, although annular bulge and marginal osteophytes resection via an arthroscopic approach may be beneficial in management of a selected patient population who are suffering from lateral recess stenosis [36]. Individuals with sequestrated migrated herniated disc may require open laminotomy and decompression.

The inclusion criteria for arthroscopic or endoscopic microdiscectomy do not differ from those selected for laminotomy and discectomy and are as follows. Patients with a herniated lumbar disc who are selected for minimally invasive operative procedures must demonstrate signs and symptoms of mechanical pressure or tension upon the nerve root and should meet the following criteria:

A. Unremitting or recurrent episodes of radicular pain.
B. Radicular pain greater than back pain.
C. Failure to respond to a well-planned conservative management including use of steroidal and non-steroidal anti-inflammatory medication, physical therapy, and an exercise and conditioning program as tolerated. A minimum period of 4 – 6 weeks of consecutive therapy is recommended unless the neurological status of the patient is deteriorating in which case a prompt surgical management will have to be considered.
D. Absence of a history of drug abuse and psychosocial disorder.

E. Positive tension signs.
F. Correlative computerized tomography (CT), magnetic resonance imaging (MRI), or myelographic evidence of disc herniation.
G. Neurological deficit or positive correlative electromyographic findings.

37.7 Patient Education and Preoperative Consent

Smart marketing tactics which have been used for the promotion of various minimally invasive operative procedures have caused certain confusion and misunderstanding among the consumer. It is a false perception that a laser can be aimed toward the intervertebral disc without a skin incision, minimally invasive surgery is merely band-aid surgery, and patients are able to resume activities and return to work immediately.

Patients must be educated and informed that arthroscopic disc surgery is an operative procedure. It is performed in a sterile operating room environment. Although rare, it carries with it all of the potential complications which are associated with an open operative procedure. The chance of recurrent herniation and reappearance of the symptoms or possible future need of an open operative procedure should be emphasized.

When surgery is being performed adjacent to the nerve root ganglia, the possibility of postoperative development of skin hypersensitivity of the involved limb (sunburn syndrome) within 4–5 days following the surgery should be reviewed [40].

The importance of a postoperative functional restoration program and rehabilitation of the abdominal and paraspinal muscles for overall recovery and prevention of recurrence of discogenic pain must be explained. Patients must understand that the intervertebral disc, which is herniated, is also dehydrated and degenerated. This degeneration process will continue regardless of their already planned operative intervention. At times, degenerated discs become symptom producing and will require medical or surgical attention.

Individuals with multilevel degenerative disc disease and those with a longstanding history of sciatic pain may have a suboptimal outcome following arthroscopic disc surgery or an open laminotomy/discectomy. This may be attributed to chronic edema and perineural fibrosis.

37.8 Anatomical Consideration

In contrast to the translaminar approach to the content of the spinal canal where the larger cannula of approximately 10 mm I.D. is inserted from a distance of 2 or 3 cm from the midline, a distance of 10 or 12 cm from the midline is required for satisfactory intradiscal or transforaminal access to the nerve roots or content of the spinal canal. The proper docking of the working cannula on the posterolateral annulus at the onset of the operative procedure is essential for adequate access and successful performance of minimally invasive spine surgery via a posterolateral approach.

The triangular working zone is designated as an appropriate and safe site for positioning of the instrument at the onset of the operative procedure [19, 25, 31, 40]. The exiting and traversing roots form the anterolateral and medial boundaries of the above triangle. Although the vertebral plate of the inferior segment generally has been designated as the inferior boundary of the triangular working zone, during the posterolateral access to the intervertebral discs in the course of arthroscopic anterior column stabilization, the proximal plate of the inferior segment may be partially resected. This will provide a broader access to the intervertebral disc and the vertebral plates of the adjacent segments [34].

Taking into consideration the mobility of both traversing and exiting nerve roots, a larger cannula 7 mm in height and 12 mm in width can be inserted posterolaterally into the triangular working zone and the intervertebral disc for performance of a variety of intradiscal surgical procedures [34, 40].

Parke [56–58] and other investigators have described the significance of epidural, perineural and intraneural venous system in prevention of postoperative development of neural scaring, tethering of the nerve roots, and development of postoperative pain. Therefore, undue coagulation of the venous structures surrounding the nerve roots and the dural sac must be avoided during transforaminal intracanalicular surgery. The transforaminal access to the content of the spinal canal should be reserved for retrieval of migrated herniated disc fragments.

The posterior longitudinal ligamentum and its lateral expansion are innervated via branches of the sinovertebral nerve [41, 56]. During minimally invasive surgery via a posterolateral approach, prior to annulotomy, the lateral fibers of the posterior longitudinal ligamentum should be anesthetized via a local injection of Xylocaine solution.

The iliac arteries and veins are located anterior to the vertebral bodies and the intervertebral discs. These structures may be injured when a long penetrating instrument is used during an intradiscal access to the disc herniation.

37.9 Surgical Technique

37.9.1 Operating Room Setup and Patient Positioning

Arthroscopic and endoscopic microdiscectomy is a technology-dependent operative procedure. As such, it requires a large operating room and specially trained nurses, a radiologic technician, and an assistant.

The C-arm monitor and video screen must be visually accessible to the surgeon while standing on the right or left side of the patient. At the onset of the operative procedure, I prefer to stand on the asymptomatic side of the patient and proceed with needle positioning and instrument insertion across the table, on the patient's symptomatic side. This approach has given me a better hand-eye coordination for proper needle placement. Usually, I move to the symptomatic side of the patient when proceeding with retrieval of herniated fragments.

Ample visual access to the video monitor is provided when it is positioned on the foot of the operating room table (Fig. 37.1).

The C-arm is properly covered with a sterile drape or a plastic sheath and placed on the patient's symptomatic side. In order to prevent contamination, the C-arm should rotate under the table.

The patient is placed in a prone position on a radiolucent operating room table and frame. The flattening of the lumbar lordosis is achieved by providing adequate support under the patient's anterior superior iliac spine and flexion of the table adjacent to the hip joints. In order to reduce the traction on the sciatic nerve, the knees are also kept in flexion. Adherence to the strict sterile principles which are practiced for open spine procedures is essential. The use of prophylactic antibiotics is advisable.

37.9.2 Anesthesia

The majority of patients undergoing arthroscopic or endoscopic microdiscectomy will require conscious sedation anesthesia. However, with adequate visualization, a trained surgeon should have no hesitation to perform this operative procedure under general or spinal anesthesia. Park and co-workers [41, 56] have shown that the posterior longitudinal ligament and its expansion into the foramina and the posterolateral surface of the annulus are highly innervated by branches of the sinovertebral nerve. When conscious sedation is being used, local infiltration of the posterolateral annulus with a long 18-gauge needle which is passed through the previously positioned cannula is necessary prior to the annular fenestration.

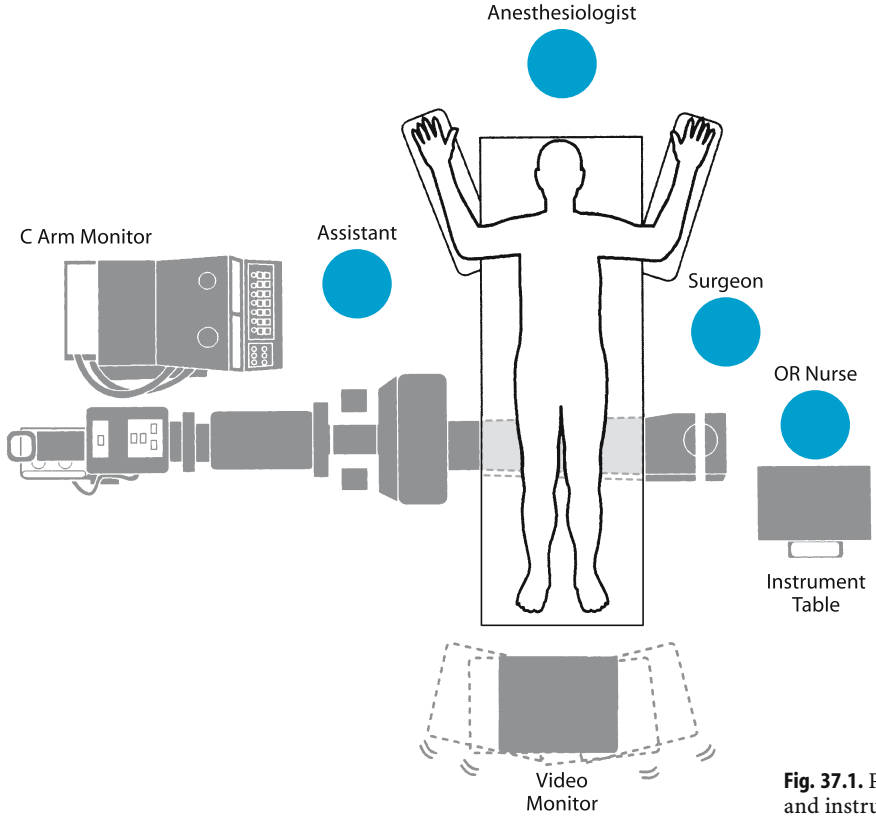


Fig. 37.1. Proper positioning of the patient and instruments in the operating room

The inserted 18-gauge needle is not only useful for delivery of local anesthetic, but by walking the needle through the four corners of the cannula, the surgeon makes certain that the medial end of the cannula is indeed centered on the annular surface and not on the vertebral plate.

The local delivery of a mixture of 1 cc fentanyl (Elkins-Sinn, Cherry Hill, NJ, USA) and 3 cc saline solution to the triangular working zone prior to positioning of the instruments will provide ample annular and ganglionic anesthesia. This may reduce the incidence of the postoperative pseudocausalgic type of pain in the involved extremity.

In the past, we advocated the use of Versed (Midazolam, Roche Laboratories) intraoperatively, but we have now abandoned the use of this agent during arthroscopic disc surgery. Although some patients responded well and felt comfortable, certain individuals lost their inhibition, became disoriented, and unduly apprehensive.

37.9.3 Positioning of the Instruments

The instruments are positioned in the triangular working zone (Fig. 37.2) adjacent to the spinal canal between the traversing and exiting roots.

In the coronal plane, the triangular working zone may be subdivided into three sections (Fig. 37.3), the medial pedicular line (representing the lateral boundary of the spinal canal) and the mid and lateral pedicular lines.

The majority of minimally invasive posterolateral disc operations are performed via a mid pedicular positioning, while the evacuation of extraforaminal herniations will require the placement of instruments in alignment with the lateral pedicular line.

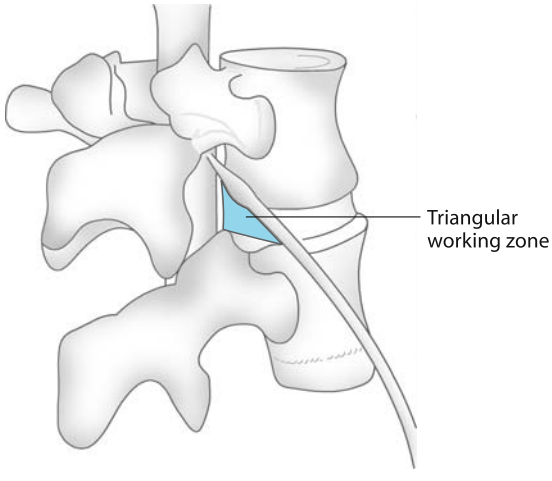


Fig. 37.2. The triangular working zone. The exiting nerve root forms the anterolateral boundary of the working zone. Inferiorly, it is limited by the vertebral plate of the inferior segment, while medially it extends to the traversing root and the dural sac

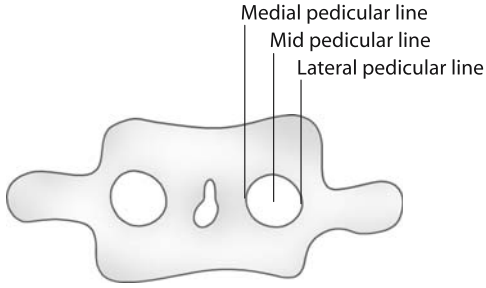


Fig. 37.3. The relation of the tip of the inserted needle to the pedicle of the vertebra as observed in an anteroposterior fluoroscopic examination

The skin entry point is approximately 10–12 cm from the spinal process. The degree of lateralization of the skin entry of the 18-gauge needle is dictated by the size of the patient, dimensions of the facet joints, and the desired location of the tip of the needle in the triangular working zone.

In heavy-weight and larger individuals, the proper positioning of the needle at the mid pedicular region requires further lateralization of skin entry. The size of the facet joints in the mid or upper lumbar region allows the passage of the inserted needle from an entry point shorter from the midline than the lower lumbar region. The needle should be advanced toward the triangular working zone with a twisting and rotatory movement. This prevents the deviation of the needle by its beveled tip as it is passed through the soft tissue structures. In addition, it provides a palpable tissue differentiation between the soft paraspinal muscle and the relatively firm fibrous annular tissue.

The needle should not be inserted into the annular fibers at the onset of the procedure. This will distort the radiographic appearance and positioning of the needle in the anteroposterior and lateral projection. When the needle is properly positioned in the anteroposterior projection, the tip of the needle is seen at the mid pedicular line (Fig. 37.4a) while in the lateral projection it is seen in alignment with the posterior borders of the adjacent vertebral bodies (Fig. 37.4b). At this time, the stylet of the needle is replaced by a guide wire. A skin incision is made and a soft tissue dilator (cannulated obturator) is passed over the guide wire and directed toward the annulus. This step is then followed by the introduction of the universal cannula (Fig. 37.5a, b) and withdrawal of the cannulated obturator.

The operating surgeon must hold the access cannula firmly against the annular fibers, otherwise periannular bleeding interferes with arthroscopic visualization and identification of the structures.

When the working cannula does not have an attached fluid sealer, the fluid-sealing adaptor is used and

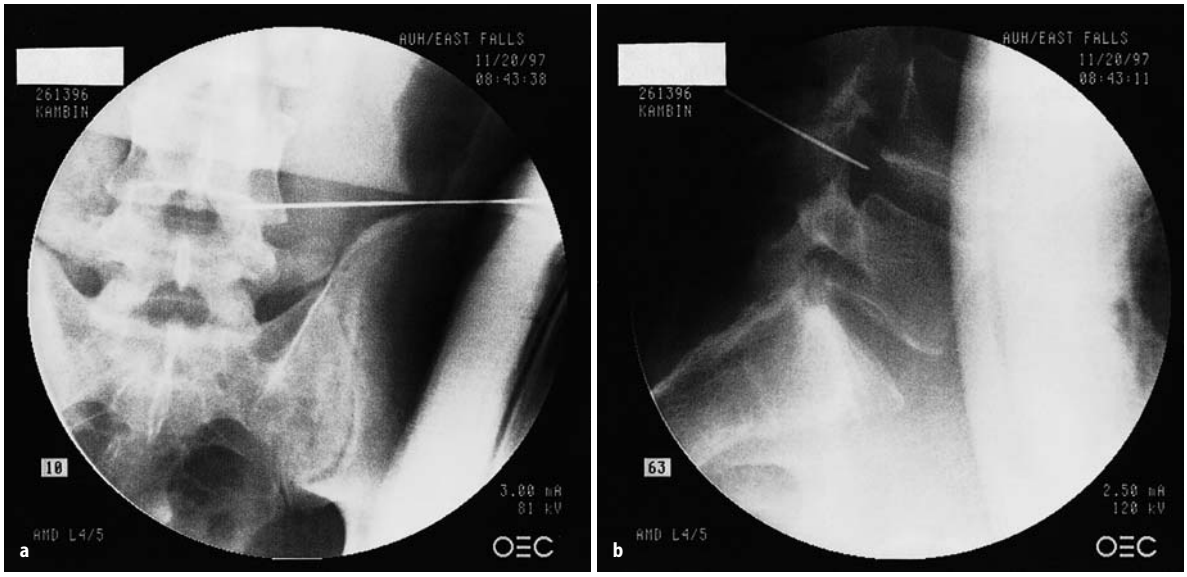


Fig. 37.4. a Proper positioning of the needle at the mid pedicular line in an anteroposterior fluoroscopic examination. **b** Same needle positioning shown in **a**. In the lateral projection, the tip of the inserted needle is in alignment with the posterior border of the adjacent vertebral bodies

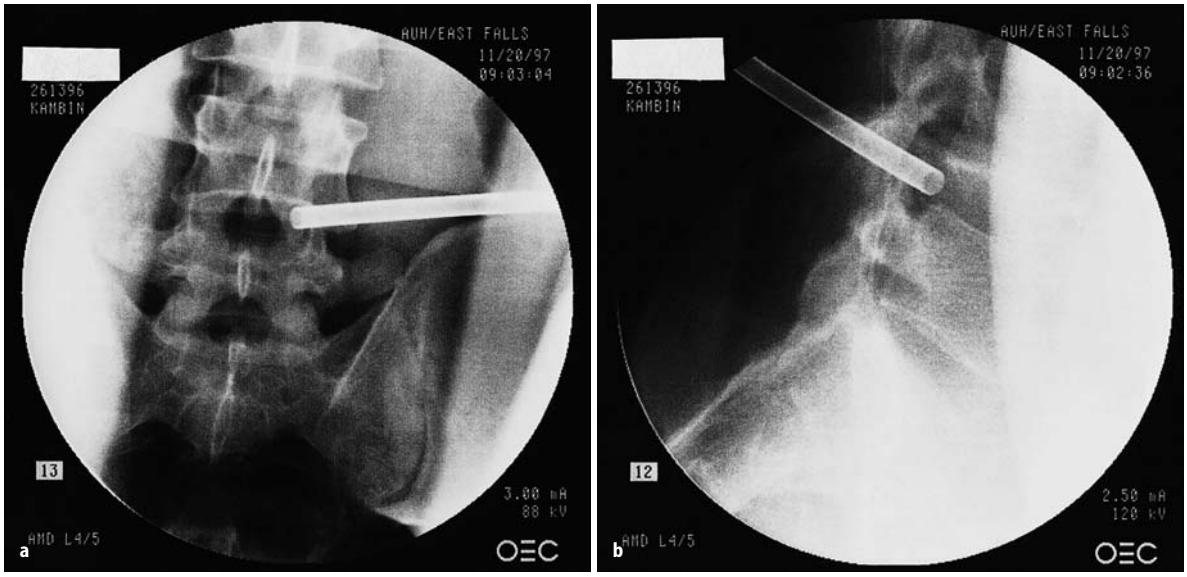


Fig. 37.5. Anteroposterior (**a**) and lateral (**b**) interoperative fluoroscopy demonstrates proper positioning of the cannula adjacent to the spinal canal

attached to the proximal end of the access cannula (Fig. 37.6) prior to introduction of the arthroscope. The above adaptor has an outflow valve for the attachment of the suction tube. In addition, the tight rubber washer on the top of the adaptor minimizes the fluid leakage and allows for the inward and outward telescoping of the arthroscope inside the inserted cannula.

A working channel endoscope is suitable for inspection of the annulotomy site (Fig. 37.7). It should be noted that when the cannula is seated on the annular surface in the triangular working zone, the exiting root is situated under the pedicular notch and is posterior to its distal opening. However, if the needle positioning and the subsequent cannula placement are too medial, one will observe the adipose tissue and or the traversing root.

Usually the globs of epidural fat are larger than the periannular adipose tissue and more importantly move in and out of the cannula as the patient breaths. The periannular fat may be removed with forceps via the working channel endoscope or wiped off with a cottonoid inserted through the cannula. This will

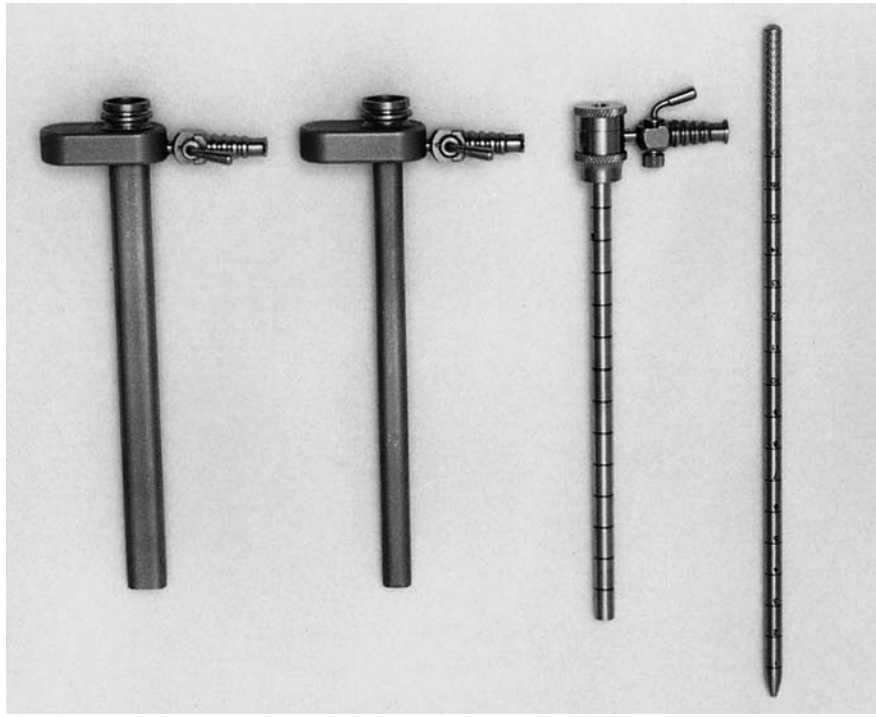


Fig. 37.6. From *right* to *left* 4.9-mm-O.D. blunt-tipped cannulated obturator, 5-mm-I.D. access cannula with removable suction irrigation valve, 5×8-mm-I.D. oval cannula, 5×10-mm-I.D. oval cannula

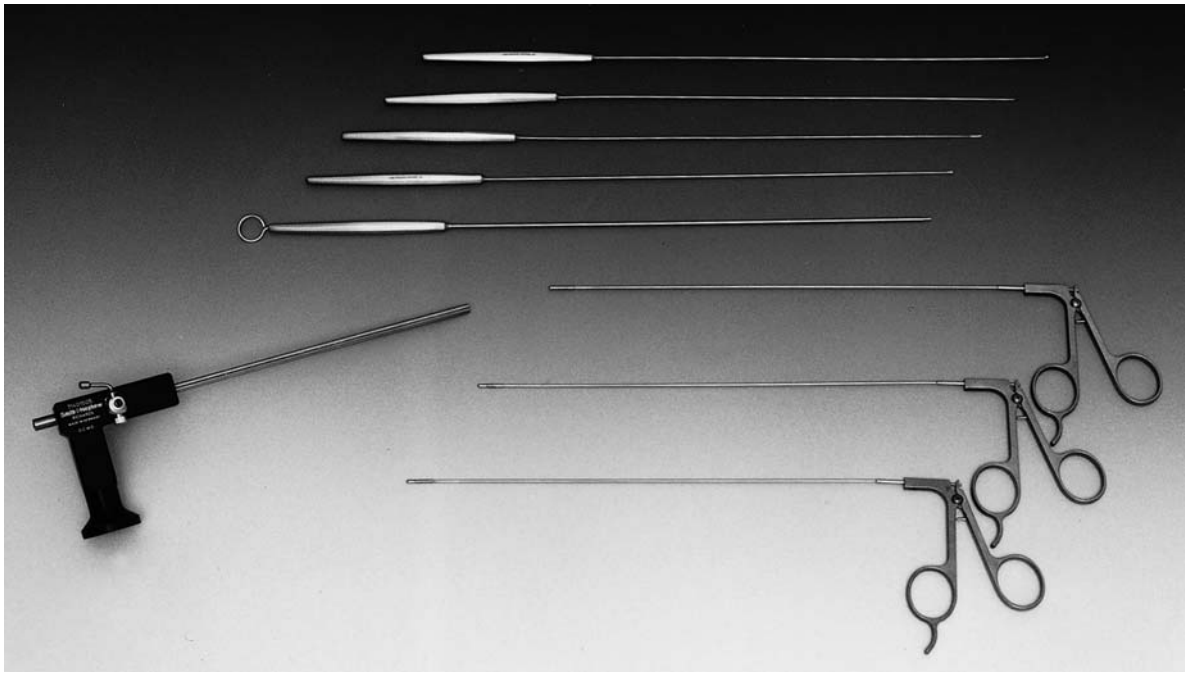


Fig. 37.7. Working channel endoscope

permit clear visualization of the annular surface (Fig. 37.8).

Annular fenestration may be accomplished under direct visualization through the working channel endoscope or with a trephine.

37.9.4 Posterolateral Arthroscopic Approaches

37.9.4.1 Intradiscal Subligamentous Approach

This approach is most commonly used for the retrieval of paramedial or small central herniations [13, 40, 42].



Fig. 37.8. Epidural adipose tissue is seen at the *top* extending from 9 to 12 o'clock. The annulotomy site is cleared for subligamentous disc evacuation



Fig. 37.10. Same patient as in Fig. 37.8. The medial end of the oval cannula is tilted cephalad for visualization of the traversing root (*top* extending from 11 to 12 o'clock). Note the partially resected herniated disc tissue from an area under the posterior longitudinal ligamentum

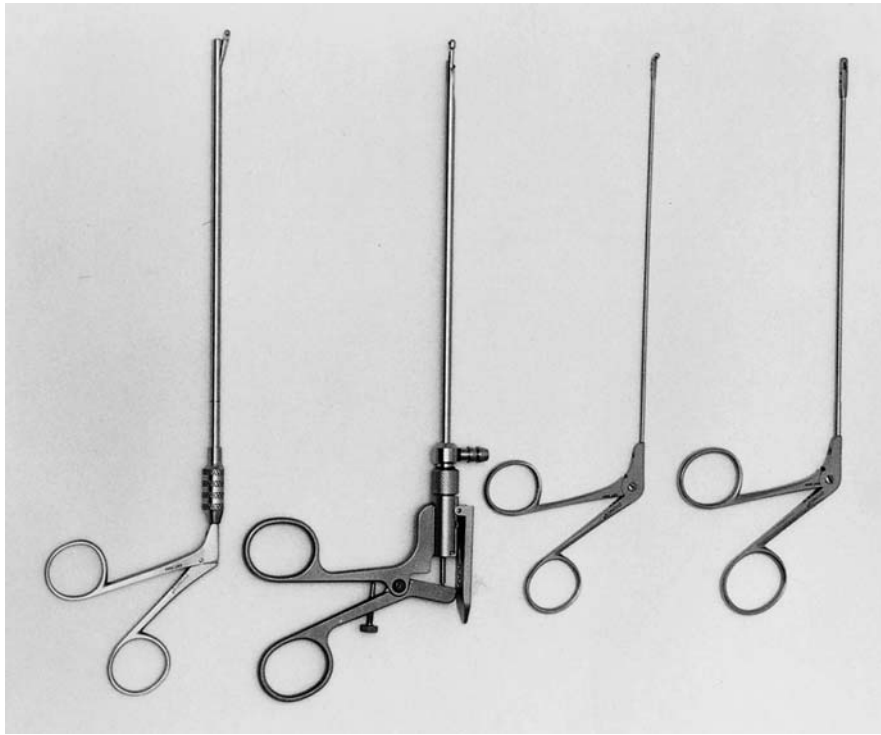


Fig. 37.9. From *right* to *left*, straight cup forceps, upbiting forceps, deflecting suction forceps allows zero to 100° deflection, deflecting tube and flexible forceps (allows zero to 40° deflection)

The epidural adipose tissue is first identified (Fig. 37.8) and the annular fenestration is made just lateral to the intracanalicular segment of the posterior longitudinal ligament. Such a positioning permits the trephine or inserted instruments to sweep under the traversing nerve root and the lateral dura as it enters the intervertebral disc.

If necessary, the introduction of an oval cannula (Fig. 37.6) permits the simultaneous introduction of a zero or 30° arthroscope, flexible tip or upbiting forceps for (Figs. 37.6, 37.9) visualization, and extraction of disc fragments from an area under the traversing root and lateral dura (Figs. 37.10, 37.11).

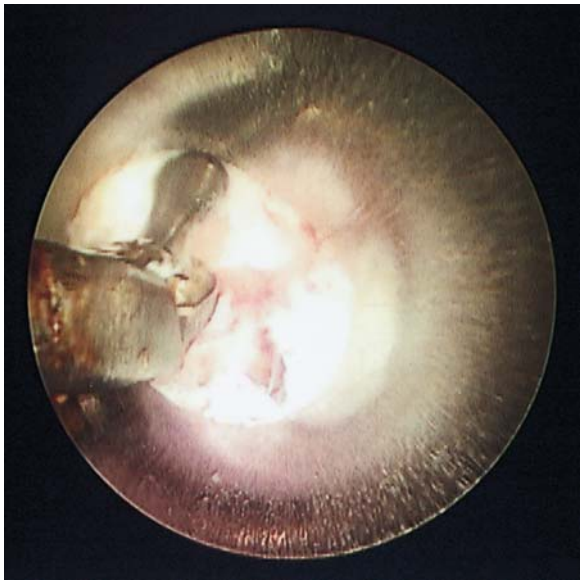


Fig. 37.11. Same patient as in Figs. 37.8 and 37.10. Upbiting forceps being used and the herniated disc material is pulled out from an area under the traversing nerve root



Fig. 37.12. Intradiscal view of the ventral surface of the dural sac



Fig. 37.13. Interoperative anteroposterior fluoroscopy demonstrates off-center intradiscal positioning of the cannulas for the removal of a left paracentral disc herniation

The medial end of the cannula must be stabilized and engaged into the annular fibers for a few millimeters prior to the above evacuation. The power driver suction disc resectors should not be used when this approach is being utilized.

37.9.4.2 Intradiscal Bilateral Approach

The retrieval of large or non-migrated sequestrated disc fragments may require a biportal access to the intervertebral discs [28, 40, 42] (Fig. 37.13). The triangulation inside the intervertebral disc provides an ample sense of depth perception for manipulation and extraction of herniated disc fragments.

A 30° or 70° arthroscope and articulating instruments are used for the evacuation of posterior and posterolateral herniated disc material. The arthroscope is introduced from one portal while the articulating instruments are used from the opposite side. The ventral surface of the dural sac may be visualized following intradiscal removal of an extraligamentous or sequestered fragment (Fig. 37.12).

In order to minimize unnecessary nuclear reaction, the cannulas are advanced into the intervertebral disc and centered over the herniation site at the onset of the operative procedure. This position is confirmed via an anteroposterior radiographic examination (Fig. 37.13). A cavity is created adjacent to the inner annular fibers posteriorly. A radiofrequency probe and bipolar coagulators may be used to achieve the latter. During a biportal approach, the inflow of saline solution is attached to the irrigation sheath of the arthroscope, while the suction is used in conjunction with the deflecting forceps or attached to the cannula that is inserted from the opposite side.

37.9.4.3 Periannular Foraminal and Extraforaminal Approach

In the opinion of this writer, arthroscopic microdiscectomy is the procedure of choice for treatment of foraminal and extraforaminal herniations [42, 59]. A 5×5- or 5×8-mm cannula may be used for the evacuation of the above herniations. When lateral stenosis is produced by a degenerated bulging annular and posterior mar-

ginal osteophytosis of the vertebral bodies, the exiting root may be decompressed by posterolateral annulectomy and resection of osteophytes [36].

While the lumbar spine is maintained in flexion, the marginal osteophytes arising from the facet joints and partial facetectomy may also be performed through a working channel endoscope of a larger cannula which is positioned over the facet joints [24].

37.9.4.4 Periannular Foraminal Approach to the Spinal Canal

Further lateralization of the skin entry point permits introduction of a cannula into the foramen and access the content of the spinal canal. However, in a clinical setting, often the epidural adipose tissue and bleeding interferes with clear visualization of anatomical and pathological tissue. In recent years, we have satisfactorily used free outflow of the saline solution, diluted epinephrine, and radiofrequency probe for epidural hemostasis during intracanalicular surgery via a transforaminal access [28, 40, 42, 71]. Partial removal of fibers of the posterior longitudinal ligament ventral to the herniation site provides a broader access to the spinal canal and the disc herniation.

37.9.4.5 Posteromedial Interlaminar Approach to the Spinal Canal

In the early 1990s in our institution, we began to experiment with the use of a 10-mm-I.D. cannula for endoscopic laminotomy and intracanalicular surgery [20, 24, 31, 33]. Our original prototype cannula had a side window for insertion of the available straight endoscope while the surgical instruments were introduced through the proximal end of the cannula (Fig. 37.14). This provided a broader surgical field for insertion of a variety of instruments. The cannula was positioned at the interlaminar space following insertion of the guide wire under fluoroscopic control. This step was followed by insertion of a soft tissue dilator and positioning of a 10-mm-I.D. working cannula. Due to the limited available space within the cannula and the restricted operative field, this approach was later discontinued.

In recent years, a modified version of the above technique has been used by other investigators [9]. In addition, the industry has produced a novel tubular retractor cannula (Endius, Plainville, MA) that allows a broader access to the laminae, facets, and transverse processes for performance of a variety of spinal surgical procedures. The distal end of the later cannula is usually expanded following its insertion (Fig. 37.15).

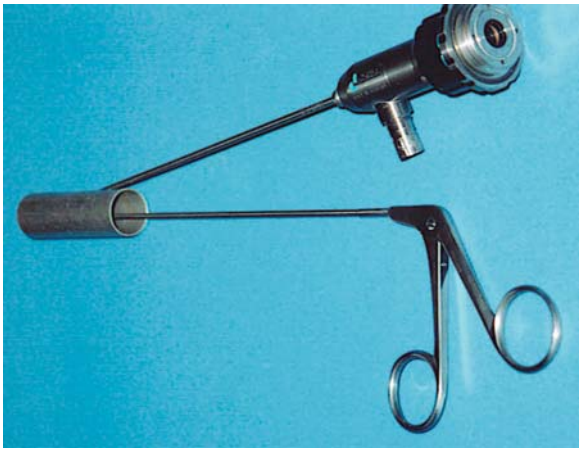


Fig. 37.14. A 12-mm-I.D. cannula with side portal may be used for endoscopic laminotomy and foraminotomy. Note that the insertion of the endoscope from the side portal allows the insertion of multiple surgical instruments from the proximal end of the cannula

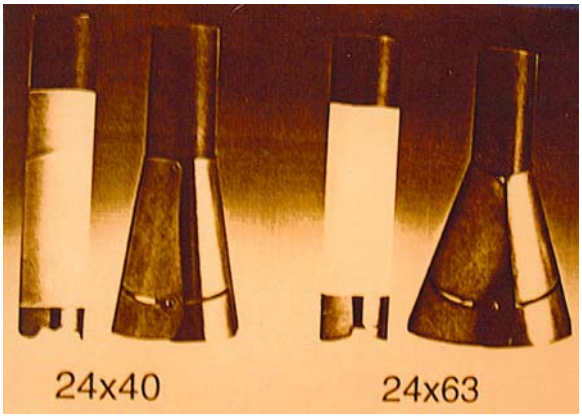


Fig. 37.15. Photo of two tubular retractors (cannulas). Note the expansion of the distal end of the cannula following its insertion

37.9.4.6 Unilateral, Biportal Extra-annular or Intradiscal Approach

The anteroposterior dimension of the triangular working zone [19, 25, 40, 52] allows the positioning of two cannulas of a single oval cannula (6.4×12 mm O.D.) in the triangular working zone (Fig. 37.6). A 6.4×8-mm-O.D. cannula is sufficient and is commonly used for uniportal or biportal discectomy [33, 45]. However, the 6.4×12-mm-O.D. cannula is reserved for arthroscopic interbody fusion [29, 34, 40, 65].

The oval cannula permits the ipsilateral insertion of a zero, 30°, or 70° discoscope and larger resecting instruments for intradiscal and extra-annular surgery according to the surgeon's needs. When a bilateral biportal access is being used for the retrieval of a large herniated fragment, the oval cannula may be used ipsilaterally while the 5-mm-I.D. cannula is introduced form

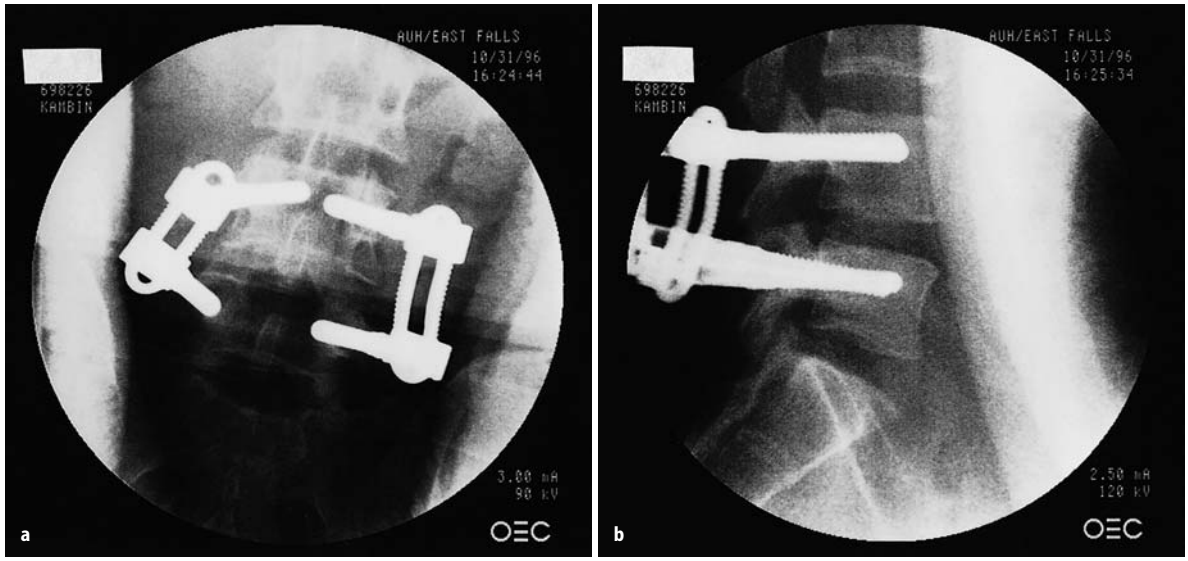


Fig. 37.16. Anteroposterior (**a**) and lateral (**b**) roentgenographic view of arthroscopic interbody fusion at L4-5. Extension bars are used for the elongation of the pedicular bolts. Plates are positioned under the skin above the lumbar fascia

the opposite portal. This allows for a more rapid development of communication between the right and left portals and retrieval of larger herniated fragments. Placement of the oval cannula is accomplished with the aid of a specially designed jig which is placed over the proximal end of the previously inserted cannulated obturator into the intervertebral disc.

The above jig permits parallel insertion of a half-rail or full auxiliary obturator into the disc space. This step is then followed by removal of the jig and insertion of the appropriate oval-shaped cannula. The 5×10-mm-I.D. oval cannula has permitted us to use specially designed decorticators and curettes for decortication of the concave surface of the vertebral plates in preparation for bone grafting for arthroscopic anterior column stabilization (Fig. 37.16).

37.10 Postoperative Care

Arthroscopic microdiscectomy is an outpatient surgical procedure and does not require hospitalization. All patients receive 1 g Ancef (cefazolin; SmithKline Beecham, Philadelphia, PA, USA) preoperatively. If the patient is allergic to Ancef or has a prior history of penicillin sensitivity, then vancomycin (Elkins-Sinn, Cherry Hill, NJ, USA) is used intravenously.

The second dose of Ancef is usually administered in the short procedure unit of the hospital 4 – 6 hours following the surgery prior to the patient's discharge. In addition to the above, patients are provided with two capsules of 500 mg Keflex (Dista) to take orally 8 hours later. Most patients do not require injectable analgesics following the surgery. However, a prescription for oral analgesics to be used if necessary is provided.

The incision is covered with a Band-aid and a plastic dressing (Tegraderm 3 M, St. Paul, MN, USA). Patients are permitted to become ambulatory following surgery. The plastic dressing of the surgical site allows them to take showers the following day.

In order to maintain a low level of intradiscal pressure, we advise our patients to refrain from long periods of sitting for several days following their surgical procedure. The first postoperative office visit is usually scheduled 7 – 10 days following surgery. At this time, if the patient has continued to show progress and improvement, they are encouraged to participate in swimming and water exercises. This step is then followed by isokinetic and more strenuous exercises which are designed to strengthen their abdominal and paralumbar musculature.

37.10.1 Hazards and Potential Complications

The outcome of arthroscopic microdiscectomy has been the subject of multiple prospective studies, scientific presentations, and peer review publications. Arthroscopic microdiscectomy is within the reach of every trained orthopedic or neurologic surgeon. Positioning of the instruments in the triangular working zone may be time consuming and requires attention to the detail of the operative procedure.

37.10.1.1 Hazards Associated with Needle Positioning

The patient is positioned prone on a radiolucent operating room table. At no time should the needle be inserted in a vertical position. Introduce the needle at an angle of 30 – 40° from a horizontal plane. Palpate the facet joint, withdraw the needle, reinsert it at a slightly larger angle, bypass the facet joint, and position the tip of the needle at the mid pedicular line.

An inadvertent vertically inserted needle may enter the bowel or major vessels. In addition to the above, a far lateral skin entry may be associated with entry to the abdominal cavity and cause visceral injury.

37.10.1.2 Hazards Associated with Insertion of Cannulated Obturator

When the cannulated obturator is not introduced parallel to the previously positioned guide wire, it may bend the medial end of the wire and make its withdrawal difficult. In this case remove the obturator first, then take the wire out. The surgeon will have to start again with the needle placement and follow the steps which have been described previously.

37.10.1.3 Hazards Associated with Periannular Bleeding

The most common cause of periannular bleeding is the loosely positioned cannula on the annular surface. Maintain the blunt end of the cannulated obturator firmly against the annulus. Then advance the cannula and hold it firmly against the annulus while inspecting the annulotomy site. Bleeding may be controlled via a radiofrequency coagulator or laser which is introduced through a working channel endoscope.

37.10.1.4 Hazards Associated with the Use of Power Drive Suction Instruments or Laser Adjacent to Neural Structures

Suction, which is used in conjunction with various nucleotomy or disc resectors, should not be used adjacent to the traversing root or dural sac. The herniated disc fragments are best removed manually under direct arthroscopic control. In addition, the use of a heat-producing laser adjacent to the neural structures is potentially hazardous.

We have performed more than seven hundred arthroscopic disc operations. The incidence of complications in our hands has been relatively low and within an acceptable range [42, 43, 64].

We have reported two postoperative infections which were treated with intravenous antibiotic therapy for 6 weeks following arthroscopic debridement and culture sensitivity testing.

We have reported two instrument breakages where the tip of the flexible forceps broke off during an intradiscal fragmentectomy. In both patients, the above foreign bodies were retrieved arthroscopically with no sequelae.

Two patients were treated for neurapraxia following their surgery. In one patient, the postoperative findings were attributed to compression of the peroneal nerve by a strap which was placed behind the patient's knee intraoperatively.

In our reported series, five patients developed skin hypersensitivity (sunburn syndrome) of the involved extremity 4 – 5 days postoperatively and required additional treatment. Most of these patients were treated for lateral stenosis or foraminal herniation. The symptoms were attributed to postoperative bleeding and/or interoperative trauma to the nerve root ganglia. Use of Hemovac when bleeding is encountered, intraoperative injection of fentanyl in the periannular region, and avoidance of the use of power tools and vibratory trauma adjacent to the neural structures has minimized later complications. Our preliminary clinical experience suggests that foraminal injection of corticosteroids when symptoms are severe is helpful in management of the above complication.

37.11 Results

The outcome of arthroscopic microdiscectomy has been the subject of multiple publications. A satisfactory result varying from 75 % to 90 % has been reported by various authors [16, 22, 27, 35, 51, 59, 63, 64, 71].

In a consecutive prospective study of 175 patients who underwent microdiscectomy with a minimum of 24 months of follow-up [42], we reported 86 % incidence of good and excellent outcome in uniportal procedures and 92 % satisfactory outcome in those requiring a biportal access for the retrieval of their herniated fragments. Uniportal access was required for 95 patients, while a biportal approach was used in 54 patients who presented with a large central or non-migrated sequestrated disc herniation.

Arthroscopic microdiscectomy failed in 20 patients and 6 patients were lost to follow-up.

The effectiveness of arthroscopic microdiscectomy for the retrieval of herniated disc fragments was objectively demonstrated via pre- and postoperative imaging studies by Casey and his co-workers [3].

In a recent prospective randomized study of 60 patients who underwent arthroscopic and endoscopic disc resection, Hermantin and co-workers [13] reported shorter hospitalization, less need for narcotic use, and more reported patient satisfaction in the group of patients who underwent arthroscopic and endoscopic surgery.

37.12 Critical Evaluation and Discussion

Arthroscopic and endoscopic disc surgery represents a new concept and approach for the retrieval of offending and symptom-producing disc herniations of the lower thoracic and lumbar spine.

A distinction must be made between the minimally invasive procedures which are geared toward debulking and decompression of the nuclear tissue and arthroscopic and endoscopic microdiscectomy which simulates the principle of open laminotomy and requires the extraction of herniated disc fragments.

The success of arthroscopic or endoscopic microdiscectomy hinges on proper positioning of the cannula adjacent to the spinal canal without the need for violating intracanalicular structures. As such, knowledge of visual diagnosis of the anatomical structures plays an important role in the prevention of unwarranted complications. It should be comforting to realize that the annular surface in the triangular working zone avoids neural structures. The exiting root in this zone is also protected under the pedicular notch.

The scope of arthroscopic and endoscopic spine surgery via a posterolateral approach has evolved in recent years. A variety of spinal disorders are now being treated under arthroscopic or endoscopic illumination and magnification.

Arthroscopic anterior column stabilization for the treatment of unstable motion segments was previously discussed. In our clinic we have used percutaneously inserted pedicular bolts for both diagnosis and treatment of segmental instabilities of the lumbar spine [30].

The outcome of intradiscal debridement of annular tears and annular rim lesions [30, 37] in selected patients who were suffering with symptomatic degenerative disc disease also has been encouraging. Early arthroscopic visual diagnosis of bacterial discitis [30] and management of vertebral osteomyelitis via minimally invasive technology has, in our hands, been successful [11].

The ongoing investigations on nuclear replacement via a cannula that is inserted posterolaterally into the intervertebral disc is encouraging [49].

Minimally invasive spine surgery has a learning curve and requires commitment and patience. Future technological advancement will further enhance the capability of the surgeons to treat additional spinal disorders via percutaneously positioned cannulas under arthroscopic or endoscopic visualization.

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38 The Full-endoscopic Interlaminar Approach for Lumbar Disc Herniations

S. Ruetten

38.1 Terminology

Full-endoscopic interlaminar approach is the term for a newly developed method for full-endoscopic uniportal operation of the lumbar spinal canal and neighboring structures under visual control and continuous fluid flow via a minimally invasive access through the interlaminar window.

38.2 Surgical Principle

Minimally invasive techniques may reduce tissue damage and its sequelae [71, 86, 100]. Endoscopic operations offer advantages which raise these procedures to the standard in many areas. Working with lens optics under fluid enables excellent visual conditions, and bleeding can be reduced. The use of the laser or high-frequency bipolar current is possible in the immediate vicinity of neural structures [22, 81]. Prerequisite is that the technical possibilities of such operations guarantee that the surgical goals will be attained [57].

The most common full-endoscopic uniportal procedure is the *transforaminal* or *extraforaminal* operation with posterolateral access [42, 46, 47, 55, 59, 85, 89, 95, 97, 106]. Retrograde resection of pathologies within the spinal canal is technically demanding and often not possible. Through an extreme lateral approach the posterior annulus and the spinal canal can be reached using the foramen intervertebrale as corridor. This transforaminal approach may be impeded at the caudal levels by the pelvis. Another limitation is the restricted mobility in the spinal canal due to the bony borders of the foramen [43].

The newly developed full-endoscopic uniportal *interlaminar* technique is applicable in transforaminal technically inoperable lumbar pathologies when specific criteria are taken into account. With minimized traumatization, the spinal canal is reached through the interlaminar window, guaranteeing working conditions under excellent visual control like those in conventional techniques, but in a minimally invasive procedure. The known consecutive problems of open, microscopically or endoscopically assisted techniques can be reduced [71, 86, 100].

38.3 History

Reaching the spinal canal via an interlaminar access using total or partial laminectomy has been described since the early twentieth century [2, 10, 64, 74, 92, 94]. Alternative methods were developed for the operation of intravertebral disc pathologies only 30 years later [38]. Transforaminal mechanical disc decompression has developed through chemonucleolysis [90] since the early 1970s [31, 35, 45, 58, 70]. The corresponding posterolateral approach was first described in the late 1940s as part of vertebral body biopsies [98]. Optical systems have been used since the 1980s [26]. The operative procedure currently consists of a full-endoscopic procedure under continuous fluid flow in a uniportal technique. Clinical results and further technical developments have been published to date in numerous articles [42, 43, 46–48, 55, 59, 61, 85, 89, 95, 97, 106].

In conjunction with the interlaminar approach, a microsurgical procedure was developed in the late 1970s [11, 28, 29, 105]. Since the late 1990s, publications have appeared about endoscopically assisted procedures [9, 16, 67, 72, 86]. But there are no reports on full-endoscopic uniportal techniques for sufficient mechanical decompression of the spinal canal under visual control via interlaminar access.

38.4 Advantages

Conventional open operation procedures will remain as indispensable in the future as they are today. The possible complications and consecutive damage of such procedures are known [1, 5, 13, 17, 27, 32, 33, 37, 41, 49, 50, 52–54, 56, 75, 80, 82, 87, 88, 99]. New techniques must at least guarantee possibilities of attaining the operative goal equal to those of known procedures

[57]. However, it is unthinkable that problems in spinal surgery can be completely avoided.

As a truly minimally invasive procedure, the full-endoscopic uniportal interlaminar operation offers the following possibilities and advantages:

- Sufficient working within the spinal canal and its neighboring structures under excellent visual conditions and short operation times.
- Preservation of epidural lubricating tissue, reduced epidural scarring, and avoidance of a post-discotomy syndrome.
- Minimized resection of bone and ligaments, possible reduction of surgery-induced instabilities.
- Subsequent operations are not made more difficult.
- No surgery-related increase in back pain.
- Reduced traumatization of the surrounding tissues.
- Reduced complication rate, such as dural injury, bleeding, infections, etc.
- Short hospitalization, rapid rehabilitation, high rate of return to earlier level of activity in sports and occupation.
- No increase in morbidity in concurrent illnesses and advanced age.
- High patient acceptance.
- Applicable in transforaminal technically inoperable pathologies.

38.5 Disadvantages

The mobility within the spinal canal is limited by the size of the interlaminar window. At levels cranial to L5/S1, the size frequently hinders access without bone removal. More extensive bony resections are technically more demanding with the currently available instruments since the use of high-speed burrs or bone punches is limited by the size of the access. This is especially true in pronounced spinal canal stenosis and fusions, in which parts of the lamina must be removed to reach the intervertebral space.

Compared to the transforaminal approach, the interlaminar procedure results in a defect in the ligamentum flavum and possibly resection of bony structures, despite its minimal invasiveness. Thus, the full-endoscopic uniportal transforaminal operation can be rated as less traumatic and can offer advantages in appropriate indications, taking the clear limitations into account.

38.6 Indications

The indication for operation corresponds to currently valid standards [3, 63]. The most experience has been gained in the therapy of disc prolapses and lateral spinal canal stenoses. New instruments are constantly expanding the spectrum of indications. Extensive central spinal canal stenoses have been operated on only for a short time and procedures are still in development. Existing concurrent pathologies, such as instabilities, may have to be co-therapied with other procedures. The following indications are presently clear:

- Sequestered or non-sequestered disc herniations within the spinal canal: in extensive dislocation to the next level, a bilevel procedure may be necessary, in combination with intra- or extraforaminal prolapses, an additional full-endoscopic transforaminal operation may be performed.
- Recurrent disc herniations after conventional or full-endoscopic operations.
- Lateral bony and ligamentary spinal canal stenosis.
- Zygapophyseal joint cysts.
- Intervertebral monosegmental fusions with expandable cages in combination with percutaneous dorsal transpedicular or translaminar stabilization: an interlaminar instead of transforaminal procedure is only used when decompression is necessary within the spinal canal or a transforaminal procedure is technically not possible.

38.7 Contraindications

In addition to general surgical contraindications, the following limitations are given currently for the full-endoscopic interlaminar procedure because of a lack of experience or because of technical limitations:

- Compressive intra- or extraforaminal pathologies: a full-endoscopic trans- or extraforaminal procedure with posterolateral to extreme lateral access is indicated in such cases.
- Extensive central spinal canal stenoses.
- Fusions in instabilities which cannot be reduced by positioning, and in spondylolysis: conventional systems with repositioning possibilities must be used in such cases.
- Multisegmental fusions.
- Pronounced bony shift in the interlaminar window to the cranial levels: due to the required demanding bone resection with currently available instruments, a conventional procedure should be considered in transforaminal technically inoperable pathologies.

38.8 Patient's Informed Consent

As with conventional procedures, patients must be informed about their disease, its possible long-term course and consequences, as well as all known side effects, complications, and therapeutic possibilities, despite the minimal invasiveness and the resultant advantages for the surgical procedure [60]. In addition, it must be emphasized that therapy of a possible complication may require a change of the surgical strategy to an open procedure.

38.9 Surgical Technique

As with all microsurgical techniques, surgery must be planned preoperatively based on imaging findings. The goal is to resect spinal structures as sparingly as possible, depending on the pathology. This applies especially to the selection of access in relation to the size of the interlaminar window and the craniocaudal level of the interlaminar window in relation to the level of the pathology (Figs. 38.1, 38.2a, b).

The full-endoscopic interlaminar operation is usually performed under general anesthesia. This is more comfortable for the patient and the surgeon, enables positioning as required, and also enables extensive working within the spinal canal. The procedure may be performed under local anesthesia only in case of excessive risk for general anesthesia. In such cases, local anesthesia of the route of access and also of the neural structures is necessary. Due to inflammatory processes, epidural anesthesia alone is usually not sufficient, so intrathecal administration of local anesthetic must be made. In addition, systemic sedation is necessary for immobilization. Due to positioning, this requires costly control of vital parameters, and correction of anesthesiological problems is difficult. Thus, in weighing possible risks, performance of the procedure under local anesthesia is reserved for rare exceptions.



Fig. 38.1. The spinal canal can be reached without bone resection from L5/S1 to L3/4 in appropriate anatomy



Fig. 38.2. a There is no limitation by the size of the disc prolapse. **b** The minimal traumatization is visible 2 hours postoperative. The intervertebral space L5/S1 is still filled with lavage fluid

The operation is performed with the patient in a prone position on an X-ray permeable table under orthograde radiological control in two planes. To relieve abdominal and thoracic organs, the patient lies on a hip and thorax roll. The operating table is adjustable to enable a lordotic or kyphotic positioning. Single-shot antibiosis is applied for infection prophylaxis.

Access is first created under anterior-posterior X-ray control. The penetration site in the skin is directed craniocaudal depending on the anatomical and pathological situation and the preoperative planning toward the target spot within the spinal canal. The entry point is chosen close to the midline in order to reach the spinal canal lateral below the zygapophyseal joints with no or as little bone resection as possible. After a puncture incision of 7 mm in length, the dilator is inserted flat to the lateral edge of the interlaminar window. Incision of a thick muscle fascia may facilitate penetration. The subsequent steps are performed under lateral fluoroscopic control. The working sleeve with beveled opening is inserted through the dilator toward medial. After the dilator is removed, the endoscope is inserted and the operation performed under visual control and gravity-operated fluid flow (Fig. 38.3).

First the ligamentum flavum is exposed then incised with the micropunch. The fluid flow causes displacement of the cauda equina from the ligament. If the interlaminar window is not large enough, the bone is first resected with a burr, depending on the finding, without opening the ligamentum flavum. Then the incision in the ligament is increased to maximum of 5 mm to enable entry into the spinal canal. The neural structures are exposed, preserving the epidural lubricating tissues (Fig. 38.4). The further surgical steps depend on the pathology. Disc herniations, cysts of the zygapophyseal joints and lateral spinal canal decompression can usually be handled without further access-related resections. In extensive sequester dislocations, preoperative planning may show that resection of parts of the lamina might be necessary prior to opening the ligamentum flavum. Whereas medial excision of the superior articular process is usually sufficient in pure recessus stenosis, more advanced stenosis may require more extensive bone resections.

The operating sheath with beveled opening serves as a second instrument and as a nerve hook. By rotating the opening, the neural structures can be held aside and protected. Using optics with the joystick principle enables mobility within the spinal canal. Various stiff or flexible instruments of different sizes, as well as shavers and grinders are available for the individual working steps (Fig. 38.5). High-frequency bipolar current is used for preparation and to stop bleeding. The use of the holmium:YAG laser for tissue ablation can be helpful only in exceptional cases.

At the conclusion of the operation, the instruments are removed and the puncture incision sutured. No drainage is necessary.

In revision operations, the dilator is inserted further lateral to contact with the bony parts of the zygapophyseal joint in order to avoid injury to the neural structures due to an already-existing defect in the ligamentum flavum. Preparation is made from this safe zone under visual control toward medial to the end of the



Fig. 38.3. Full-endoscopic uniportal operation with interlaminar access

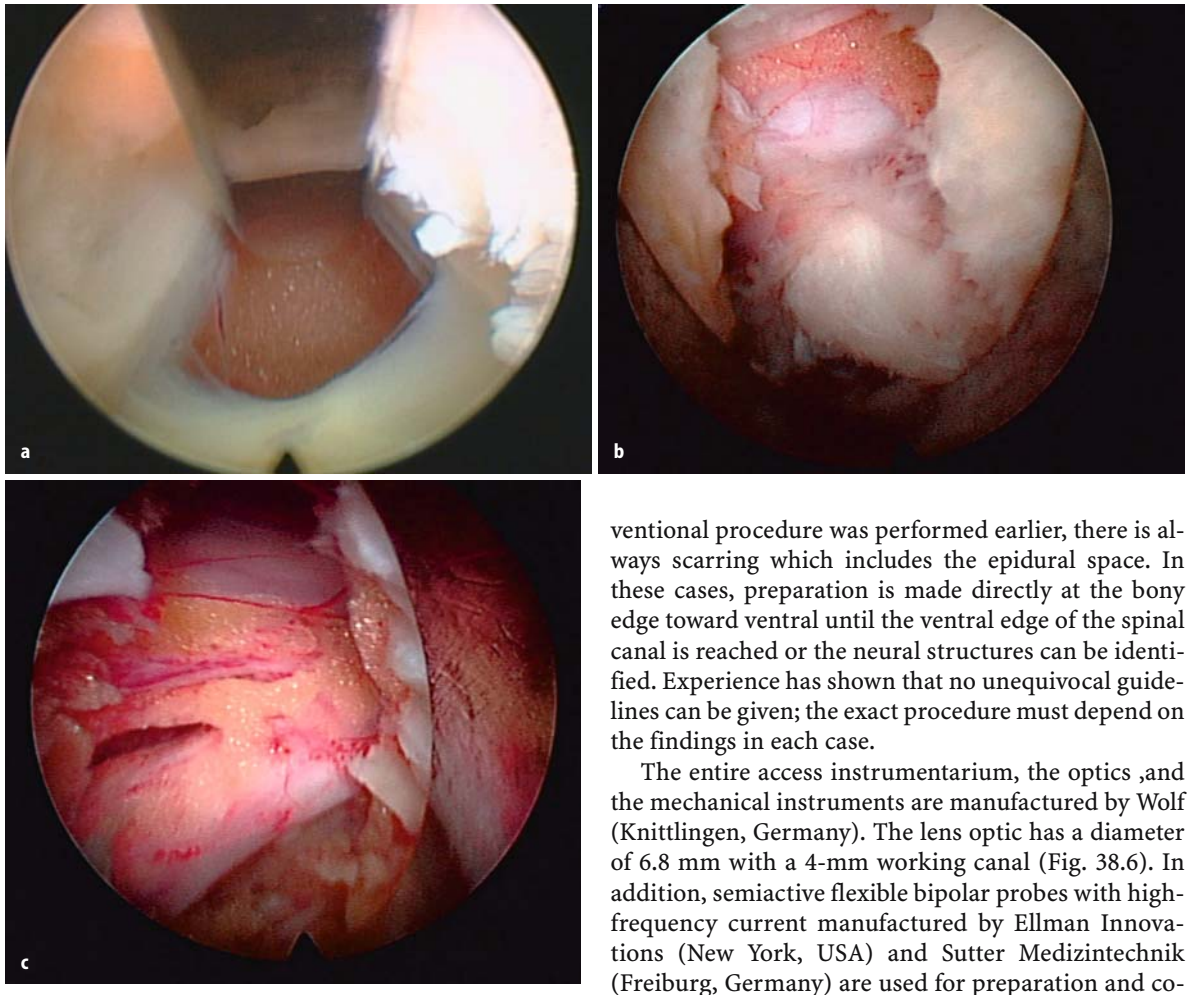


Fig. 38.4. a Incision of the ligamentum flavum. **b** Opened ligamentum flavum, traversing nerve pushed dorsal due to the sequestered material. **c** Cauda equina, traversing nerve, and axilla after decompression



Fig. 38.5. Instruments and burr with a maximum diameter of 4 mm

bone and start of the spinal canal. When a prior full-endoscopic operation was performed, the former access in the ligamentum flavum is sought and reopened. There is no severe difficulty due to scarring. If a conventional procedure was performed earlier, there is always scarring which includes the epidural space. In these cases, preparation is made directly at the bony edge toward ventral until the ventral edge of the spinal canal is reached or the neural structures can be identified. Experience has shown that no unequivocal guidelines can be given; the exact procedure must depend on the findings in each case.

The entire access instrumentarium, the optics ,and the mechanical instruments are manufactured by Wolf (Knittlingen, Germany). The lens optic has a diameter of 6.8 mm with a 4-mm working canal (Fig. 38.6). In addition, semiactive flexible bipolar probes with high-frequency current manufactured by Ellman Innovations (New York, USA) and Sutter Medizintechnik (Freiburg, Germany) are used for preparation and coagulation.

38.10 Postoperative Care and Complications

The length of stay in hospital depends on the operative measures. Nucleotomies alone or simple decompressions require short stays or, if the patient can be adequately cared for at home, can be performed on an outpatient basis. Mobilization is immediate, that is as soon as the patient has recovered from general anesthesia. Operation-related pain medication is not necessary. With the exception of patients with motor deficits, no rehabilitative measures are necessary. The patient may perform isometric and coordination exercises on his own after a training phase, and a passive lumbar brace is prescribed for daytime use for about 6 weeks. The loading level can be increased depending on pathology and subjective well-being. Return to work and sports is possible under the same conditions after wound healing. Limitations are imposed only in that there should be no increase in pain under the activity. In the case of



Fig. 38.6. Endoscope for uniportal procedure and oblique operation cannula

more extensive spinal canal dilatations or fusions, possibly with dorsal stabilization, the postoperative treatment scheme is usually more restrictive and depends individually on the measures performed.

Possible complications are known to be associated with microsurgical procedures and are reported in numerous publications [12, 60, 76–78, 93, 100, 102, 104]. A minimally invasive procedure reduces the rate of complications [71, 86, 100]. In more than 1,500 full-endoscopic interlaminar operations performed, there have been no operation-related complications. Statistically, however, these can be expected in future, even if only to a relatively low degree. Results today after decompressions especially show no symptomatically epidural scarring, no post-discotomy syndrome, and no difficulties in subsequent operations. As known today, operation-induced instabilities are minimized when bony resection of stabilizing structures is restricted to a minimum [1, 32, 37, 41, 49, 52, 53, 88].

38.11 Results

Results of full-endoscopic uniportal operations have been published only for posterolateral access in a transforaminal technique [42, 43, 45, 46, 55, 59, 85, 89, 97, 106]. Since its development in 2001, more than 1,500 patients have undergone interlaminar operation. As an excerpt, prospective 1-year results of 204 patients with sequestered lumbar disc herniation are presented.

Two surgeons operated on 263 patients. Thirty-one non-German-speaking patients were excluded because of validation problems. The study population thus consisted of 232 patients, 128 women and 104 men. The age range was from 17 to 76 years, mean 41 years. The duration of pain ranged from 1 day to 16 months, mean 87 days. Fourteen patients had undergone prior conventional surgery at the same level, and 19 at a different level. Conservative treatment had been used in 182 patients for a mean of 10 weeks, and 50 had undergone acute operation. The indication was defined according to current standards on the basis of radicular symptoms and existing neurological deficits [3, 63]. One hundred and fifty-seven interventions were made at level L5/S1, 68 at L4/5, 5 at L3/4, and 2 at L2/3.

In addition to psychometric tests in pain therapy, the following validated measuring instruments were used: visual analog scale (VAS) for back and leg pain (always for the period of 1 week before re-examination), German version North American Spine Society Instrumentarium (NASS) [14, 73], and Oswestry Low Back Pain Disability Questionnaire [23]. (This score has not been unequivocally validated for German language use, but it was used in a translated version since it is broadly used internationally.) With respect to general criteria, the focus was on the following parameters: sufficient decompression, complications, operation time, bleeding, scarring, postoperative pain, postoperative therapy, pain reduction, reduction of neurological deficits, rehabilitation time, work disability, occupational capacity, athletic capability, recurrence, revisions, and subjective satisfaction.

Two hundred and four (88%) patients were included in the complete postoperative examination program. There was no dependence on gender, age, height, weight, educational level, insurance status, status on the job market, or concurrent diseases. The mean operation time was 29 minutes. There was no measurable blood loss. No patient experienced operation-related complications. Mobilization was possible without exception a few hours after operation.

Seventy-six patients without prior operation presented intraoperative with extensive epidural adhesions. In 16 patients (8%), contrary to the MRT findings, only hard tissue histological annulus ligament or

cartilaginous nucleus tissue were found intraoperative. In these cases, there was a significant relationship to existing back pain and duration of complaints of more than 6 months. Of these patients, 3 were reoperated using fusion.

Three patients (1.6%) suffered recurrent disc prolapse during the first 6 months. All revisions were performed using the same technique. Of these, another recurrence was suffered in one case, which was also endoscopically operated. The recurrent prolapses consisted histologically of more than 75% of endplate components.

The results of the measuring instruments of 198 non-recurrent patients showed a constant improvement with the exception of the isolated backpain rating. No further leg pain was reported in 162 patients (82%), 26 (13%) had only occasional or greatly reduced leg pain, and 10 (5%) reported no essential improvement. The latter belonged without exception to the group of patients with prior operation at the same level or intraoperatively diagnosed hard tissue and epidural adhesions. There was no significant operation-related deterioration of existing symptoms. No post-discotomy syndrome occurred. Significant dependencies were found between poorer results and longer history of back pain. Of all 204 patients, 186 (91%) reported subjective satisfaction and would undergo the procedure again. This applies as well to 192 (97%) of the 198 non-recurrent patients.

The 156 patients who were neither unemployed nor retired returned to work or to sports activities; 9 were unable to do so because of persistent pareses. The mean postoperative work disability was 11 days.

An MRT was recorded 31 times postoperative after a period of 3 months. Epidural scarring was not diagnosed either at that time or during revision procedures. The closure of the defect in the ligamentum flavum proceeded without involving the epidural space, and the fatty tissue was preserved. The primary operation did not make the revision procedure more difficult.

There were no differences in results within the various levels. An access-related bony resection was necessary above the level L5/S1 in 24 cases. This affected exclusively dorsal segments of the inferior articular process and the inferior part of the cranial lamina. The use of bipolar high-frequency probes was found to be necessary in all cases for preparation and to stop bleeding. Measurement of the lavage inflow and outflow showed a maximum of 100 cc of fluid remaining intracorporally.

38.12 Critical Evaluations

The goal of operations for lumbar disc herniations is sufficient decompression with minimization of surgery-induced traumatization and its sequelae. The present results show that the full-endoscopic uniportal interlaminar operation is able to achieve these goals for the indications described.

The constant reduction of leg pain, as one of the main therapeutic criteria, is to be rated as a causal success of sufficient decompression under visual control. The results of microscope-assisted operations, which are between 75% and 100%, are attained [4, 21, 25, 34, 53, 62, 69, 103]. Operation times, tissue traumatization, and complications such as dural injury, nerve damage, bleeding, or infections are minimized [12, 76–78, 93, 100, 102, 104]. The remaining levels in NASS pain and Oswestry result from the lack of reduction in back pain, which is to be expected in the present indications [4, 20, 21, 53, 78]. In accordance with the published advantages of a minimally invasive intervertebral and epidural procedure [7, 24, 65, 79], there is no progredience of existing symptoms. The possibility of reducing or dispensing with osseous and ligamentary resection and the minimally traumatic evacuation of the intervertebral space serves in today's understanding to avoid operation-induced instabilities [19, 24, 30, 39, 40, 44, 53, 65, 66, 68, 79, 107]. No operation-related rehabilitative measures are necessary. There is a comparably high return to the preoperative level of occupational and athletic activity [18]. Criteria such as gender, age, height, weight, educational status, insurance status, or status in the job market had no influence. There was no increased morbidity with secondary factors [12, 76, 93].

The recurrence rate of 1.6% after 6 months lies within the range for conventional techniques [8, 36, 91, 101]. Revisions can be made using the same technique. The negative effects of complete resection of a degenerated nucleus, of which the biomechanical value is questionable, have not yet been completely elucidated [54, 56, 65, 108]. Minimization of the anulus defect may have greater protective influence than preservation of the nucleus [108]. Since evacuation at least of the dorsal area appears to reduce the frequency of recurrences, the authors resect the nucleus material with minimal trauma using new flexible instruments depending on the configuration of the anulus defect. Complete avoidance of recurrences cannot be expected since more than 75% consists of endplate material.

No case of post-discotomy syndrome occurred during the entire postoperative observation period. Epidural scars were not found either in MRT examinations nor revision surgeries were more difficult. Such scars are to be expected in conventional techniques and may lead to clinical symptoms in up to more than 10% [5, 27, 54, 56, 82, 87]. Subsequent endoscopic or conventional procedures can be performed without severe difficulty and show none of the prolongation of operation time described for other procedures [96]. In addition, the epidural lubrication tissue is preserved. This agrees

with descriptions of better results and reduced traumatization of the ligamentum flavum [6, 15].

The general relationship between longer history and poorer outcome is currently not rated as a decisive indication for early operation in light of the minimally invasive procedure. Patients with poor results in the present study presented without exception with additional secondary factors in the sense of degenerative fibroses which could not be clearly diagnosed by imaging [82, 83] such as are known in endoscopic operations in the absence of disc herniation [51, 83, 84].

Complete and safe resection of disc fragments and other pathologies within the spinal canal must be performed under visual control. In a full-endoscopic uniportal procedure, the transforaminal operation can be rated less traumatic than the interlaminar operation due to the reduced osseous and ligamentary resections. At the same time, it does have clear technical limitations. Thus, in transforaminal technically inoperable pathologies, the interlaminar approach is indicated, taking the appropriate criteria into consideration. In general, anatomy and pathology dictate the surgical approach. Newly developed optics with a 4-mm working canal and corresponding actively flexible instruments enable resections of hard tissues. However, at present extensive bone resections, for example in central stenosis, are demanding.

In summary, the present study results show possibilities of sufficient decompression which are equal to those of conventional procedures, a minimum which must be attained by a new procedure [57]. At the same time, all of the advantages of a truly minimally invasive procedure with low traumatization and rapid operation time are given. Complications or increased morbidity of elderly patients are slight. Brief hospitalization, rapid rehabilitation, and high patient acceptance are observed. There are still problems with extensive bone resections. The authors consider the presented technique to be a sufficient and safe alternative or supplementation to open, microscopically or endoscopically assisted procedures. With the possibility of selecting an interlaminar or transforaminal posterolateral to extreme lateral access, sequestered disc herniations outside and inside the spinal canal can now be sufficiently operated in a full-endoscopic uniportal approach, taking the criteria into account. The same applies to cysts of the zygapophyseal joints and lateral spinal canal stenoses. In fusions, the intervertebral procedure is possible, taking the indication criteria into account. Possible advantages with respect to destabilization and scarring when the procedure is extended to more serious pathologies with the consecutive necessity of more extensive ligamentary and osseous resections must be demonstrated by future events.

Overall, a development potential is seen from a technical point of view which may lead to expanded indications. However, complete avoidance of the known problems in spinal surgery is hardly imaginable even with new techniques. In addition, in the future as now, open procedures will remain indispensable.

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39 Outpatient Microsurgical Lumbar Discectomy and Microdecompression Laminoplasty

R.S. Biscup, V. Podichetty

39.1 Terminology

Lumbar "disc" [Gr. *diskos* quoit] "ectomy" [Gr. *ektomì* (*ek-* out + *temnein* cut)] (synonym: discotomy) is defined as the excision in part or whole of an intervertebral disc.

39.2 History

This procedure has evolved as one of the most common spinal surgeries performed in the United States, with many regions reporting at least 30 % higher rates than the national average. The surgical treatment of lumbar disc disease has challenged spine surgeons throughout the world since the first reported case in 1929 by Dandy [11]. Lumbar disc herniation was not identified as the cause of nerve root compression until 1911 [18]. The lumbar discectomy technique for this condition was described by Mixter and Barr in 1934 [16, 30]. The technique involved an extensive removal of the lamina and the offending ruptured disc through an intradural approach in 19 patients. This surgical innovation gained prominence into the later part of the twentieth century. A less invasive microsurgical dissection was developed in the late 1960s, which was introduced in order to decrease surgical morbidity, shorten hospital stays, and allow for a faster return to work for the patient [17, 20, 21, 44, 45, 47, 48].

Caspar [10] and Yasargil [52] documented the microsurgical approach for lumbar disc herniations in 1977, followed by Williams [47], who demonstrated the significance of a conservative surgical technique in a series of 532 patients by removing only a segment of the aberrant disc to decompress the affected nerve root. The first reported series of ambulatory microsurgery for lumbar disc herniation with satisfactory outcome by Cares et al. in 1988 [8] was a stepping-stone for several subsequent series that followed explicating its efficacy and safety [7, 22, 23, 35, 39].

Surgery in patients with lumbar spinal stenosis is elective except in the instance of progressive neurologic deficit. Indications for surgery for lumbar spinal stenosis include progressive neurologic deficits, intractable pain, and functional limitations due to the previously described symptoms. Although medical comorbidities influence outcomes, age alone is not a contraindication to surgery for lumbar spinal stenosis. In order to achieve the functional goals in patients with lumbar stenosis, complete decompression of the neural elements is required. The number of levels involved should be correlated with the physical examination and, accordingly, these should be decompressed. With appropriate training, this can be accomplished using minimally invasive techniques. The advantage of a minimally invasive laminoplasty is that the spinous process and the vertebral ligaments are spared. It has been postulated that the preservation of the posterior elements may minimize the risk of progression. Accordingly, with a limited dissection of the soft tissues, the morbidity of this minimally invasive approach is far less than for open surgical decompressions.

39.3 Surgical Principle

Using the microscope in lumbar microdiscectomy affords several advantages to both the surgeon and the patient. The surgeon can limit the amount of soft tissue dissection by working through smaller exposures directly over the pathology to be removed. Additionally, epidural fibrosis is minimized by preserving the ligamentum flavum and epidural fat. This way, the disc herniation can be removed, the lateral recess may be decompressed, and the nerve root manipulation is minimized.

A number of studies published since 1995 have noted little difference in the ultimate outcomes between microsurgical discectomy and standard laminectomy and discectomy [28].

The benefit of using an operating microscope in terms of magnification and coaxial illumination far overweigh the inconvenience of draping and positioning the microscope at the operating table [40]. The advantage of the operating microscope is the ability to

more accurately identify the anatomic structures and minimize the risk of damage to dura and nerve roots. This application of microsurgical techniques to lumbar discectomy has dual value as mentioned: minimal disruption of the integrity of normal anatomy and meticulous hemostasis helping to speed the process of convalescence, and the retention of epidural fat around the nerve root helping to prevent adhesions, a common cause of the late, "Failed Disc Syndrome" [50].

39.4 Advantages

The advantages of outpatient spine surgery and its economic impact have become an important reality to hospitals, patients, and physicians (with respect to convenience, cost containment, and acceptable outcomes). As a result outpatient spine surgery has continued to increase dramatically in the past 20 years. Microdiscectomy is at the forefront of outpatient procedures performed by spine surgeons. More recently, microdecompression laminoplasty has demonstrated significant efficacy in the treatment of symptomatic central and lateral lumbar canal stenosis as an alternative to much larger aggressive operations.

Microsurgical techniques have greatly minimized the intraoperative morbidity associated with spine surgery. Activity restrictions after microdiscectomy and microdecompression laminoplasty have been uniformly shorter than for the same procedures performed using conventional means.

Aggressive mobilization techniques and shorter postoperative convalescence is now the norm following microdiscectomy. As a result of this practice, the sick-leave time after surgery has been markedly reduced. The mean duration of sick leave in 152 working patients after microdiscectomy was found to be 1.2 weeks [9]. Approximately 25% of patients retuned to work within 3 days.

The direct medical costs of the over 200,000 lumbar discectomies performed annually in the United States exceeds 5 billion dollars [19, 26, 41]. Lumbar microdiscectomy itself has been determined to be a safe outpatient procedure [2, 5, 7, 8, 22, 35, 36, 53], and offers an effective alternative to traditional inpatient surgery for radicular disc disease. In healthy patients with no complicating medical conditions this surgery can be performed as an outpatient procedure, and the patient can be discharged from the hospital in as little as 3 hours after the procedure has been performed [7]. Several authors have [20, 49] reported excellent clinical results and decreased length of hospital stay with lumbar microdiscectomy when compared with traditional open surgical techniques.

39.5 Disadvantages (see also Chapters 31 and 32)

Outpatient microsurgical discectomy has its share of limitations and disadvantages. Management of potential early postoperative complications (e.g., epidural hematoma, early wound infection, nerve root swelling) may be delayed or limited [14].

For other general disadvantages associated with the procedure itself see chapter (Chapter 31).

39.6 Indications

A prudent history taking and physical examination in the outpatient clinic are crucial in selecting appropriate surgical candidates for outpatient microsurgical lumbar discectomy. Young age, radicular distribution of pain present below the knee and extending to the foot, positive straight-leg raising examination, reflex asymmetry with no preoperative comorbid conditions, no previous non-spinal surgery, and an absence of a Workers' Compensation claim are the clinical predictors of a good outcome from outpatient lumbar surgery [1, 4, 12, 25].

In a prospective multiple-outcomes study of outpatient lumbar microdiscectomies by Asch et al. [4] 38% of Workers' Compensation cases accounted for a disproportionate share of treatment-related failures in all the measured outcome categories (Table 39.1). For the six outcome categories shown in Table 39.1, the average final success rates for patients not receiving compensation ranged from 72% to 87% compared with 42% to 72% for those receiving Workers' Compensation (with statistically significant differences for each outcome). It

Table 39.1. Final outcomes of patients receiving and not receiving Workers' Compensation. Reprinted with permission from Asch et al. (2002) J Neurosurg 96:34–44 [4]

Instrument	Success rate (%)[a]	Number of successful cases (%)		
		Compensation	Non-compensation	*P* value[b]
Leg pain	80	56 (71.8) of 78	114 (85.1) of 134	0.031
Back pain	77	53 (67.9) of 78	111 (82.8) of 134	0.017
Oswestry	78	40 (63.5) of 63	96 (86.5) of 111	0.001
Satisfaction with surgery	76	48 (63.2) of 76	111 (83.5) of 133	0.001
ADL	65	40 (51.3) of 78	95 (72.5) of 131	0.003
Return to work	61	32 (42.1) of 76	93 (71.5) of 130	<0.0001

[a] The number of scored cases ranged from 174–212
[b] The comparison was made

is generally understood that patients who are claiming Workers' Compensation, report worse outcomes and this study confirms the disparity in outcomes between cases in which compensation is being sought and those in which it is not.

With appropriate patient selection criteria and a good surgical experience, 95% success rate in the relief of sciatic pain with one-level microlumbar discectomy can be expected. Poor results frequently are a result of poor patient selection rather than poor technique [34, 40]. Our anecdotal experience suggests similar results in our outpatient population.

Discectomy is considered mainly because of acute intractable pain. Additionally, mild paresis, persistent less severe pain, or the possibilities of permanent disability are strong factors that may favor surgical intervention. The absolute indication for disc excision is serious neurologic injury due to cauda equina syndrome. This is a very rare phenomenon.

In patients without severe neurologic loss or symptoms, sciatica has been shown to resolve with time with either expectant care or aggressive rehabilitation. However, separate studies by Weber and Saal and Saal [37, 45] indicated a mean work loss of 4 months or longer in non-surgical patients. Many patients (after consultation) will request surgical intervention because it is perceived that surgery will more quickly relieve pain and allow an early return to usual activities. In our experience, patients are more likely to proceed with operative intervention that can be performed in an outpatient setting. Accordingly, microsurgical techniques can achieve these goals in most patients [45].

The indications for microdecompression laminoplasty are important to the ultimate success of the procedure in terms of patient satisfaction. As McCulloch states, "there is no seek and find microsurgery" [29]. The nature of the pathology (in this case, spinal stenosis) and the precise location must be elucidated preoperatively (see also Chapter 44). Larequi-Lauber and associates [24] evaluated the appropriateness of surgical indications in 328 consecutive patients undergoing laminectomy for lumbar spinal stenosis. They concluded that in 38% of the patients, surgical indications were inappropriate, particularly because of an inadequate trial of non-surgical treatment.

39.7 Contraindications

For general contraindications, see Chapter 44. Specific contraindications to outpatient microdiscectomy include patients with multiple medical issues, necessitating a monitored postoperative environment.

39.8 Patient's Informed Consent

As in any surgical intervention, detailed counseling prior to surgery on the risks of surgery as well as its potential benefits is mandatory. Appropriate preoperative counseling can help prepare back patients for outpatient surgery. There is evidence that such positive reinforcement can improve treatment results for back pain [42, 43]. Patient education and preoperative psychological preparation is essential to ensure positive clinical outcomes for outpatient spinal surgery [5, 15, 39, 51]. In general a well-informed patient is more likely to recover faster and experience less pain [33, 46]. It is important to stress to patients that microsurgery, although less traumatic, is in many ways as invasive as open procedures. Accordingly, these risks must be clearly elucidated to the patient including the possibility of conversion of a micro-procedure into an open surgical procedure.

39.8.1 Anesthesia

Lumbar outpatient procedures may be performed using a spinal anesthetic. Advocates of general anesthesia for such procedures cite the control of the airway and sedation. However, this is not straightforward when the patient is in the prone position.

Spinal anesthesia can offer an advantage for outpatient lumbar microdiscectomy by limiting the side effects of general anesthesia and the risks involved with endotracheal intubation as well as decreasing the postoperative nausea and vomiting [32]. There are several advantages of a spinal anesthesia. These include a shorter time spent in the recovery room, faster return of orientation and alertness, and better monitoring of vital structures (i.e., patient's eyes from the effects of pressure while in the prone position). Finally, because spinal anesthesia has a vasodilatory effect on the lower extremities, intraoperative bleeding is thought to be decreased. The disadvantages of spinal anesthesia include the limited duration of the anesthesia as well as the difficulty in establishing an airway in the event of a complication. Other factors to be considered include the possibility of patient movement during the procedure (if not adequately sedated) as well as the possibility of complications from placement of the spinal anesthetic itself, including neurologic injury and dural tears.

Spinal anesthetics can cause urine retention. Hence, it is important for patients to micturate prior to discharge. It is also generally good practice to inform the anesthesiologist which level(s) are to be exposed surgically so they might choose to administer the spinal anesthetic at a different level to avoid a persistent dural leak after surgery. Should a dural leak be identified from a needle puncture, it should be repaired or covered with a dura sealant.

39.9 Microsurgical Technique

39.9.1 Patient Positioning

The patient is positioned prone for this procedure on a Jackson table with attached Wilson frame or placed on a Wilson frame positioning it on top of the AMSCO 3080 operating table (Fig. 39.1). The abdomen is free, thus relieving pressure on the abdominal venous system and decreasing venous backflow through Batson's plexus into the spinal canal. This is in order to decrease the amount of lumbar lordosis, thus keeping the posterior ligament taut. With the posterior longitudinal ligament taut, the interlaminar spaces are widened and this opens the neural canal (Fig. 39.2). Thus, it is



Fig. 39.1. Patient positioning on the AMSCO 30 – 80 electric OR table with the underlying Wilson frame

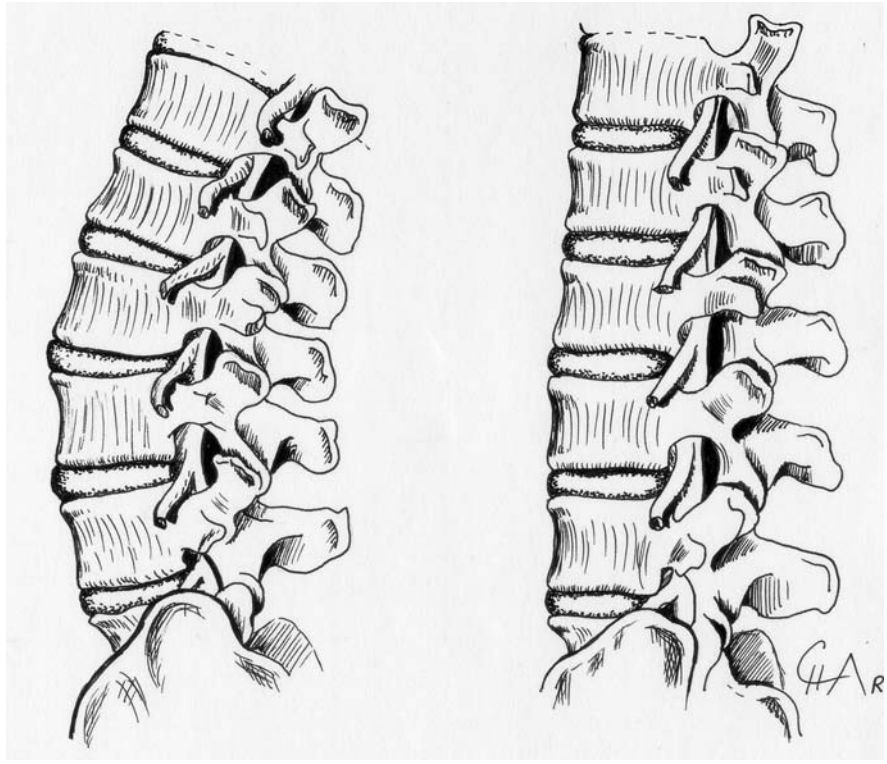


Fig. 39.2. Artist's drawing of the change in foraminal dimensions with patient position. Note the foraminal narrowing and superior facet migration that occurs when the spine is extended. The Wilson frame permits spine flexion thus facilitating the surgical procedure

easier to enter the epidural space and decompress the neural elements. The main disadvantage of using this flexed position is that certain anatomic regions of the spine are enlarged, such as the foramina. These areas may have to be overdecompressed in order to ensure that they remain adequately patent when the patient is upright with the spine extended.

39.9.2 Identification of the Level of Surgery

The level of the disc to be decompressed or removed must be localized by fluoroscopy or plain radiography. It is paramount to always have plain radiographic images of the patient's spine in order to ensure that any anatomic variants are identified and appropriate preoperative planning is possible.

The technique most frequently used to identify the correct level to decompress is to place a spinal needle approximately 1 – 2 cm to the side of the spinous process on the side opposite that of surgery (Fig. 39.3). The spinal needle is typically placed to the level of the lamina and the skin is marked accordingly. The more symptomatic side typically determines the side of entry. It is imperative to take a radiograph with a marker at the appropriate level after the exposure has been made. In this way, wrong level surgery, the most common complication of microdiscectomy, may be avoided.

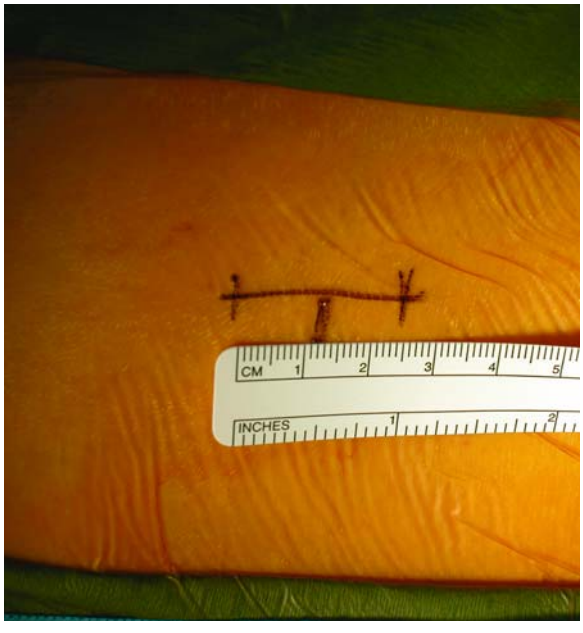


Fig. 39.3. Incision length for microsurgical procedure

39.9.3 Surgical Exposure of Affected Level

Skin incision lengths appear to be proportional to surgical experience. The skin incision is typically 2 – 3 cm in length and is made in the midline, although up to 1 cm lateral to the spinous process on the affected side is an acceptable method. After the skin is incised, a Bovie cautery is used to split the lumbar fascia in line with the incision. Blunt finger dissection and muscle/fascial elevation are done at the interlaminar level being exposed. It is imperative to have meticulous hemostasis during the dissection. In such a manner, it will be easier to perform the microdiscectomy with proper identification of the nerve roots. A localizing radiograph may be taken at this time with a nerve root retractor located in the interlaminar space. When the radiographic studies are complete, self-retaining microblade retractors or a tubular system are placed in the wound and the microscope (or endoscope) is brought into position. In order to best visualize depth of field and in order to best enhance the utilization of instruments, a smaller aperture is selected and the microscope is brought into position to allow instrument facilitation during the procedure.

39.9.4 Entry into Spinal Canal

A high-speed burr (TPS Stryker-Howmedica, variable speed model) is used to remove approximately one third to one half of the inferior portion of the ipsilateral cephalic lamina (just superior to the insertion of the ligamentum flavum) and about one third of the superior portion of the caudal lamina (Fig. 39.4). The ligamentum flavum is easily seen at this time since it attaches to the medial edge of the superior facet as well as to the upper and lower laminae. Anatomically, the ligamentum flavum attaches at the very cephalic edge of the lower lamina but approximately halfway up the upper lamina. Thus, up to 50 % of the upper lamina as well as the medial aspect of the inferior facet overhang can be removed without the exposure of the nerve root or dural sac, as they are covered by the ligamentum flavum. The lateral pars (that portion which lies between the superior and inferior articular facets) would be preserved. It is extremely important to leave at least 6 – 7 mm of the lateral pars in order to prevent a iatrogenic pars fracture (Fig. 39.5).

Attention is now turned to the ligamentum flavum. The ligamentum flavum is released from the medial edge of the superior facet and from the upper and lower laminae with a forward-angled curette. After the release of the ligamentum flavum, the medial edge of the superior facet is resected with 2- and 3-mm Kerrison rongeurs. The resection goes from the lower pedicle to

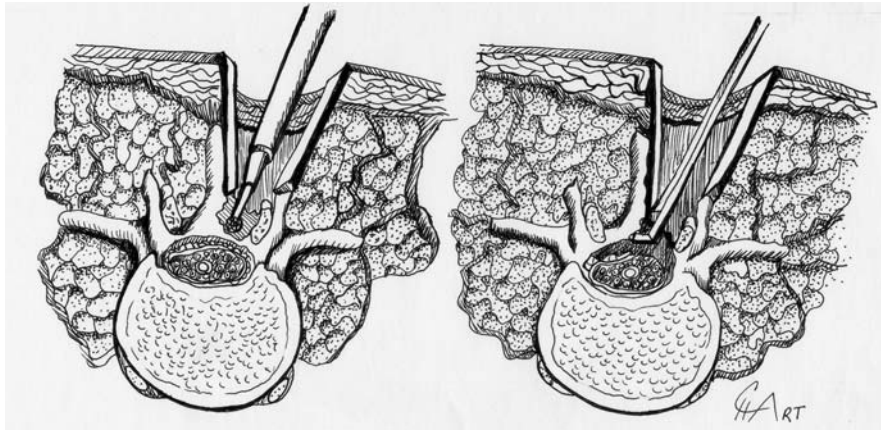


Fig. 39.4. Artist's drawing of microscopic lumbar laminoplasty technique. After the hemilaminotomy is performed, a high-speed burr and Kerrison rongeurs are used to undercut the midline and contralateral lamina thus effecting a central decompression

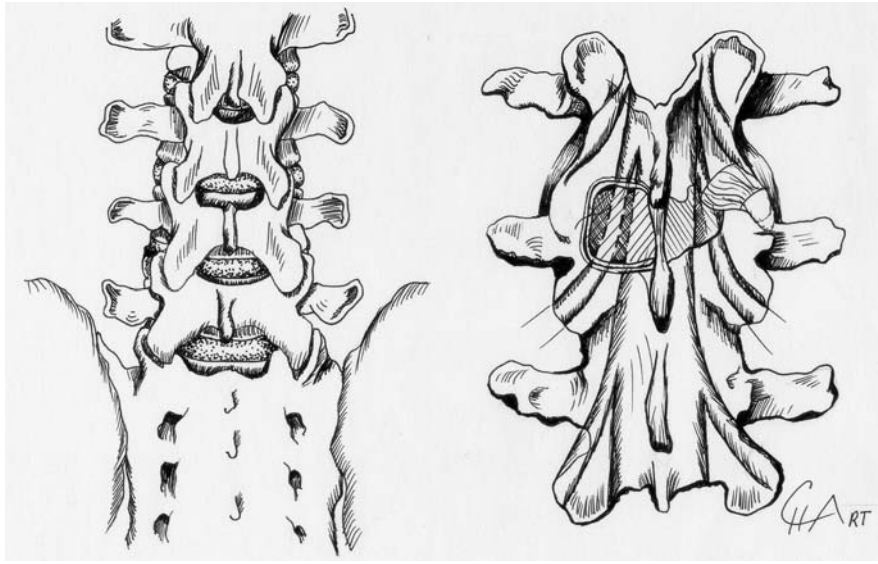


Fig. 39.5. Artist's drawing of the interlaminar window created with the ligamentum flavum and nerve roots depicted

the tip of the superior facet. It is the removal of the medial edge of the superior facet that decompresses the lateral recess stenosis and allows for easy exposure of the lateral disc space. If a microdecompression laminoplasty is performed simultaneously, the undersurface of the spinous process and contralateral lamina are undercut at the proximal and distal extents of the hemilaminotomy to provide adequate central decompression without the removal of excess bone. The base of the spinous process is thinned down and this allows visualization of the contralateral side.

Meticulous hemostasis is critical to visualization, as previously indicated. The bipolar cautery is used for all aspects of hemostasis at this level of dissection. This permits easy visualization of the disc space. The nerve root retractor is placed in the lateral disc space, and ligamentum flavum, epidural fat, and nerve root are retracted across the herniated disc toward the midline. This maneuver provides excellent exposure of the disc herniation. Any large fragments of the disc herniation can be removed using a rongeur. Frequently, the annulotomy is created by the disc herniation and is all that is necessary to allow cleaning out of any loose nucleus pulposus inside the disc space. At this juncture, the disc is forcefully irrigated with a long Frazier suction tip attached to a syringe. This forces any loose fragments of the nucleus pulposus outside of the disc space. The spinal canal is examined and palpated underneath the nerve root and across the vertebral body toward the midline for any residual disc fragments. Accordingly, these are removed.

After the decompression is complete, the wound is irrigated and hemostasis is achieved. In our institution, we prefer to use a pain paste, which is composed of:

- Cellulose powder
- DuraMorph, 3 – 5 mg
- Fentanyl, 150 mcg
- SoluMedrol, 100 mg

We place this directly into the wound, in the deep dissection. We also prefer to place a drain in the wound in order to allow a venue for decompression of any bleeding from the bone or fluid accumulation. This drain is

removed later in the day prior to discharge or the next morning prior to the patient's discharge.

The wound is closed in three layers. The dorsal lumbar fascia is closed with 0-Vicryl sutures in a single interrupted fashion. This is followed by the subcutaneous layer, which is closed with 2 – 0 Vicryl sutures. Finally, the skin is closed using a 4 – 0 Monocryl suture, in a subcuticular fashion. After wound closure, the skin can be injected with 0.5 % Bupivacaine with epinephrine, thus providing immediate early postoperative pain relief.

39.10 Postoperative Care

Most lumbar microdiscectomies and microdecompression laminoplasties can be done on an outpatient basis. In general, we prefer to discharge microdiscectomy patients on the day of surgery and laminoplasty patients the next morning (23-hour admission) (Table 39.2). All drains are removed prior to discharge. Ambulation is encouraged the day of surgery and return to work within a week, depending on occupation. In addition to optimizing the patients physical conditioning preoperatively, we also involve patients in postoperative physical therapy programs. Specifically, the utilization of water therapy and pool aerobic exercises are strongly encouraged once the wound has healed. The postoperative course of each patient is individualized and dependent on the patient's overall medical condition as well as the neurologic and comprehensive recovery.

Table 39.2. Outpatient discharge criteria

I.	Vital signs are stable for at least 1 hour at levels that are within 20 % of preanesthetic levels
II.	No evidence of respiratory depression
III.	Dry and clean dressing without evidence of open-ended bleeding
IV.	Neurologic examination must be at a baseline level as assessed by the spine surgeon
V.	Nausea must have subsided and patient should be on minimal oral narcotics
VI.	Patient discharge does not involve travel longer than 1 hour and has continued personal assistance throughout initial recovery

39.11 Complications (see Chapters 32 and 44)

39.12 Conclusion

Significant success rates in microdiscectomy range between 88 % and 98.5 % as reported in several series [1, 3, 13, 20, 27, 38, 50]. More recently, these results have been questioned and 75 – 80 % has been suggested as being more rational and accurate for clinical outcome expectations [43]. On the outpatient front, a published series of 103 consecutive outpatient microdiscectomies [53] showed good to excellent results in 88 % of patients with early return to employment and regular activities without any major complications [12]. Several studies have demonstrated outpatient spinal surgeries to be less expensive and have better clinical and surgical outcomes than similar procedures performed traditionally in hospitals [6, 7, 31]. Our unpublished data of over 200 cases per year in patients between 16 and 94 years of age performed over 5 years (60/40 microdiscectomy/microdecompression) with 90 % of the cases operated under spinal anesthesia had an overnight hospital stay rate of 2 – 3 % (due to, e.g., dural leak, multilevels, distance to home) and a readmission rate of 2 % (dural leak). These results suggest that microdiscectomy and microlaminoplasty are excellent procedures for maximizing neural decompression while minimizing the destabilization and resection of uninvolved structures. A thorough preoperative analysis including analysis of imaging studies will serve to guide the surgeon as to the most appropriate treatment for each patient. Accordingly, with meticulous surgical technique and appropriate training, outpatient microsurgical discectomy and laminoplasty have excellent clinical outcomes with far less morbidity than similar open procedures.

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40 Nucleus Reconstruction by Autologous Chondrocyte Transplantation

H.-J. Meisel, T. Ganey

40.1 Terminology

The structure of the spine is not unique to the human body, but one conserved in basic design across several classes of living organisms. Although interspecies variation occurs with regard to the number of individual vertebrae, the metameric nature of the spine permits continued axial growth. Both our uniqueness in upright posture and that of serpentine segmentation is accommodated by the spine.

It is impossible to discuss an intervertebral disc without defining the integral unit of a motion segment. The term motion segment designates two hemivertebrae and the disc connecting them [7]. Within the motion segment, each intervertebral disc has two distinct components: a central nucleus pulposus and an outer ring of connective tissue described as the anulus fibrosus. Together the two components function to dissipate the compressive component of axial loading via the tensile, collagenous properties of the anular fibers. In balance the force exchange is efficient, coupling progressive recruitment of concentric, collagenous fibers radially in response to central deforming action of the nucleus centrally. Within the context of the two components lies a more subtle balance, with anatomical differences between the two components more a spectrum than an interface. Separate from these two main components lies the vertebral endplate of each vertebra, which itself has distinctions along its entire margin. It is disparate harmony between the structures that results in disc failure, and without adequate knowledge of the structure, designing an effective strategy for treating disc degeneration is not possible. Numerous scientific studies have provided observations concerning the biochemistry and biomechanics of the disc, offering insights and theories into structure-function-failure relationships [9, 11, 12].

Spine dysfunction, back pain, and an accompanying quality-of-life reduction are pervasive in the human population. Theories for the epidemic prevalence of lower back pain include anatomy, biochemistry, postural bias, obesity, and a host of other structural-functional paradigms. Strategies to repair the dysfunctional spinal segment have historically utilized symptomatic relief as an endpoint outcome, where functional recovery did not necessarily correlate with anatomical correction. A consensus of opinion exists that prosthetic replacement to restore motion is a necessary component of any strategy. Clearly, the development of prosthetic components for other applications has brought to the table a separate but similarly troubling set of patient symptoms. Component loosening, periprosthetic osteolysis, fibrosis, bursitis, and even unintended arthrosis, while limited in prevalence remain problems nonetheless in other applications of joint replacement.

Our project summons two key intents in design and eliminates the dependence on a mechanical or prosthetic interface. The first goal is to retain spinal segment motion, and the second goal is to create a biological interface to promote repair even though complete restitution to native function currently does not seem possible. Most assessments of intervertebral disc failure have focused on degenerative change, changes in morphology that affect the biomechanical performance of the motion segment. In this consideration, mechanical failure is little more than a corollary of matrix structure, which in turn depends on balanced cell metabolism for efficient maintenance of the disc matrix. Given the value of cells to the metabolic health of the disc, our therapeutic strategy has been to replace, regenerate, or in some other manner augment the intervertebral disc cell with a goal of correcting matrix insufficiencies, thereby restoring normal segment biomechanics. If, however, the biological basis for function is removed, replaced, or fusion is performed, then no further option to a biological basis for treatment remains, and the potential loss of motion within the disc segment is virtually assured.

40.2 Surgical Principle

Annually, over 300,000 patients are surgically treated for disc herniation in the United States and an additional 70,000 are operated on in Germany. What should be understood in even a minimally invasive procedure

is that discectomy creates a defect. Tissue is removed and not replaced. Furthermore, surgery has been shown to intensify the degenerative process, potentially hastening additional symptoms and the requirement for later intervention [2].

Previous studies have demonstrated that disc tissue removed in surgery contains viable chondrocytes that retain the ability to undergo predictable proliferative capacity and express disc-specific components [14]. Understanding the basis for disc degeneration as a matrix failure, the goal of this reparative procedure is first to replace material previously removed during the surgical discectomy and to interconnect a stable construct of the tissue that remained after the initial procedure. The intents of a reparative model are threefold: first, to remove symptoms and correct anatomical structures so that healing can be accommodated; second to stabilize disc height to reduce neural compression; and third to effectively reconstitute the central nucleus pulposus with a matrix that sustains metabolic balance.

Following discectomy, tissue is delivered to cell culture for appropriate isolation of the chondrocytes. Cells are expanded under good manufacturing practice (GMP) conditions and assayed for chondrocyte-specific markers. From an initial sampling often below 100,000 cells, a final yield in the millions of cells was obtained over 15 days. When viability and proliferative capacity of the cells has been assured, the cells are frozen to allow time for anular healing. From clinical experience, 3 months represents a postsurgical time point at which the anulus has healed, and applied pressure can be kept over time.

Three months after the initial discectomy, the cells are transplanted by percutaneous puncture of the central nuclear area of the disc after a pressure-volume test has proven the strength and completeness of the anular healing. This remains a fundamental part of the need for assurance and provides a gauge by which both the location and the surrounding tissue can be assured to be competent prior to cell replacement. The process of providing cells by percutaneous technique satisfies the ultimate criterion for minimally invasive correction. It accommodates medical intervention without compromising the wound site or the patient with unnecessary trauma.

40.3 Cell-culturing Technique

Disc material obtained from surgery was minced and enzymatically digested in a 50-ml Falcon tube using 20 – 25 mg collagenase type II (Biochrome, Germany) at 37° C for 8 hours in a gyratory shaker (110 rev/minute). Isolated cells were washed and resuspended in culture medium with the addition of 10 % autologous serum that had been obtained prior to surgery from the respective patients. Disc chondrocytes are propagated in monolayer culture under good manufacturing practice conditions (co.don AG, Teltow, Germany), and maintained under strictly autologous conditions throughout the protocol using each patient's serum to supplement individual cultures. Such care eliminated the risk of immune response, and at the same time afforded sterile working conditions at all times within a class S100 working area [17].

The sampled disc cells were expanded in culture through several passages, with a goal of establishing a population of disc chondrocytes capable of producing matrix and sustaining an expanded volume within the damaged disc. The average number of cells expanded and transplanted was approximately 15 million cells per disc.

40.4 Canine Preclinical Study

As our intent was to develop a clinical model for cell transplantation, we chose a canine model comparably representing a large animal disc articulation. The goal of this study was to test the hypothesis that restoration of intervertebral disc morphology could be achieved by transplantation of cultured autologous chondrocytes into the nucleus pulposus [7].

Lumbar intervertebral discs at three levels (L1-2, L2-3, and L3-4) were identified as study levels for the procedure and disc tissue was collected. In this study, the L1-2 intervertebral disc had tissue removed but did not receive chondrocyte transplantation, the L2-3 disc was approached but not violated and served as a surgical control, and the L3-4 level had disc material removed and received chondrocyte transplantation 12 weeks later. None of the animals developed problems related to the surgery and all regained full function.

The study was designed to demonstrate postimplantation time points of 3, 6, 9, and 12 months. MRI, radiography, gross pathology, and histology were performed at each time point, and immunohistochemistry was done after 6 months. Transplanted level, normal disc, and those levels only surgically treated were each examined by all of the techniques. Spines that were evaluated after 3 months demonstrated areas of acute damage, active bone remodeling, and marrow edema that became less apparent 6 and 9 months after transplantation, although all levels that had surgical treatment were identifiable 12 months after transplantation (Fig. 40.1). Subchondral resolution of the marrow and re-establishment of the vertebral margin with the disc of the L3-4 level was the primary positive change associated with time.

Individual discs were radiologically compared for differences and examined for statistical relationships in

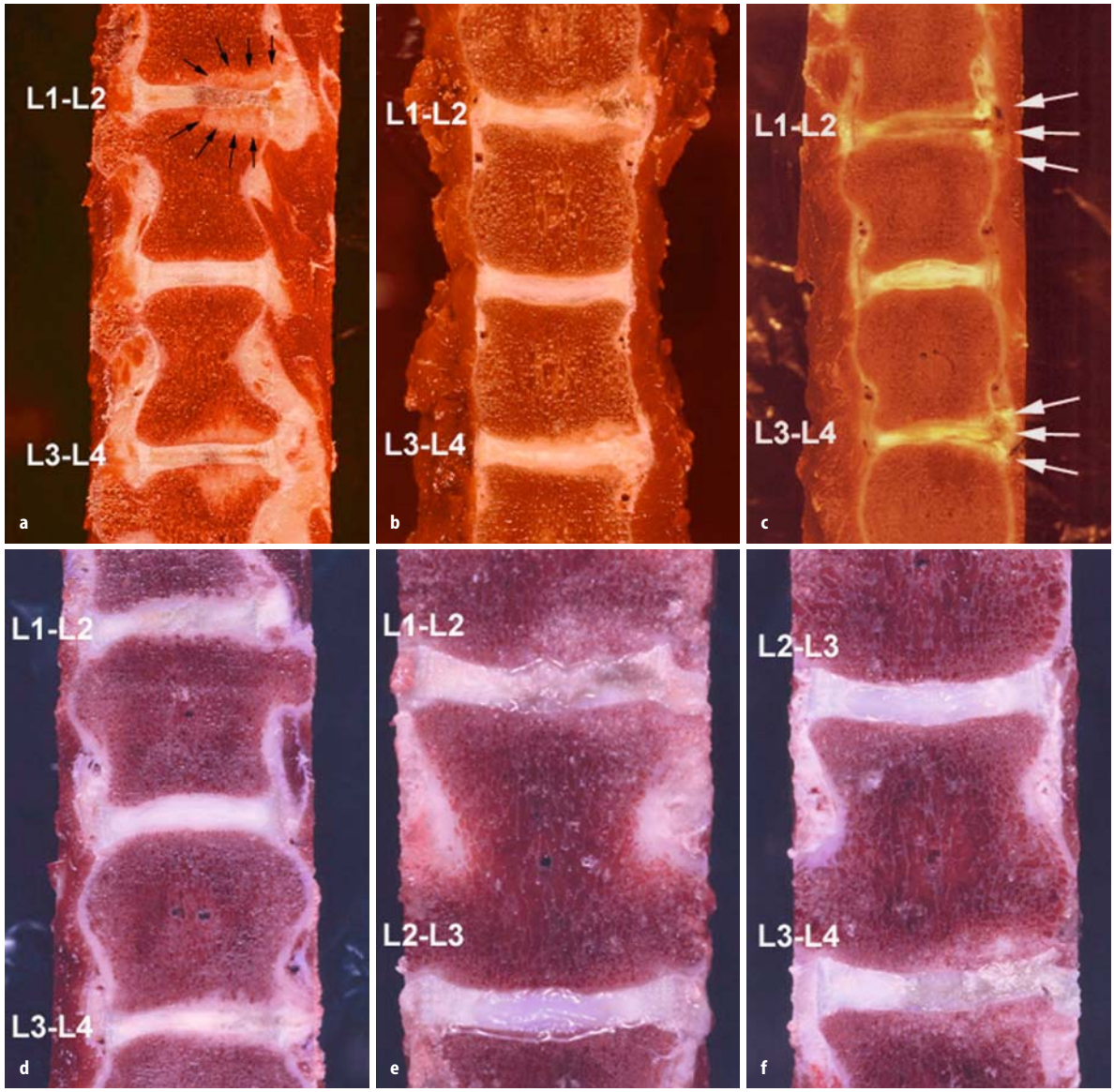


Fig. 40.1. The hallmark of healing was seen in the reduction of inflammation, the margination of the intervertebral disc at the levels treated, and in the formation of scar tissue in the untreated levels. All healing was progressive and separation of the intervertebral disc a key positive feature of the longer time intervals. **a** Canine spine 3 months after procedures; *black arrows* delineate the surgical injury site. **b** Canine spine 6 months after procedures. **c** Canine spine 9 months after procedures; *white arrows* show the periosteal lateral margin involvement of the vertebral body. **d** Canine spine 12 months after procedures. **e**, **f** Closer analysis comparing the control (L2-3) with the surgically untreated level (L1-2) (**e**) and the level having received the cells (L3-4) (**f**) demonstrates that the intervertebral disc that had received the cells attained a more lucent matrix centrally, suggesting a richer proteoglycan content

disc height [8]. When the analysis was expanded to include the 12-month data, the variation in disc height achieved significance (P=0.04). Levels that had been treated with chondrocyte transplantation retained a greater height. This suggests that the change in mean height was time dependent and that the 12-month dogs were driving the change, supporting the hypothesis that more animals over longer intervals would likely yield statistically relevant differences based on the treatment.

Cut sections of the intervertebral discs provided a visual assessment of the repair process in terms of subchondral remodeling of the vertebral endplate and restoration of the disc matrix. Differences in morphology reflected the selective organization of the tissues, and the interface between disc and the subchondral interface of the vertebral body. Intervertebral discs receiving cells achieved a distinction from the bone margins, while the untreated levels did not develop a clear interface with the bone (Fig. 40.2).

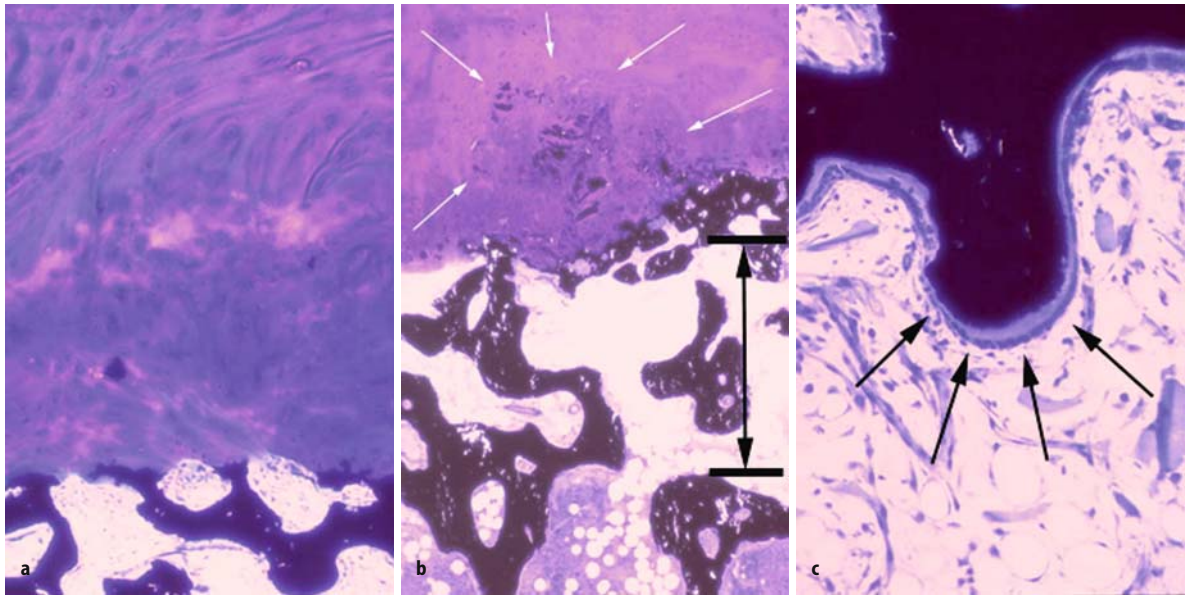


Fig. 40.2. a The vertebral margin with the disc was an active site of remodeling in the level that had received disc chondrocyte transplantation (200×). **b** The level that had not received cells was also establishing a margin between the disc and the vertebral bone, although calcification was apparent and indicated by the *white arrows* (100×). Stratification of the cellular and acellular marrow is indicated by the *bracketed area*. **c** Active remodeling of the trabecular surfaces could be seen in both the levels receiving transplanted cells and those untreated following surgery (400×)

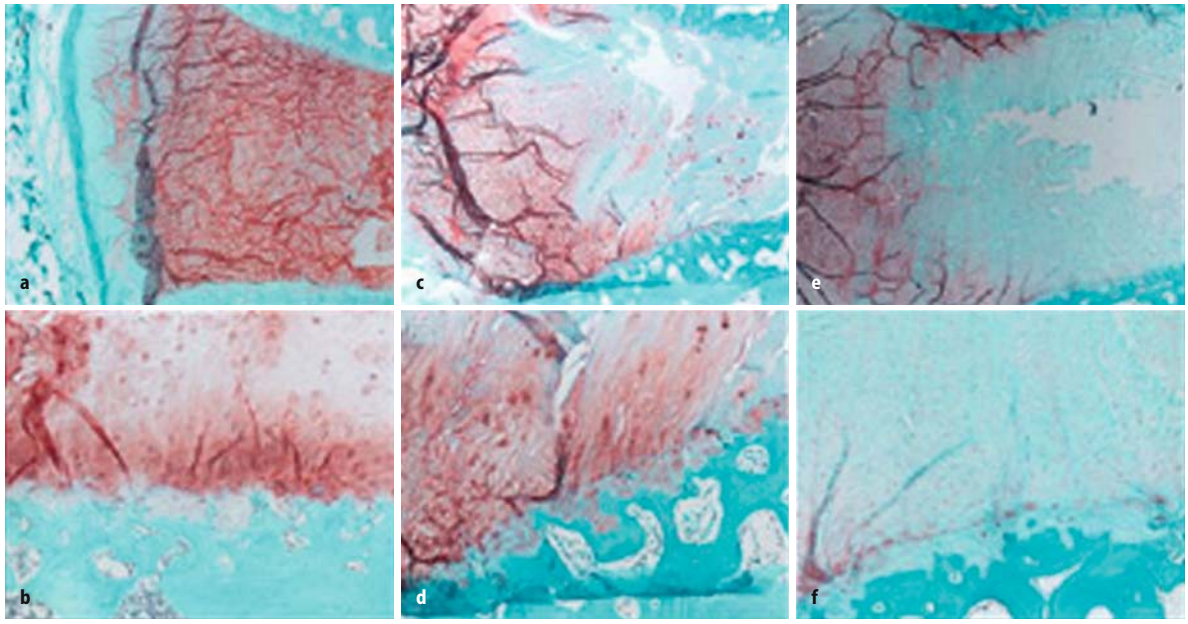


Fig. 40.3. Safranin O staining of intervertebral discs. Hyaline cartilage-specific proteoglycans stain *red*, bone and damaged cartilage stain *green*. **a**, **b** Untreated, healthy disc. **c**, **d** Damaged disc treated by autologous disc chondrocyte transplantation (ADCT); after 6 month. **e**, **f** Damaged untreated disc; after 6 month. **a**, **c**, **e** Lateral aspect macroscopic overview with anulus fibrosus and nucleus (25×). **b**, **d**, **f** Bone/disc interface (200×)

The longer the cells were allowed to integrate (i.e., 6, 9, and 12 months), the more complete the demarcation between the subchondral vertebral bone and the intervertebral disc. Progressive consolidation and restoration of the disc morphology was evident in the 6-, 9-, and 12-month tissues. Matrix staining with safranin O-Fast Green to evaluate proteoglycan content further supported the advantage of cell transplantation in regenerative therapy (Fig. 40.3). Staining intensity was more intense within the vertebral bone/intervertebral

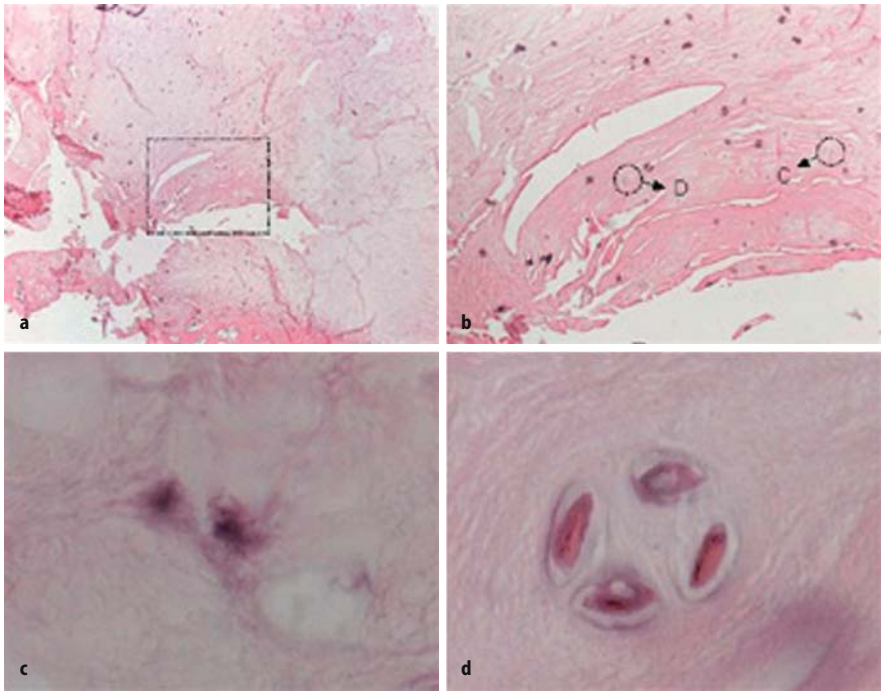


Fig. 40.4. Staining of paraffin sections of the regenerated intervertebral disc 6 months following ADCT. BrdU-labeled chondrocytes were stained by immunohistochemical procedures using DAB as the chromogen. Sections were counterstained by eosin. BrdU-positive cells are colored *black*. **a** Nucleus regenerate overview (25×). **b** BrdU-stained transplanted cells (200×). **c**, **d** Single BrdU-stained transplanted chondrocytes, pericellular *de novo* synthesis of nucleus matrix (1,000×). Matrix elaboration accounts for space between cells

disc interface of the treated disc. Safranin O-positive pericellular matrices within the nucleus of the treated disc indicated matrix regeneration after cell transplantation. Tissue staining for both type I and type II collagen could be demonstrated after disc chondrocyte transplantation in the extracellular matrix, and type II collagen was apparent at the vertebral bone-intervertebral disc cartilage interface as well.

In addition to tissue-specific matrix components, it was also necessary to verify that the transplanted cells were an integral part of the new tissue (Fig. 40.4). Using a specific nuclear marker (BrdU) [18], cells with label were seen in the levels that had received transplanted chondrocytes but not in other levels. In some cases the label could be seen within individual cells within a chondrocyte clone, and in other sections of the tissue, individual chondrocytes with matrix domains were observed. Based on the number of cells transplanted and the fact that the cells were expanded under monolayer culture conditions prior to injection, spacing between labeled cells indicated that the transplanted chondrocytes had undergone the anticipated shift in morphology and produced appropriate disc matrix.

40.5 Clinical Studies

Disc chondrocyte cultivation has been approved as a therapeutic drug in Germany since 1997. German law permits physicians to address clinical projects from the purview of their own experience, and regulates therapy-controlled studies rather than requiring prospective clinical trials. Such a regulatory architecture permits promising technologies to be implemented in a timely manner, and offers a current basis for the most advanced interpretation to date. Applications that show clinical promise continue under carefully controlled clinical parameters so that they will meet standards of acceptable practice for worldwide clinical treatment.

40.5.1 Pilot Autologous Disc Chondrocyte Transplantation Study

Stimulated by the results of the canine trial, a project was designed to assure patient safety under defined conditions as a clinical feasibility assessment. The ability to utilize a minimally invasive procedure positively in patient care formed a key component of the hypothesis. Fifteen patients were enrolled in the initial study. They ranged in age from 17 to 46 years with a mean age of 30 years. Nine men and six women comprised this initial study group. Indication for inclusion in the study was a requirement for surgery following lumbar disc herniation. Eight of the 15 patients had injured their discs traumatically. Only three of the patients enrolled in this study were smokers. No patient demonstrated Modic changes by MRI. All of the patients had failed conservative treatment. Patients were evaluated for pain (VAS), neurological function (Jenny Score), and spine mobility prior to surgery. Assessments were scheduled postoperatively and at 3, 6, 12, 24, and

36 months following autologous disc chondrocyte transplantation.

Disc material removed during open microdiscectomy was placed into sterile buffered saline. Cells were transported immediately to the culturing facility (co.don AG). As previously described for the canine study, transplantation was scheduled approximately 3 months following their initial surgery. Cells were not transplanted until intradiscal pressure could be assured through a pressure volume test (Fig. 40.5). A pressure of 300 mm Hg was kept over 2 minutes to demonstrate complete healing of the anulus [5]. Central positioning in the center of the nucleus was ascertained using fluoroscopy prior to transplanting cells. Patients remained strictly supine for 12 hours following transplantation, after which they were mobilized and an orthosis was provided for 3 weeks.

At transplantation time, all discs were contained by pressure-volume confirmation. No reherniation occurred in any of the patients. Stable disc height was maintained over the entire follow-up period, and no progressive degeneration of the adjacent endplates could be determined. Neurological deficit, both sensory and motor, as well as spinal mobility improved in 90.1 % of the patients within this study. Such a positive outcome is also highly correlated with the microdiscectomy success rate. Mean follow-up of 24 months has been achieved for this study, demonstrating adjunctive benefit of cell transplantation in addition to the surgical procedure particularly in maintenance of disc height in all patients, and water content maintenance in 90.1 % of the patients. In the final analysis, this pilot study demonstrated that the technique was safe, minimally invasive, and that it demonstrated efficacy in terms of disc height retention and functional restoration (Fig. 40.6) [15].

40.5.2 EuroDisc Randomized Trial

With confidence that cells could be delivered safely to a select group of patients, a prospective, randomized, multicenter clinical trial was initiated to further assess the long-term efficacy of autologous disc chondrocyte transplantation in a broader population. By removing some of the restrictions of the pilot study, the goal was to embrace a more representative patient group, examining not only the traumatic, less degenerative disc, but also to include patients with persistent symptoms that had not responded to conservative treatment where an indication for surgical treatment was given.

Patients having exclusively one level requiring surgical intervention were eligible for participation in the trial; patients requiring treatment at more than one level were excluded from the study. Prior to their participation, all patients were advised of the potential risks and signed a letter of consent. No placebo group was committed to this study; each patient participating in the clinical trial will undergo surgical treatment for their disc prolapse, and the prospective basis of cell transplantation will constitute and separate the active treatment from the control group. Patients were not blinded to their treatment. Randomization was done after the open microdiscectomy. Eligibility was limited to patients between 18 and 60 years of age, with a body mass index (BMI) below 28. Exclusion criteria for participating in the study included sclerotic changes, edema, Modic changes of grade II or III, and spondylolisthesis among other accepted criteria such as pregnancy, etc.

One hundred patients have been enrolled in the *EuroDisc* Study so far; the primary criteria follow-up is

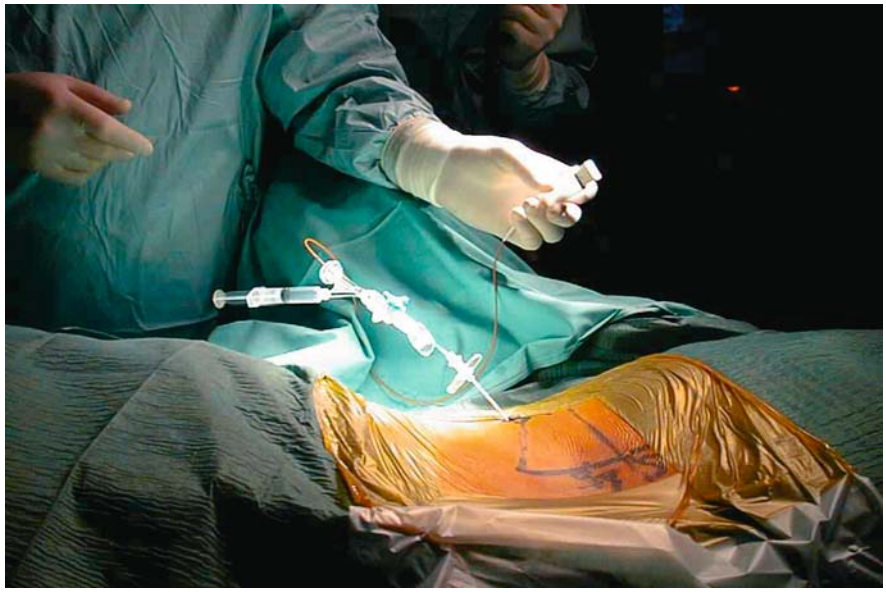


Fig. 40.5. Prior to patients receiving cells, pressure-volume determination was performed to assure that an intact anulus would retain the cells

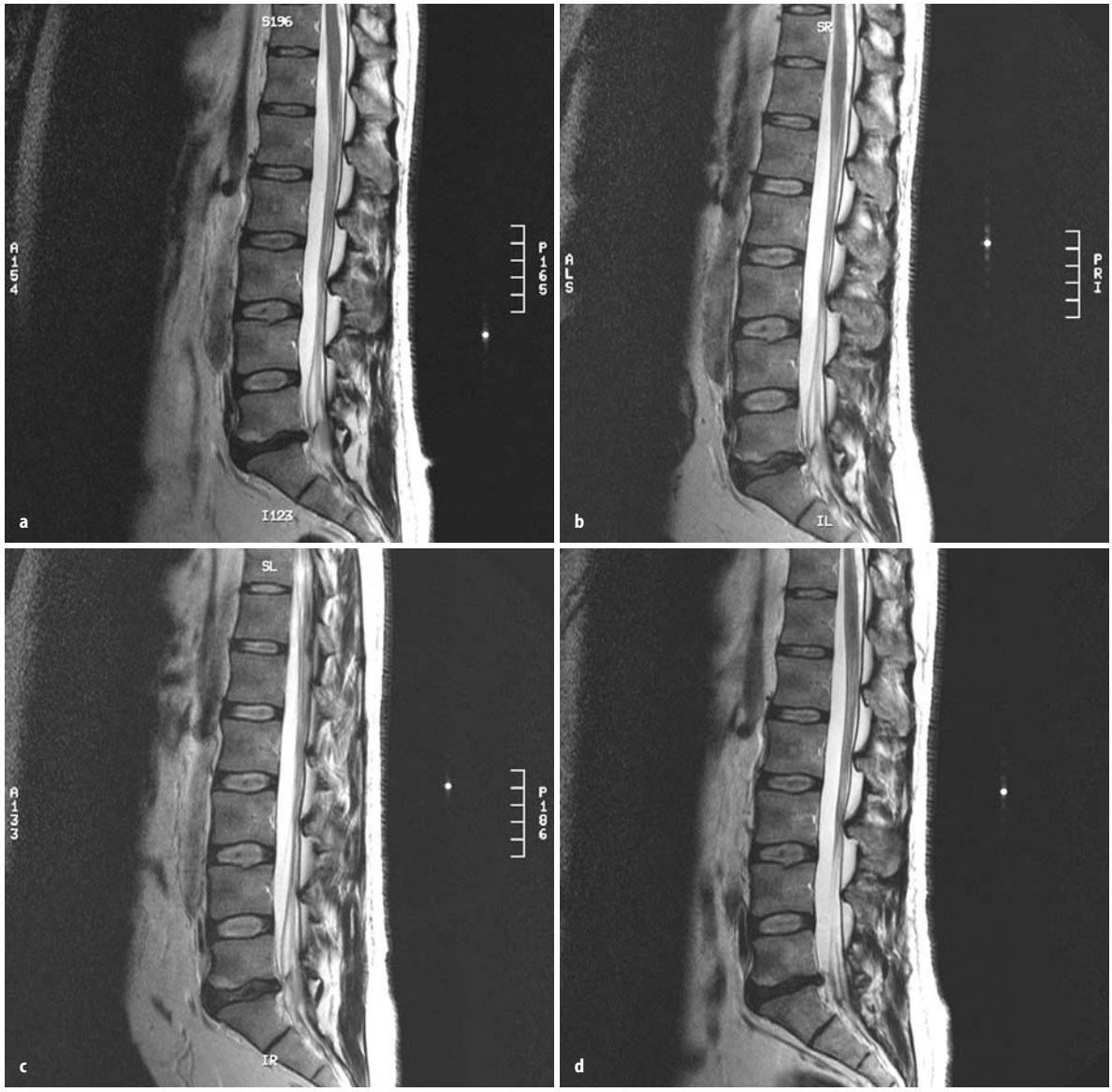


Fig. 40.6. A single patient with an L5-S1 disc herniation prior to transplantation and through a timeline of follow-up. **a** Pretransplantation. **b** One day after transplantation. **c** Three months following transplantation. **d** One year following transplantation

intended to occur at 1 year. Long-term follow-up will be completed at 4 years. The primary clinical evaluation criterion is the Oswestry Low Back Pain Disability Questionnaire. Secondary criteria are SF-36, PROLO, Quebec Back Pain Disability Scale, MRI, and X-ray evaluation.

40.6 Critical Evaluation

Spine degeneration and low back pain affect the adult population to a sufficient extent that personal risk should be considered only an ancillary basis of the etiology. This does not discount previous studies validating genetics [1, 13, 19, 21] or disc nutrition [20] as factors in the degenerative process, but suggests that the high prevalence reflects yet unidentified risks that effect similar symptoms. Over the course of a lifetime, the human disc undergoes marked changes in shape, volume, and composition, all factors that affect performance and mechanical function. Even in asymptomatic patients, 93 % of individuals older than 60 years demonstrate evidence of degenerative change [4]. In other retrospective analyses of cadaver material, a comparable prevalence indicates degenerative anatomical change as a progressive, age-dependent phenomenon that is present in 97 % of individuals who are

50 years old [16]. Ultimately, it is a loss of correct anatomical structure that potentiates disc herniation and leads to pain and the subsequent need for surgical intervention.

Numerous scientific studies have provided observations that lead to understanding the biochemistry and biomechanics of the disc itself, offering insights into structure-function relationships that attribute inclusive cause-effect relationship [7]. General agreement has it that intervertebral discs lose water over time and in doing so reduce the functional capacity to resist axial loading [3]. What remains challenging is to intercept the water loss as a function of matrix binding, addressing composition and decomposition in terms of binding capacity, and ultimately to examine loading as an incendiary to shifting metabolic capacity. Knowing that intervertebral disc degeneration leads to slow but insidious desiccation and eventual loss of morphology associated with the disc itself the inherent challenge in seeking remedy will be to recognize aspects of the causal condition and redress changes that will relieve symptoms and effect conditions that will maintain functional morphology. Although cells form only 1% of the adult disc tissue by volume, their role in balancing constitutive expression of matrix synthesis and metabolic turnover is vital. Most assessments of intervertebral disc failure have focused on degenerative change, changes in morphology that affect the biomechanical performance of the motion segment. In this consideration, mechanical failure is little more than a corollary of matrix structure, which in turn depends on balanced cell metabolism for efficient maintenance of the disc matrix. Given the value of cells to the metabolic health of the disc, our therapeutic strategy has been to replace, regenerate, or in some other fashion augment the intervertebral disc cell in order to correct matrix insufficiencies and restore normal segment biomechanics. Understanding the basis for structure in the context of degeneration is critical to appreciating the potential value of cells as a means of therapy. To address this goal we have taken several steps to ensure that a strategy could be matched with outcome. Several key issues needed to be tested.

- Is it possible to harvest disc chondrocytes and assure that they retain not only viability, but essential metabolic capacity?
- Can the cells be propagated under defined conditions to satisfy regulatory oversight?
- Does a means exist to deliver the disc chondrocytes to the central intervertebral disc?
- Following transplantation, do the chondrocytes remain viable, and do they produce the appropriate extracellular matrix?
- Will autologous disc chondrocyte transplantation affect patient's symptoms?
- Is the anatomy of the disc restored with regard to disc height?
- Can the patient achieve a functional outcome that retains/restores quality of life in objective analysis?

Answers to these questions in every instance have been yes. As noted in the project design, therapeutic use of autologous cultured disc chondrocytes has been permitted since 1997. The use of autologous cells is regulated by the German Drug Law (Arzneimittelgesetz) according to good manufacturing practices. Distribution of autologous cells is certified according to the internationally approved DIN EN ISO 9001 standards. This broad regulatory oversight satisfies the phenotypic expression of the cell line as well as assures that cells meet minimal viability standards (Fig. 40.7).

A single puncture with a minimal caliber cannula offers a precise delivery with minimal trauma to the pa-

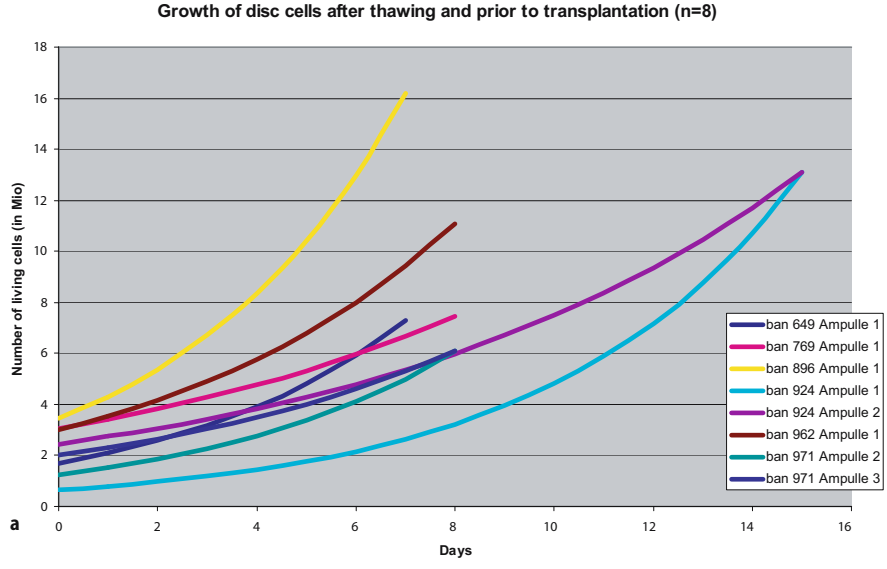
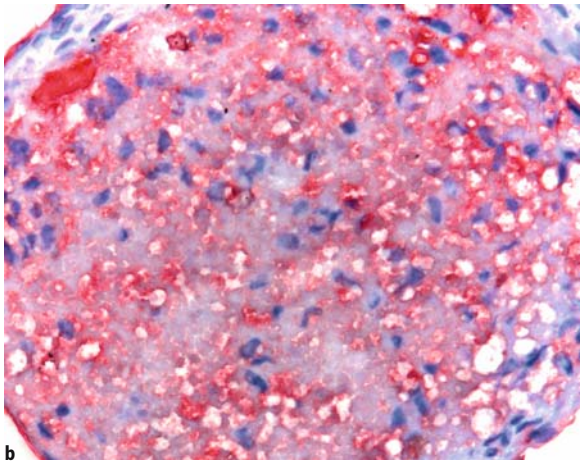


Fig. 40.7. Viability and phenotypic stability were determined for cells prior to transplantation. **a** Proliferation over the course of culturing.



b

Fig. 40.7. (cont.) b Type II collagen within the cell culture demonstrates its capacity for expression of appropriate matrix components

tient and to the anulus. The technique was developed with respect to literature that has demonstrated a size-specific correlation of anular injury to disc degeneration. In this study, a needle of smaller than 21 gauge did not result in degeneration in a rabbit model. The technique used in all of our preclinical and clinical studies utilized a 25-gauge needle to deliver the cells, making it a safe and dependable one for placing cells in the central nucleus region of the disc. A simple minimally invasive technique was necessary to reduce the wound site trauma and effectively. Coupled to the delivery is the assurance that the anulus has healed and will contain the cells. Using a pressure-volume test prior to the delivery of any chondrocytes, we were confident that the cells would remain where placed.

Shown in our preclinical study, the cell-labeling technique and matrix evaluation demonstrated that cells were producing the appropriate matrix, and the cells within the repaired intervertebral disc were those that had been transplanted. In some cases, the labeled cells were seen within a nest of chondrocyte, clonal morphology demonstrating that the cells were not only viable, but also maintained the ability to proliferate. In independent analysis (Holzhausen and Bilkenroth, internal communication, data on file, co.don AG) [10], a direct and positive correlation could be seen that reflected time following transplantation with disc morphology, disc height, and appropriate matrix composition. From this analysis, it could also be concluded that an ordered repair was achieved not only in the disc but at the vertebral margins as well, which demonstrated chondrocyte extracellular matrix deposition that was coupled with chondrocyte distribution. The discs which had received cell transplantation demonstrated chondrocyte stimulation and a coordinated repair of the endplate followed by normalization of chondrocyte density. In discs that did not receive cells, the vertebral endplate demonstrated irregular cloning and thickened endplate cartilage that was up to twenty times thicker than normal endplate cartilage. Transplantation appeared to overlay a clear timeline of regenerative change that effected endplate stability and established a metabolic continuity to the matrix regeneration.

To date, the patient follow-up has demonstrated improvement in all patients who had received autologous disc chondrocyte transplantation. The original pilot study was performed to show safety. The *EuroDisc* study on the other hand was intended to reinforce the safety data, but to also show long-term efficacy. Due to the study design, it is not yet possible to fully conclude that the prospective trial will yield outcomes similar to the feasibility study. What we can determine at this juncture is that the safety in a broader population is no different than microdiscectomy alone. What we hope to show long-term at the completion of this study is that autologous cell transplantation may have a distinct role in prevention of degenerative change.

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41 Autologous Disc Chondrocyte Transplantation

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41.1 Terminology

- ACT: Autologous chondrocyte transplantation
- ADCT: Autologous disc-derived chondrocyte transplants

41.2 Principle

Removal of disc herniations often includes removal of nucleus pulposus material from within the disc space. This is routinely performed in cases with wide perforations of the posterior annulus. Following discectomy, the lumbar disc is left with a more or less destroyed nucleus pulposus with a low potential for spontaneous regeneration. In a prospective randomized study, the efficacy and the safety of transplantation of autologous disc-derived chondrocyte transplants (ADCT) were evaluated. Patients who had to undergo removal of a sequestrated disc fragment in the lumbar spine were randomly assessed to two treatment groups. Group B only had microsurgical discectomy. In group A the removed disc fragments were cultivated and a cell suspension of disc-derived chondrocytes was reinjected into the disc 3 months following the operation [1].

The assignment of the selected patients to treatment group A or B was performed in a blind manner (Fig. 41.1). For all patients, a biopsy of intact cartilage tissue was taken from the sequester during the sequestrectomy as well as a defined volume of patient blood for culturing of the chondrocytes.

Chondrocytes were isolated from the biopsy by co.don AG (Teltow, Germany) and cultured for 2 – 4 weeks. After proliferation the chondrocytes were stored frozen until 7 – 10 days before the scheduled transplantation.

Three months after sequestrectomy for group A the disc was punctured through a posterolateral approach under local anesthesia. A volume-pressure measurement of the affected disc was performed and a suspension of the autologous disc-derived chondrocytes was transplanted into the affected intervertebral disc (Fig. 41.2).

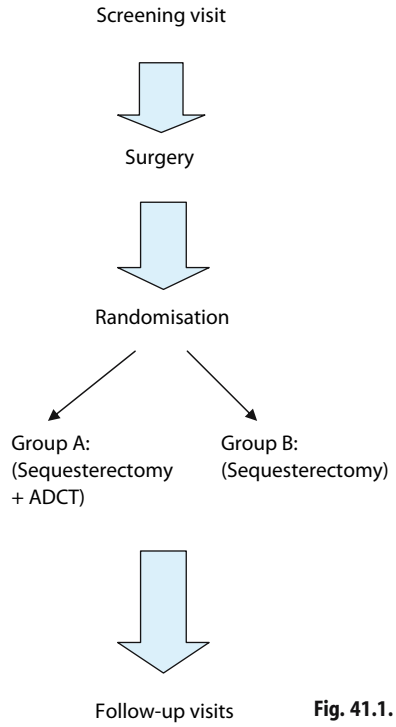


Fig. 41.1. Course of the study

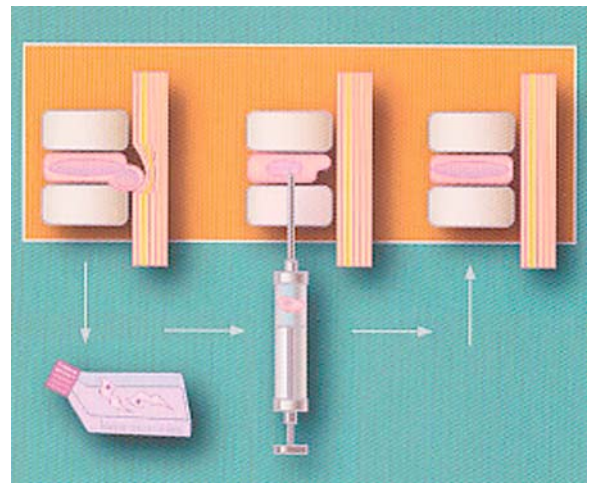


Fig. 41.2. Isolated chondrocytes cultured for 2 – 4 weeks. ADCT follows 3 months after sequestrectomy. With permission of co.don AG

Demographic data and history of complaints were collected during the follow-up visits of the patients. For further clinical evaluation the participating physician filled in two scores (Prolo Economic/Functional Rating Score and Jenny scale). The patients' status was evaluated by four other measures: modified Oswestry Low Back Pain Disability Questionnaire, Quebec scale, VAS, and SF-36 at the screening visit and 3, 6, 9, 15, 27, and 63 months after the first surgery (sequestrectomy). Plain X-rays of the lumbar spine and MRI were analyzed as secondary parameters. For safety reasons, adverse events and laboratory values were investigated.

41.3 History

Degenerative changes of the lumbar segments are a consequence of the aging process and are often a reason for chronic back pain and neurological complications. In Germany, about 60,000 surgeries for herniated lumbar discs are performed each year [10, 18].

The development of chronic back pain after discectomy cannot be avoided completely. No attempts have been made in the past to slow down the progression of degeneration after disc surgery. In this context, the question about the ability of the intervertebral disc to regenerate its morphology has often been raised. In cases of mild degeneration of the disc at the time of herniation, regeneration of disc substance has been proven in animal models [11, 13, 16].

In vitro studies of chondrocytes as a monolayer have been performed by several investigating groups [13, 14, 17]. It was reported that chondrocytes were able to proliferate in vitro and that they are able to regain their chondrocyte-specific properties after contact with collagenous media [5, 8]. This led to the assumption that in vitro expanded intervertebral disc chondrocytes can be (re)transplanted into the disc and perhaps be integrated into pre-existing collagenous structures.

Since 1991, several investigating groups have shown in in vitro and in vivo analyses that degenerative changes of the intervertebral disc can be retained or positively influenced within the meaning of repair of the annulus fibrosus and the nucleus pulposus [6, 7, 15]. The clinical relevance of these investigations is still under discussion.

The aim of this trial is to investigate the clinical relevance of the repair of intervertebral disc tissue by ADCT in a controlled clinical study.

41.4 Advantages

- The procedure is designed to be minimally invasive.
- The main target of this new method is to slow down the complex degeneration process of the lumbar intervertebral disc after discectomy for disc herniation.

41.5 Disadvantages

Additional risks of the transplantation procedure: hematoma, epidural bleeding, infections, neurological deterioration, lesions of the cauda equina, retroperitoneal lesions (large vessels, ureter, intestine).

41.6 Inclusion criteria

Inclusion criteria (prior to screening visit):

- Written informed consent to participate in screening visit prior to any protocol-specific procedures
- Patients of both sexes, aged between 18 and 60 years
- Body mass index < 28
- Monosegmental disc protrusion or disc prolapse or sequester
- Pathological level between L3 and S1

Inclusion criteria (prior to acute phase):

- Written informed consent to participate in acute phase and follow-up prior to any protocol-specific procedures
- Large intact posterior longitudinal ligament
- Expectation of a high compliance during follow-up

41.7 Exclusion criteria

Exclusion criteria (prior to screening visit):

- Ankylosing spondyloarthritis
- End-plate edema or sclerosis = Modic changes types I or III
- Prior surgeries of the above-mentioned segments
- Intradiscal surgery (e.g., chemonucleolysis, PLDD) prior to the study
- Chronic facet syndrome
- Stenosis of the spinal canal
- Spondylodiscitis

- Spondylolisthesis
- Severe motor deficit or cauda equina disorder
- Congenital abnormalities of the spinal nerves
- Pelvic and inguinal angiopathy
- Neurogenic inguinal syndrome
- Syringomyelia, diastematomyelia
- Traumatic neurological disorders
- Peripheral arterial occlusive disease
- Severe diseases of any other major body system as judged by the investigator
- Regular intake of systemic steroids
- Borreliosis
- Malignant diseases of any kind during the previous 5 years
- Patients whose compliance is expected to be poor
- Patients who have participated in a clinical trial within the last month prior to inclusion
- Pregnancy (and planned pregnancy during the following 6 months)

41.8 Patient's Informed Consent

Prior to screening, each patient's written informed consent to screening will be obtained in response to a fully written and verbal explanation of the screening visit.

Prior to being enrolled into the study (acute phase and follow-up), each patient's written informed consent to study participation will be obtained in response to a fully written and verbal explanation of the nature of the study. The patient information leaflet for the study participation will explain the nature of the study, its objectives, and potential risks. Furthermore it will detail the requirement of the participant, the trial treatment, and the probability for random assignment to each treatment group, all trial procedures, alternative procedures, and the fact that he/she is free to withdraw his/her consent at any time without reason. Details of indemnity and insurance are also stated. The patient should be informed separately of the following approach-specific risks:

- Sequestrectomy: nerve root, cauda equina lesions with postoperative neurological deficits, dural tears, injury to retroperitoneal structures, meningitis, spondylodiscitis with epidural abscess, epidural scarring, segmental instability, chronic low back pain, and radicular symptoms ("failed back surgery" syndrome).
- Chondrocyte transplantation: hematoma up to epidural bleedings, infections (local infections, spondylodiscitis, meningitis), neurological deterioration, retroperitoneal lesions. No additional risk due to the application of the autologous chondrocyte suspension itself is known.

41.9 Surgical Technique

The operative treatment of lumbar disc herniation will be performed identically for both treatment groups. Surgical access for sequestrectomy and biopsy is the microsurgical interlaminar paramedian approach [4]. Opening of the facet joint should be avoided. Excluded are minimally invasive approaches making a sequestrectomy impossible and dorsal or lateral surgical approaches with dissection of the muscle.

The biopsy has to be taken out of pure chondral tissue of the sequester without connective tissue, and 1.5 – 2 cm^3 intervertebral disc material from the sequester is needed. The biopsy packaging and transport is standardized by the general operating procedure of co.don Chondrotransplant DISC.

For the ADCT (only for the active treatment group), the time of transplantation will be about 3 months after taking the biopsy, i.e., after healing and achieving of stability of the ligamentum longitudinale posterior. ADCT is carried out as follows:

1. OP-sterile tract
2. Marking of the intervertebral disc space under fluoroscopy control
3. Skin disinfection
4. Superficial local anesthesia with Xylocaine 1 % or comparable
5. Insertion of a small cannula into the lumbar disc space through a posterolateral approach opposite to the former surgical approach (Fig. 41.3)
6. Manipulation under fluoroscopic control in two dimensions (Fig. 41.4)
7. Performance of the intradiscal pressure measurement and instillation of the chondrocytes without using contrast media and without radiological control to avoid adverse effects on the cells



Fig. 41.3. Insertion of cannula into lumbar disc space

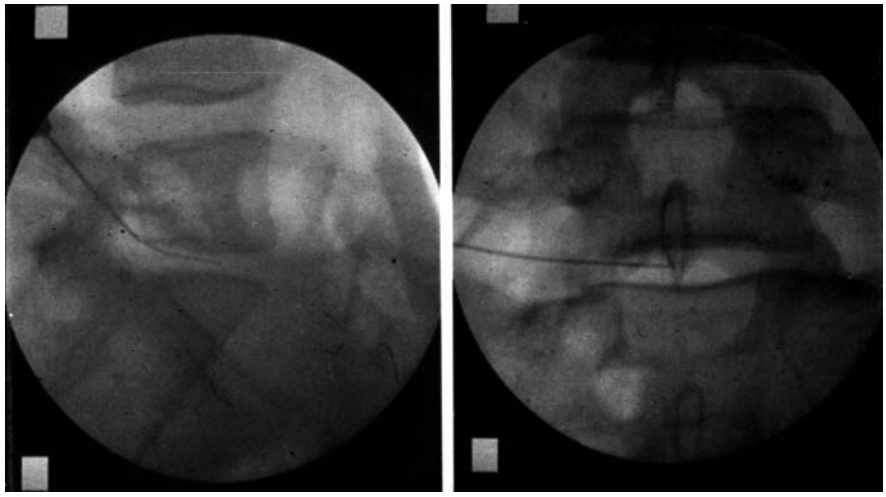


Fig. 41.4. Correct placement of cannula under fluoroscopic control

8. Injection of 0.1 ml NaCl solution to rinse remaining cells from the cannula
9. Removal of the application system and wound closure

41.10 Postoperative Care

After sequestrectomy the patient is allowed to be mobile 6 hours following the operation. From the first postoperative day, isometric exercises should be performed. The duration of hospitalization ranges from 3 to 6 days depending on the individual case.

Following ADCT the patient is in hospital for 3 days:

- 0 – 12 h: strict bed rest, if necessary with angled legs
- 12 – 24 h: bed rest
- 24 – 48 h: bed rest, isometric exercises

A stable lumbar orthosis is used from day 2 for 3 weeks. Instruction for positioning/movement is given before release from hospital.

41.11 Results

Since October 2002, 22 patients (7 women, 15 men; age range 28 – 60 years) have been included into the study in Munich. In all cases, a disc herniation with radicular symptoms was the indication for microdiscectomy and sequestrectomy. Affected levels were L4/5 in 3 cases and L5/S1 in 19 cases. In all of these patients, disc surgery and ADCT were performed without complications.

ADCT has been performed in 8 cases after assignment of the patients in a blind manner. So far, all patients having the ADCT procedure were satisfied with the result of the operation, and scored better values in the postoperative VAS and Oswestry score as compared to preoperatively. There did not seem to be a difference in clinical outcome between the ADCT group and the control group. However, due to the small number of patients and short follow-up, no statistical analysis has been carried out so far. A sample case is shown in Fig. 41.5.

41.12 Critical Evaluation

Degenerative disc disease of the lumbar spine is an inevitable consequence of the aging process and often a reason for chronic back pain and neurological symptoms. About 80% of the population suffer from low back pain at least once during their lifetime [9]. Degenerative changes of the lumbar spine have become an outstanding medical problem in the industrial nations [9]. During recent decades, a variety of surgical procedures have been developed to treat lumbar disc degeneration and low back pain. Unfortunately, the procedures currently available fail to offer a procedure which helps the disc to recover from surgery. The development of chronic back pain especially after surgical procedures is a common phenomenon. In addition to conservative methods, total intervertebral disc prosthesis as well as replacement of the nucleus are now used in clinical studies for the treatment of chronic back pain after disc herniation [2, 3, 12]. Nevertheless, no clinically established procedure is available that slows down the progression of degeneration after an intervertebral disc operation The results of studies in an animal model suggest that restoration of disc matrix is technically practicable and that autologous chondrocytes are capable of regenerating disc tissue. The autologous chondrocyte transplantation might be an appropriate therapeutic treatment to repair disc damage and inhibit degeneration.

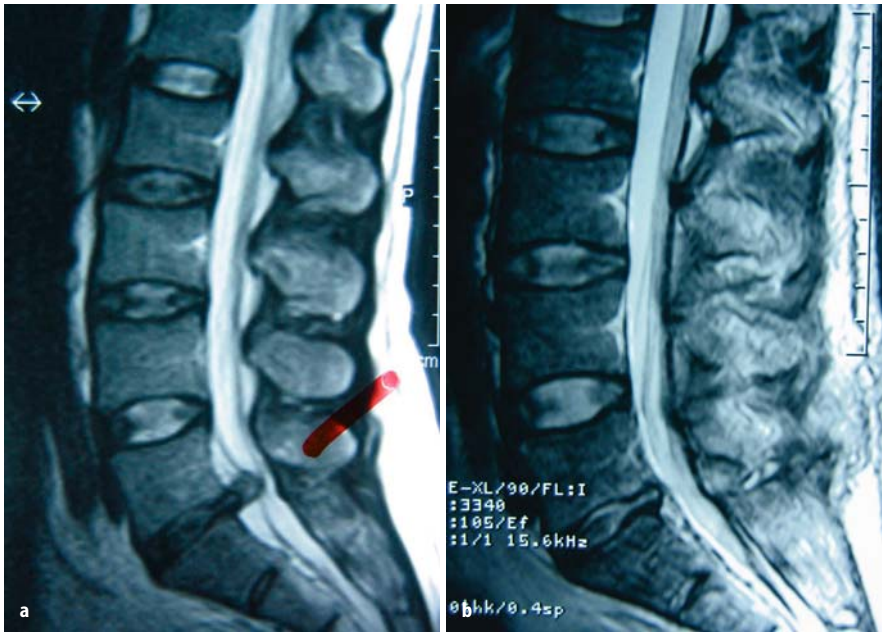


Fig. 41.5. Sample case: 34-year-old man, lumbar disc herniation L5/S1. **a** Microdiscectomy and ADCT 3 months postoperative. Good clinical result. **b** MRI 1 year post-transplantation. Note good recovery of the disc with hyperintensity in T2-weighed image

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The ALPA Approach for Minimally Invasive Nucleus Pulposus Replacement

42

R. Bertagnoli

42.1 Terminology

The posterior approach is standard for lumbar decompression surgery. To avoid disrupting the posterior structures of the spine as well as the disruption of the strong anterior tension bands (the ALL and PLL), the *a*ntero*l*ateral trans*p*soatic *a*pproach (ALPA) [3] has been developed.

42.2 Surgical Principle

In an exact 90° lateral position of the patient with the surgeon standing on the posterior side of the patient, an orthograde projection of the disc space to the skin is generated by tilting the operating room table under fluoroscopic control to get a perpendicular access (Fig. 42.1). An oblique skin incision of approximately 3 – 4 cm is carried out. In a typical manner the retroperitoneal space is accessed by a muscle-splitting technique of the three lateral abdominal wall muscle layers. In blunt dissection the psoas muscle is accessed. The psoas muscle is dissected in the direction of the muscle fibers to reach the affected disc in the midline of the disc's AP distance. The disc anulus is cut to create a flap, the nucleus pulposus material is removed, and the prosthesis is implanted into the disc cavity. The procedure concludes with the anulus flap being sutured in place over the opening to the nucleus, and the wound is closed in a normal manner.

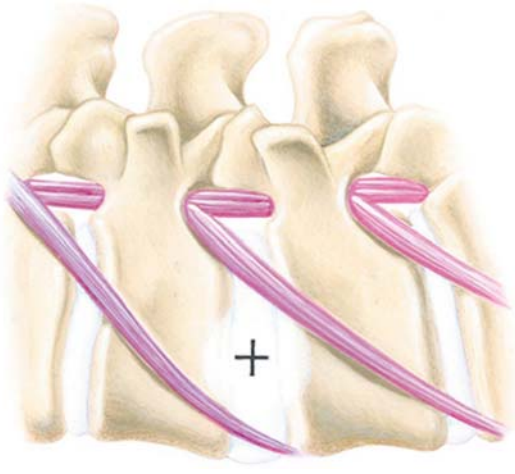


Fig. 42.1. Orthograde lateral access to the disc space

42.3 History

Spinal fusion has become the standard treatment for patients suffering from degenerative disc disease. Though this approach stabilizes the problem area and provides pain relief, it also results in a decreased range of motion and in some cases initiates a degenerative cascade in adjacent segments as these are called upon to compensate for the restricted mobility of the fused vertebrae [2, 5, 8, 9].

To offer patients with symptomatic degenerative disc disease an alternative to spinal fusion, research has recently focused on replacing all or part of the diseased disc with devices designed to retain some of the disc's normal functions. For patients with advanced degeneration, total disc replacement products such as the Link SB Charite (Waldemar Link) and the Prodisc (Spine Solutions) have been developed. For patients with only moderate degeneration, nucleus replacement products such as Aquarelle (Stryker Spine) [12], Newcleus (Sulzer Medica) [12], and the PDN device (Raymedica) [11] are being developed/tested, with the latter being commercially available in many countries.

These nucleus replacement devices have typically been implanted by way of an open posterior approach. Though this surgical technique has proved successful in the majority of cases, there are risks associated with the procedure. Ligament and bone material must be removed, with possible damage to the facet joints inducing an increased instability of the segment. Moreover, exposure of the dura and traversing nerves increases the chance of nerve tissue damage and epidural scarring and bleeding. Due to the defect in the PLL and posterior anulus a higher rate of complications, mainly implant expulsions, have been observed.

To avoid the risks associated with the posterior approach, the anterolateral transpsoatic approach (ALPA) has been developed. Instead of entering the disc from the back, the disc is now accessed laterally through the psoas muscle, with little chance of damage to the osseo-ligamentous tension band structures, located in the direct AP direction, that are in charge of the flexion–extension motion of the lumbar spine. Moreover, because a larger section of the disc can be exposed from a lateral approach, disc enucleation in the lateral direction, parallel to the spinal canal, and prosthetic device implantation can be accomplished faster and with more ease and lesser risks.

42.4 Advantages

- Atraumatic, muscle-sparing access to the anterolateral part of the disc space
- Posterior tension band system unaffected
- Easy introduction of artificial nucleus
- Closure of anulus postimplantation

42.5 Disadvantages

- Risk of damage to the lumbar plexus
- L5-S1 not accessible through this approach

42.6 Indications

- Nucleus replacement
- Anterior lumbar interbody fusion

42.7 Contraindications

- L5-S1
- Previous ALPA approach on the same side (as an alternative the approach can be performed from the contralateral side)

42.8 Patient's Informed Consent

The patient should be informed about the possible complications of anterior approaches (see Chapters 45–48). The specific risk of damage to the lumbar nerve plexus due to direct injury or retractor pressure should be mentioned.

42.9 Surgical Technique

In contrast to the anterior lumbar interbody fusion (Mini-ALIF) approach [6], where the patient is positioned at a 60–70° angle, the ALPA patient is placed in a 90° lateral decubitus position on an adjustable surgical table. The surgeon can stand behind or in front of the patient (Fig. 42.2). To increase the distance between the iliac crest and the inferior border of the twelfth rib, the table is flexed slightly to arch the patient's side. Arms and legs are supported as necessary, and the patient is immobilized to prevent shifting during the procedure.

With the patient secured, the operating table is tilted to position the affected vertebrae perpendicular to the floor. This orientation is important for the fluoroscopic imaging that is used to guide device placement within the disc as well as for precise and easy working in the disc space with optimal orientation of the instruments.

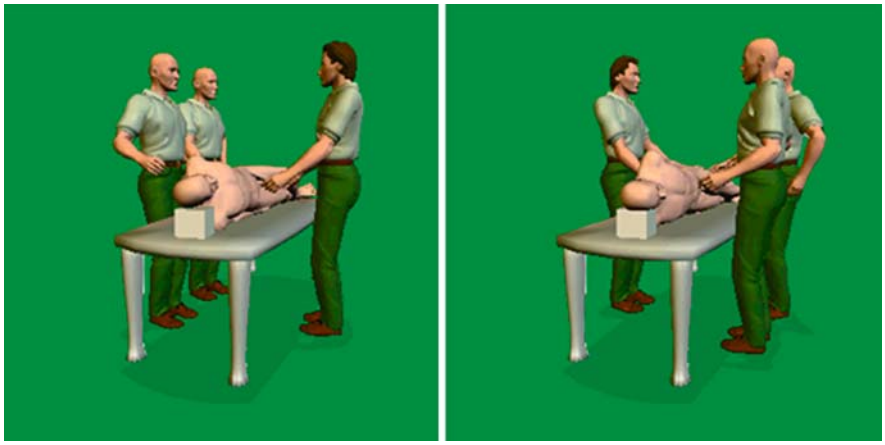


Fig. 42.2. *Left* Position of surgeon in front of the patient. *Right* Position of surgeon behind the patient

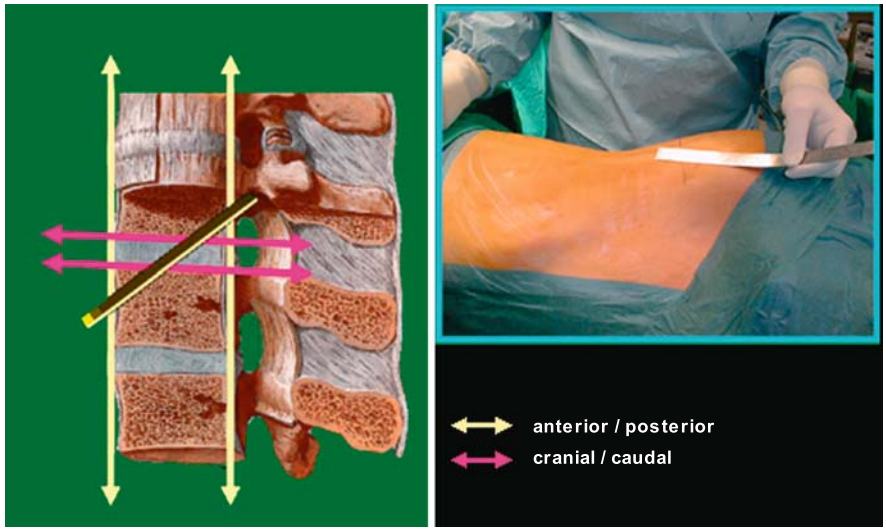


Fig. 42.3. Marking of the anterior and posterior borders of the segment (*yellow lines*) in projection to the skin level. Marking of superior and inferior border of disc space (*red lines*). Oblique skin incision centered over the disc space (*black line*)

Before any incision is made, the exact location of the disc is identified with K-wire and C-arm fluoroscopy. The projection of the disc on the skin is then outlined with a marker on the patient's lateral abdomen (Fig. 42.3).

42.9.1 Incision and Disc Exposure

The surgeon stands behind the patient to maximize access and improve the working angle away from the spinal canal (Fig. 42.2 *right*). A 3- to 4-cm oblique incision is made over the target area, the incision running parallel to the fibers of the external oblique muscle. Blunt dissection through the external oblique, internal oblique, and transversus muscles is done in the direction of the fibers, and self-retaining retractors are placed in the wound to keep the surgical field open. The retroperitoneal space is then identified and followed medially toward the lateral aspect of the psoas muscle. The anatomic safe zone (approximately 2- to 3-cm width through the psoas muscle) corresponds with the lateral middle-third of the disc (Figs. 42.4, 42.5). Care is used not to deviate too far toward the anterior margin of the lumbar spine, where injury to major blood vessels and the sympathetic nerve chain is possible. It is also important not to deviate too far posterior, where the exiting nerve roots of the spine as well as the lumbar plexus can be damaged (see also Fig. 42.1). To avoid damage of the exiting nerve roots or plexus, an additional nerve root detection device, e.g., NeuroVision nerve avoidance system (NuVasive, 10065 Old Grove Road, San Diego CA 92131, USA), can be used. If the psoas is accessed correctly and a strict lateral path is taken through the muscle, a tunnel is formed through the psoas and the fibers of the muscle serve to protect the sympathetic nerve chain and the nerve roots that exit the spine (Fig. 42.6). Once dissection through the

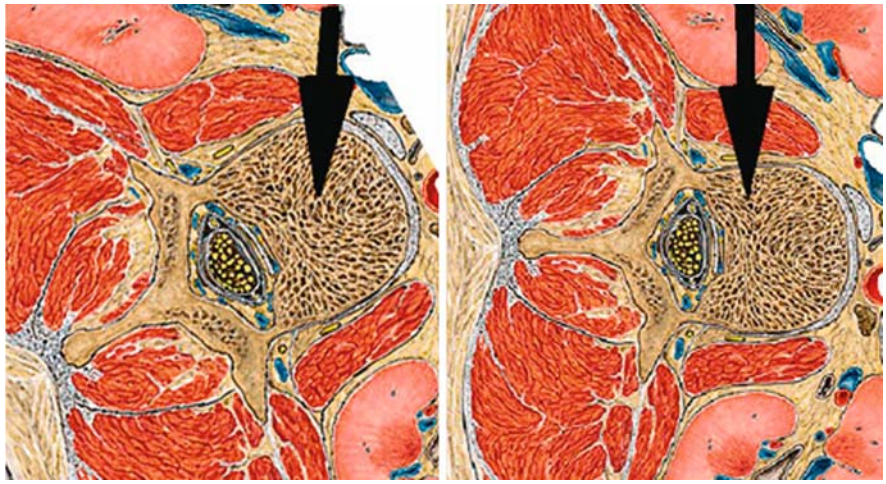


Fig. 42.4. *Left* Access direction in conventional mini-ALIF access. *Right* Access direction with the ALPA approach

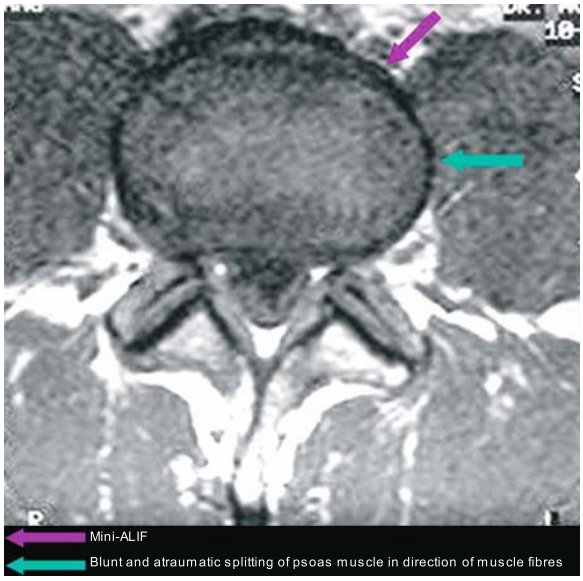


Fig. 42.5. Access route of ALPA approach in an axial MRI (*green line*) as compared to Mini-ALIF approach (*red line*)

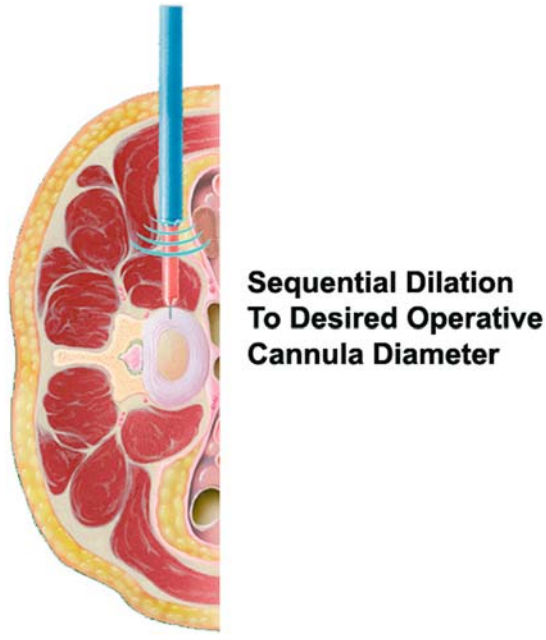


Fig. 42.6. Step-by-step enlargement of access route through the psoas muscle

psoas muscle is complete and the affected disc has been localized, the surgical field is kept open with long self-retaining systems (e.g., Synframe, MIASPAS, or Endoring) (Fig. 42.7).

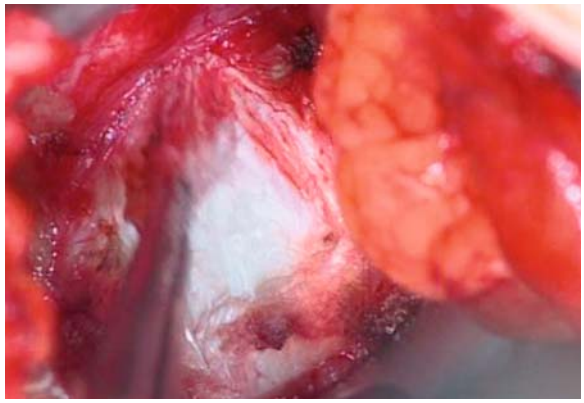


Fig. 42.7. Exposure of the lateral disc circumference

42.9.2 Anulus Incision and Anulotomy

The outer 6–10 layers of the anulus are cut using a small scalpel blade. Two parallel incisions are made (approximately 15 mm long) along the lateral margins of the disc, and one perpendicular incision is made between the preceding two incisions. The goal is to create a flap in the outer anulus layers that can be readapted following implantation of the device. A suture is run through the flap, and the flap is retracted away from the surgeon so that it remains out of the operative field during the procedure. A single midanular incision is then made through the remaining anulus layers [1] to gain access to the nuclear cavity without creating significant damage to the lateral anular layers.

42.9.3 Nucleus Excision

After dilating the incised lateral anular layers, the nucleus material is removed using pituitary rongeurs, suction devices, or automatic shaver systems. The use of sharp curettes or other sharp instruments should be avoided as these can puncture the opposing margin of the anulus or damage the vertebra endplates. All nucleus pulposus material is removed from the lateral regions and from the ventral and dorsal aspect of the disc. Due to the working direction in the lateral plane it becomes easy to clean the nucleus material on the left as well as on the right side from the canal.

Of paramount importance to successfully implanting a prosthetic nucleus device is the surgeon's ability to completely evacuate the disc cavity. Fluoroscopic imaging is helpful in determining whether additional nucleus material needs to be removed. A water-soluble contrast agent is introduced into the nucleus, and the disc space is viewed under fluoroscopes to determine when the disc has been adequately prepared. A nucleus replacement device or interbody fusion device (e.g.,



Fig. 42.8. Readaptation of psoas muscle fibers before closure

cage, bone dowel, etc.) can then be introduced with specific instruments.

42.9.4 Wound Closure

The anulus flap is closed and sutured in place. Retractors are removed, and the psoas muscle is allowed to close (Fig. 42.8). Retroperitoneal drainage can be inserted into the wound at this time. The wound is closed in a normal manner by applying adaptation sutures to the three muscle layers in the abdominal wall and by repairing the subcutaneous tissue in such a way that the overlying dermis aligns properly. This is followed with subcuticular closure of the skin and is finished by the application of sterile connective strips across the closed incision to facilitate healing and reduce scarring.

42.10 Postoperative Care

The patient is mobilized on the first postoperative day. No further restrictions are necessary.

42.11 Hazards and Complications (see also Chapters 44 – 48)

Problems with the ALPA technique include the possibility of inducing neurapraxia of the nerve roots as well as the plexus, especially when pressure on the neurogenic structures to the spinal process with a posterior retraction blade is too high. However, our experience indicates that this side effect diminishes as the surgeon gains experience with the procedure. One technical limitation of the ALPA technique is its inability to access the L5-S1 disc level (where the iliac crest acts as a barrier) without creating a bone defect to the ilium. It is, however, possible to access this disc by creating an osteotomy through the iliac crest and removing the disc material with the aid of an endoscope [7].

42.12 Conclusion

For implantation of nucleus replacement devices as well as interbody fusion devices the ALPA surgical technique has benefits compared with any traditional posterior approach:

1. ALPA allows access to the intervertebral disc with minimal disturbance to posterior structures, the bony elements of the spine are not compromised, and there is no risk of damage to the dura and associated nerve tissue.
2. ALPA simplifies device implantation by allowing lateral access to the disc space: the devices can be directly implanted parallel to the canal. Thus, much less manipulation is required to achieve optimal device alignment.
3. Because the ALPA technique accesses the disc from the side, through a lateral anulus incision and not a posterior anulotomy, the posterior section of the anulus as well as the anterior tension band structures (PLL, posterior anulus, ALL, anterior anulus) remain intact, as does the posterior longitudinal ligament.
4. Intradiscal access to the lumbar spine in the ALPA approach can be carried out from the left as well as from the right side of the patient with the same ease. Therefore, previous surgery in the same region is no longer an exclusion criterion due to higher risks approaching the spine through the same site.

Although larger studies must be implemented to better understand the risk/reward ratio of the ALPA technique, at present this approach shows promise as an alternate means to the posterior hemilaminotomy approach for intradiscal surgeries from L2 to L5.

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Mini-open Midline Accesses for Lumbar Total Disc Replacement

43

H.M. Mayer

43.1 Terminology

Mini-open retroperitoneal approaches are described for total disc replacement in the lumbar spine. The approaches are performed through small skin incisions (4–5 cm) exposing the anterior circumference of the levels L2-S1 through a retroperitoneal route.

43.2 Surgical Principle

Total lumbar disc replacement requires the anterior exposure of the disc circumference to an extent of at least 2 cm each side of the midline. Through small transverse or longitudinal skin incisions, a mini-laparotomy can be performed. According to the topographical anatomy of the abdomen, the retroperitoneal blood vessels, and the weight and stature of the patient, individualized surgical approaches to the anterior circumferences of the levels L2-3-4-5-S1 are possible. The level L5/S1 can be approached through a left or right retroperitoneal approach as well as through a midline transperitoneal approach. For the levels L2/3, L3/4, and L4/5 either a retroperitoneal approach from the left side or transperitoneal approaches are feasible.

43.3 History

Total disc replacement has become an option for the treatment of degenerative disc disease of the lumbar spine. A new implant generation has been developed which can be implanted through minimally invasive anterior approaches to the lumbar levels L2/3, L3/4, L4/5, and L5/S1. The standard mini-open approaches described for anterior lumbar interbody fusion (see Chapters 45–48) have been modified to meet the requirements for lumbar disc replacement [1, 5].

43.4 Advantages

- Decreased iatrogenic access trauma
- Low perioperative morbidity
- Small skin incisions
- Low blood loss (>150 cc)
- Low perioperative complication rate
- Decreased vascular complication rates
- Short operating times
- Good clinical results

43.5 Disadvantages

- Learning curve
- Limited manipulation of vascular structures (preoperative planning necessary)
- Potential risk of indirect trauma to structures surrounding the target area
- Previous abdominal operation might influence the strategy

43.6 Indications

The surgical approaches are indicated for all types of disc replacement [6]. There is currently no international consensus about the indications for disc replacement. Disc replacement has, however, been described for the following pathologies with accompanying discogenic low back pain:

- Degenerative disc disease (DDD) with/without disc herniation
- Post-discectomy segments
- Degenerative discs adjacent to a previous fusion
- DDD with retrolisthesis
- DDD with Modic type I changes
- DDD with frontal plane deformities
- DDD in combination with other pathologies in adjacent segments requiring lumbar fusion

No evidence-based data are available for the clinical efficacy of total disc replacement in the pathologies listed.

43.7 Contraindications

The currently accepted contraindications for total disc replacement are listed in Table 43.1.

There are no general contraindications for mini-open anterior midline accesses. The type of access may, however, be modified. In patients with complicated vascular situations, an open conventional anterior approach may be advisable. The same is true for patients with severe intra-abdominal scarring following previous abdominal operations.

43.8 Patient's Informed Consent

Besides information about the general complications of spine surgery, the patient should be informed about the following potential risks:

- Denervation of the rectus muscle due to dissection of iliocostal nerves
- Abdominal hernias
- Vascular injury in the retroperitoneal space (ascending lumbar vein, common iliac veins and arteries, segmental veins and arteries) with retroperitoneal hematoma and necessity of intervention of a vascular surgeon
- Deep venous thrombosis and arterial thrombosis or injury due to extended retractor blade pressure
- Injury of peritoneum, bowel, ureter, kidney
- Extensive epidural bleeding or bleeding from the subchondral vertebral bone
- Anterior dural tears with CSF fistula
- Lesion to superior hypogastric plexus which can result in postoperative retrograde ejaculation in men or disturbances of lubrication and vaginal dysesthesia in women

43.9 Surgical Techniques

43.9.1 Preoperative Planning

Total disc replacement requires an anterior midline approach for the majority of implants which are currently (2005) on the market. The access to the intervertebral space must be performed strictly in the midline. This requires meticulous preoperative planning as well as a modification of the surgical technique especially at L4/5 and higher levels. Plain X-rays of the lumbar spine including flexion-extension views are standard. They give information about the curvature, disc space height as well as about the anterior bony circumference of the disc space to be approached (Fig. 43.1).

The preoperative planning should also include MRI investigation of the lumbar spine to show the target pathology, the surrounding structures in the spinal canal, the degree of disc degeneration as well as the Modic type of degenerative changes in the adjacent vertebral bodies (Fig. 43.2).

The knowledge of the vascular topography of the retroperitoneal blood vessels allows the planning of individualized approaches. We thus routinely include three-dimensional CT angiography to evaluate the size, shape, and the topography of the retroperitoneal blood vessels (Fig. 43.3a, b). Venous and arterial bifurcation can be clearly visualized. The topographical relationship between the arterial and venous branches and the underlying lumbar spine can be shown. With these preoperative data, surgical planning can be performed in detail. The knowledge of the individual vascular situation of the patient influences the surgical technique and, in rare cases, might lead to a contraindication for disc replacement (e.g., venous bifurcation completely covering the anterior circumference of the target disc space). It also helps to decide whether the help or the availability of a vascular surgeon is necessary during the operation to avoid medicolegal problems in case of complications. All other preoperative planning criteria correspond to the ones which are described for mini-

General	Specific
Osteopathies: Osteoporosis Osteopenia Inflammatory disorders: e.g., Ankylosing spondylitis Deformities: Kyphosis (including juvenile) (Degenerative) lumbar scoliosis Fractures Tumors Spondylitis Psychosocial factors	Disc herniation: With predominant radicular symptoms Posterior element pathology: Facet joint osteoarthritis (°II–V) Post-laminectomy Translational instability: Anterolisthesis Central, lateral spinal canal stenosis Severe endplate irregularities Failed Back Surgery syndrome Post-abdominal operations (?)

Table 43.1. Contraindications for total disc replacement

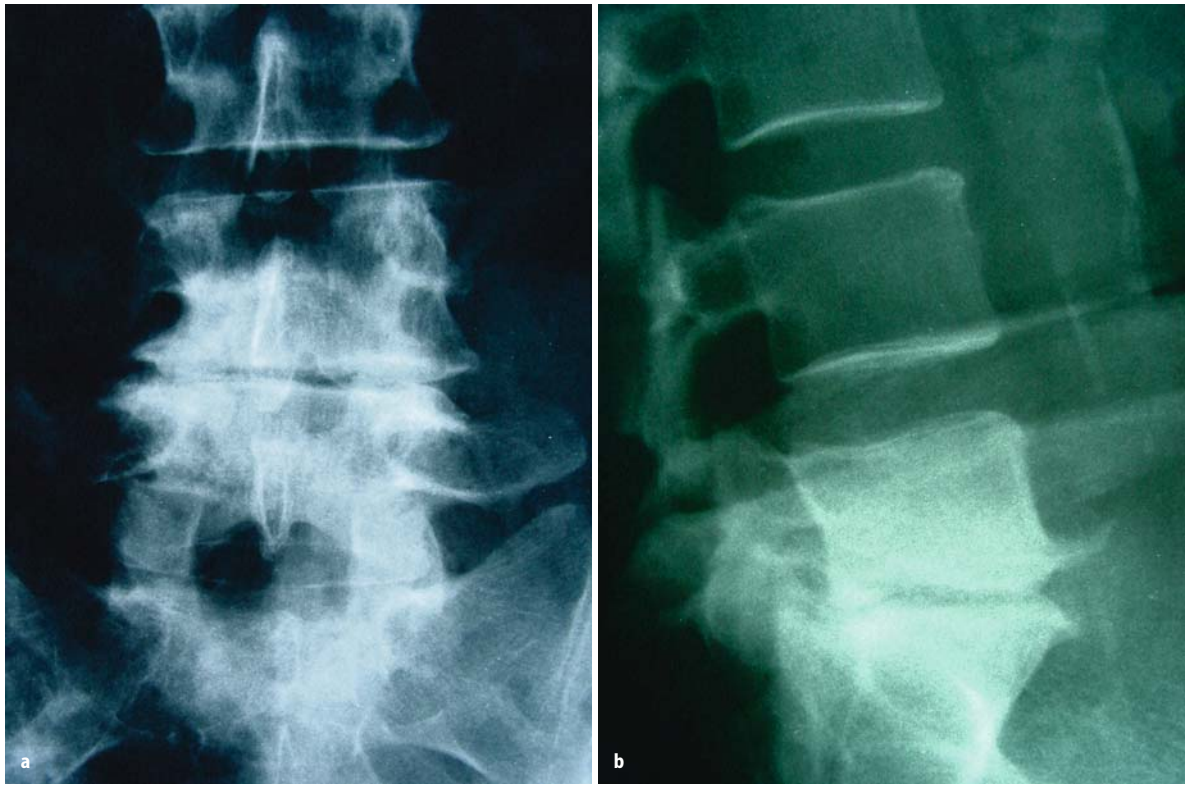


Fig. 43.1. Plain X-rays of the lumbar spine. **a** AP view showing a horizontal tilt at L3/4 with lateral osteophyte formation. **b** Lateral view showing anterior osteophytes at L5/S1 and collapsed disc space



Fig. 43.2. MRI of the lumbar spine. Note the degenerated discs at L4/5 and L5/S1 with Modic type I changes in the subchondral bone at L5/S1 indicating an active degenerative process

mally invasive anterior interbody fusion (Mini-ALIF; see Chapters 45, 46).

43.9.2 Patient Positioning

All implantations can be performed through a midline mini-laparotomy. The patients are placed in a neutral da Vinci position (Fig. 43.4a, b). The position should be neutral, and hyperextension of the lumbar spine should be avoided. A surgical table which allows intraoperative tilting of the legs is recommended (Fig. 43.5). Thus, the orientation of the disc space can be adjusted to ease the implantation of the disc prosthesis.

43.9.3 Localization

The target level is localized under AP and lateral fluoroscopic control and marked on the skin. In obese patients, it can be marked as described in Chapter 46. In

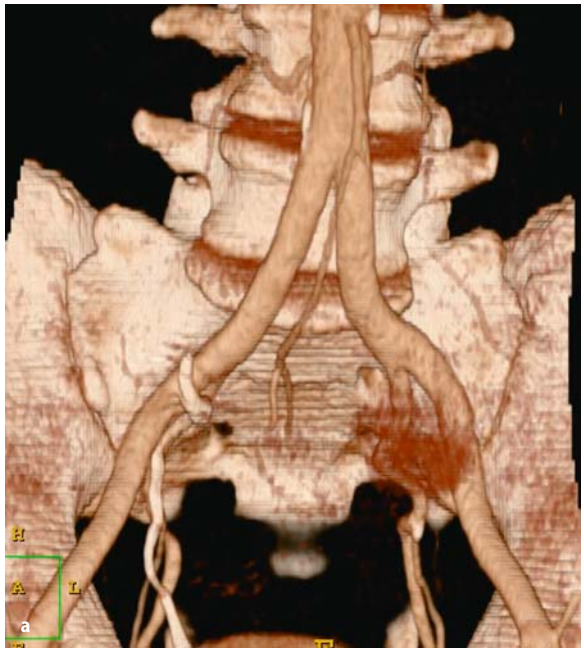
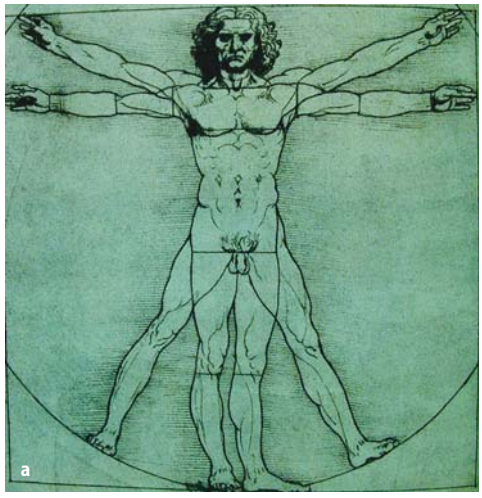




Fig. 43.3. Three-dimensional color-coded CT angiography of the retroperitoneal lumbar blood vessels. **a** Arterial phase. **b** Venous and arterial phase



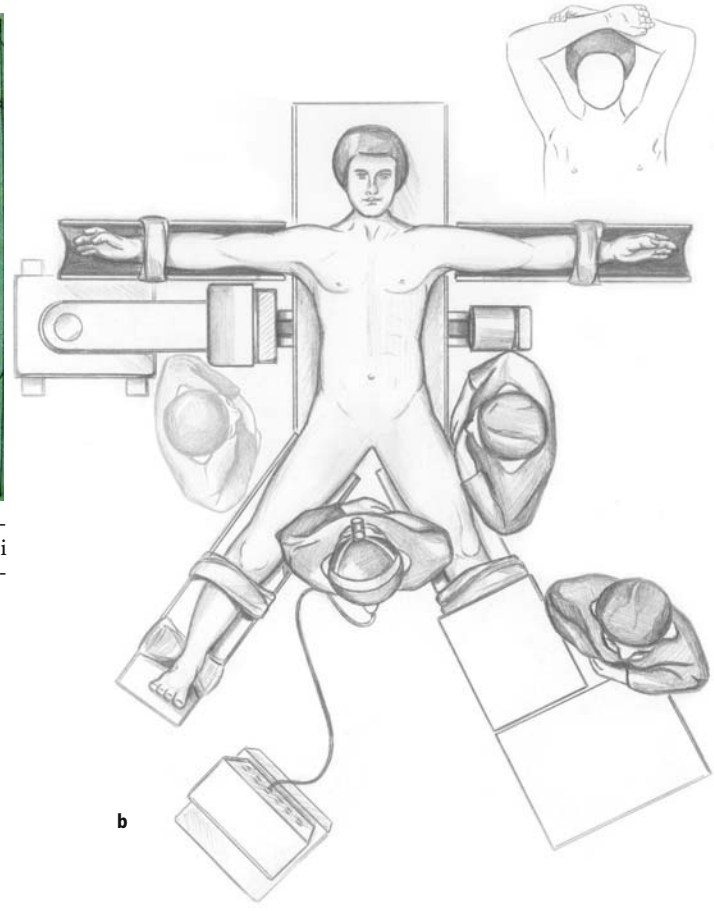


Fig. 43.4. a Positioning of the patient on the operating table with arms and legs abducted (da Vinci positioning). **b** Note alternative position of the patient's arms





Fig. 43.5. a Neutral supine positioning of the patient, lateral view. **b** Position of the surgeon after sterile draping of the patient

slim patients, the abdominal wall is slightly indented with a metal marker to show the position of the marker in the skin surface in relation to the anterior border of the target disc space (Fig. 43.6a, b).

All implantations are performed through small 4- to 5-cm transverse skin incisions. Because of anatomical and topographical details, each level has very specific technical demands.



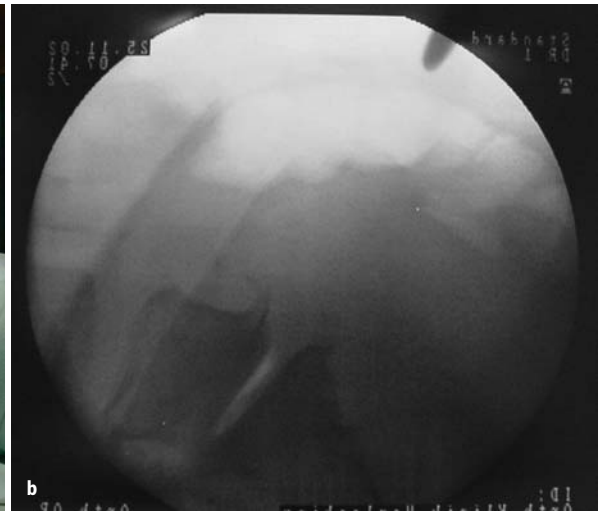


Fig. 43.6. a Indentation of the abdominal wall with a metal marker under lateral fluoroscopic control. **b** Metal marker and anterior entrance of the disc space at L5/S1 are visible. The skin incision is placed above the disc space at the position of the metal marker

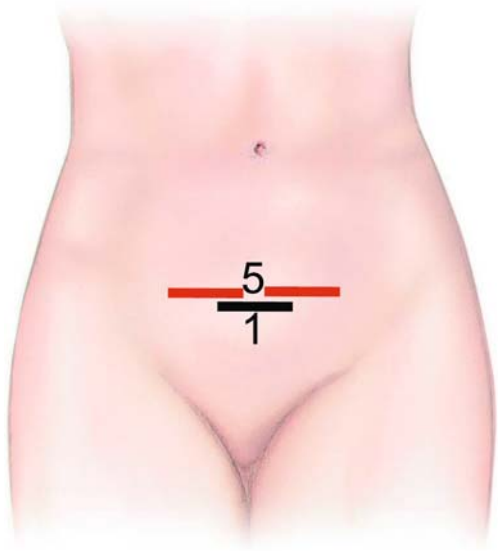


Fig. 43.7. Possible skin incisions for the anterior approach to L5/S1. *Black line* Retro- and transperitoneal in slim patients. *Red lines* Retroperitoneal left or right in obese patients

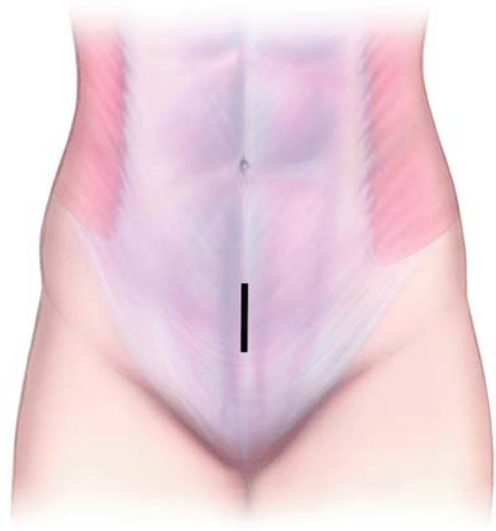


Fig. 43.8. Splitting of the linea alba in the midline to expose the peritoneum

43.9.4 L5/S1

The first choice of access to the L5/S1 disc is retroperitoneal from the right side. The right side is chosen to decrease the risk of injury to the superior hypogastric plexus (see Chapter 45) in men and women and to leave the left side untouched for a potential future approach to the level L4/5 (e.g., in adjacent level degeneration requiring an anterior approach). The second choice is retroperitoneal from the left side. This approach is alternatively chosen in cases with previous abdominal surgery in the lower right quadrant (e.g., appendectomy, gynecological operations, operation for abdominal hernia). The third choice is transperitoneal which we prefer in extremely obese patients.

The skin incision is either placed in the midline in slim patients or slightly asymmetric to the approach side in obese patients or in patients with a very broad stature (Fig. 43.7). This is the easiest segment to approach. After exposure of the rectus fascial sheet, the linea alba is split in the midline, and the peritoneum is exposed (Fig. 43.8)

43.9.4.1 Retroperitoneal Access from the Right Side

This approach should be the first choice. The peritoneum is bluntly detached from the inner abdominal wall on the right side. The transverse fascia has to be incised to mobilize the abdominal contents adequately. The psoas muscle as well as the common iliac artery with the ureter are identified. Preparation is continued toward the midline between the ureter (displaced medially) and the artery. Medial to the common iliac artery, the lateral circumference of L5/S1 can be exposed. In this area, the superior hypogastric plexus is very thin with rare and small branches, which decreases the risk of damaging this plexus. Blunt dissection of the prevertebral fat tissue including the plexus exposes the medial sacral artery and vein, which can then be clipped or coagulated and dissected. Thus L5/S1 can be exposed easily. The left common iliac vein can be retracted carefully to the left. This is the safest and easiest approach to L5/S1.

43.9.4.2 Retroperitoneal Access from the Left Side

The dissection process is the same as on the right side. Dissection is performed across the common iliac vein to the disc space L5/S1. This can be difficult especially if the vein has a large diameter and covers part of the disc space. The superior hypogastric plexus has to be pushed medially with care avoiding any coagulation. These two factors make this approach the "second-choice approach"; however, exposure of L5/S1 can be achieved as properly as from the right side.

43.9.4.3 Transperitoneal Access

In very obese patients, in patients who have had conventional abdominal surgery, and in revision cases the transperitoneal minimally invasive approach is the adequate technique. It is the most direct way to L5/S1 and can be performed easily even in obese and previously operated patients.

In all instances, the medial sacral vessels have to be coagulated/ligated and dissected away from the anterior circumference of the disc space.

43.9.5 L4/5

The anterior access to L4/5 is from the right side.

43.9.5.1 Retroperitoneal Approach

A retroperitoneal approach is the first choice. This is the most difficult level to access because of the vascular anatomy. The disc space is, in most cases covered by vascular structures. Vascular anatomy thus determines the approach to L4/5. Due to the venous anatomy, the retroperitoneal approach from the left side has been preferred in conventional anterior approaches. However, vascular mobilization across the midline has its limitations using a minimally invasive approach. Mobilization of the abdominal contents is more difficult through a 4- to 5-cm skin incision. The same is true for preparation and retraction of the blood vessels. Since vascular injury or arterial occlusion can result in a life-threatening complication, all efforts should be directed to avoid such a type of complication. An individualized access which considers the individual vascular topography is recommended to access the L4/5 disc space. Preoperative three-dimensional CT angiography determines the individual mobilization of the blood vessels. Intraoperative monitoring includes the continuous measurement of oxygen saturation in the left big toe to avoid prolonged ischemia of the leg due to retractor pressure on the arteries (Fig. 43.9).

After localization of the level, the skin incision it is placed slightly paramedian to the left side (Fig. 43.10). The rectus fascia is exposed from the linea alba to its lateral border. It is then incised transversely to allow mobilization of the rectus muscle (Fig. 43.11).

The muscle belly is then mobilized medially to expose the posterior rectus sheath and the linea arcuata (Fig. 43.12). The posterior rectus sheath is incised longitudinally and the peritoneum is exposed. Care has to be taken not to open the peritoneum. The retroperitoneal space is entered lateral to the rectus muscle to facilitate vascular preparation and dissection in the lower left quadrant with only low retraction pressure on the rectus muscle. The peritoneum is mobilized from the lateral abdominal wall and the psoas muscle is identified. Medial to the psoas muscle, the common iliac vein and artery are exposed. The ureter is dissected from the common iliac artery and mobilized medially together with the peritoneum. The lateral border of the disc space L4/5 is then identified. The next surgical target is the lateral border of the common iliac vein and the entry of the iliolumbar and ascending lumbar venous branches. It is essential to first identify these venous branches. They have to be occluded with sutures or vascular clips and dissected. This surgical step is paramount since in the majority of the cases, the common iliac vein cannot be mobilized without the risk of a tear injury to the iliolumbar and ascending lumbar branches. The mobilization of the common iliac artery is simple, since there are no exiting branches in this region. Once this step is completed, the retroperitoneal



Fig. 43.9. Measurement of oxygen saturation in the left big toe

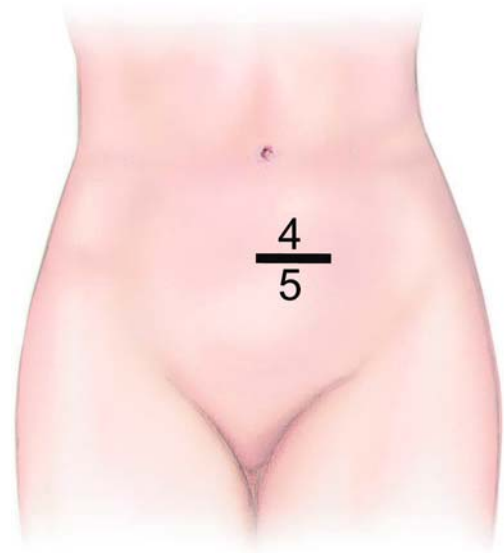


Fig. 43.10. Skin incision for the anterior approach to L4/5

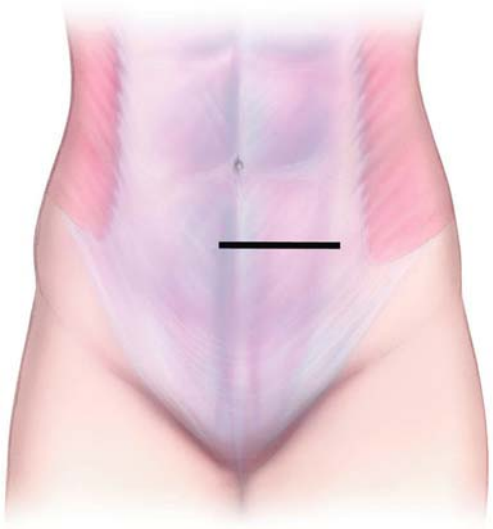


Fig. 43.11. Transverse incision of the anterior rectus sheath

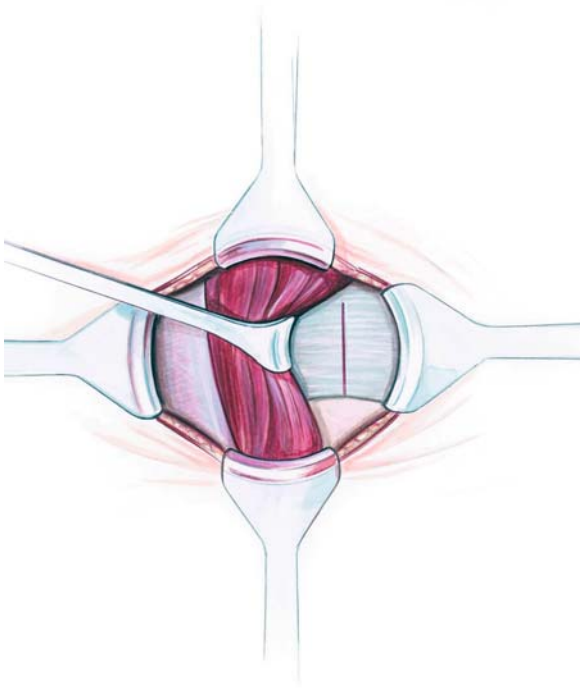


Fig. 43.12. Mobilization of rectus muscle belly medially and exposure of the posterior rectus sheath and the linea arcuata

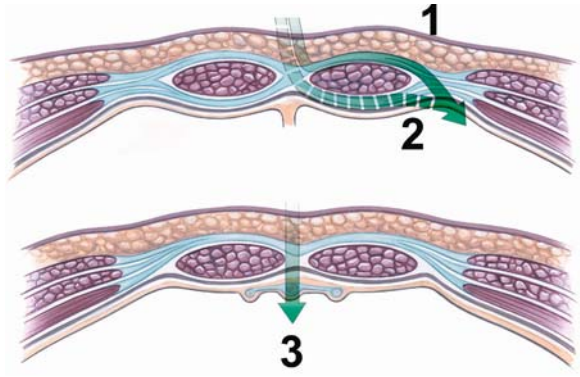


Fig. 43.13. After the peritoneum is mobilized lateral to the rectus (*1*), the retroperitoneal space is entered again medial to the rectus muscle (*2*) and exposure of the anterior circumference of the disc space is completed through a midline approach between the rectus muscle bellies (*3*)

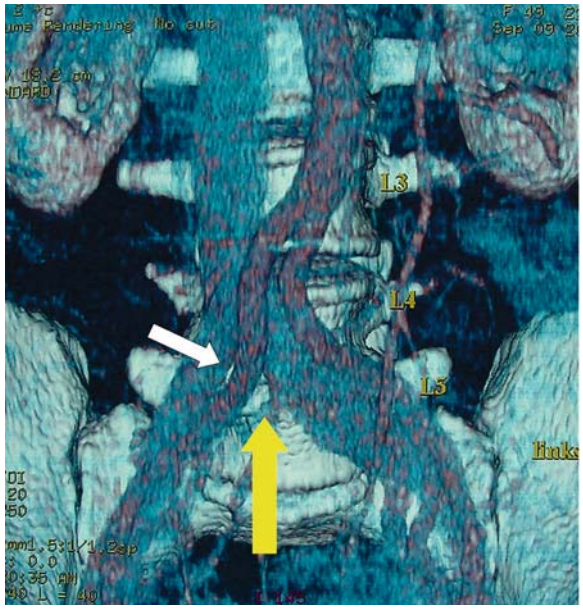


Fig. 43.14. Three-dimensional CT angiography. Note, arterial bifurcation is well above the disc space L4/5. Venous bifurcation is above the superior rim of the disc space (*white arrow*). Exposure of the disc space from caudal between arterial and venous bifurcation (*yellow arrow*)

space lateral to the rectus muscle is left and is entered again medial to the muscle belly (Fig. 43.13).

Further mobilization of the vascular structures should follow the individual vascular anatomy. Although, three-dimensional CT angiography shows a great variety of vascular situations in front of the L4/5 disc space, there are three variations of vascular mobilization which are recommended.

43.9.5.1.1 Variation 1

If venous and arterial bifurcations are located cranial to the superior border of the L4/5 disc space, the access can be between the bifurcations (Fig. 43.14). In this situation, mobilization and dissection of the ascending lumbar veins is not necessary. The median sacral vessel, however, should be ligated and dissected. This is a rare situation at the level L4/5.



Fig. 43.15. Three-dimensional CT angiography. Arterial bifurcation at the level of disc space L4/5, venous bifurcation below. Mobilization of arteries and veins across the midline

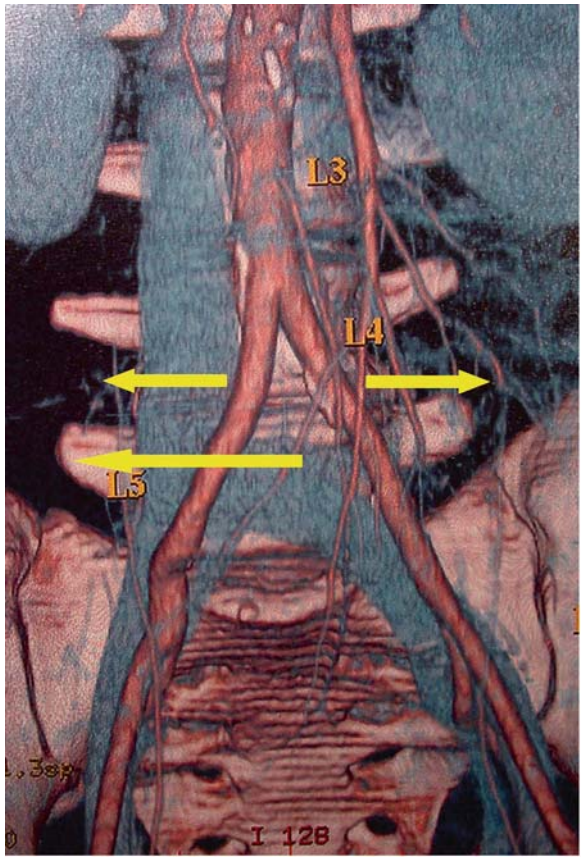


Fig. 43.16. Three-dimensional CT angiography. Arterial bifurcation well above L4/5, venous bifurcation below. Exposure of the disc space is between the common iliac arteries to avoid extensive pressure on the left common iliac artery. Common iliac vein and vena cava mobilized to the right side

43.9.5.1.2 Variation 2

If the arterial bifurcation is located on the level of the disc space, it should be mobilized together with the venous structures across the midline (Fig. 43.15). However, it is recommended to carefully monitor the oxygen saturation in the left big toe and, if necessary, to relieve the pressure of the retractor blades on the artery every 30 – 40 minutes. With this type of mobilization, ligature of the left segmental artery and vein L4 is mandatory.

43.9.5.1.3 Variation 3

If the arterial bifurcation alone is well above the disc space L4/5, a dissection between the arteries is recommended (Fig. 43.16). Only the common iliac vein or the inferior cava vein is mobilized across the midline, whereas the common iliac arteries are slightly pushed to both sides of the disc space. Ligature of the segmental vein L4 on the left side is necessary.

43.9.5.2 Transperitoneal Approach

A direct, transperitoneal approach would be the second-choice approach. The superior hypogastric plexus and the perivascular tissues have to be dissected carefully. The mobilization of the blood vessels will be the same as described above.

43.9.6 L2/3/4

The approach to L3/4 and L2/3 needs modifications of the skin-to-spine route. The skin incision is usually at the level of or above the umbilicus (Fig. 43.17). If it is at the umbilical level, a small, longitudinal paramedian incision on the left side is preferred. Retroperitoneal exposure is much more difficult at these levels, since the peritoneum is adherent to the posterior rectus sheet. Innervation of the rectus muscle must be preserved and the integrity of the fascial indentations at these levels must be respected. It is thus recommended

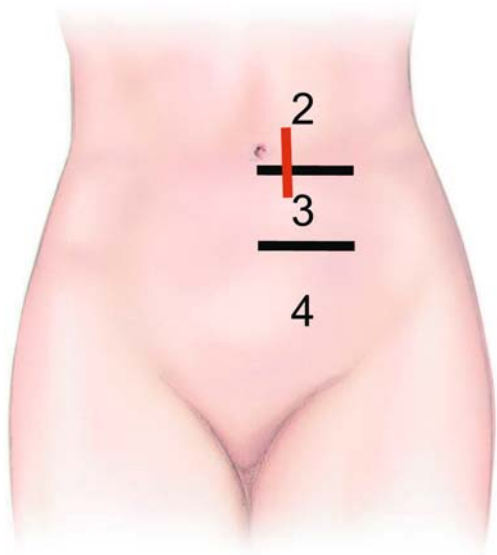


Fig. 43.17. Skin incisions to approach the level L2/3 or L3/4 (*black lines*). Alternative skin incision for L2/3 (*red line*)



Fig. 43.18. Three-dimensional CT angiography. Mobilization of aorta and vena cava inferior (*white arrows*) to access L2/3 or L3/4. Segmental veins L2, 3, and 4 on the left side as well as segmental arteries L2, 3, and 4 on the right side have to be ligated and dissected

to expose the retroperitoneal space in two steps: longitudinal midline incision of the anterior rectus sheet 5 mm lateral to the linea alba and exposure of the left rectus muscle followed by dissection anterior to the muscle to its lateral border and opening of the retroperitoneal space. Thus, the peritoneum can be detached from the posterior rectus sheet from left lateral to the midline. The exposure is then continued by opening of the posterior rectus sheet close to the midline and retroperitoneal dissection from the left to the right. In obese patients again, a transperitoneal route is recommended. The variable options of vascular preparation are shown in Figs. 43.18 and 43.19

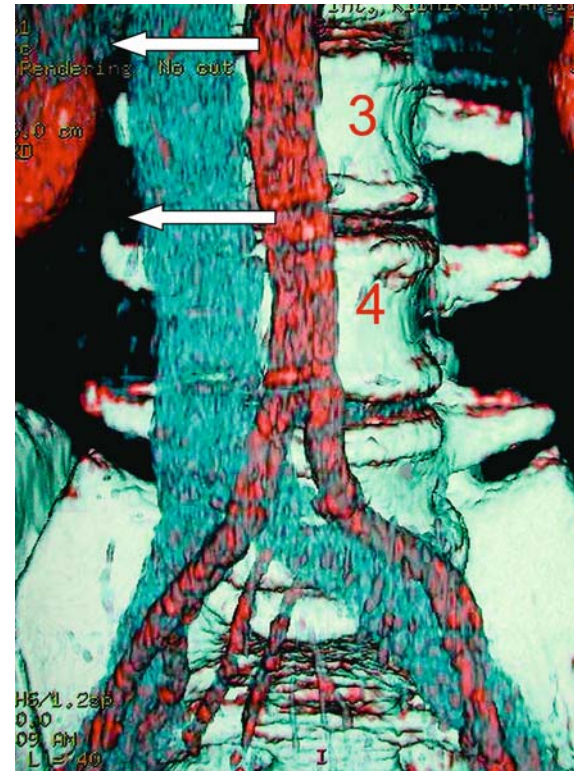


Fig. 43.19. Three-dimensional CT angiography. In this vascular situation, aorta and vena cava inferior are mobilized across the midline to the right side (*white arrows*). Segmental arteries and veins L2, 3, and 4 have to be ligated and dissected on the left side

43.9.6.1 Variation 1

In this individual anatomical situation an approach between aorta and vena cava inferior is recommended to avoid exerting pressure on the aorta (Fig. 43.18). Segmental veins on the left side as well as segmental arteries on the right side have to be dissected before mobilization.

43.9.6.2 Variation 2

Since the aorta is located in the midline, it is, together with the vena cava, mobilized across the midline to the right side (Fig. 43.19). Segmental arteries and veins on the left side need to be ligated. At the level L2/3 care should be taken to avoid tethering or indirect rupture of the renal vessels.

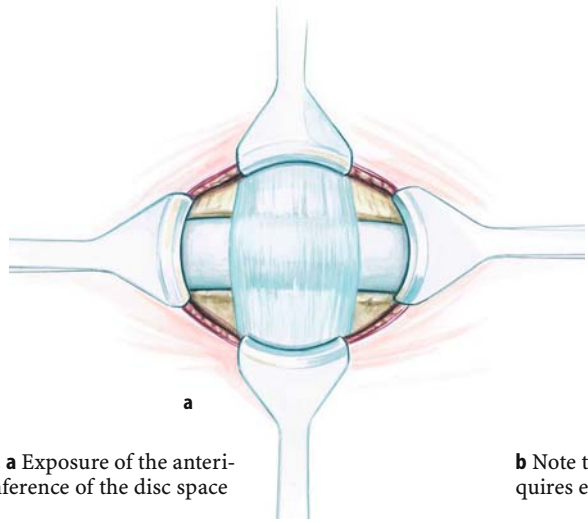
43.9.7 Exposure of the Disc Space

Once the peritoneum and the vascular structures are shifted away from the anterior circumference of the spine, the disc space can be exposed (Fig. 43.20). The approach corridor is then secured by the insertion of a frame-type retractor (Fig. 43.21).

After removal of the disc, preparation of the disc space, and release of the segment, total disc replacement can be performed. However, because of the mini-open access, disc replacement is only possible with the latest generation of implants [3, 5].

43.10 Postoperative Care

The patients can be mobilized on the day of surgery. The average hospital stay is between 2 and 5 days. Using the Prodisc implant (Fig. 43.22) postoperative bracing is not necessary. The patients are restricted from heavy physical activities and sports for 6 – 8 weeks. After a period of 3 – 4 weeks postoperative, we recommend an outpatient rehabilitation program to strengthen the abdominal and back muscles.



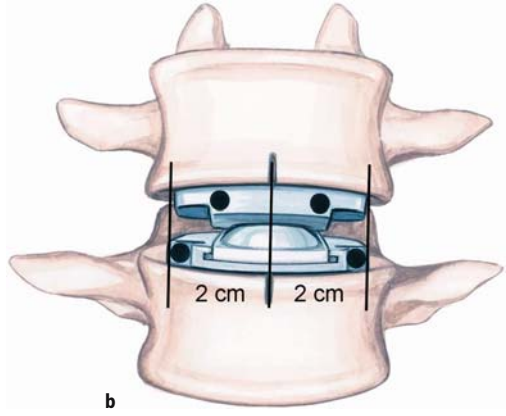


Fig. 43.20. a Exposure of the anterior circumference of the disc space **b** Note that implantation of an artificial disc (Prodisc L) requires exposure of at least 2 cm on each side of the midline

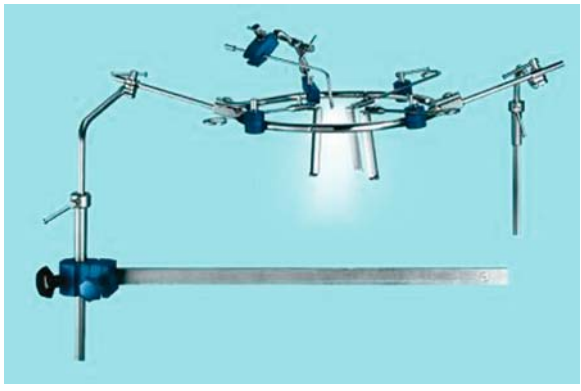


Fig. 43.21. Synframe (Synthes, Oberdorf, Switzerland) retractor





Fig. 43.22. a Prodisc implant. **b** Lateral X-ray of the lumbar spine showing disc implant in place

43.11 Hazards and Complications

The perioperative complication rate is less than 10%. In a recent unpublished series of 152 patients, no vascular injury was observed. One patient suffered from a postoperative deep venous thrombosis with could be treated successfully. This low vascular complication rate can be attributed to the individualized preparation of the vascular structures. It is significantly lower as compared to other techniques which are characterized by a uniform retraction of the blood vessels from the left to the right side, irrespective of their individual anatomy (Table 43.2).

Table 43.2. Vascular complication rates according to the type of anterior access to the lumbar spine

	Complication	Rate (%)	Total (%)
Uniform conventional approach, venous complications [7]	Venous injury, pararectal approach	18.4	26.1
	Venous injury, lateral approach	7.7	
Uniform conventional approach, arterial complications [2]	Arterial thrombosis	2.3	3.7
	Vasospasm	0.9	
	Intimal fracture	0.5	
Uniform mini-open approach [1]	Arterial thrombosis	0.9	2.8
	Venous injury	0.9	
	DVT	1.0	
Individualized mini-open approach (own data)	DVT	0.43	0.4

43.12 Conclusions

Minimally invasive approaches are possible even in difficult anatomical regions such as L4/5 and higher lumbar levels. The perioperative results show, that iatrogenic morbidity is very low. All patients could get out of bed the day after the operation. Intraoperative data are virtually the same as with anterior interbody fusion except for the fact that there is no comorbidity at the donor site for bone grafts [4]. The most striking finding is the fact that individualized mobilization of the retroperitoneal blood vessels can lead to a significant reduction of vascular complications.

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Microsurgical Decompression of Acquired (Degenerative) Central and Lateral Spinal Canal Stenosis

44

H.M. Mayer

44.1 Terminology

Microsurgical decompression of the spinal canal is defined as a mono- or multisegmental, uni- or bilateral internal enlargement of the central and/or lateral volume of the spinal canal without performing a laminectomy. "Internal laminoplasty" is proposed as a synonymous term.

44.2 Surgical Principle

The spinal canal is approached through a modified microsurgical interlaminar route (see Chapter 32) usually from the (most) symptomatic side. In cases with associated degenerative lumbar scoliosis, the approach from the convex side is preferred.

- The interlaminar window is opened ipsilaterally by resection of the hypertrophied yellow ligament.
- The insertions of the yellow ligament are resected by osteoclastic undercutting of the cranial and caudal lamina.
- Subarticular ipsilateral decompression is achieved by undercutting or partial resection of the medial parts of the superior facet of the infradjacent vertebra.
- Enlargement of the central parts of the spinal canal is achieved by dome-shaped undercutting of the laminae and resection of the ventral parts of the interspinous ligament.
- Contralateral decompression is performed through an "over-the-top" approach.

44.3 History

Wide laminectomies still are considered to be the treatment of choice in degenerative spinal stenosis without instability [4–7, 13, 14, 15]. Due to the risk of destabilization of the motion segment, a limited approach was proposed by Poletti in 1995 [12]. The microsurgical interlaminar approach for the treatment of lumbar disc herniations has been adopted and modified. An extension of the ipsilateral approach to the contralateral side has been proposed in order to decompress the lateral recess bringing in the working instruments "over-the-top" of the thecal sac to the contralateral side. The approach was refined by McCulloch and described first in detail in 1998 [10].

44.4 Advantages

The advantages include all advantages described in the chapters on microdiscectomy (Chapters 31, 32, 34). There are other advantages which can be divided into technical and clinical categories. The typical technical advantages are:

- Decreased trauma to paravertebral muscles on the ipsilateral side, no trauma to paravertebral muscles on contralateral side.
- Bilateral decompression of the spinal canal through a unilateral approach.
- Microsurgical internal enlargement of the spinal canal preserves completely the posterior tension banding system (supraspinous, interspinous ligaments, spinous processes as well as paraspinal muscles on the contralateral side.
- Complete preservation of the laminae as well as of the lateral two thirds of the facet joint on the ipsilateral side.
- Preservation of the outer contour and more than 75% of the facet joint of the contralateral side (see also Fig. 44.14).
- Complete decompression of the thecal sac as well as of the spinal nerves on both sides from their dural sleeve exits to their entrance into the foramen.

The clinical advantages result from the technical advantages:

- Decreased trauma to paravertebral muscles results in early mobilization, negligible postoperative wound pain, and an early start to rehabilitation.

- Decreased blood loss even in multisegmental approaches.
- Since the average age of the patients is >70 years (see also Section 44.12) early mobilization is an important factor to decrease postoperative complications such as deep venous thrombosis, urinary tract infection, or pneumonia due to prolonged immobilization.
- The risk of increasing instability is very low even in those patients who already show signs of mild (grade I) degenerative spondylolisthesis (personal observations). This is the reason why this kind of decompressive procedure can be performed without stabilization even in these patients.

44.5 Disadvantages

There are several mainly technical disadvantages associated with this approach:

- The time for monosegmental decompression is slightly longer as compared to open central laminectomy. However, multilevel decompression occasionally results in considerably longer operating times.
- Decompression of the contralateral side is a technically demanding procedure. Insufficient exposure can lead to enforced intraoperative manipulation of the thecal sac and cauda equina which can result in temporary and/or permanent neurological deficits.
- Inadequate decompression especially of the contralateral side can lead to unfavorable clinical outcomes.

44.6 Indications

The procedure is indicated in all patients showing the clinical symptoms of acquired degenerative lumbar spinal stenosis without or with insignificant and mild vertebral body translations.

The following clinical signs and symptoms should be present:

- Uni- or bilateral symptoms in the legs. In contrast to clear radicular symptoms, for example in disc herniations, the patients complain about weakness or heaviness in the lower extremities particularly when walking. Mild sensory deficits or paresthesias can be present as well. The symptoms usually get better when the patient stops walking, as well as in inclination. On physical examination, the symptoms can rarely be verified unless there is a long history of complaints. However, there may be patients in whom mono- or oligoradicular symptoms due to lateral canal stenosis dominate the clinical picture.
- Diminished walking distance ("spinal claudication").
- Reduced standing time.
- Low back pain.
- Loss of segmental motion (stiffness of the low back).
- Loss of lumbar lordosis.
- Radiological investigations such as plain X-ray, MRI, (functional) myelography or myelo-CT should prove a narrowing of the central and/or lateral spinal canal in relation to the topography of the lumbar nerve roots (Fig. 44.1). Older classification systems which refer to measurement of the sagittal and/or transverse diameter of the spinal canal are not helpful for the indication for surgery since it is not the absolute width of the spinal canal



Fig. 44.1. MRI sagittal view. Multilevel spinal stenosis

which determines compromise of neural structures. The relation between the size and topography of neural structures and the space available is the only reliable measure which determines the clinical symptoms.

- Electrophysiological parameters such as electromyograms (EMG), nerve conduction studies, or somatosensory-evoked potentials (SSE) contribute mainly to rule out other diagnosis such as peripheral neuropathies.
- Decompression without stabilization is performed in all patients without radiological signs of vertebral body translation, in patients without low back pain despite vertebral body translation or degenerative scoliosis, in patients older than 75 years, and in patients with severe osteoporosis and multisegmental pathology.
- Decompression with segmental stabilization (usually posterior–anterior 270° fusion or TLIF) is performed in patients exhibiting grade I or higher-type spondylolisthesis on rest or functional X-rays with significant low back pain as well as in patients with unstable lumbar degenerative scoliosis.

44.7 Contraindications

There are no disease-specific contraindications for decompression of the spinal canal. Modern anesthetic techniques and monitoring equipment make it possible to perform general anesthesia even on old patients with a low risk. However, there may be a few absolute contraindications for general anesthesia such as:

- Severe respiratory insufficiency
- Unstable angina pectoris
- Severe arterial hypertension

44.8 Patient's Informed Consent

The patients should be informed about the risks which are immanent of microsurgical mono- or multilevel approaches to the lumbar spinal canal:

- Nerve root, cauda equina, and/or conus medullaris lesions with postoperative neurological deficits including bladder and bowel dysfunction
- Dural tears with menigocele and/or CSF fistulas
- Postoperative epidural hematoma
- Meningitis
- Spondylodiscitis with epidural abscess
- Epidural scarring with neurological deficits or permanent sciatica
- Segmental instability chronic low back pain and radicular symptoms ("Failed Back Surgery" syndrome) requiring stabilizing surgical procedures

44.9 Surgical Technique

The surgical technique can be divided into microsurgical decompression without and with segmental stabilization. The indications are described above.

44.9.1 Microsurgical Decompression without Instrumented Fusion

44.9.1.1 Preoperative Planning

Technical preoperative planning is performed using the information given by plain X-rays of the lumbar spine, MRI, and/or CT scan/post-myelographic CT scan.

44.9.1.1.1 Plain X-rays

All patients require plain X-rays of the lumbar spine. We routinely perform AP and lateral views. If instability with vertebral body translation is suspected, functional X-rays in flexion and extension are performed as well. The X-rays give the gross picture of the curvature of the lumbar spine. They reveal degenerative scoliosis and segmental rotational or translational instability. For surgical planning, it is important to know the size and shape of the interlaminar window since this is the entrance into the spinal canal. In most of the cases, the interlaminar space is small, sometimes completely closed (Fig. 44.2). The width of the laminae cephalad and caudad to the interlaminar space represents the safety range for bony decompression without performing a hemilaminectomy. The width of the isthmic area can be judged in order to preserve it intraoperatively.

44.9.1.1.2 Magnetic Resonance Imaging, CT Scan, and Post-myelographic CT Scan

These are the surgeon's most important preoperative sources of information. MRI is, in my opinion, the imaging technique of choice, as in most of the patients this investigation gives sufficient information. The size and contour of the facet joints are clearly visible. This facilitates intraoperative orientation. It is important to know how much if the medial part of the inferior facet of the cephalic vertebra can be removed without sacrificing



Fig. 44.2. AP X-ray of a lumbar spine showing extremely narrow interlaminar spaces

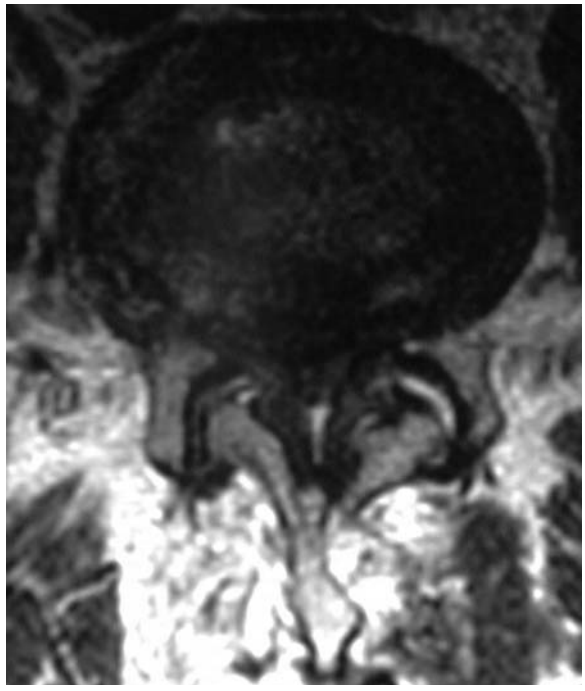


Fig. 44.3. MRI axial view. Hypertrophied yellow ligament contributing to central and lateral spinal stenosis

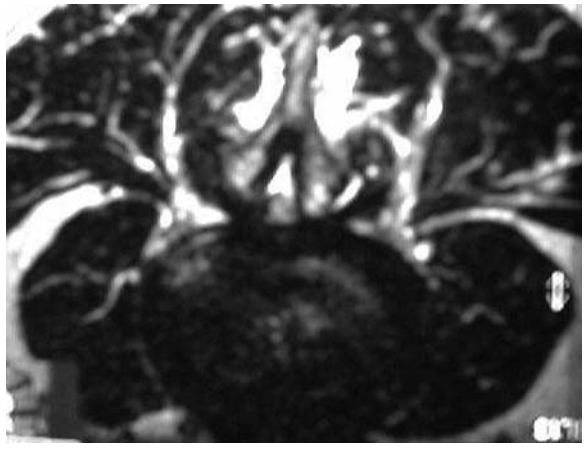


Fig. 44.4. MRI axial view L5/S1. Epidural fat is preserved in the dorsal parts of the spinal canal

more than one third of its size. The thickness of the yellow ligament, its extension underneath the adjacent laminae as well as the thickness of the lamina itself can be evaluated. The extension of the yellow ligament as well as the thickness of the flavum determine the amount of undercutting which is necessary for sufficient decompression (Fig. 44.3). The size and topography of the neural structures at the level of compression as well as above and below should be evaluated carefully to avoid damage during decompression. The distribution of epidural fat tissue can lead to a modified surgical strategy which helps to protect the neural structures: for example, in an extremely narrow canal it is more advisable to enter the spinal canal through a more medial posterior route where more epidural fat protects the thecal sac (Fig. 44.4). Note the shape of the spinal canal (round, oval, trefoil; Fig. 44.5), and estimate whether it is mainly soft tissue (yellow ligament, joint capsule, intervertebral disc) or bone (superior facet, lamina, osteophytes) which leads to a compression of neural structures. If, as in the majority of acquired spinal stenoses, it is mainly soft tissue compression, try to preserve the bony structures as much as possible.

44.9.1.2 Anesthesiological Aspects

The operation is performed under general anesthesia. Patients with spinal stenosis carry, due to their age and other concomitant diseases, higher risks and require reliable intraoperative monitoring. We recommend the introduction of a central venous line, to perform arterial blood pressure monitoring, as well as the introduc-

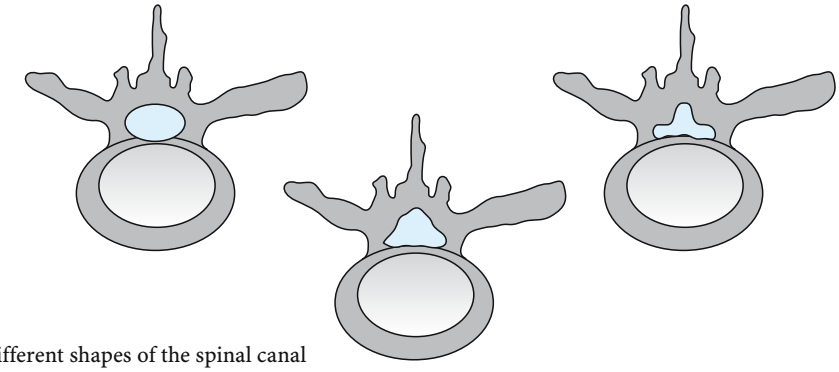


Fig. 44.5. Schematic drawing of the different shapes of the spinal canal

tion of a urinary catheter irrespective of the expected time for the operation. Blood transfusions are not routinely necessary, and own blood donations are not required. However, if more than a two-level decompression is intended, we recommend intraoperative blood collection for retransfusion.

44.9.1.3 Positioning

The patient is placed in a prone "Mecca" position as described in Chapter 32 (Fig. 44.6). The principles of positioning for lumbar microdiscectomy are valid. However, there are some special aspects which have to be considered in patients with acquired spinal stenosis:

- It is important to rule out hip joint contractures (not rare in this group of patients). Watch the hip joint and avoid luxation in patients with artificial hip joints!
- Watch the knees of the patient! Patients often have gonarthrosis or total joint replacement in the knee as well. Since decompression sometimes lasts more than 2 hours take care to pad the knees with a gel cushion to avoid pressure sores.
- Pay attention to the cervical spine! Mobility of the cervical spine is decreased in these patients. Rotation of the head is restricted. Put a soft pad under the forehead of the patient in order to avoid head rotation.
- Pay attention to the shoulders! Patients can have limited mobility of the shoulder joint. This requires modification of positioning of the upper extremities.
- Use as many gel cushions or pads as are needed to protect the neural and surface structures at risk (ulnar nerve, brachial plexus, peroneal nerve, knee, eyes, nose).

44.9.1.4 Localization

The level(s) which have to be approached for microsurgical decompression are localized according to the principles described in Chapter 32. The skin incision is centered exactly over the lumbar segment of interest. If



Fig. 44.6. Positioning of the patient

two or more levels have to be exposed for decompression, the skin incision is enlarged. If two non-adjacent levels have to be approached (e.g., L2/3 and L4/5), two separate approaches with separate skin incisions are recommended.

Avoid movements of the patient (table) in the sagittal or transverse plane after localization is performed and the skin incision is marked as this may lead to the wrong level. As soon as the right level is approached, the table can be tilted.

44.9.1.5 Skin to Interlaminar Space

The operation is started with the microscope from the skin level. The interlaminar space is approached using the same technique as described in Chapters 31 and 32. The fascia is opened in a semicircular manner leaving the medial parts attached to the supraspinous ligament and the lamina. The paravertebral muscles are retracted after subperiosteal elevation. Retraction does not extend beyond the lateral border of the facet joint in order to avoid disruption of segmental innervation. The laminae of the adjacent vertebrae are exposed and the interlaminar window is cleaned of soft tissue (Fig. 44.7).

Usually the window is very small and the yellow ligament is bulging. The speculum-retractor is then inserted. Make sure that the inferior (ventral) part of the interspinous ligament is exposed as well and that the visual axis toward the midline is not obstructed by a hypertrophied or dysplastic spinous process.

44.9.1.6 Microsurgical Ipsilateral Decompression

Decompression is started with the removal of the inferior parts of the cephalic lamina. This is performed step by step using a high-speed burr. I recommend to start this microsurgical "laminotomy" at the transition zone between the lateral aspects of the lamina and the spinous process. The reason is that even in severe spinal stenosis you always find remnants of epidural fat underneath the posterior yellow ligament. Resection of the inferior parts of the lamina is extended until the insertion of the yellow ligament "fades out" and the dura or epidural fat can be identified. Laminotomy is extended laterally and caudally. Depending on the size of the inferior facet, its medial aspect is removed until the medial parts of the superior facet can be identified. Note that the spinal canal is not yet opened except for its cranial and medial part.

Exposure of the yellow ligament is completed by resection of the superior part of the caudad lamina. It is now that the yellow ligament can be easily removed with rongeurs including the ventral parts of the interspinous ligament. Thus the "back" of the thecal sac is exposed. Adhesions of the dura to the yellow ligament can now be gently dissected from medial to lateral. After removal of the yellow ligament and its insertion underneath the lamina in most of the cases the central portion of the spinal canal is already decompressed. However, if there is still narrowing by a hypertrophied lamina, undercutting has to be continued in cranial and caudal directions.

The surgeon now looks onto the back of the thecal sac and the roof of the lateral recess which is formed by the medial aspects of the superior facet and the remains of the yellow ligament and joint capsule (Fig. 44.8). "Subarticular" decompression can be the most difficult part of the operation. Usually there is no space between the lateral parts of the thecal sac, the nerve root, and the superior facet. With a blunt microdissector, the neural structures are gently mobilized from the yellow ligament. With a 1.5- or 2-mm Kerrison rongeur, the lateral recess is opened stepwise. I recommend to start in the middle portion and to proceed first in a caudal

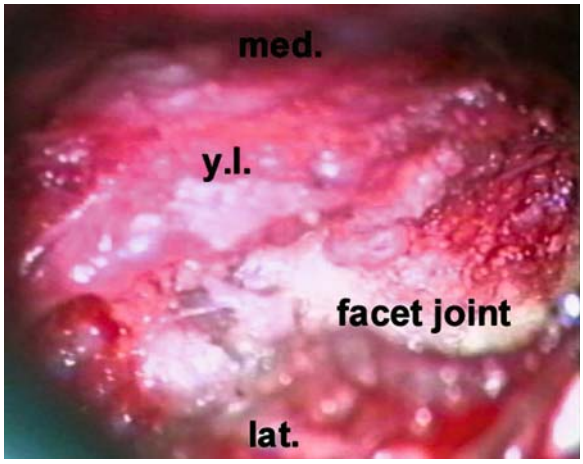


Fig. 44.7. Interlaminar window exposed. *y.l.* Yellow ligament

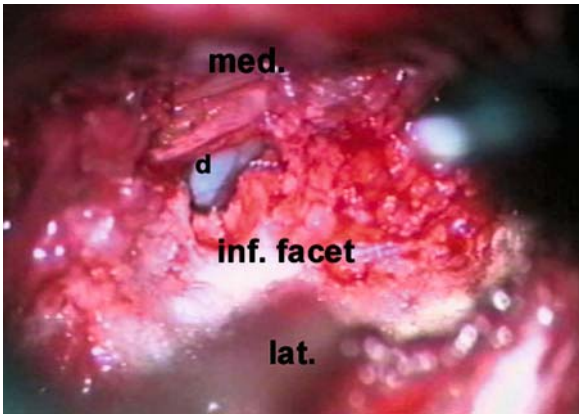


Fig. 44.8. Part of the dura (*d*) is exposed. Narrow lateral recess ipsilateral

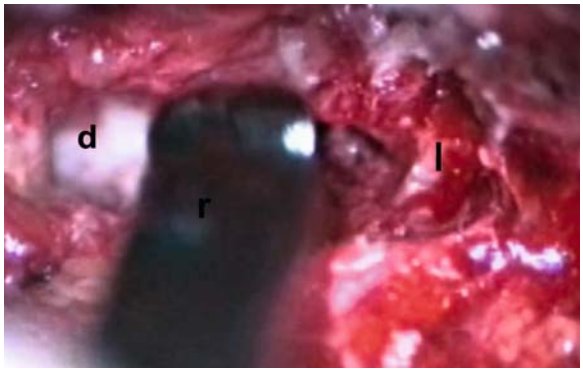


Fig. 44.9. Direction of Kerrison rongeur for decompression of the ipsilateral recess. *d* Dura, *r* rongeur, *l* lamina of supradjacent vertebra

direction. This means that the "shoe" of the rongeur is always introduced parallel to the route of the nerve. It thus can slide over the nerve and the risk of dural laceration or nerve injury is minimized (Fig. 44.9). Thus first the posterior aspect and then the lateral border of the nerve are exposed. At this stage, the caudal part of the lateral recess is already decompressed. However, there is still compression at the "shoulder" of the spinal nerve as well as at the entrance into the foramen.

First, decompression is extended along the nerve until the medial border of the pedicle can be visualized (Fig. 44.10). In rare cases, the medial border of the pedicle leads to a kinking or compression of the nerve root. It is difficult to drill and smooth the medial parts of the pedicle since the high-speed burr has to be introduced into the narrow space between the nerve and the pedicle border. In these cases, the pedicle can be opened with the high-speed burr and the medial half is "eggshelled" and then broken off with a rongeur (Fig. 44.11). Decompression of the "shoulder" of the nerve root is now completed by removal of the yellow ligament in the superior

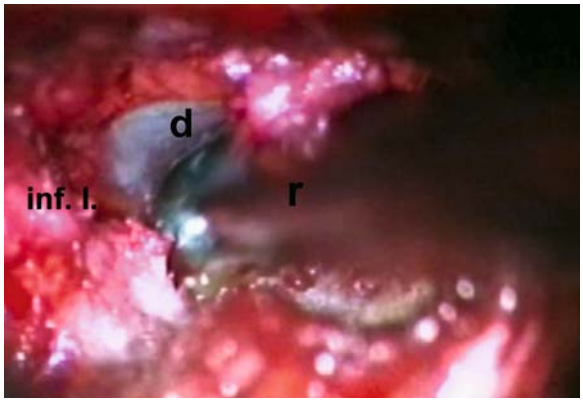


Fig. 44.10. Decompression in caudal direction down to the entrance of the foramen. *r* Rongeur, *d* dura, *inf. l.* lamina of infradjacent vertebra

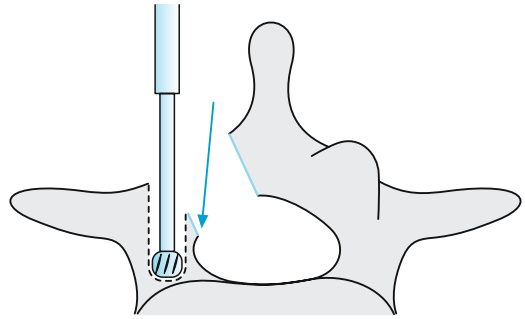


Fig. 44.11. Resection of the medial half of the pedicle

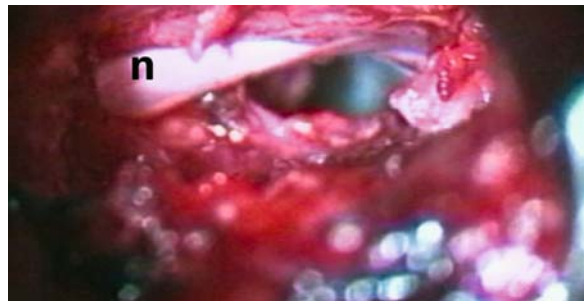


Fig. 44.12. Complete ipsilateral decompression (intraoperative view). *n* Nerve root

lateral corner of the surgical field. Decompression in this area must be performed until the inferior border of the exiting nerve root can be identified or palpated with the blunt nerve hook (Fig. 44.12). In cases with pronounced narrowing of the intervertebral space there is often impingement of the exiting nerve root by the tip of the superior facet. This tip can now be removed with a rongeur thus achieving a complete decompression of the exiting nerve root in the foramen.

44.9.1.7 Microsurgical Contralateral Decompression

The table is now tilted away from the surgeon and the microscope is adjusted to give an oblique view into the spinal canal (Fig. 44.13a, b). The next step is the resection of the ventral parts of the interspinous ligament and its transition zone into the fibers of the contralateral yellow ligament. The rongeur can now be introduced underneath the yellow ligament of the contralateral side. The ligament is resected to create more space posterior as well as posterolateral on the contralateral side. It is occasionally necessary to resect ventral parts of the base of the spinous process. It is always necessary to continue undercutting of the supra- and infradjacent lamina to increase the spinal canal volume as well as to have a free visual axis toward the contralateral recess and foramen entrance. Decompression is facilitated if the surgeon first follows the inner surface of the infradjacent lamina to identify the medial border of the con-

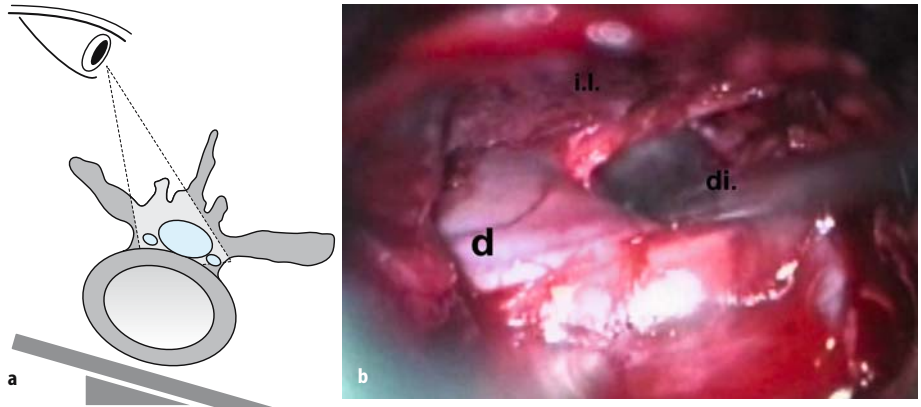


Fig. 44.13. a Oblique view into the contralateral spinal canal (schematic drawing). **b** Oblique view into contralateral compartment of the spinal canal (intraoperative view). *d* Dura mater, *di.* blunt dissector, *i.l.* interspinous ligament

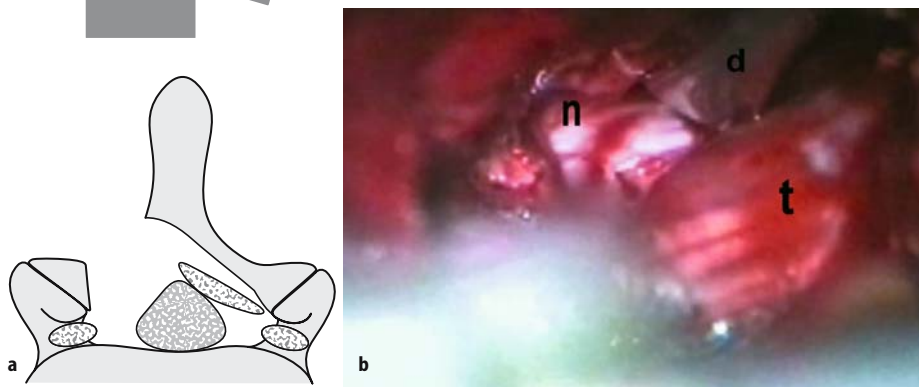


Fig. 44.14. a Decompression contralateral (schematic drawing). **b** Decompression of the contralateral compartment (intraoperative view). *n* Contralateral spinal nerve, *t* thecal sac, *d* blunt dissector in contralateral recess

tralateral inferior pedicle. This can be achieved with minimum retraction of the thecal sac. Then decompression by subarticular undercutting as well as by undercutting of the supradjacent lamina can be accomplished (Fig. 44.14a, b). Although it will be occasionally necessary to use a blunt dissector or a nerve hook to temporarily retract the dura, it is possible to achieve this in most of the cases simply by using the metal sucker probe.

44.9.1.8 Closure

At the end of the procedure there should be dural pulsations and four free nerves (two traversing and two exiting nerves). The bone surface is sealed with small amounts of bone wax if significant oozing of blood is visible. Hemostatic agents such as FloSeal (Baxter Healthcare, Fremont, CA, USA) or Arista (Medafor, Bad Wiessee, Germany) can be used.

If possible, the insertion of a drain is avoided. We recommend not to place any foreign material (e.g., Gelfoam, Surgicel, etc.) into the spinal canal. If there is a significant amount of epidural fat tissue left, the spinal nerves can be covered after gentle mobilization of the fat. The surgical field is irrigated with saline solution, and the fascia and the skin are closed with resorbable sutures.

44.9.2 Microsurgical Decompression with Instrumented Fusion

44.9.2.1 Posterior Approach

The surgical technique of posterior–anterior instrumented fusion in patients with spinal stenosis and vertebral body translation is described in detail elsewhere [9]. The anterior part of the operation is described in Chapters 45 and 46. We prefer, for biomechanical reasons, the combination of posterior instrumented fusion with a pedicle screw system in combination with anterior interbody fusion or a TLIF using a microsurgical approach. Since the posterior approach is not a "minimally invasive" approach, it will not be described in detail in this chapter.

44.9.2.2 Preoperative Planning

Preoperative planning includes the acquisition of CT scan data for intraoperative navigation. The pedicle screws are inserted with the help of a spinal navigation system (Stealth system; Sofamor Danek) [2, 3, 8, 11] (Fig. 44.15). If no navigation system is used, measurement of the pedicle diameter, as well as of the sagittal length of the vertebral body is performed manually and the size and length of the pedicle screws is determined.



Fig. 44.15. Stealth system

MRI as well as CT scans give an impression about the angles of the pedicles as well as the localization of the retroperitoneal vessels in relation to the bony structures.

44.9.2.3 Anesthesiological Aspects

The operation is performed under general anesthesia. Patients with spinal stenosis carry, due to their age and other concomitant diseases, higher risks and require reliable intraoperative monitoring. We recommend the introduction of a central venous line, to perform arterial blood pressure monitoring, as well as the introduction of a urinary catheter irrespective of the expected time for the operation. Blood transfusion are not usually necessary.

44.9.2.4 Positioning

The patient is placed in a prone, comfortable position on a soft foam frame on a radiolucent table. The general principles of protection of neural structures and the skin are respected. The hips and knees are slightly (20 – 30°) flexed, and the anterior iliac crest is padded in order to avoid pressure on the lateral femoral cutaneous nerve.

44.9.2.5 Localization

Localization of the level(s) to be approached follows the criteria described above. If the pedicle screws are inserted without the help of an intraoperative navigation system, the level of the pedicle entrances are marked as they project onto the skin surface in AP fluoroscopic control. Lateral fluoroscopy is added to gain an impression of the inclination in the sagittal plane of the vertebrae to be instrumented.

44.9.2.6 Skin to Interlaminar Space

The operation is started without the microscope. The interlaminar space, the facet joints of the segment to be decompressed and fused, as well as the facet joint above are exposed bilaterally using a conventional technique [1].

Even in cases which afford segmental instrumented fusion, we try to avoid retraction of the muscles beyond the lateral border of the facet joint. Since we do not perform intertransverse fusion, the transverse process does not need to be exposed. However, it must be palpated as well as the transition zone between the transverse process and the superior facet.

The operation is continued with the following steps:

1. Insertion of pedicle screws (Click'X, Synthes).
2. Opening of the facet joint capsule and mobilization of the facet joint.
3. Insertion of the mono- (Click'X, Synthes) or multisegmental (USS II, Synthes) internal fixation system (Fig. 44.16).
4. Reduction and reconstruction of normal curvature.
5. Microsurgical decompression (see above). Removal of cartilage from the rest of the facet joints. Interfacet bone grafting using the removed parts of the laminae.

44.9.2.7 Closure

In these patients, two wound drains are inserted underneath the fascia without applying suction. The wound is then closed as described above.

44.9.3 Anterior Interbody Fusion

The anterior microsurgical approach for interbody fusion is described in detail in Chapters 44 and 45. Usually the operation is performed in the same session, however, it can be also be performed in a second session after an interval of 7 – 14 days.

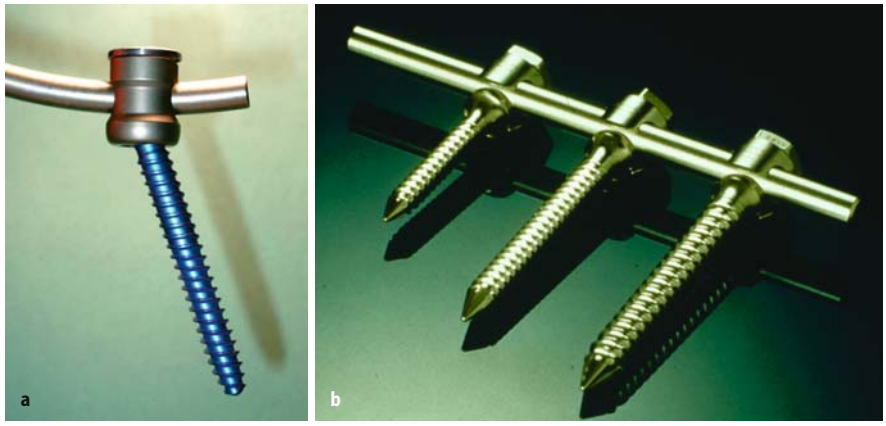


Fig. 44.16. Pedicle screw systems. **a** Click'x Pedicle screw system. **b** USS II Pedicle Screw System, Synthes Oberdorf Switzerland

44.10 Postoperative Care

The patients are allowed to mobilize within 6 hours in cases without instrumented fusion. Otherwise, the patients get out of bed the day after the operation. In patients with more than two-level decompression, as well as in patients with instrumented fusion, a short Boston brace is recommended for 4–6 weeks postoperatively.

44.11 Complications

- Dural tears leading to a pseudomeningocele or even CSF fistulas are the most common complications during decompressive procedures in spinal stenosis. They are described to be as high as 13% [18]. In the group of patients described above, we had 2/57 (3.5%) dural tears which had to be sutured. There are several reasons for the high rates of dural injuries. The dura usually is very thin in this old patient population. If the patient is placed correctly (see Section 44.9), the spinal CSF pressure is low so that the dura does not behave like a taut, well-rounded structure. Introduction of the rongeurs can lead to infolding of parts of the dura. This increases the risk of dural laceration.
- The cauda equina is at risk especially in patients with spinal stenosis. The nerve roots are compromised usually for years, and the arterial supply may be diminished by other concomitant diseases (e.g., diabetic microangiopathy, microangiopathy due to arterial hypertension). This makes the fibers of the cauda equina more vulnerable as compared to the young patient. Moreover, the surgical technique includes the risk of temporary direct compression of the cauda equina roots during decompression of the contralateral side (see Section 44.9). We had one patient with a postoperative transient hemicauda syndrome (1/57 = 1.75%).
- Epidural hematoma.
- Special attention has to be made to complications secondary to positioning. The risk for such complications is higher as compared to microsurgical discectomy, since microsurgical decompression requires longer operating times and thus the patient has to remain in the intraoperative position for a longer time which increases the risk of pressure injury to the structures mentioned above.
- Care must be taken to avoid pressure on the eyes since this might lead to postoperative blindness or corneal lesions.

Delayed complications:

- Segmental instability
- Destabilization of the adjacent segment
- Arachnoiditis
- Epidural scar formation

44.12 Results

Comparative analysis of the results of microsurgical segmental decompression with conventional laminectomy techniques is difficult because we could not find any prospective, comparative studies in the literature. McCulloch has reported recently about a good and excellent outcome in 90.9% of 22 patients with acquired degenerative spinal stenosis. In these cases, microsurgical decompression was combined with a minimally invasive modification of intertransverse fusion [10]. Pseudoarthrosis rate was 13.6%, and complications ranged from 4.5% (urinary tract infection) to 9.1% (deep venous thrombosis, upper respiratory tract infection, superficial wound infection).

Between March 1998 and April 2002 we have treated a total of 702 patients with the techniques described above. The consecutive series of the first 275 patients (men 52 %, women 48 %) is presented here. The average age was 69 years (range 34 – 89 years). The average history of complaints was > 2 years. All patients had had several unsuccessful trials of conservative therapy. Two hundred patients (73 %) complained of sciatica with increasing pain during walking and standing as well as heaviness and/or sensory disturbances in the leg after different walking distances/standing times. In all cases, the leg symptoms were predominant. Only 75 patients (27.3 %) complained about sciatica alone. Neurogenic claudication was evident in 252 patients (91.6 %). A relatively high percentage of patients presented with neurological deficits (125/275 = 45.5 %). The average preoperative walking distance was 250 m. Pain-free standing time was 10 min on average.

In 99 % of cases, surgery was elective, however, due to neurological deficits in 52 % of the patients, it was performed usually within 1 – 2 weeks of first presentation in our hospital.

In 1 % of the patients there was a chronic cauda equina syndrome with bladder and bowel dysfunction. A total of 568 segments (in 275 patients) were decompressed (2.1 segments/patient).

The mean operating time was 37 min/segment, blood loss averaged 57 cc/segment, and all patients were mobilized within 24 hours.

After a mean follow-up of 24 months, the average pain-free standing time was 82 min (as compared to 10 min preoperative). Pain-free walking distance was increased from 250 m preoperative to 5,017 m postoperative. In 45 % of the patients there was also a significant decrease of low back pain.

Overall complication rate was 15.6 %, with 5 % intraoperative dural leaks. In 3.8 % of patients postoperative epidural hematomas needed early revision. Together with persistent symptoms (2 %) they presented the most frequent postoperative complications.

Microsurgical decompression with instrumented posterior–anterior fusion was performed in 18 patients. The age range in this group was between 43 and 76 years, averaging 62 years. Indication for fusion was the association of spinal stenosis with degenerative spondylolisthesis grade I or more in all cases. In 86 % of the patients, surgery was elective. Only 14 % presented with progressive or severe neurological deficits. There were no emergency cases.

The mean operating time for decompression as 70 min/level for microsurgical bilateral decompression and 140 min/level for decompression and posterior instrumentation with pedicle screws. The average blood loss for decompression was 240 ml and for decompression and instrumentation 760 ml. We observed a total of 4/57 (7 %) complications. There were two patients with dural tears (3.5 %), one patient with a hemi-cauda equina syndrome (1.7 %), and one patient with a superficial wound infection (1.7 %). The cauda equina symptoms resolved within 2 weeks, and the wound infection healed without intervention.

Hospitalization was between 5 and 10 days in patients with just microsurgical decompression and between 12 and 14 days in patients with additional instrumented fusion. Preliminary results with a follow up time of between 3 and 12 months showed a significant improvement in leg symptoms in 90 % of patients, and a significant improvement in low back pain in 80 % of the fused patients. The walking distance was significantly improved in 70 % of the patients. In one third of our patients, there was partial or complete regression of neurological deficits.

44.13 Critical Evaluation

The goal of surgery in degenerative spinal stenosis is the improvement of leg and low back symptoms, to increase the pain-free walking distance, and to improve the quality of life in a group of old-aged patients. No patient will be completely free of complaints and no patient will have a new lumbar spine after the operation. Extensive surgery is associated with increased risks in old patients with various associated diseases. Therefore, in this population in particular, the principle of "maximum effect with minimum trauma" should be applied. Our experience with microsurgical decompression, although limited, strongly supports our efforts to further miniaturize the surgical approaches to the spinal canal. Postoperative mobilization as well as rehabilitation is facilitated since peri- and postoperative morbidity is decreased. The patients virtually have no or only slight wound pain. They experience a very quick improvement of their leading symptoms, such as increase of walking distance. Low back pain is not a significant problem even in those cases in which instrumented fusion is performed. Microsurgical anterior approaches even allow for "circumferential" fusion which is associated with low pseudarthrosis rates [9].

We believe, that in acquired degenerative spinal stenosis there is no need to perform wide laminectomies. This may not be true for congenital central spinal stenosis. This disease requires a more extensive decompression which often ends with a conventional multisegmental laminectomy. The reason for this is that narrowing of the spinal canal not only affects the interlaminar interval but also the sublaminar space in multiple segments. Efficient decompression thus requires laminectomy, a technique which is not microsurgical and therefore not dealt with in this book.

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Microsurgical Anterior Lumbar Interbody Fusion (Mini-ALIF): The Lateral Retroperitoneal Approach to L2/3, L3/4, and L4/5

45

H.M. Mayer

45.1 Terminology

The term "mini"-*a*nterior *l*umbar *i*nterbody *f*usion (Mini-ALIF) was created to describe new anterior approaches to the lumbar spine for the purpose of performing interbody fusion. These approaches are based on conventional surgical techniques for exposure of the anterior parts of the lumbar spine to which the general principles of microsurgery have been applied.

45.2 Surgical Principle

The approach is performed with the help of a surgical microscope, or alternatively "open" video endoscopy can be used. The anterolateral circumference of the motion segments L2/3, L3/4, and L4/5 is exposed through a limited skin incision (4 cm). The lateral abdominal wall is crossed using a blunt muscle-splitting technique. The anterolateral circumference of the lumbar spine is exposed by blunt dissection medial to the psoas muscle. The approach corridor is kept free by frame-type retractors which can be either anchored in the adjacent vertebral bodies by bone screws or which can be fixed to the operating table. The exposure allows different types of interbody fusion techniques (e.g., iliac crest autografts (preferred by the author), homografts (bank bone), as well as auto- or homografts augmented by allografts (e.g., titanium cages).

45.3 History

The first type of this operation was performed in 1995. The surgical approach as well as preliminary results were described first in 1997 [1].

45.4 Advantages

The general advantages are:

- The anterior retroperitoneal surgical approach to the lumbar spine is well known to spine surgeons. There is no need to learn a completely new surgical technique.
- The approach can be performed with the help of only one assistant (costs!).
- No additional medicolegal problems as compared to conventional anterior approaches.
- No additional potential complications with this technique (e.g., no gas in the abdomen).
- Short learning curve, no laboratory training necessary.
- No laparoscopic surgeon necessary.

The main technical advantages are:

- Small skin incision (cosmesis!).
- Blunt, muscle-splitting approach and preservation of innervation of abdominal muscles (early rehabilitation possible!).
- The retractor frame is fixed in the vertebral bodies by bone screws and protects all structures at risk (retroperitoneal blood vessels, bowel, ureter etc.).
- Increased safety due to illumination and magnification of the surgical field by the use of optical aids (surgical microscope). Thus meticulous preparation in the prevertebral area is possible.
- Low blood loss (< 100 cc).
- Large and rapid exposure of the situs is possible in case of complications.
- Low complication rate.
- Good clinical results.
- Shorter operating times even in learning curve.
- The technique is not bound to an implant (e.g., type of fusion free to the surgeons philosophy).

45.5 Disadvantages

The main disadvantages are:

- The surgeon should have microsurgical or video endoscopic experience.
- Approach limited to L2-5.
- Bisegmental approach to the levels L4/5/S1 is not possible.
- Due to the small exposure, the indication is limited to mono- or bisegmental pathologies.
- Potential risk of indirect trauma to structures surrounding the target area.
- The possibility of anterior instrumentation is limited.
- Reduction of the spine in cases of kyphotic or scoliotic deformities from anterior is not possible.
- Additional posterior instrumentation (pedicle screw system or translaminar screw fixation) is recommended.

45.6 Indications

The approach has been used for anterior lumbar interbody fusion in the following diseases (in the majority of my own cases combined with posterior instrumentation):

- Degenerative instability (mainly with Modic type I changes in MRI)
- Degenerative spondylolisthesis
- Isthmic spondylolisthesis
- Spinal stenosis with instability
- Failed Back Surgery syndrome
- Fractures
- Spondylitis/spondylodiscitis
- Pseudoarthrosis following other types of fusion (e.g., posterolateral, PLIF)

45.7 Contraindications

There are no absolute contraindications to this surgical approach, however, the following situations can be relative contraindications:

- Previous surgery through a retroperitoneal approach (e.g., kidney surgery) on the same side
- Spondylitis/spondylodiscitis with large prevertebral soft tissue mass or psoas abscess
- Extremely lateral course of common iliac vein of the left side covering the lateral aspect of the L4/5 intervertebral space

45.8 Patient's Informed Consent

Besides information about general complications of spine surgery (deep venous thrombosis, pulmonary embolism, infection) the patient should be aware of the following potential complications and risks:

- Denervation of the rectus muscle due to dissection of the iliocostal nerve
- Abdominal hernia due to suture insufficiency
- Spinal nerve irritation or compression due to forceful retraction of the psoas muscle
- Groin pain due to compression and irritation of the genitofemoral nerve
- Vascular injury in the retroperitoneal space (segmental vessels, ascending lumbar vein, common iliac vein and artery on the left side) with retroperitoneal hematoma and necessity for reintervention
- Nerve and spinal cord injury with incomplete or complete neurological deficits
- Dural tears with pseudomeningocele or CSF fistulas
- Restriction of spinal mobility due to interbody fusion
- Temperature differences (usually temporary), dysesthesias, and disturbance of sweat secretion in the lower extremities due to dissection of the sympathetic trunk
- Injury of peritoneum, bowel, ureter, kidney, and spleen leading to infection, hemorrhage, scar tissue, or disturbances and constrictions of the urinary tract
- Donor site complications, including hematoma, irritation of lateral femoral cutaneous nerve, donor site pain, fatigue fracture of anterior superior iliac spine, hypertrophy callus formation, infection, injury to sacroiliac joint in case of harvesting the bone graft from the posterior iliac crest

45.9 Surgical Technique

45.9.1 Preoperative Planning and Preparation of the Patient

The surgical approach is performed from the left side. Thus, topographical anatomy of the anterolateral circumference of the target segment must be studied preoperatively. In addition to information about the underlying pathology, MRI of the lumbar spine and its surrounding structures gives all the anatomical information which is needed to perform meticulous preoperative planning (Fig. 45.1). It facilitates the operation if the surgeon is well informed and aware of the size, shape, and localization of the psoas muscle in relation

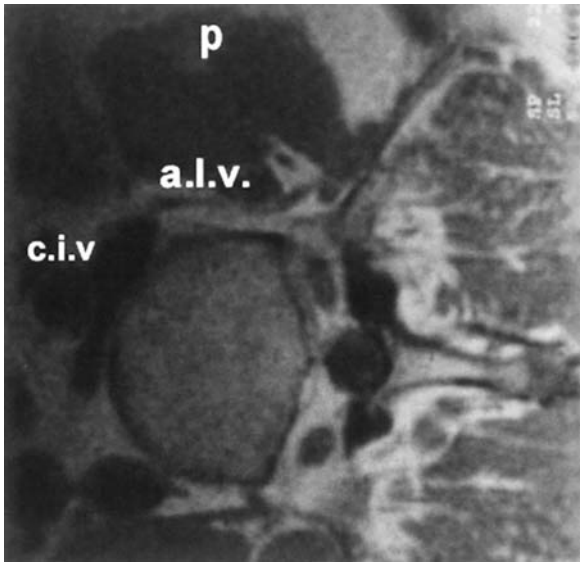


Fig. 45. 1. MRI of the lumbar spine for preoperative planning. Motion segment L4/5. Note the common iliac vein as well as the course of the ascending lumbar vein. *p* Psoas muscle, *c.i.v.* common iliac vein left side, *a.l.v.* ascending lumbar vein



Fig. 45.2. Plain X-ray lumbar spine. Note the lateral osteophytes at L2/3 left

to the anterolateral border of the lumbar spine, and the size and course of the retroperitoneal vessels. For the approach to L4/5, MRI examination should be focused, in particular, on the size and shape of the common iliac vein as well as on the presence and size of an ascending lumbar vein on the left side (Fig. 45.1).

Preoperative conventional X-rays of the lumbar spine in two planes are mandatory in order to gain enough information on the spine curvature as well as the height of the intervertebral space to be approached. Additional information on the shape of the inferior borders of the ribcage, which is important for the approach to L2/3, can also be obtained. It is important to realize that there might be huge lateral osteophytes of the vertebral bodies adjacent to the segment which is to be fused (Fig. 45.2).

Starting 24 hours prior to surgery, the patients are treated with routine mechanical large bowel preparations to empty the colon.

45.9.2 Anatomical Considerations

The disc spaces L2/3, L3/4, and L4/5 are reached through a left-sided retroperitoneal approach. The disc space is reached through an anterolateral route along the medial border of the psoas muscle. To facilitate the surgical preparation (especially in obese patients), the patient is placed in a right lateral decubitus position (see Section 45.9.5). The corridor to the intervertebral space is limited by the size of the psoas muscle, as well as by the size and course of the common iliac vein at L4/5. In contrast to the conventional macrosurgical approach, the segmental lumbar arteries and veins are not routinely exposed nor due they need to be dissected in the majority of cases. However, one has to be aware of the segmental vessels since they are at risk for indirect tension due to retraction of their "mother vessels" (vena cava, aorta, common iliac vein). At L4/5, special attention should be paid to the ascending lumbar vein. Sometimes it must be dissected, clipped, and cut in order to achieve a safe retraction of the common iliac vein from the intervertebral space.

45.9.3 Surgical Microscope

Surgical preparation is usually started with the use of a head lamp until the medial circumference of the psoas muscle is exposed. It is then continued with the help of a surgical microscope. The microscope should have either a variable focus length or a focus length of at least 350 mm (Fig. 45.3). We prefer a "2-in-1" model which means that two optical lines are integrated into one surgical microscope. The advantages are that the surgeon and the assistant are able to adjust magnification and focus independently of each other according to their individual needs. For true three-dimensional vision, the oculars of the microscope can be replaced by two digi-



Fig. 45.3. Zeiss NC 33 surgical microscope



Fig. 45.4. Surgical microscope linked to head-mounted displays for "true" improved three-dimensional vision

tal chip cameras which are connected to a head-mounted display through a computer system (Fig. 45.4). While three-dimensional vision is enhanced with such devices, the digitally transferred optical quality is still inferior as compared to the view through optical lenses.

45.9.4 Anesthesia

The operation is performed under general anesthesia. Once the patient is anesthetized, a Foley catheter and a nasogastric tube are inserted. Arterial and central venous pressure lines are placed because hemodynamic monitoring is important.

45.9.5 Positioning

The operation is performed with the patient in a right lateral decubitus position on an adjustable surgical table. The table is tilted to create a left convex bending of the lumbar spine. This increases the distance between the iliac crest and the inferior border of the rib cage. Due to this positioning, the surgical approach is facilitated especially in obese patients since all the abdominal contents "fall away" from the surgical field making way for the approach corridor (Fig. 45.5a).

According to the level to be approached, the table is then tilted backward in the axial plane for 20° (L4/5), 30° (L3/4), or 40° (L2/3) (Fig. 45.5b). The anterior longitudinal ligament has a convergent course from the caudal to the cranial direction. Since the lateral border of the anterior longitudinal ligament is the important landmark for the insertion of the anchoring screws, this adjustment of the surgical table shifts this border on top of the target area (Fig. 45.6). The orientation of the lumbar motion segment is then checked with lateral fluoroscopy. If necessary, the tilt of the table is adjusted in order to achieve a parallel projection of the vertebral endplates of the level to be approached (Fig. 45.7). The orientation of the disc level ("orientation line") as well as the center of the disc space ("center line") are marked onto the skin. The line of the skin incision is centered over the target point (intersection of the orientation and center lines) in an oblique direction (parallel to the fiber orientation of the external oblique abdominal muscle) (Fig. 45.8).

45.9.6 Surgical Steps

45.9.6.1 Skin to Retroperitoneal Space

A 4-cm skin incision is sufficient for the exposure of one segment. The retroperitoneal space is exposed through a blunt, muscle-splitting approach. Each muscular layer (external oblique, internal oblique, transverse abdominal muscle) is dissected in the direction of their fiber orientation (Fig. 45.9).

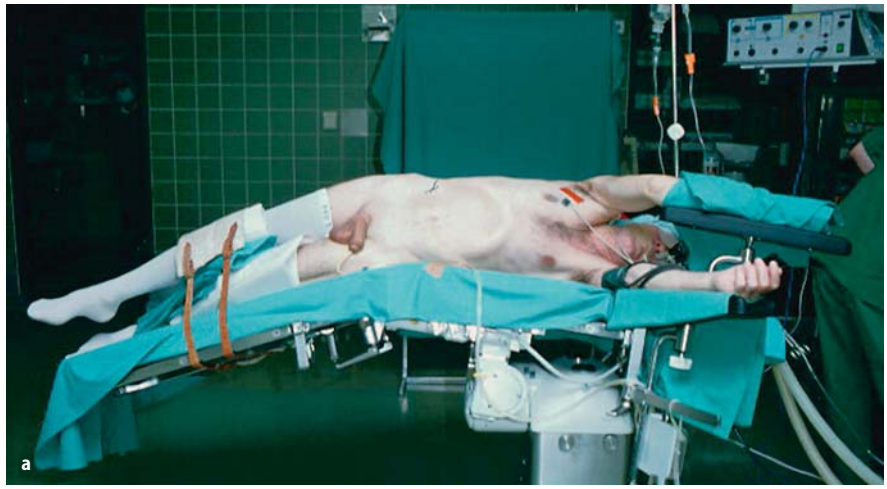




Fig. 45.5. Positioning of the patient for retroperitoneal anterior microsurgical approach. **a** View from anterior: table is tilted to "open" the distance between iliac crest and rib cage. **b** View from the side: table is tilted backward between 20° and 40° to facilitate the approach medial to the psoas muscle as well as the identification of the lateral borders of the anterior longitudinal ligament



Fig. 45.6. Drawing of vertebral body. Backward tilt of the patient leads to a shift of the lateral border of the anterior longitudinal ligament to the top of the target area

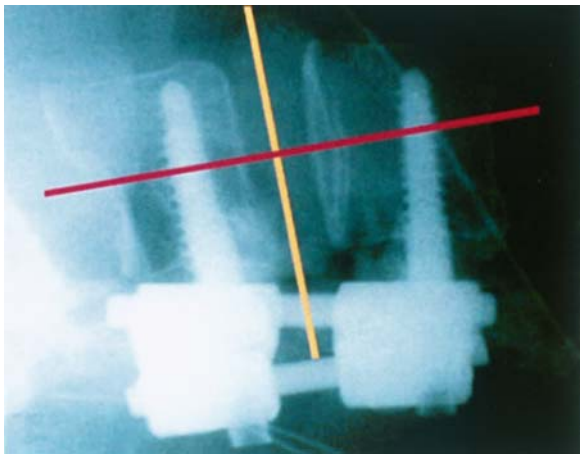


Fig. 45.7. Lateral fluoroscopy for localization and adjustment of the spatial orientation of the motion segment. Parallel projection of endplates. Determination of disc space orientation (*red line*), determination of center of the intervertebral disc (*yellow line*)

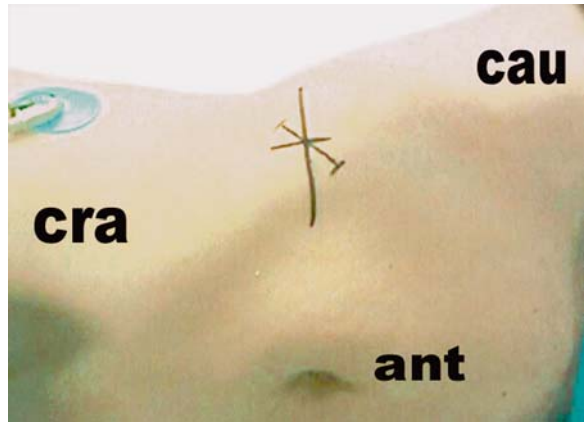


Fig. 45.8. Skin incision centered over the target point. *cau* caudal, *cra* cranial, *ant* anterior

The branches of the intercostal nerves 10 – 12 as well as the iliohypogastric/ilioinguinal nerves which occasionally cross the surgical field at the level of L4/5 between the layers of the internal oblique and transverse abdominal muscles are the only structures at risk during muscle splitting. They must be preserved in order to maintain innervation of the rectus abdominis muscle. Blunt splitting of the transverse abdominal muscle should be performed as far lateral as possible to avoid

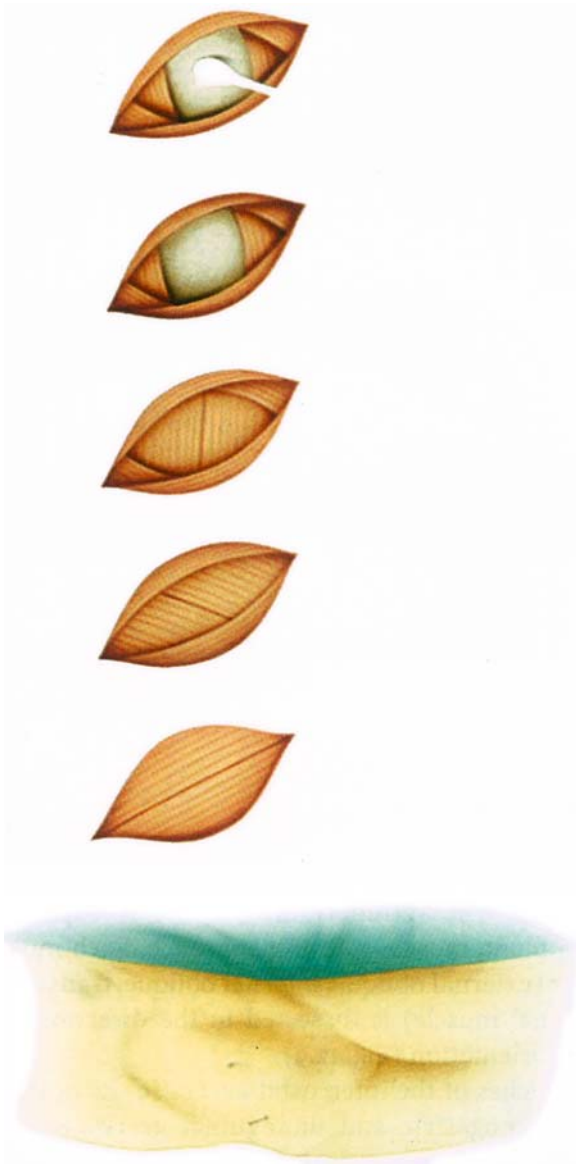


Fig. 45.9. Schematic drawing of the blunt muscle-splitting approach to the retroperitoneal space: surgeon's view

accidental opening of the peritoneum. Even in very slim patients, there is usually enough retroperitoneal fat tissue beneath the lateral part of the transverse muscle and the peritoneum which is more adherent to the inner fascia of the medial part of this muscle.

45.9.6.2 Retroperitoneal Space to Intervertebral Region

Blunt dissection is continued in the retroperitoneal space using peanut swabs and modified Langenbeck hooks for preparation. Small bridging veins between the fat tissue and the inner wall of the lateral abdomen are closed with bipolar coagulation and dissected. The

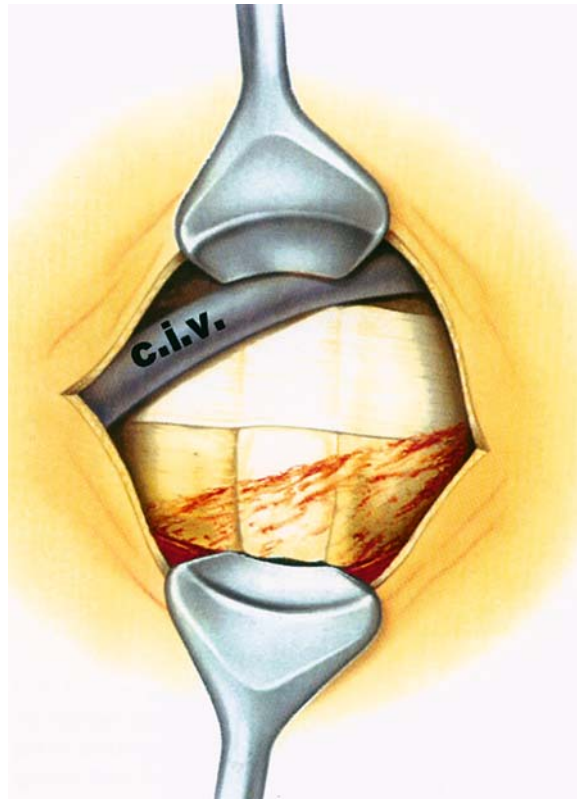


Fig. 45.10. Incision and dissection of anteromedial insertions of the psoas muscle to the lumbar spine. *c.i.v.* Common iliac vein

anterior and medial circumference of the psoas muscle is identified. The peritoneal sack as well as the ureter and the common iliac artery at L4/5 are gently retracted toward the midline using the blunt hooks.

The operation is now continued with the help of the surgical microscope. Anteromedial attachments of the psoas muscle to the lumbar spine can be identified and incised and sharply dissected from the anterolateral circumference of the disc space and adjacent vertebral body borders after bipolar coagulation (Fig. 45.10). Dissection should not be extended posterior to the pedicle entrance in order to avoid irritation of the lumbar nerve roots. Very rarely the segmental vessels of the inferior vertebral body need to be ligated with endoclips, cut, and dissected from the vertebral surface (Fig. 45.11).

At L4/5, the common iliac vein may cover the mediolateral aspect of the intervertebral space. The vein can be gently retracted after mobilization in most of the cases. However, this may be a very difficult task in patients with spondylitis/spondylodiscitis since there are often adhesions between the vessel and the infectious granulation tissue. The use of the surgical microscope is essential in such situations. The main branch of the sympathetic chain can now be identified. It can occa-

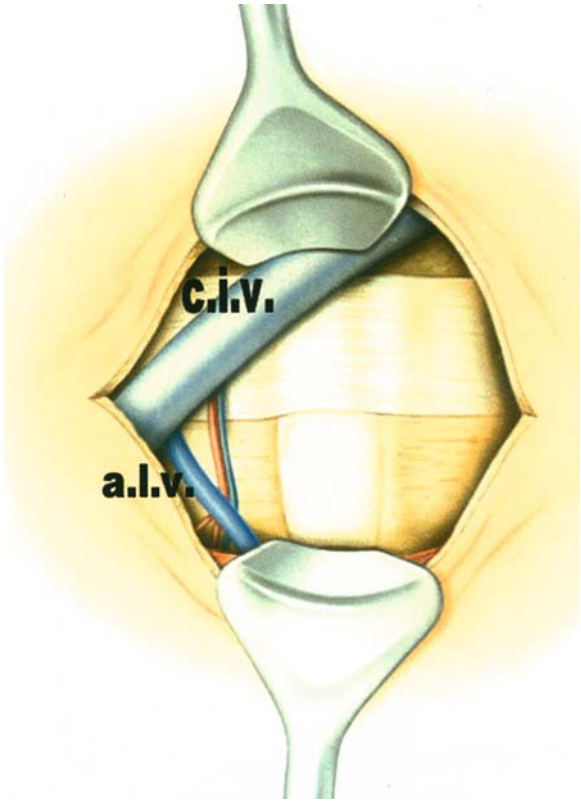


Fig. 45.11. Anatomical situation at L4/5. Note the course of the common iliac vein (*c.i.v.*) as well as of the ascending lumbar vein (*a.l.v.*). The segmental blood vessels are visible in only 20% of the cases (personal observation)

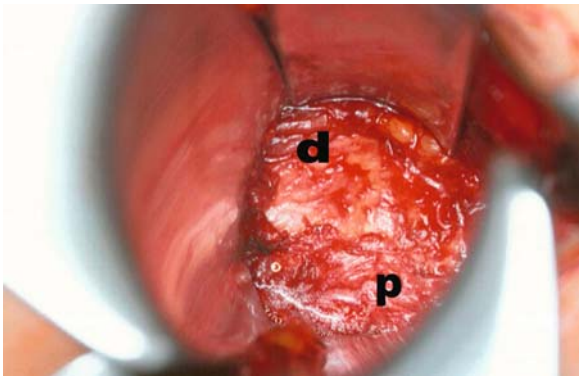


Fig. 45.12. Exposure of the anterolateral circumference of disc space. *d* Intervertebral disc, *p* psoas muscle

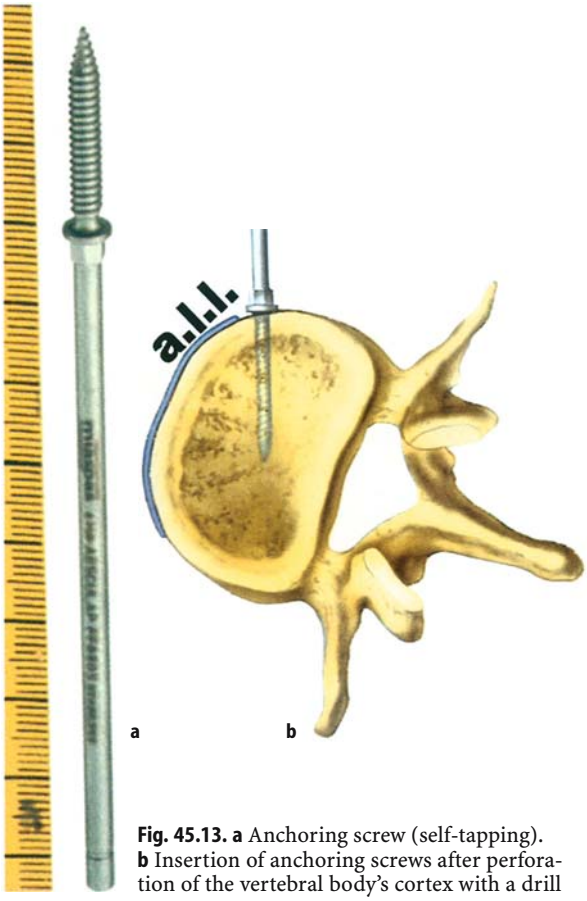


Fig. 45.13. a Anchoring screw (self-tapping). **b** Insertion of anchoring screws after perforation of the vertebral body's cortex with a drill

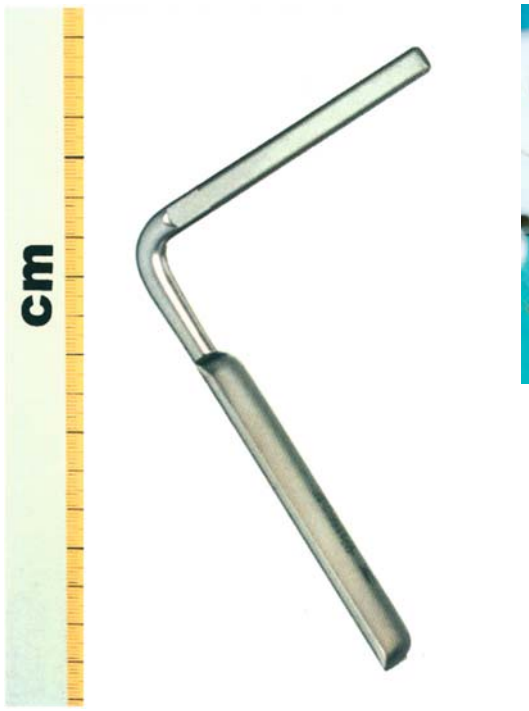
sionally be mobilized and preserved; however, in the majority of cases cauterization and dissection is necessary. *Attention:* Please consider that this is not a complication of surgery. In more than 80% of patients, no postoperative temperature differences in the legs are noted. In those patients who experience temperature differences in the lower extremities, this usually resolves after 6–9 months.

The lateral border of the anterior longitudinal ligament is now visible and blunt dissection is completed when 5–10 mm of the adjacent vertebral bodies are exposed (Fig. 45.12).

45.9.6.3 Placement of the Self-retaining Spreader Frame

After verification of the disc space level under fluoroscopic control, the retractor can be inserted. The self-retaining retractor frame is anchored with bone screws. First the cortex of the adjacent vertebral bodies is perforated with a high-speed burr 5–8 mm from the endplate borders in a strictly vertical direction to create the hole for the anchoring screws. The drill has a safety range of 10 mm and penetrates only the anterolateral cortex of the vertebral body. The self-tapping anchoring screws are inserted (Fig. 45.13a, b) and these serve as an anchor for the cranial and caudal spreader valves which are then inserted (Fig. 45.14a, b).

A self-retaining frame-type retractor is attached to the blades with a ballpoint locking device (Fig. 45.15). A sharp muscle blade is attached laterally to deflect the psoas muscle whereas a blunt vessel blade is inserted medially to retract the retroperitoneal vessels. Both



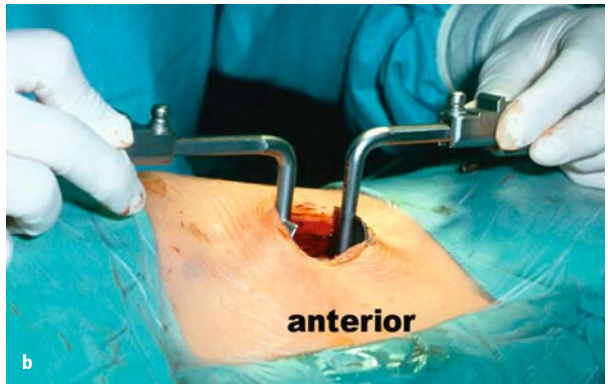


Fig. 45.14. a Soft tissue blade for retraction of the soft tissue cranial and caudal to the intervertebral space. **b** Blades inserted onto the vertebral body screws



Fig. 45.15. Self-retaining frame retractor

blades can be adjusted independently of each other. Limited intervertebral distraction can be applied by adjusting the cranial and caudal blades in patients without posterior instrumentation. The anterolateral circumference of the segment to be fused is now exposed (Fig. 45.16a).

As an alternative to the retractor described above, a self-retaining ring-type frame retractor (Synframe; Synthes Oberdorf, Switzerland) can be used. The retractor ring is fixed to the surgical table, and the retractor blades can be adjusted according to the individual anatomical situation (Fig. 45.16b).

45.9.6.4 Interbody Grafting

Anterior lumbar interbody fusion with an autologous iliac bone grafts is preferred and described. However, other types of anterior interbody fusion including the use of homografts or allografts (e.g., fusion cages) are possible with this approach.

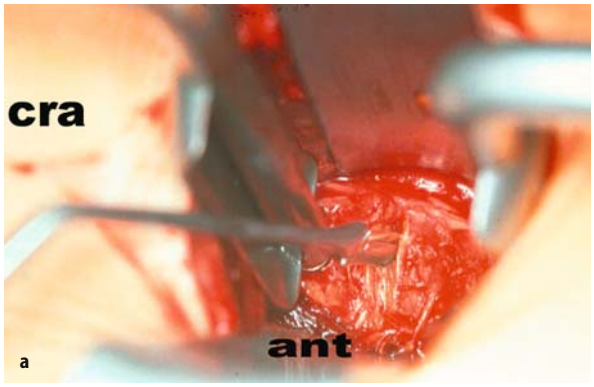




Fig. 45.16. a Surgical field after placement of the frame retractor. *ant* Anterior, *cra* cranial. **b** Synframe retractor system with soft tissue blades

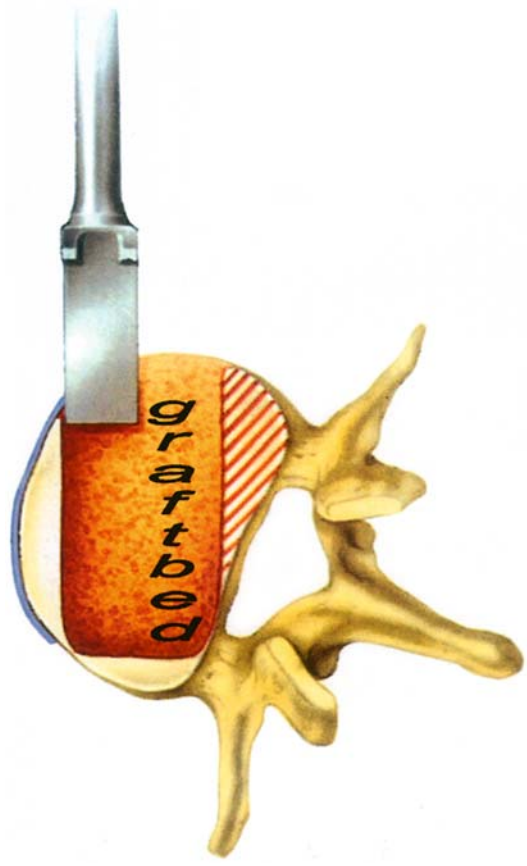


Fig. 45.17. Removal of the cartilaginous endplate with chisels

45.9.6.4.1 Discectomy and Preparation of Graft Bed

The anulus fibrosis is incised from the middle of the anterior longitudinal ligament to the medial border of the incised psoas muscle. The anterolateral anulus as well as the nucleus pulposus are removed with curettes and rongeurs. In patients with inferior bone quality due to osteoporosis, the subchondral bone is preserved. The endplates are removed carefully with curettes. If there is significant subchondral sclerosis removal of the endplates is started with specially designed chisels (Fig. 45.17). The subchondral bone is then smoothed with a high-speed drill (Fig. 45.18a). The height and depth of the iliac crest graft needed is measured with a sliding caliper after completion of graft bed preparation (Fig. 45.18b).

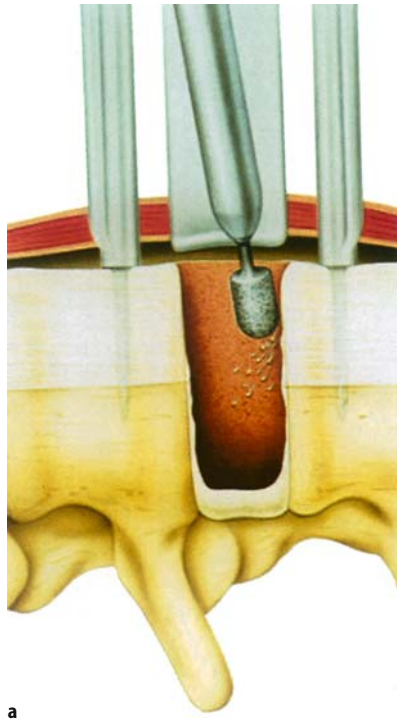
45.9.6.4.2 Graft Harvesting

A tricortical iliac bone graft is harvested through a separate small incision over the lateral iliac crest on the same side. The skin incision is placed at least 4 cm lateral to the anterior superior iliac spine in order to prevent dissection of the lateral femoral cutaneous nerve.

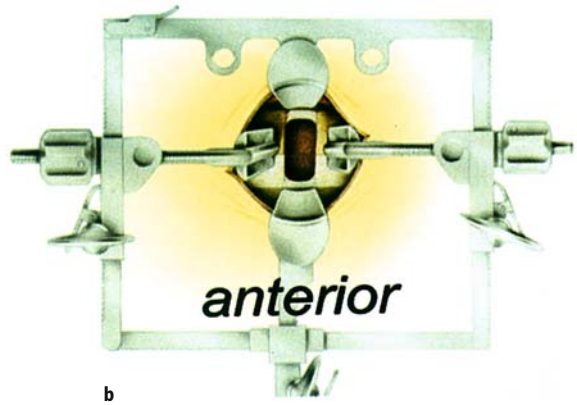
The bone graft is removed using a parallel, oscillating saw which can be adjusted to the size needed (Fig. 45.19a). The graft is cut with the help of a graft cutter (Fig. 45.19b). In addition, as much cancellous bone as possible is harvested from the ilium. The bone defect is filled with Gelfoam, a drain is inserted, and the wound closed in layers.

45.9.6.4.3 Modifications

At L4/5, the bone graft can be harvested through the same incision which is used for interbody fusion. The skin is incised over the target area (Fig. 45.20a) and then retracted after subcutaneous dissection to expose



a



b

Fig. 45.18. **a** Smoothing of graft bed with high-speed burr. **b** Graft bed



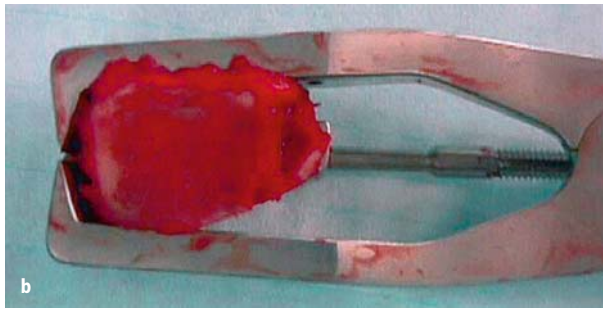
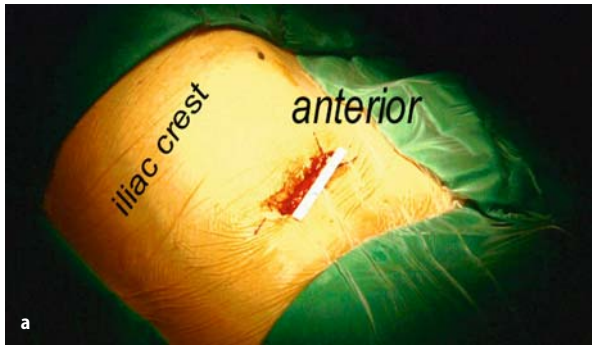


Fig. 45.19. a Parallel oscillating saw for removal of iliac crest bone graft. **b** Graft cutter with bone graft removed from the iliac crest



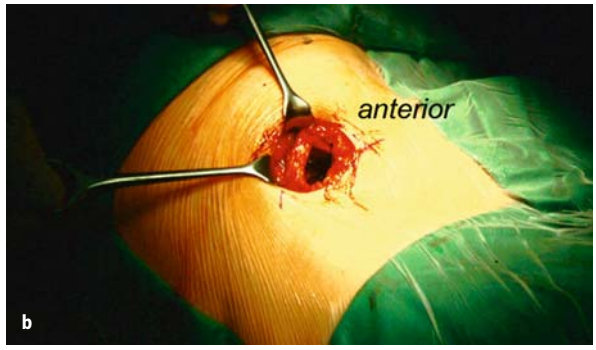




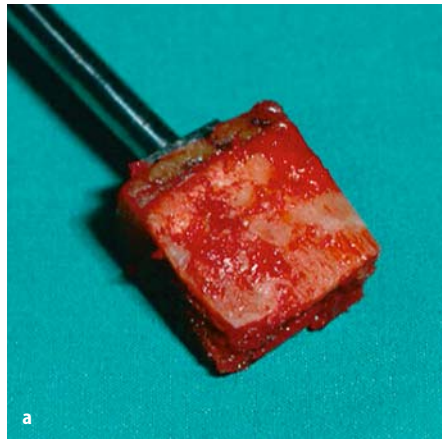
Fig. 45.20. a Four-centimeter skin incision for interbody fusion L4/5. **b** Removal of bone graft through the same incision before exposure of the intervertebral space. Preservation of iliac crest. **c** Bone graft after removal from iliac crest

the iliac crest (Fig. 45.20b). In slim patients, the lateral part of the iliac crest is preserved (Fig. 45.20b, c).

If posterior instrumentation is performed in the same session, I prefer to harvest the bone graft through the dorsal incision from the posterior iliac crest. This can be easily achieved by an interfascial approach.

45.9.6.4.4 Grafting

First, the contralateral part of the intervertebral space is filled with cancellous bone. The graft is mounted on-



▷
Fig. 45.21. a Bone graft mounted on graft holder

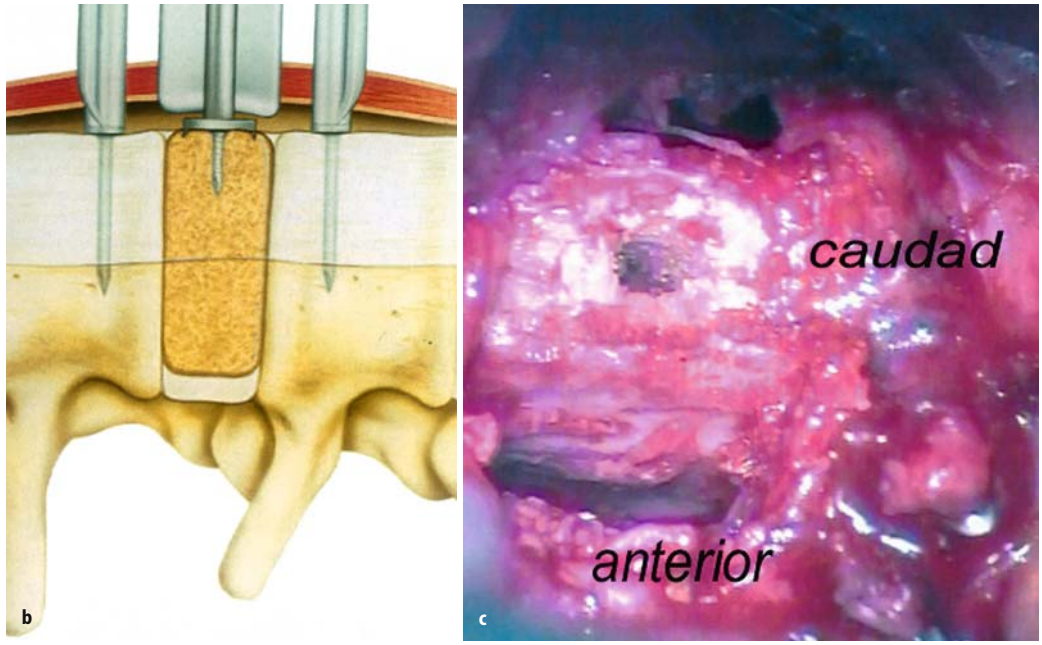


Fig. 45.21. (contin.) b Graft impacted into the intervertebral space. **c** Intraoperative picture showing the graft in place. The remaining gaps are filled with cancellous bone

to a graft holder (Fig. 45.21a) and impacted into the intervertebral space (Figs. 45.21b, c, 45.22). The remaining gaps anterior and posterior to the graft are filled with cancellous bone from the iliac crest as well as from the removed parts of the vertebral bodies.

45.9.6.5 Retreat

After removal of the retractor, the holes for the anchoring screws are sealed with bone wax and the fusion area is covered with Surgicel. The muscle layers are closed with absorbable sutures, and the skin is closed with an intracutaneous suture.

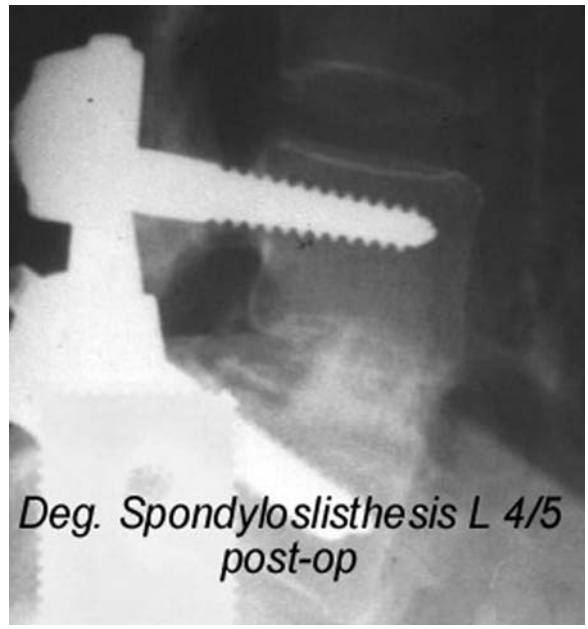


Fig. 45.22. Postoperative X-ray, lateral view: bone graft in place. Note posterior instrumentation

45.10 Postoperative Care

Usually there are no drains placed at the fusion site. The wound drainage at the donor site of the iliac crest bone graft is removed on the second postoperative day. Since most of the patients have had an additional posterior instrumented fusion by an internal fixator, they are allowed to get out of bed the day after the operation. The physiotherapy program begins on the first postoperative day starting with isometric exercises. Thromboembolic prophylaxis is performed with fractionated heparin. If there are no complications, the patients can leave the hospital between the seventh and fourteenth postoperative days. No brace is necessary in monosegmental stabilizations with posterior instrumentation. However, we use a Boston brace in patients with bisegmental approaches, in hyperactive young patients as well as in patients with osteoporosis. The brace should be worn for 8 – 10 weeks postoperatively.

45.11 Complications, Pitfalls, and Hazards

There is a variety of potential complications, pitfalls, and hazards which can arise at various steps of the operation:

- Wrong positioning of the patient: It is common to all microsurgical procedures that positioning of the patients significantly contributes to the success of the operation. The patient should be positioned as described above. Special attention must be made to the parallel orientation of the disc space borders as well as to the tilt of the surgical table. This is emphasized because all anatomical landmarks (iliac crest, psoas muscle, anterior longitudinal ligament) are helpful and valid only when they are oriented the right way. Take care that the endplates are in a parallel projection. If there is a tilt which cannot be corrected it is necessary to modify the insertion of the anchoring screws in a way that perforation of the tip of the anchoring screw into the intervertebral space is avoided.
- Skin incision too close to iliac crest: This can happen in patients with "high" iliac crests. It results in difficulties placing the caudal anchoring screw. If this situation occurs during localization of the skin incision (usually at L4/5), I recommend to tilt the table slightly more backward which will shift the incision line more anteriorly. The same is valid for patients with hypertrophy of the psoas muscle.
- High muscle tension due to insufficient relaxation of the patient: Note that the patient has to be completely relaxed, otherwise high forces are needed to retract the abdominal muscles.
- Ureter: The ureter is rarely seen during exposure of the target area. It usually courses in the retroperitoneal fat which is mobilized anteriorly.
- Common iliac artery: The left common iliac artery can only be exposed at L4/5. In patients with severe arteriosclerosis, the vessels might kink laterally and thus reach into the approach corridor. It is not a problem to retract the vessel. However, if there are calcifications the retraction should be very gentle in order to avoid lesions to the calcified wall of the vessel.
- Genitofemoral nerve: This nerve courses at the medial surface of the psoas muscle. It is exposed to damage by pressure of the retractor blade or by bipolar coagulation. The nerve should be preserved since irritation causes postoperative paresthesias, pain, and discomfort projecting into the groin and medial thigh.
- Common iliac vein, segmental vessels, and ascending lumbar vein: See comments above.
- Donor site complications: The most common postoperative complications at the iliac crest are pain, irritation of the lateral femoral cutaneous nerve, hematoma, and fatigue fracture of the anterior superior iliac spine. Most of these complications can be avoided if the graft is taken at least 4 cm lateral to the anterior superior iliac spine. This helps to preserve the lateral femoral cutaneous nerve, decreases the risk of fatigue fracture as well as postoperative pain. Hematomas can be avoided by meticulous hemostasis, including the use of bone wax, as well as by a sufficient wound drainage.

Table 45.1. Complications following 360° Fusion with retroperitoneal Mini-ALIF

Complication	Number of patients affected
DVT	1
Fracture of the os ilium	3
Non-union	4
Loosening of implant	1
Loss of correction	1
Fracture of the pedicle	1
Hematoma donor site	2
Irritation n. genitofemoralis	3
Total	**16 (13.3 %)**

In our series of patients described below, we have observed a total of 16 complications (13.3 %). Five of them were donor site complications (see Table 45.1). There was one general complication (deep venous thrombosis) as well as three complications from the posterior approach (pedicle fracture, implant loosening, loss of correction). There were seven complications specific to the anterior approach: four pseudoarthrosis and three patients with irritation of the genitofemoral nerve (Table 45.1).

45.12 Results

Microsurgical anterior lumbar interbody fusion has been performed in 120 patients (66 women, 54 men; age range 26 – 84 years (average 56.3 years). All the procedures were performed as part of a 270°-fusion philosophy which includes posterior instrumentation (with/without decompression of the spinal canal) with pedicle screw systems or translaminar screws, arthrodesis of the facet joints combined with anterior lumbar interbody fusion. The indications are listed in Table 45.2.

The average time for surgery was 102.2 minutes. This time includes 16 double-level cases as well as all cases which were performed in the early learning curve (Fig. 45.23). Time for surgery ranged between 50 and 195 minutes. The average blood loss was 139.8 cc (67.3 cc at the fusion site, 78.1 cc at the graft donor site). None of the patients received any blood transfusion for the anterior approach. Preoperative evaluation of the

Table 45.2. Indications for microsurgical anterior lumbar interbody fusion. Mini-ALIF was part of a 270°-fusion concept

Indication	Number treated
Virgin backs:	
Degenerative spondylolisthesis	37
Spinal stenosis	31
Degenerative instability	19
Isthmic spondylolisthesis	2
Fracture	2
Failed backs:	
Post-discectomy	23
Post-spondylitis	2
Non-union	4
Total	**120**

economic and functional status of the patients was performed with the help of the EFR score published by Prolo in 1986 [2]. All patients had a bad score preoperatively (Fig. 45.24a). After an average follow up period of 24 months, 62% of the patients showed excellent or good clinical results, 23% showed satisfactory results, and 15% had bad results (Fig. 45.24b). The patients were asked to give a self-rating of the result of surgery. A total of 73% were either completely satisfied or reported a significant improvement of their symptoms (Fig. 45.25), 19% of the patients reported unchanged symptoms, and 8% stated that their symptoms had become worse after the operations. Radiological reevaluation showed a fusion rate of 95.9% among those patients with a follow up of more than 6 months.

45.13 Critical Evaluation

The approach described in this chapter is a microsurgical modification of the well-known conventional retroperitoneal approach to the lumbar levels L2-5. The approach has been standardized as far as possible and microsurgical principles have been applied to the development of instruments as well as to the surgical technique. Positioning of the patient has been changed slightly in a way to create a more lateral approach. This has the advantage that the lumbar spine can be reached through a 4-cm incision even in obese patients. Due to the lateral positioning, the abdominal contents "fall away" from the surgical field and thus facilitate the approach. The lateral approach, however, can be disadvantageous in patients with a wide pelvis or a high iliac crest since these anatomical variations create a long distance between the skin levels and the target area on the lumbar spine.

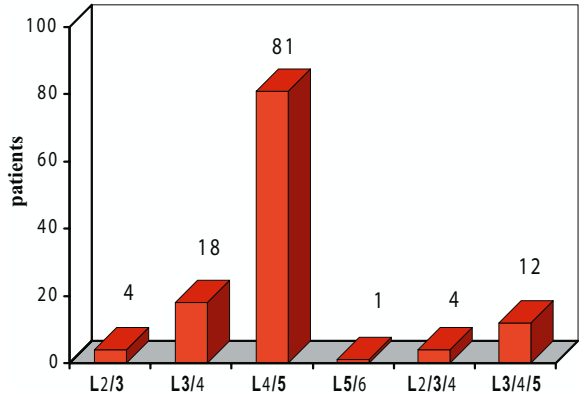


Fig. 45.23. Lumbar levels treated with Mini-ALIF

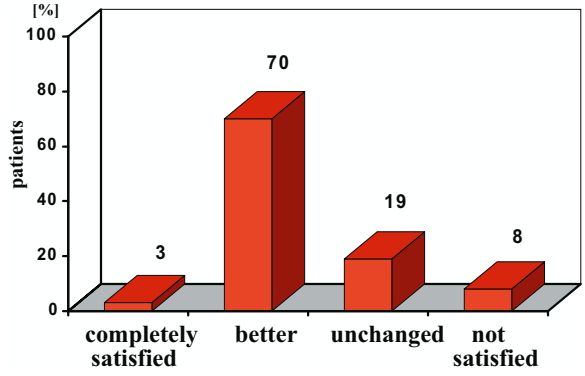
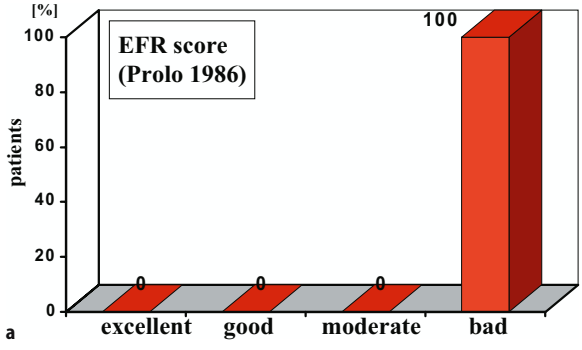


Fig. 45.25. Self-evaluation of clinical result by the patient



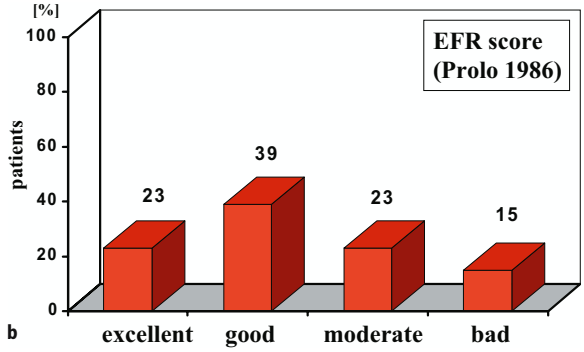


Fig. 45.24. a Preoperative EFR score [2]. **b** Postoperative EFR score [2]

The function of the muscular abdominal wall is preserved using a blunt muscle-splitting approach. Orientation anterior to the psoas muscle can be difficult in patients with big muscle diameters (e.g., young athletes). We recommend to tilt the table more backward in order to achieve a more anterior route. The psoas must be incised 1 – 1.5 cm; beware the genitofemoral nerve! (see above). The retractor frame makes it possible to perform the operation with only one assistant. In my experience, it is easier to handle the retroperitoneal blood vessels (common iliac vein, segmental vessels, ascending lumbar vein) when the microscope is used. The risk of direct injury to these vessels is minimized. This is supported by the fact that we have not had any vascular complications so far. Injury to the sympathetic chain does not seem to play a significant role in clinical follow up. Only about 25 % of the patients complained of postoperative temperature differences in the lower extremities. In the vast majority (> 90 %) this resolved within 6 – 9 months postoperatively.

There are several points of criticism:

- The technique is only applicable to the levels L2-5.
- Due to the standardization of the surgical steps and the size of the approach, a maximum of two levels can be approached through one skin incision.
- Spatial orientation in the target area is strongly dependent on the exact positioning of the patients.
- The majority of complications occurred during the posterior instrumentation and not during anterior surgery.
- A considerable number of complications have been donor site complications, the consequence of which is to think about fusion alternatives to solid iliac bone grafts (e.g., vertical cages).

The major advantages of the technique turned out to be:

- A reproducible technique with a short learning curve
- The low peri- and postoperative morbidity including the negligible intraoperative blood loss
- The possibility of early mobilization and rehabilitation due to the preservation of the functional integrity of the abdominal wall
- The good clinical results (at least as good as with conventional techniques)
- The acceptable pseudarthrosis rate (< 5 %)
- The acceptable complication rate
- The good acceptance by the patients themselves
- The different options for the type of interbody fusion [autogenous iliac bone graft, augmented horizontal and vertical cages, homogeneous bone grafts (bank bone) etc.]

References

1. Mayer HM (1997) A new microsurgical technique for minimally invasive anterior lumbar interbody fusion. Spine 22:691 – 700
2. Prolo DJ, Oklund SA, Butcher M (1986) Toward uniformity in evaluating results of lumbar spine operations. Spine 11:601 – 606

Microsurgical Anterior Lumbar Interbody Fusion (Mini-ALIF): The Transperitoneal Approach to L5/S1

46

H.M. Mayer

46.1 Terminology

Mini-ALIF L5/S1 describes a microsurgical modification of a transperitoneal surgical approach to L5/S1 through a "mini-laparotomy" in the midline.

46.2 Surgical Principle

The L5/S1 disc space is reached through a midline surgical approach. A 4-cm skin incision is performed after localization of the corridor line to the promontorium in the midline of the abdomen. A transperitoneal route to L5/S1 is created in the form of a mini-laparotomy through the linea alba of the rectus sheath. The small intestines and the sigmoid colon are retracted from the promontorium with a special soft tissue retractor. The prevertebral peritoneum is split and dissected from the right to the left in front of the promontorium. The median sacral vessels are ligated with vascular clips and dissected. Once the anterior circumference of L5/S1 intervertebral disc is exposed, interbody fusion with autogenous bone graft or cages is performed after removal of the disc. For retroperitoneal access, see Chapter 43.

46.3 History

The approach was described first by the author in 1997 [17].

46.4 Advantages

The general advantages are:

- The transperitoneal surgical approach to the lumbosacral junction is well known to spine surgeons. There is no need to learn a completely new surgical technique.
- The approach can be performed with the help of only one assistant (costs!).
- No additional medicolegal problems as compared to conventional anterior approaches.
- No additional potential complications with this technique (e.g., no gas in the abdomen).
- Short learning curve, no laboratory training necessary.
- No laparoscopic surgeon necessary.

The main technical advantages are:

- Small skin incision (4 cm; cosmesis!).
- Increased safety due to illumination and magnification of the surgical field by the use of optical aids (surgical microscope). The use of the microscope facilitates preparation in the prevertebral space. The risk of postoperative intra-abdominal fibrosis is decreased, as is the risk of injury to the superior hypogastric plexus.
- The type of interbody fusion is optional.
- Low blood loss (< 100 cc).
- Large and rapid exposure of the situs is possible in case of complications.
- Low complication rate.
- Good clinical results.
- Shorter operating times even in learning curve.

46.5 Disadvantages

The main disadvantages are:

- The surgeon should have microsurgical or video endoscopic experience.
- Approach limited to L5/S1 (L5/L6).
- Potential risk of trauma to vascular bifurcation and superior hypogastric plexus.
- Additional posterior instrumentation (pedicle screw system or translaminar screw fixation) is recommended.

46.6 Indications

The approach has been used for anterior lumbar interbody fusion in the following diseases (in the majority of my own cases combined with posterior instrumentation):

- Degenerative instability (mainly with Modic type I changes in MRI)
- Degenerative spondylolisthesis
- Isthmic spondylolisthesis
- Spinal stenosis with instability
- Failed Back Surgery syndrome
- Spondylitis/spondylodiscitis
- Pseudoarthrosis following other types of fusion (e.g., posterolateral, PLIF)

46.7 Contraindications

The following situations should be considered as absolute contraindications to the microsurgical transperitoneal approach:

- Previous major abdominal or gynecological surgery through a transperitoneal route (e.g., hysterectomy, colon resection, etc.)
- Low vascular bifurcation (in front of L5/S1)
- Spondylitis/spondylodiscitis with large prevertebral soft tissue mass or psoas abscess
- Previous transperitoneal anterior interbody fusion

Relative contraindications are:

- Previous minor abdominal surgery (e.g., appendectomy, laparoscopic surgery)
- Abdominal diseases (e.g., Crohn's diseases, colitis ulcerosa, etc.)
- Adipositas permagna

46.8 Patient's Informed Consent

Besides information about general complications of spine surgery (deep venous thrombosis, pulmonary embolism, infection) the patient should be aware of the following potential complications and risks:

- Injury to bowel, ureter, bladder with peritonitis, urosepsis, gastrointestinal and urogenital disturbances
- Injury to blood vessels (common iliac artery and vein, median sacral vessels)
- Injury to superior hypogastric plexus with retrograde ejaculation in men, sensory disturbance, genital muscular function and lubrication in women
- Intra-abdominal fibrosis with adhesions, ileus, or constrictions of ureter

46.9 Surgical Technique

46.9.1 Preoperative Planning and Anatomical Considerations

Meticulous preoperative planning is paramount for the successful performance of a transperitoneal minimally invasive approach to L5/S1. Conventional X-rays of the lumbar spine give information on the anterior height of the intervertebral space L5/S1, on the sacral inclination as well as on the orientation of the intervertebral disc space plane (Fig. 46.1). The level of the bifurcation of the aorta and vena cava must be determined preoperatively. This can be achieved in the majority of the patients with a conventional MRI (Fig. 46.2a). Three-dimensional color-coded CT angiography can be helpful in uncertain cases (Fig. 46.2b). The prevertebral space at the level of the lumbosacral junction must be evaluated very carefully on MRI and, in particular, the course of the common iliac artery and vein on both sides must be determined. In addition, MRI gives information on the thickness of the retroperitoneal fat pad in front of the L5/S1 disc space.

When previous abdominal operations have been performed, the indication for a minimally invasive transperitoneal approach must be evaluated individually. It is possible to start with a microsurgical approach. In case of larger intra-abdominal scar tissue or fibrous bands, it is possible to enlarge the approach; however, when starting with this new surgical technique, I recommend beginning with a longer skin incision in previously operated cases.

The L5/S1 interspace is reached through a mini-laparotomy in the midline. Since the surgeon stands be-

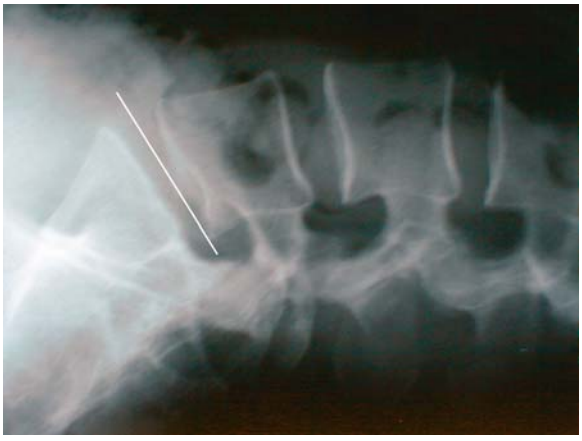
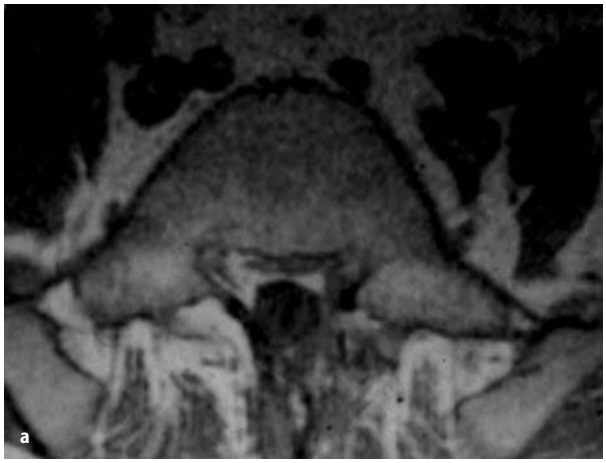


Fig. 46.1. X-ray of the lumbar spine in supine position. Note the orientation of the L5/S1 disc space



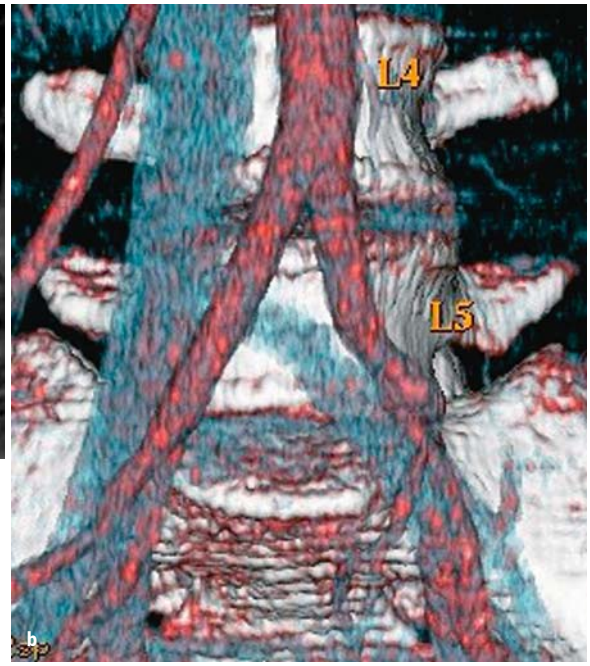


Fig. 46.2. a MRI axial view of the lumbosacral junction at the level of the L5/S1 disc. Note the common iliac artery and veins on both sides. **b** Three-dimensional color-coded CT angiography of the prevertebral area L4-S1

tween the abducted legs of the patient, abduction of the hip joints should be determined preoperatively. The patients are treated with routine mechanical large bowel preparations as well as purgatives starting 24 hours before the operation.

46.9.2 Anesthesia

A complete relaxation of the patient is mandatory in order to be able to manipulate the small intestine as well as the sigmoid colon intraoperatively. This is paramount for the exposure of the parietal peritoneum in front of the promontory. Anesthesia is performed in the same manner as described for the retroperitoneal approach.

46.9.3 Positioning

The patients is placed in a supine Trendelenburg position (trunk tilted 20 – 30°) with the lumbar spine hyperextended and legs in maximum abduction (Fig. 46.3). The position of the surgeon is between the legs of the patient. He is thus working straight forward with his visual axis in parallel to the orientation of the L5/S1 disc space. The assistant stands at the left side of the patient and the scrub nurse obliquely behind the surgeon on his right side. The microscope is positioned on the patient's right side.



Fig. 46.3. Positioning of the patient for transperitoneal anterior approach to L5/S1

46.9.4 Localization

In obese patients the following method of localization is recommended. The orientation of the L5/S1 disc space is marked as it projects onto the skin in a lateral fluoroscopic view ("disc line"; Fig. 46.4a, b). The anterior or border (tangent) of the promontorium is also marked on the skin ("border line"). The intersection of both lines is usually located on the lateral part of the patients buttock cranial to the major trochanter. A transverse line is drawn from this intersection point onto the abdomen ("corridor line"; Fig. 46.5a). This corridor line is located in the middle third of the distance between umbilicus and symphysis. A 4-cm skin incision is centered over this line strictly in the midline ("incision line"). Either a longitudinal (Fig. 46.5b) or a transverse skin incision can be chosen (Fig. 46.5c). In slim patients, the skin incision can be determined by indenting the abdominal wall with a blunt metal marker centered over the disc space L5-S1. On lateral fluoroscopy, the marker as well as the "entrance" of L5/S1

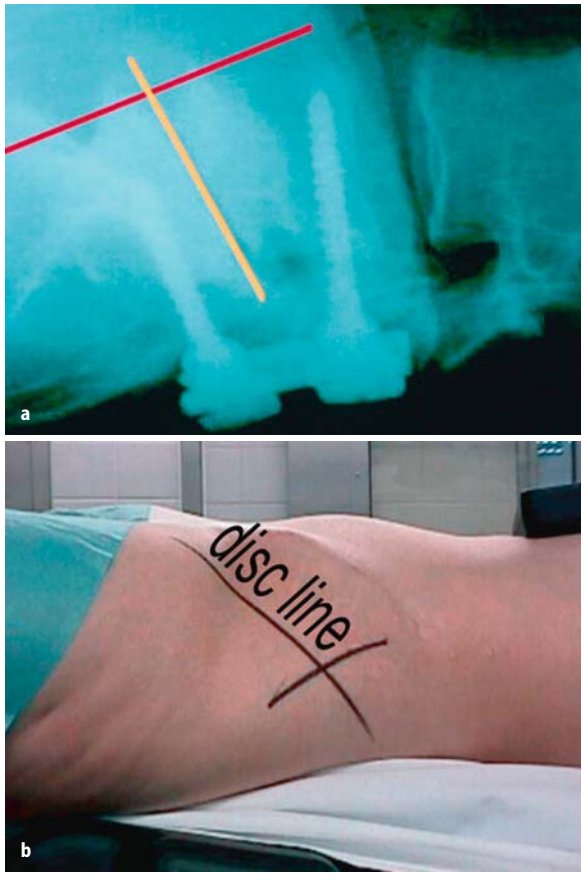


Fig. 46.4. a Lateral fluoroscopy for localization of L5/S1 (*red line* anterior border of L5/S1 interspace, *yellow line* orientation of disc space). **b** Disc line giving the orientation of the disc space



Fig. 46.5. a Corridor line drawn onto the abdomen. **b** Longitudinal skin incision marked in the midline. **c** Transverse skin incision

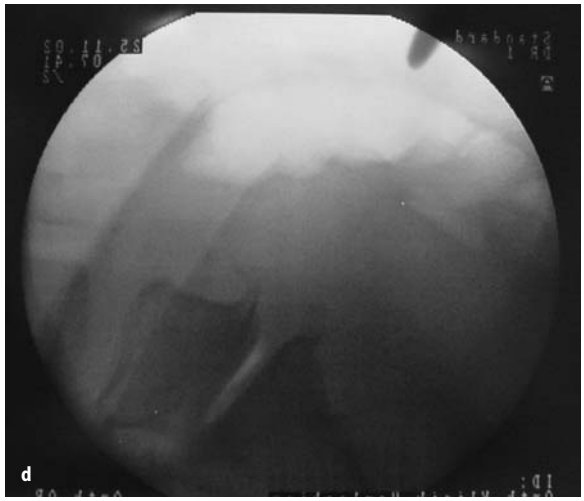


Fig. 46.5. (cont.) d L5/S1 lateral fluoroscopy. Note the metal marker above the "entrance" of L5/S1

can be identified. The skin incision is place above this entrance (Fig. 46.5d).

46.9.5 Surgical Steps

46.9.5.1 Skin to Intraperitoneal Cavity

A 4-cm skin incision is placed in the midline centered over the "corridor line." The skin incision can be placed transversely or longitudinally. The fascia of the rectus abdominis muscle is exposed and the linea alba which marks the midline is identified. The rectus fascia is opened along the linea alba and the rectus abdominis is then visible on both sides. Sometimes there are adhesions between the ligamentum urachi and the preperitoneal fat pad which have to be dissected sharply (Fig. 46.6). A soft tissue spreader with blunt blades is inserted to retract both rectus muscles from the midline. This leads to exposure of the peritoneum (Fig. 46.7). The fat pad in front of the peritoneum is mobilized from lateral to medial in order to expose the peritoneum and to facilitate laparotomy. The peritoneum is opened and armed with four sutures placed at the cranial and caudal edges (Fig. 46.8). The mesenterium with the ileum is carefully pushed into the upper left abdominal cavity using the Langenbeck hooks for blunt dissection and small abdominal towels to hold the abdominal contents in place. The same is done to

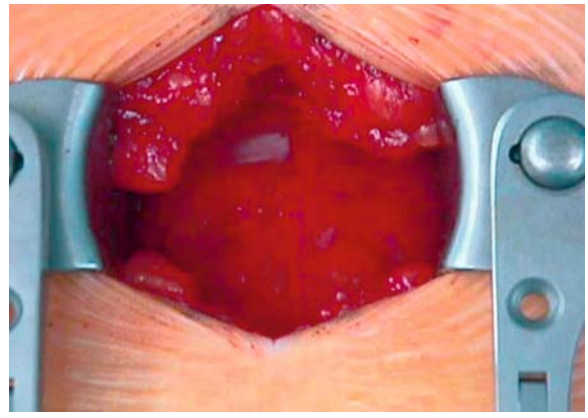


Fig. 46.7. Exposure of the peritoneum

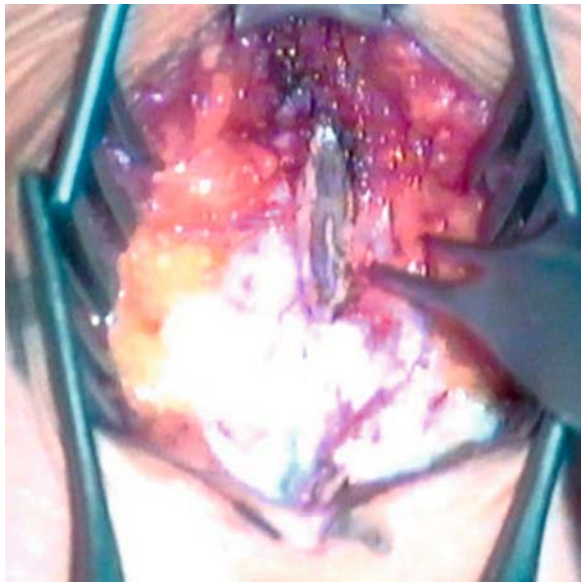


Fig. 46.6. Splitting of the rectus abdominis fascia in the midline (linea alba)

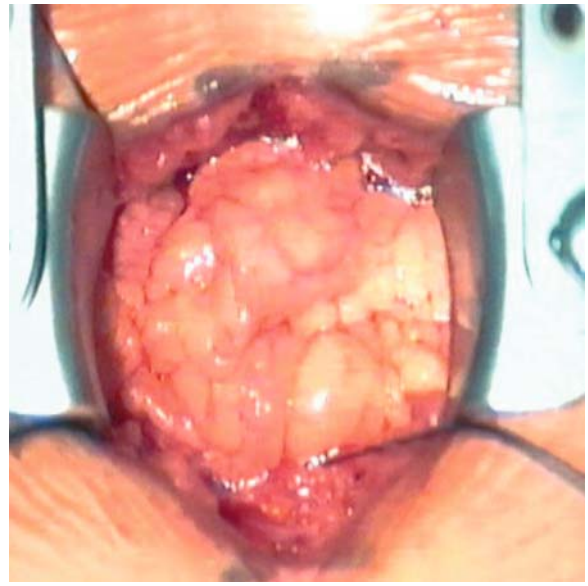


Fig. 46.8. Peritoneum is opened and armed with sutures. The greater omentum is exposed

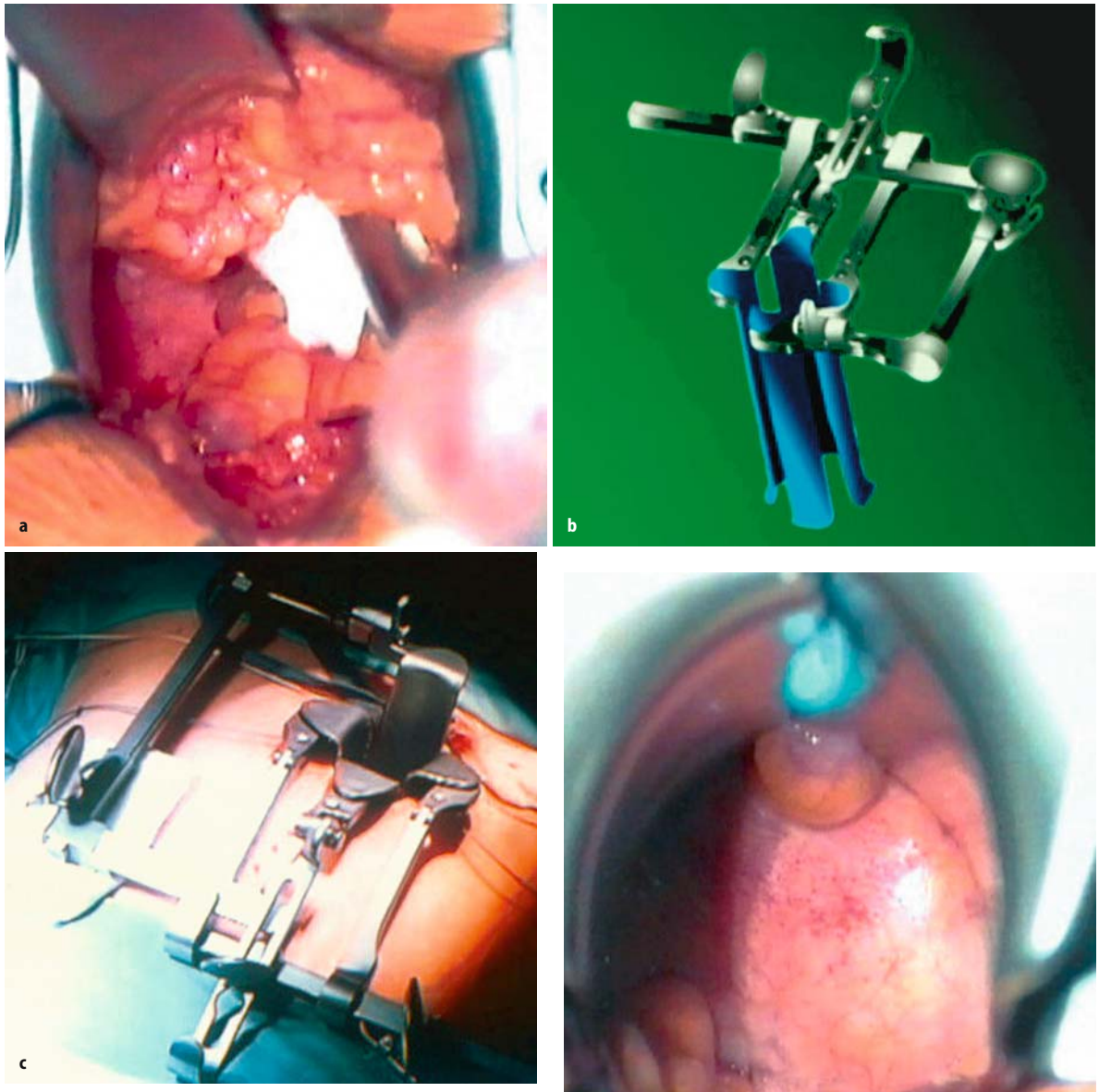


Fig. 46.9. a Mobilization and retraction of the bowel with small abdominal towels. **b** Soft tissue retractor before insertion. **c** Soft tissue retractor after insertion



Fig. 46.10. Exposure of the promontorium by the soft tissue retractor

the sigmoid colon which is carefully retracted to the left (Fig. 46.9a). A soft tissue retractor with blunt blades is inserted in order to retract the bowel to the right and to the left after identification of the common iliac artery and the retroperitoneal course of the ureter on the right side (Fig. 46.9b). Thus, the promontorium is exposed (Fig. 46.10)

46.9.5.2 Retroperitoneal Space to Intervertebral Region

The retractor is now completed with two other blades. One is positioned between the bifurcation in front of the lower anterior part of the L5 vertebral body, and the other one is centered in the presacral space (Fig. 46.9c). Now, the corridor to the anterior circumference of L5/S1 is free. Ideally, the visual axis of the surgeon is parallel to the orientation of the L5/S1 intervertebral space (Fig. 46.11).

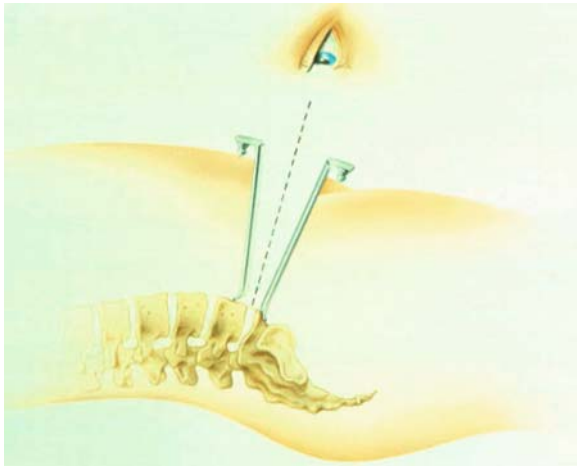


Fig. 46.11. Visual axis of the surgeon is parallel to the L5/S1 intervertebral space

The peritoneum in front of the promontorium is incised with microscissors. The incision is made about 15 mm medial to the right common iliac artery and completed in a semicircular manner. The reason for this is the fact that the main branches of the superior hypogastric plexus are usually located in the medial and left aspect of the prevertebral space at L5/S1. On the right lateral side, you can only find very small fibers of the plexus which can be identified easily under the surgical microscope. Dissection is performed bluntly and the prevertebral fat tissue including the superior hypogastric plexus is gently pushed away from the disc circumference from the right to the left using cottonoid pads (Fig. 46.12). Only bipolar coagulation is allowed. Thus, the anterior circumference of L5/S1 as well as the median sacral vessels (a.v. sacralis mediana) are exposed (Fig. 46.13a). The vessels are closed with vascular clips, dissected, and retracted from the disc surface (Fig. 46.13b).



Fig. 46.12. Opening of the prevertebral peritoneum on the right side for blunt dissection (from the right to the left side) of prevertebral fat tissue including the superior hypogastric plexus

The retractor blades can now be readjusted underneath the peritoneum in order to retract the peritoneum and the prevertebral tissues from the surgical field.

46.9.5.3 Interbody Fusion

Anterior lumbar interbody fusion with an autologous iliac bone graft is described here. However, there are

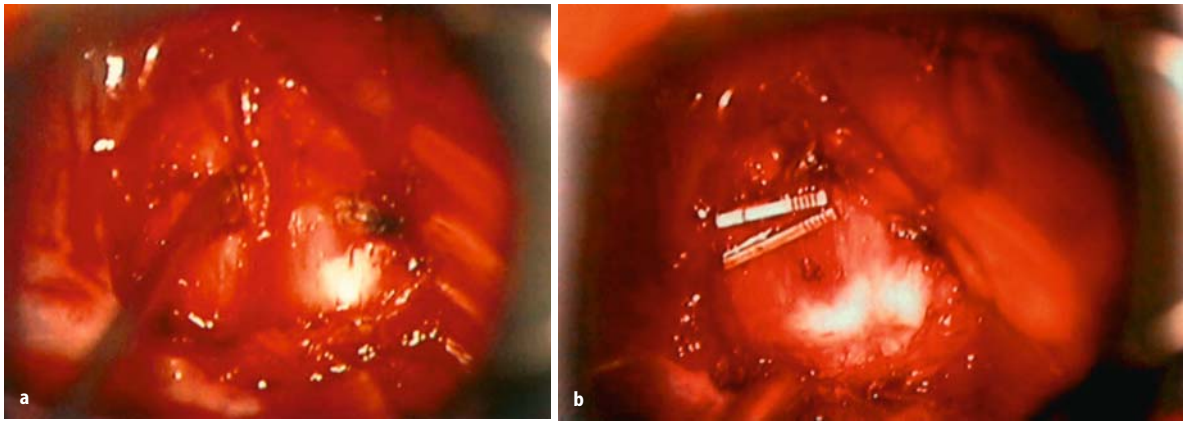


Fig. 46.13. a Exposure of anterior circumference of L5/S1 disc as well as of median sacral vessels. **b** Ligation of vessels with vascular clips and dissection

various other options for the type of interbody fusion (see also Chapter 51).

46.9.5.4 Discectomy and Preparation of Graft Bed

The anterior longitudinal ligament and the anulus fibrosis are incised in a rectangular shape (Fig. 46.14). The disc space is cleaned and the endplates are carefully removed with curettes. If the subchondral bone shows advanced sclerosis, I recommend to resect the endplate with chisels and a high-speed burr (Fig. 46.15). If necessary, the endplates can be removed as far posterior as possible until the posterior longitudinal ligament is exposed. Thus, decompression of the anterior part of the spinal canal at L5/S1 can also be performed. The height and depth of the iliac crest graft needed is measured with a sliding caliper.

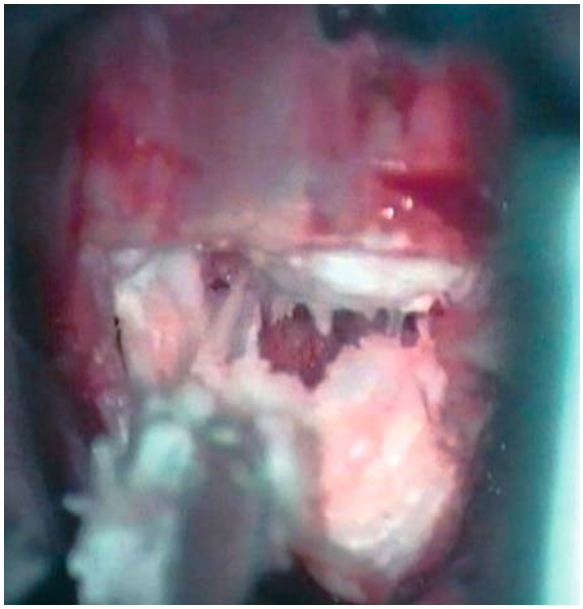


Fig. 46.14. Removal of the L5/S1 disc with a rongeur

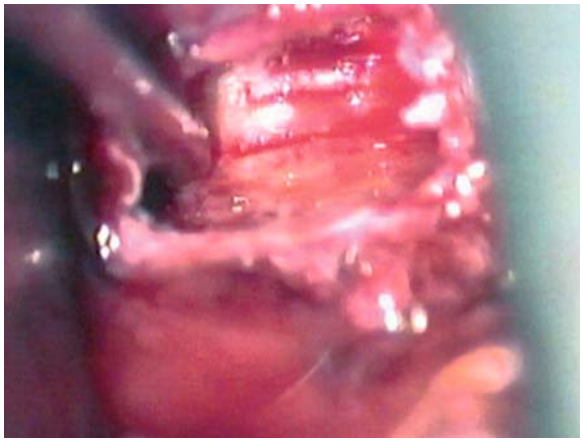


Fig. 46.15. Graft bed is prepared at L5/S1. The caudal endplate of L5 as well as the endplate of the sacrum are clearly visible

46.9.5.5 Graft Harvesting

A tricortical iliac bone graft is harvested as described in Chapter 45.

46.9.5.6 Grafting

The graft is prepared and inserted the same way as has been described for the retroperitoneal approach. However, the orientation of the graft is strictly in the midline in parallel to the sagittal plane (Fig. 46.16a). Additional cancellous bone from the iliac crest as well as from the removed parts of the vertebral bodies is impacted into the intervertebral space on both sides of the graft (Fig. 46.16b). The fusion area is covered with Surgicell.

46.9.5.7 Retreat

The peritoneum in front of L5/S1 as well as the peritoneum viscerale are closed with absorbable running sutures after removal of the abdominal towels. The rectus sheath is readapted with absorbable single sutures. The skin is closed with an intracutaneous suture.

46.10 Postoperative Care

The postoperative treatment is identical to the retroperitoneal approach. The patient is allowed to eat normally after 24 hours and is mobilized the day after the operation.

46.11 Complications, Pitfalls, and Hazards

There are some specific potential complications and hazards, due to the microsurgical technique as well as due to the instruments, which should must be mentioned:

- The first pitfalls might be wrong positioning of the patient and inadequate localization of the corridor line. If the patient does not have a Trendelenburg positioning the angle between the L5/S1 interspace and the surgeon's visual axis increases and might make it impossible to have a good insight into the disc space.

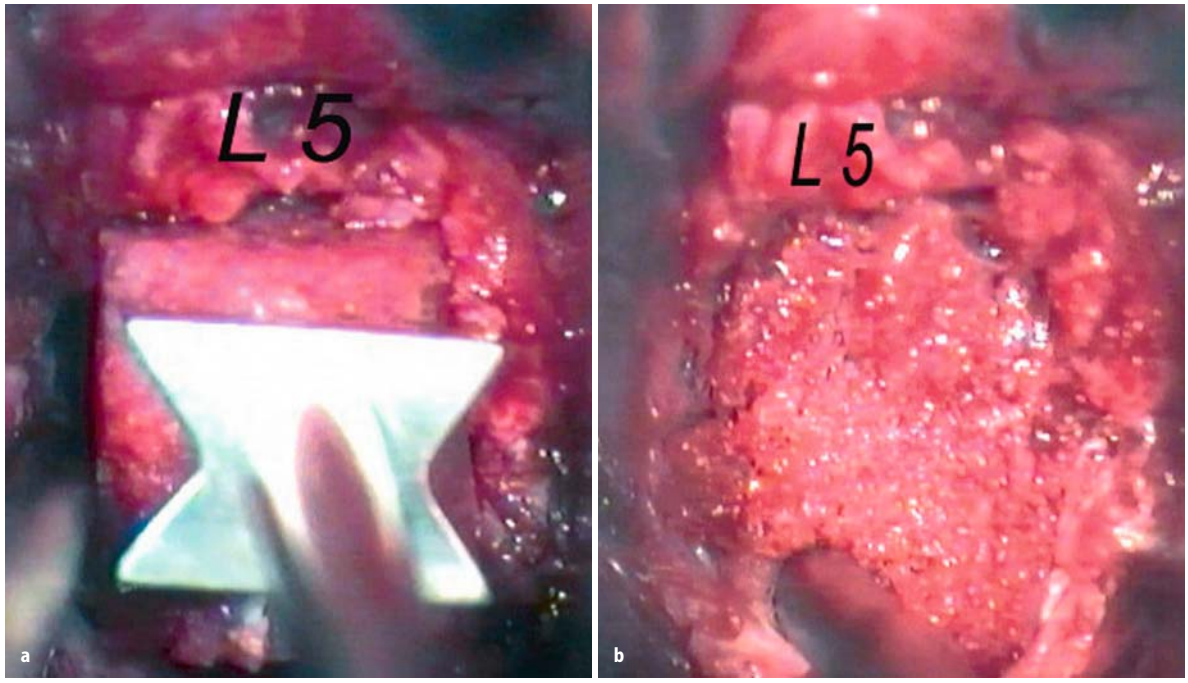


Fig. 46.16. a Tricortical bone graft is impacted at L5/S1 in the midline. **b** Gaps on both sides of the graft as well as the space anterior to the graft are filled with cancellous bone

- Exact localization of the corridor line is paramount since mobility of the skin of the patient is limited once the surgeon's approach is too far cranial or caudal.
- Retraction of the abdominal contents becomes extremely difficult if the bowel is not empty and relaxed. So preoperative bowel preparation is one of the keys to a successful operation.
- Microsurgical dissection in front of the peritoneum is safe; however, it should be performed bluntly with small swabs, and the use of bipolar coagulation must be restricted to a minimum.
- Dissection in the retroperitoneal space in front of the promontorium must start from the right side in order to decrease the risk of injury to the superior hypogastric plexus.
- The opening of the retractor in the retroperitoneal space must be performed very gently in order to avoid overdistraction of the venous bifurcation. If there is an overlap of the medial aspect of the left common iliac vein with the L5/S1 disc space, the vein should be retracted gently by the assistant (Fig. 46.17).
- Sometimes there is bleeding from intraosseous veins of the sacrum which might occur after resection of the endplate. This can be controlled with bone wax which is distributed on the bony surfaces with the high-speed diamond burr.

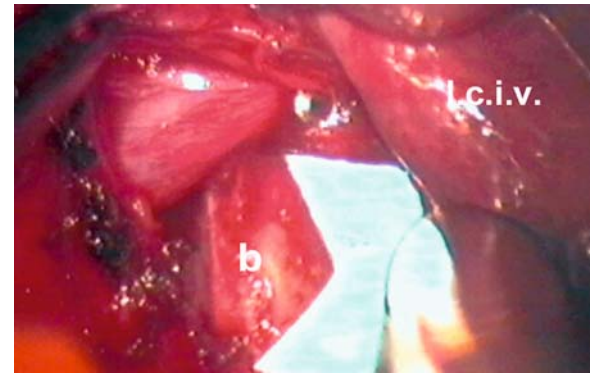


Fig. 46.17. Overlap of left common iliac vein (*l.c.i.v.*) with the L5/S1 disc space. *b* Bone graft

Table 46.1. Complications following 360° Fusion with transperitoneal Mini-ALIF

Complication	Number of patients affected
Ileus	1
Fracture of os ilium	1
Loosening of implant	1
Fracture of pedicle	1
Hematoma donor site	2
Laryngeal irritation	1
Superficial infection	1
Total	**8 (15.7%)**

In our series we had a total of 8/51 complications (15.7%; Table 46.1). However, there was only 1/51 (1.96%) specific complication. A 15-year-old boy with an isthmic type spondylolisthesis suffered from an ileus on the 5th postoperative day after microsurgical an-

terior interbody fusion at L5/S1. However, this boy had Crohn's disease which might have contributed to this postoperative complication. All other complications were either due to the posterior instrumentation (loosening of implant $n = 1$; fracture of the pedicle during insertion of pedicle screw $n = 1$) or due to the harvesting of the bone graft (fracture of the ileum $n = 1$; hematoma at the donor site $n = 2$; superficial wound infection at the donor site $n = 1$). There was one patient with a postoperative laryngeal irritation due to intubation.

46.12 Results

Microsurgical transperitoneal anterior lumbar interbody fusion has been performed in 51 patients (27 women, 24 men; age range 10–68 years (average 44.1 years). All the procedures were performed as part of a 270°-fusion philosophy which includes posterior instrumentation (with/without decompression of the spinal canal) with pedicle screw systems or translaminar screws, and arthrodesis of the facet joints (except for isthmic type of spondylolisthesis) combined with anterior lumbar interbody fusion. The indications are listed in Table 46.2.

The average time for surgery was 122.5 minutes. Time for surgery ranged between 65 and 205 minutes. The average blood loss was 78.9 cc at the fusion site and 77.5 cc at the donor site for the bone graft. None of the patients received any blood transfusion for the anterior approach.

Preoperative evaluation of the economic and functional status of the patients was performed with the help of the EFR score published by Prolo in 1986 [21]. Forty-five of the patients (89 %) had a bad score preoperatively (Fig. 46.18a). After an average follow up period of 20 months, 94 % of the patients showed excellent or good clinical results, 6 % showed satisfactory results, and none of the patients had a bad results (Fig. 46.18b). The patients were asked to give a self-rating of the result of surgery. All the patients were completely satisfied with the operation (Fig. 46.19). Radiological reevaluation showed a fusion rate of 99.6 % among those patients with a follow up of more than 6 months (Fig. 46.20).

Table 46.2. Indications for transperitoneal microsurgical anterior lumbar interbody fusion. Mini-ALIF was part of a 270°-fusion concept

Indication	Number treated
Degenerative spondylolisthesis	4
Isthmic spondylolisthesis	24
Degenerative instability	10
Failed backs	10
Spondylitis	3
Total	**51**

46.13 Critical Evaluation

The transperitoneal approach which has been described in this chapter represents a microsurgical modification of the well-known transabdominal approach to L5/S1. This route to L5/S1 follows the shortest anatomical way from the skin surface to the L5/S1 intervertebral disc. It is the most direct approach to L5/S1 which can also be recommended in obese patients.

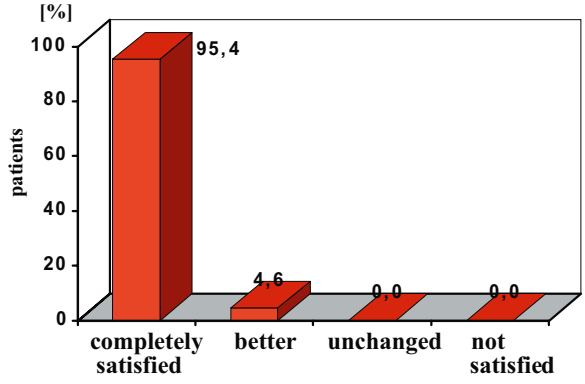


Fig. 46.19. Patient's self-evaluation of the clinical results

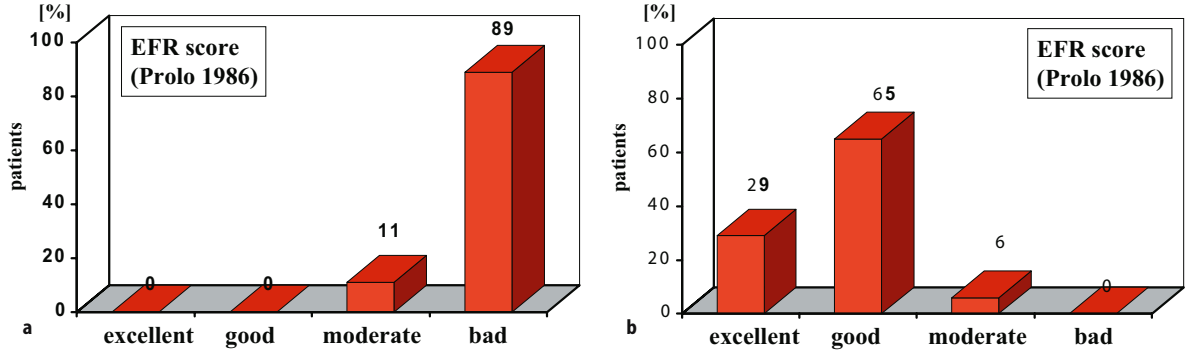


Fig. 46.18. a Preoperative EFR score [21]. **b** Postoperative EFR [21]

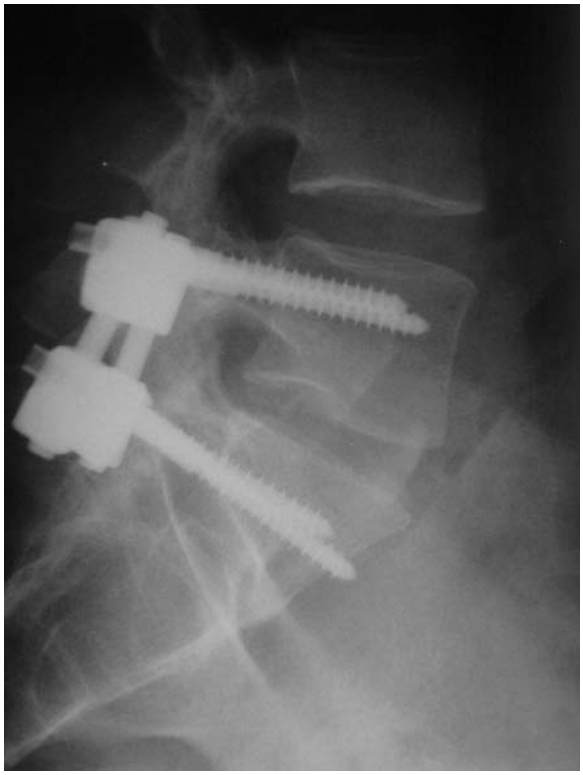


Fig. 46.20. Solid interbody fusion at L5/S1 after posterior instrumentation and microsurgical transperitoneal anterior bone grafting

Crossing the abdominal cavity bears certain risks for the anatomical structures which are located on the way to the promontorium. The bowels must be handled very gently by only using blunt instruments and hooks for preparation. The abdominal towels which are gently inserted into the abdominal cavity help to retract the bowel from the promontorium. We have not had any injury to the bowel so far. The bladder of the patients must be catheterized during the operation to decrease the risk to the bladder during dissection of the peritoneum.

In patient's with a history of abdominal surgery (see Section 46.7), mobilization of the bowel must be performed very cautiously. Since only the small surgical corridor is visible through the microscope, there is a potential risk for indirect damage to the bowel due to forceful retraction. Since this damage might occur beyond the visual field of the surgeon's eye, it might remain undetected during surgery. The same is true for indirect injury to the venous bifurcation. Although the amount of lateral retraction is limited by the skin incision and the tension of the rectus abdominis muscle, the venous bifurcation is at risk. If the common iliac artery covers part of the anterior circumference of the disc space, I recommend not to insert the retractor blades underneath the peritoneum. The assistant should carefully retract the vein during preparation of the graft bed.

Injury to the superior hypogastric plexus can be avoided if dissection in the retroperitoneal prevertebral space is performed as described above. Up to now, there have been no postoperative sexual complications. Moreover, the risk of producing postoperative fibrosis in the abdominal cavity is diminished due to meticulous microsurgical preparation. If the technique is performed the way it is described, it represents a safe and most direct way for anterior interbody fusion of the lumbosacral junction.

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Minimally Invasive 360° Lumbar Fusion

47

M. Aebi

47.1 Terminology

The term "360° lumbar fusion" means a circumferential fusion of one or several lumbar segments, including:

1. A posterior stabilization, either with translaminar screws or pedicle screws combined with a direct fusion of the facet joints, and/or a posterolateral intertransversal fusion
2. An anterior interbody fusion, either with a cage or a tricortical bone graft

The optimization of this technique is reflected in a less invasive posterior approach for the posterior translaminar screw or pedicular fixation, and an anterior retroperitoneal less invasive approach to the lumbar spine by means of a retractor system, allowing for small incision surgery, optimal illumination and visualization, and applying a special fusion technology without harvesting bone from the iliac crest.

Alternatively the anterior approach for the fusion can be replaced by a posterior lumbar interbody fusion (PLIF); however, to achieve circumferential fusion with this technique, one has to pass through the spinal canal. This specific technique will not be described in this chapter.

47.2 Surgical Principle

The usual sequence of surgery is first the posterior surgical stabilization and then the anterior interbody fusion. Experience shows that even in a posteriorly stabilized segment the intervertebral disc space can be spread open to a certain degree once the disc and two thirds of its annular circumference have been removed. This is specifically true when translaminar screws are used, which act like axes around which the facet joints rotate in the sagittal plane. When pedicle screws are used it is more difficult to spread the intervertebral disc space during the anterior procedure.

Therefore, with the translaminar screw fixation the anterior spreading still supports the creation of a lordosis, since there is no simultaneous distraction posteriorly. If the anterior distraction and cage implantation is done first, a secondary posterior tension band fixation, specifically with pedicle screws, may lead to a translational displacement of the superior in relation to the inferior vertebra, when the lordosis is forced.

It is part of the minimally invasive concept that the anterior fusion is done with local autologous bone harvested from one of the adjacent vertebrae, usually augmented by bone substitute, for instance beta tricalcium phosphate (β-TCP) granulate (Chronos). This makes any bone harvesting from the iliac crest unnecessary and excludes a relevant pain source for postoperative pain. The mechanical structure and support for the anterior interbody fusion is therefore provided by a cage, which is filled with the autologous cancellous bone-β-TCP mixture [11, 12].

47.3 History

The components of 360° fusions have been performed for many years [5]. We have gained experience with anterior interbody fusions through corticocancellous bone grafts in the 1970s with a long postoperative immobilization with bed rest and later all kinds of braces. The introduction of cages has also provided the clinical and experimental knowledge that an anterior fusion alone is usually not sufficient to guarantee a complete fusion, and that it is better if it is augmented by an additional posterior fusion and fixation [9, 10]. The Synframe has been developed from, on one side, the Buckwalter retractor and, on the other side, the Octopus retractor, which we have borrowed from visceral surgery colleagues for the anterior, either transperitoneal or retroperitoneal, approach to the lumbar spine. Gradually the surgical approach was minimized, in a similar way to Mayer's Mini-ALIF concept [6]. This experience helped us to develop the Synframe concept, which goes back to 1994 [1].

47.4 Advantages

The general advantages are:

- The retroperitoneal approach is a standard approach to the lumbar and lumbosacral spine, known by most spinal surgeons who perform anterior surgery.
- The small access through the retroperitoneal approach can be performed through different techniques and may need some extra training. Blunt dissection by the surgeon's finger is used to identify the psoas muscles and from there toward the midline (spine), with or without the help of an endoscope [3, 8]. Alternatively, instead of the finger, balloons can be used [13] even in combination with the endoscope.
- The use of the Synframe allows the surgeon practically to work alone or at maximum with one assistant.
- The use of the Synframe, a system which is stably fixed to the OR table, makes the retraction very precise, and the repositioning of blades and Hohmann levers can be used as a preparatory and dissecting tool.
- No microscope is necessary because optimal illumination is integrated into the system.
- An endoscope can be used additionally and placed on the Synframe allowing an optimal transmission of the surgical procedure to the collaborators in the OR or to a video system for transmission to lecture halls for teaching purposes.
- The legal implications of this procedure are not new and have been established in principle for many years. The small access can be expanded at any time, if necessary, to a conventional retroperitoneal access to the lumbar spine.

The main technical advantages are:

- Small skin incision.
- Bland muscle splitting, soft tissue preserving, and protecting innervation of the muscle.
- Access possible from L2/3 to L5/S1, with the "trick" of diaphragm splitting even up to T12.
- Bisegmental approach or even more is possible.
- Blood loss is usually minimal (around 150 ml).
- The Synframe is a comprehensive stable retractor system which is stabilized toward the table and the patient, in contrast to other systems which maintain retraction by using opposing forces of the retractor components not necessarily providing the precision and the stability of a stable retraction system.
- Optimal illumination without the need of a microscope. According to the preference of the surgeon, loupes can be used, providing sufficient magnification of a principally macroscopic procedure.
- Expansion to a large access incision can be done at any time if needed as a salvage procedure.
- The posterior translaminar fixation creates minimal muscle damage and a posterolateral fusion may not be necessary. The decancellation of the facet joints is mostly sufficient, except when dealing with a gross instability.
- Low complication rate, and generally good surgical results.
- The anterior surgical technique is in principle independent from the type of cage or anterior fusion technique applied.
- The posterior fusion technique also allows any implant, be it translaminar minimally open, open pedicular fixation, transcutaneous pedicular fixation, or navigation technology.

47.5 Disadvantages

The main disadvantages are:

- The surgeon may need some specific training, especially for anterior retroperitoneal surgery, and specifically at the lumbosacral level.
- The surgeon should have some experience in handling vascular injuries, specifically when operating at the bifurcation level, or he/she may want to have a general or vascular surgeon at hand.
- Potential risk of injury of to vessels, ureter, and sympathetic nerve fibers.
- The small access does not allow the use of voluminous anterior implants.

47.6 Indications

The technique can be used for:

- Degenerative painful disc disease
- Degenerative spondylolisthesis
- Degenerative short lumbar scoliosis with instability for correction and stabilization
- Failed back syndrome after posterior decompression surgery
- Spinal stenosis with instability, when posterior surgery alone is considered as not sufficient to restore stability
- Pseudarthrosis either after anterior surgery or posterior surgery
- Spondylodiscitis/spondylitis usually done as a vertebrectomy and with a posterior pedicle system
- Metastatic spine disease by spondylectomy and use of expandable cages

47.7 Contraindications

There is no absolute contraindication to this technique, however, there are alternatives consisting of purely posterior surgery (PLIF), specifically in young men to avoid the risk of damaging the sympathetic fibers especially at the L5/S1 level.

A previous anterior surgery with expected scar formation may be considered as a relative contraindication making an anterior exposure of a specific disc difficult. In tumor or infection surgery the pathology may be more expansive than expected, necessitating a bigger approach. The vascular constellation in front of L4 or L5 may be reason enough to avoid this approach or to approach the spine from the opposite (right) side.

Adipositas may be a relative contraindication necessitating a larger approach.

47.8 Patient's Informed Consent

This surgery heralds general complications (infection, anesthetic complications, embolic event, any accompanying medical problem) as well as local complications, which are:

- Deep venous thrombosis of the vena cava or common iliac vein or peripherally from them
- Denervation of abdominal muscles
- Abdominal herniations due to suture insufficiency
- Difficulties in postoperative hip flexion due to the irritation of the retracted psoas muscle including traction pain of spinal nerve roots
- Compression and irritation of the genitofemoral nerve with gross pain and dysesthesia
- Vascular injury in the retroperitoneal space
- Postoperative retroperitoneal hematoma
- Nerve root and/or cauda equina injury (extremely rare, more a problem from posterior)
- Dural leak (anterior and posterior)
- Damage to the prevertebral sympathetic trunk with temperature differences in legs, disturbances in sweat secretion, and dysesthesias
- Injury to the peritoneal content and ureter
- Impotentia coeundi in male patients due to damage to the prevertebral sympathetic nerve fibers, mainly in the area L5/S1

There could also be complications related to the bone harvesting from the vertebral body:

- Perforation of the endplates, damaging the mechanical integrity of the vertebral body
- Perforation of the posterior wall with dural damage and/or dural damage to neurostructures
- Bleeding
- Late collapse of the vertebral body
- Nerve root damage

None of these complications have so far been seen in our own clinical setting.

47.9 Surgical Technique

47.9.1 Preoperative Planning and Preparation of the Patients

Patients assigned for this kind of surgery have all necessary imaging evaluations to assess the basic pathology including regular X-rays, MRI of the lumbar spine, and CT scans occasionally combined with a myelogram. In these images there is usually sufficient information to identify the pre- and perivertebral structures (psoas, vessels, spinal canal, vertebral facet joints) to plan the surgery, specifically the surgical approach, with sufficient reliability: a decision can be taken whether occasionally a right-sided approach would be easier to perform than the regular approach from the left side. The conventional X-ray of the lumbar spine allows the evaluation of the bone quality, the form of the vertebrae, the realignment of the lumbar spine, and the disc spaces. With the image intensifier, images can be reproduced intraoperatively to mark the projection of the spine area of interest on the skin in order to make the approach as precise as possible. The patient needs a mechanical bowel preparation the day before the surgery to give optimal conditions for the surgery.

47.9.2 Anatomical Considerations

There are different ways of entering the retroperitoneum on the left side. The projection of the targeted segment(s) is marked on the skin (Fig. 47.1a, b). A horizontal line on the anterior left abdominal side indicates the level, and a sagittal line on the left side flank of the abdominal wall indicates the projection of the level of the anterior surface of the spine. The midline of the abdominal wall is marked, representing the midline of the spine (Fig. 47.1c). A horizontal incision is prepared in line with the horizontal marker line either at the transition of the middle third into the lateral third between the midline of the spine and the sagittal line corresponding to the anterior surface of the spine, or left from the midline to enter the left rectus sheet. The left rectus muscle is retracted laterally (innervation from lateral), and the linea arcuata is identified distally. Here the retroperitoneal space can be entered, and the dissection extended toward the left psoas muscle.

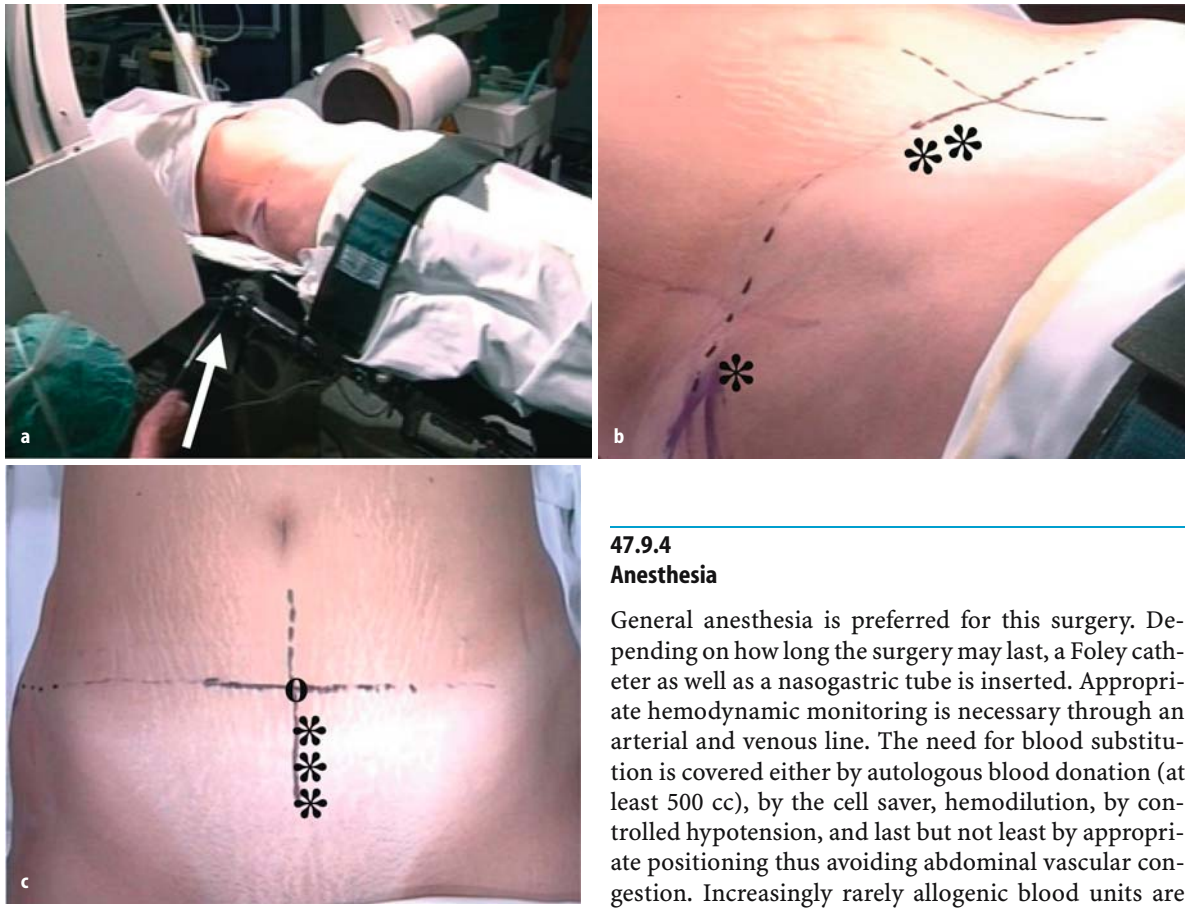


Fig. 47.1. Preparation of the patient. **a** Supine position for the anterior approach. The table can be kinked (*arrow*) at the level of surgery. Projection of the surgical level onto the skin with image intensifier. **b** *Asterisk* Projection of the promontorium, *double asterisk* horizontal line at the level L5/S1. **c** *Triple asterisk* Midline of the spine, *O* center of promontorium projected

47.9.3 Magnification

In our experience there is no need for a microscope for the anterior part of the surgery. The big advantage of the microscope is undoubtedly the focused illumination, however, this issue has been resolved with the integrated illumination within the Synframe retractor system. The use of regular operating loupes is amply sufficient for the amount of magnification which may be needed. This anterior part of the surgery is basically macroscopic surgery, where there is no need to work in a microscopic dimension. As long as the posterior surgery is a pure stabilization and fusion procedure, a microscope is not needed. However, in case anterior or posterior precise decompressive surgery may be necessary, the microscope is of help.

47.9.4 Anesthesia

General anesthesia is preferred for this surgery. Depending on how long the surgery may last, a Foley catheter as well as a nasogastric tube is inserted. Appropriate hemodynamic monitoring is necessary through an arterial and venous line. The need for blood substitution is covered either by autologous blood donation (at least 500 cc), by the cell saver, hemodilution, by controlled hypotension, and last but not least by appropriate positioning thus avoiding abdominal vascular congestion. Increasingly rarely allogenic blood units are used in degenerative spine surgery. However, in a regular surgical course, no blood needs to be replaced.

47.9.5 Positioning

As mentioned earlier, the posterior approach is usually done first. Positioning is prone on rolls and/or bolsters in the thoracic and pelvic regions leaving the abdomen free of any pressure to avoid congestion of blood in the abdomen. The incision is usually just above the spinous process of the lamina that is going to be used for translaminar screw fixation. The right level of the incision is checked with a lateral projection of the image intensifier.

For the anterior surgery the patient is positioned supine, primarily flat on the table with a minimal elevation of the left side through a sand bag under the gluteus and thoracic cage. The soft tissue preparation and the access is easier when the tissue is not under tension. However, once the anterior surface of the spine becomes visible, a hyperextension of the targeted segments is achieved by tilting the flat table (Fig. 47.1a), with the top of the kink projecting to the targeted level. This opens the disc space and so it becomes easier to access.

47.9.6 Retractor System for Lumbar Spine Surgery (Synframe)

The Synframe is a comprehensive retractor system for spine surgery, which is the basis of a less invasive spine surgery concept. The idea was to overcome the disadvantages of the existing retractor systems used in spine surgery. Most of the available systems are retractors which "hold by themselves", i.e., if a blade retracts in one direction there is a need for a counterforce on the other side to maintain the frame in place [6]. These systems are not fixed to the operating field itself, nor to the table. This is, however, possible with the Synframe. The carrier (ring) for the retractor elements is stably fixed to the operating table, and the retractor elements are stably fixed to the carrier as well as to the spine as is the case when Hohmann levers are used or K-wires in combination with the blades [1].

All the retractor elements are connected to a ring, 30 cm in diameter, which can be enlarged to an oval by interposing two extension pieces 10 cm in length (Fig. 47.2g). The concept is that the operating field comes to lay in the center of the ring, therefore every point on the circumference of the exposed surgical field is reflected on the ring (Fig. 47.2a). There are either Hohmann levers (Fig. 47.2b, c, e) or rectangular blades (Fig. 47.2d) available as retractor tools, which are connected with clamps through a mobile arm to the ring. There are additional specialized blades for the retraction of the soft tissue beyond the abdominal or thoracic cavity and for the retraction of the lung in case of a mini-thoracotomy. There is a mechanism to angle the retractor blade into the position which is required (Fig. 47.2d). The clamps mounted on the ring can be moved along the ring into any position, and the clamp can rotate around the axis of the rod of the ring. This complete free positioning of the retractor elements provides enormous versatility in exposing specific surgical targets. The ring, however, is not only a carrier for retractor elements, but also for a number of other tools: a fiberoptic light source, which can be fixed to the ring in the same manner as the retractor elements allowing free positioning of powerful illumination (Fig. 47.2d–f), a device to hold a laparoscope, providing transmission of the view of the operating field onto a screen (Fig. 47.2h, i), and a suction. The laparoscope not only allows the teaching of surgical techniques, which are done through a small surgical opening and therefore not accessible to direct vision except for one of the surgeons, but it can also be used as a magnification tool for

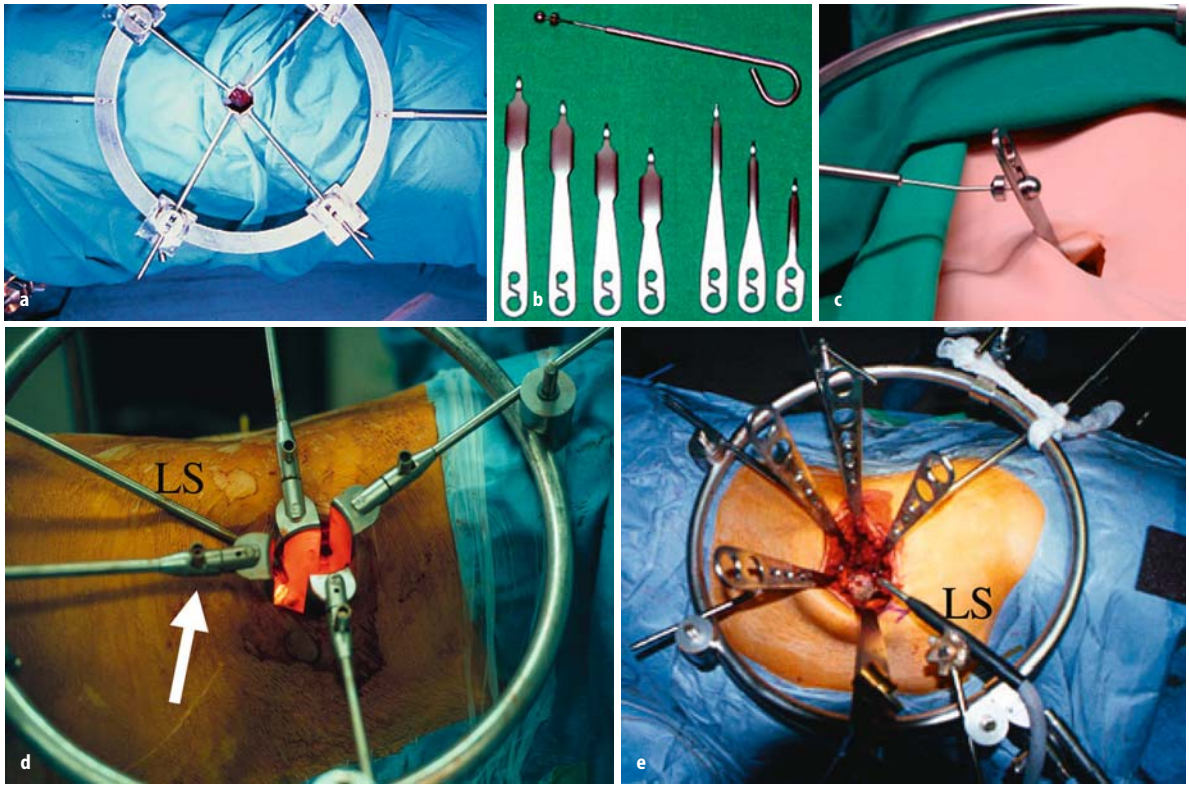


Fig. 47.2. Retractor system for less invasive access surgery. **a** Prototype of a concentric ring concept built around the surgical approach with 360° access. **b**, **c** Different sizes of specialized Hohmann levers with the flexible arm to the ring. **d**, **e** Option to use either blades or Hohmann levers to retract the surgical access. Note the strong illumination of the operating field through a fiberoptic light source (LS)

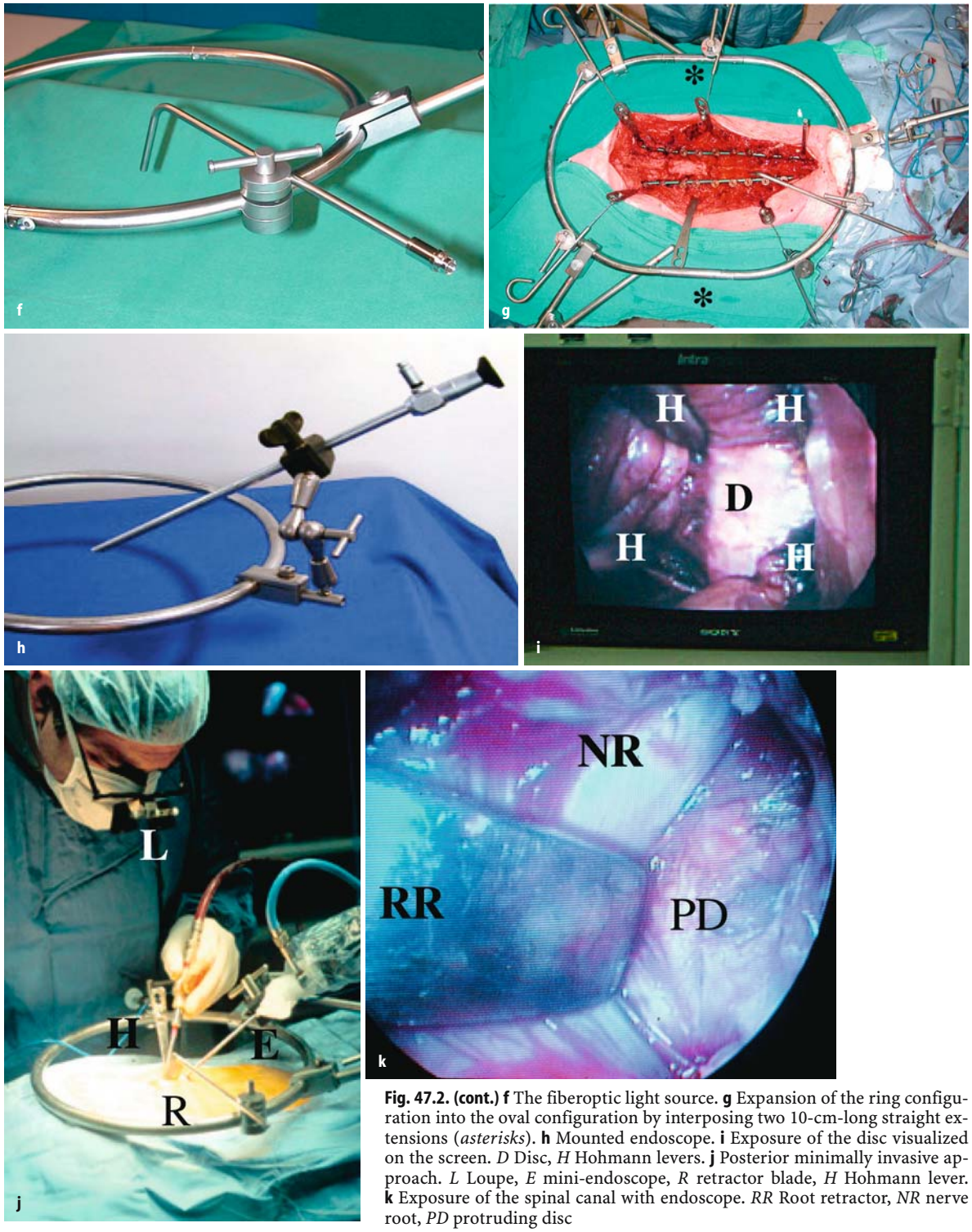


Fig. 47.2. (cont.) f The fiberoptic light source. **g** Expansion of the ring configuration into the oval configuration by interposing two 10-cm-long straight extensions (*asterisks*). **h** Mounted endoscope. **i** Exposure of the disc visualized on the screen. *D* Disc, *H* Hohmann levers. **j** Posterior minimally invasive approach. *L* Loupe, *E* mini-endoscope, *R* retractor blade, *H* Hohmann lever. **k** Exposure of the spinal canal with endoscope. *RR* Root retractor, *NR* nerve root, *PD* protruding disc

anterior (Fig. 47.2i–k) as well as posterior surgery (Fig. 47.2k). It helps the surgeon to integrate in a simple practical way magnification and direct and indirect visualization without a microscope in a regular surgical environment. This retractor technology can no longer be ignored, not only for anterior spine surgery but also for any spinal intervention including posterior surgery and even for a variety of other orthopedic interventions.

47.9.7 Surgical Steps

47.9.7.1 Posterior Surgery

The patient is positioned prone. The spinous process of the superior vertebra of a segment to be fused is identified and a 3- to 4-cm skin and fascia incision is made over the identified spinous process (e.g., L4 spinous process for the segment L4/5 to be fused; Fig. 47.3a).

With the Cobb elevator subperiosteal dissection of the paravertebral muscles is done following the lamina to the facet joint. A Hohmann lever is positioned at the lateral circumference of the facet joint at the level of the transverse process. The Hohmann lever is either held by an assistant or connected to the Synframe.

The capsule of the facet joint is resected with electrocautery and the joint cartilage is destroyed. The translaminar screw is placed either free handed or with the adjunct of navigation [4]. The same procedure is done on the opposite side. No formal fusion is done, except the decancellation of the joints. The 4.5-mm titanium regular cortical screws used are usually between 48 and 56 mm in length. The wound is closed in layers in the normal way, and the patient is turned to the supine position.

47.9.7.2 Anterior Surgery

There are two routes to be taken for the skin incision:

1. A 4- to 6-cm-long horizontal incision is made (length depending on the size of the patient) located over the lateral border of the left rectus muscle (Fig. 47.3b). The left rectus muscle is exposed by opening the anterior sheet of the muscle. The muscle is retracted laterally to avoid pulling off the innervation of the muscle coming from lateral. The surgeon's finger slides down the inner sheet of the

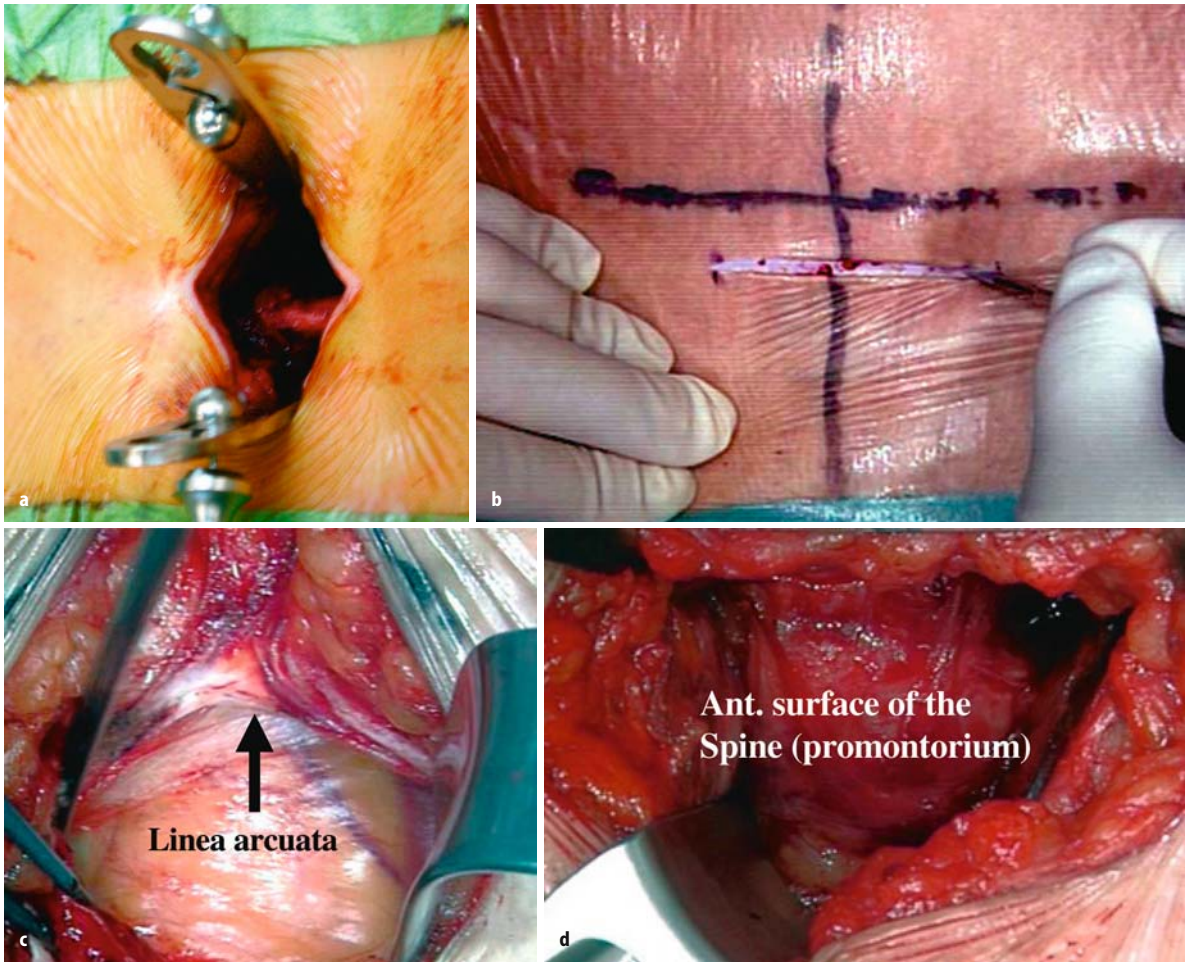
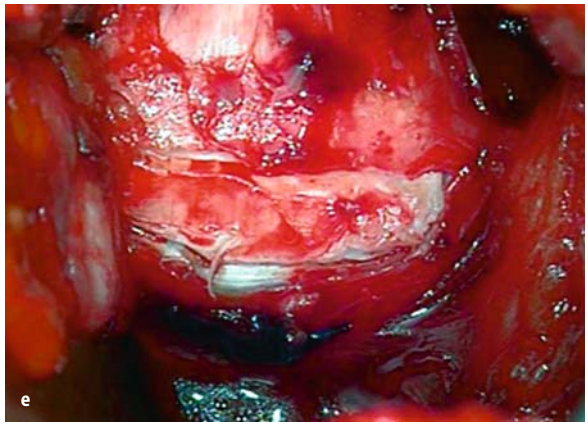
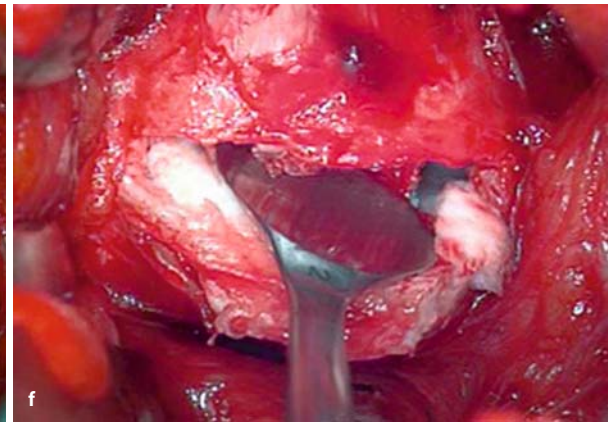


Fig. 47.3. Exposure. **a** Small incision over the spinous process, e.g., L4, in order to perform a translaminar screw fixation L4/5. **b** Anterior horizontal incision over the rectus sheet. **c** Identifying the linea arcuata caudal of the rectus sheet. **d** Exposure of the anterior surface of the lumbar spine extraperitoneally.





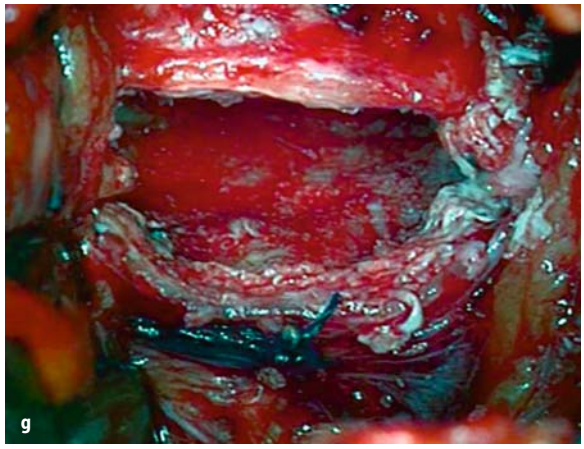


Fig. 47.3. (cont.) e Exposure of the disc to be excised. **f** Removal of the disc together with the cartilage endplate by a small sharp round Cobb dissector. **g** Evacuated disc with bleeding points on the lower endplate

rectus to the linea arcuata at the level of the middle to the lower third of the rectus sheet, where the thin transverse fascia is laying over the peritoneum (Fig. 47.3c). From the linea arcuata a blunt dissection between the transverse fascia and the peritoneal sheet is done, preferably laterally, in order to identify the psoas muscle.

2. The horizontal 4- to 6-cm-long incision is made more lateral in the so-called "regio lateralis," where the fascia of the external oblique muscle becomes the external oblique muscle. This muscle is split in the direction of the fibers, and the same is done with the underlying internal oblique muscle and the transverse muscle. Finally, after carefully splitting the transverse fascia one enters the retroperitoneal space filled with fat tissue. Through blunt dissection of this retroperitoneal fat one reaches the psoas muscle. The more lateral the entry into the retroperitoneal space, the more easy it is. More medially, there is a chance that the peritoneum is fixed to the transverse abdominal muscle, and the peritoneum can be torn.

For both approaches, once the psoas muscle is identified, blunt dissection of the retroperitoneal space toward the midline of the spine is done. Once the spine is definitely identified, a Hohmann lever is inserted into the vertebral body and it is linked to a clamp of the Synframe on the right side. This will, with one single beat, open the corridor to the spine and move the incision over the midline (Fig. 47.3d). From the anchorage of the Hohmann lever the blunt dissection can be developed cranially, caudally as well as laterally on both sides to prepare the operating field, which consists of a window including the targeted disc space, with a rim of bone from the adjacent vertebral bodies. Usually the segmental vessels do not need to be dissected, except later for the bone harvesting from the center of the vertebral body, either below or above the targeted disc space. Usually four Hohmann levers are used in order to have an ideal surgical corridor, anchoring them above the endplate, right/left of the superior vertebra, and below the endplate right/left of the inferior vertebra. These Hohmann levers are pulled with the connecting arms toward the clamp fixation on the Synframe creating a concentric operating field within the ring.

The identification of the spine in order to place the first Hohmann may not always be obvious and easy. Sometimes it may become necessary to identify the common iliac artery and vein, and to mar them with vessel loupes to pull them either laterally to the right or to the left. Sometimes it may be necessary, specifically to ligate posteriorly entering venous branches to avoid pulling of the posterior wall of either the vena cava before the bifurcation, or the common iliac vein after the bifurcation. With dissectors followed by Hohmanns or distally curved retractor blades, the anterior surface of the spine is bluntly dissected, and by levering the incision toward the midline a direct anterior approach is achieved. This normally facilitates the symmetrical evacuation of the intervertebral disc space and the centered placement of the interbody fusion, be it bone graft alone or together with a cage. This same access al-

so has major significance and implications for lumbar disc replacement in order to place a disc prosthesis.

The ureter ideally is not dissected but moved together with the retroperitoneal fat and tissue to the midline. Aiming toward L4/5, the common iliac artery is identified and gently moved laterally. A long blunt hooked blade fixed to the ring holds the right-sided vessels toward the right side. The front side of the vertebral body L4 or the disc space L4/5 is now stepwise dissected by continuous repositioning of the retractor blades, or more ideally of the Hohmann levers. With them a gentle traction toward the right side can be applied, and the targeted operating field is gradually exposed. The right common iliac vein may be identified and also pulled to the right side. Occasionally, branches need to be clipped or coagulated, and the vein itself taken on a vessel loop sling. At higher levels, the vena cava and abdominal aorta are usually pulled to the right side.

Generally speaking, only the anterior circumference of the disc space needs to be exposed (Fig. 47.3e). Segmental vessels usually do not need to be ligated. The disc space is exposed in such way that a window can be incised in the annulus allowing easy delivery of a Syncage-type cage, and an easy evacuation of the disc space, removal of the cartilaginous endplates, and freshening of the bony endplates will be possible. The best and most precise exposure is reached when a Hohmann is placed in the subchondral bone of the endplates above and below on each side left and right. In case of a retroperitoneal approach to the disc L5/S1, usually the left artery and vein may only be slightly and bluntly mobilized to the left and the right vessels to the right. The accompanying sympathetic chain may be damaged independently, whether we use a microscope or not; however, the incidence seems to be less when the microscope is used. Damage to the sympathetic chain may lead to differences in the temperature of the legs in a high percentage of cases, but with an equally high potential of recovery within a year.

Before the disc now exposed is excised, ideally in the extent of the whole anterior circumference, the table is kinked with the kink under the exposed disc thus opening it optimally (Fig. 47.1a). After incising the annulus vertically and horizontally (Fig. 47.3e), the round special Cobb elevator is used to separate the whole disc from the endplate with the adherent hyaline cartilage (Fig. 47.3f). If one succeeds, a substantial part of the disc can be removed in one piece, and the nude bony endplate shows small points of bleeding. The complete excavation of the disc is then completed (Fig. 47.3g). We do not use any burr to freshen the endplate in order not to weaken it, but we do use ring curettes and small regular angulated curettes.

The disc space is spread with a special spreader (Fig. 47.4a), which is positioned exactly in the center of the disc space. The two spreader blades are relatively slim and are designed to receive the rim in the middle of the cage template (Fig. 47.4b) as well as the definitive cage, so the cages are guided down as on a train track by simultaneously spreading the spreader further (Fig. 47.4c). With the complete fit of the spreader blade with the surface geometry of the superior and inferior endplate of the cage, the latter one acts as a spreader, which distributes the forces on the whole circumference of the vertebral endplates. This allows a perfect fit of the appropriate cage. Once the appropriate size of template is defined (Fig. 47.4d), the definitive cage is prepared for delivery.

We use either a titanium Syncage or a PEEK lumbar cage. We use cages either prefilled with β-TCP (Chronos) granula (Fig. 47.4e, f) or we may do it ourselves, or we fill them with bone (see Fig. 47.5). In both cases, we spare some bone to pack in front of the cage at the end of the surgery to enhance the anterior bony bridging

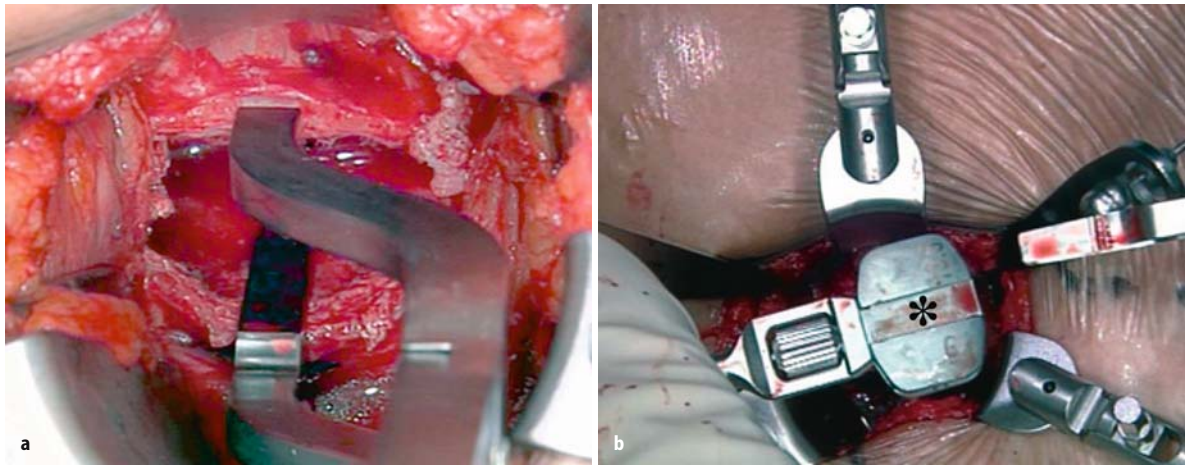


Fig. 47.4. Delivery of intervertebral cage. **a**, **b** Special spreader with narrow blades serving as railroading for the rim (*asterisk*) on the endplates of the template, as well as of the cage.

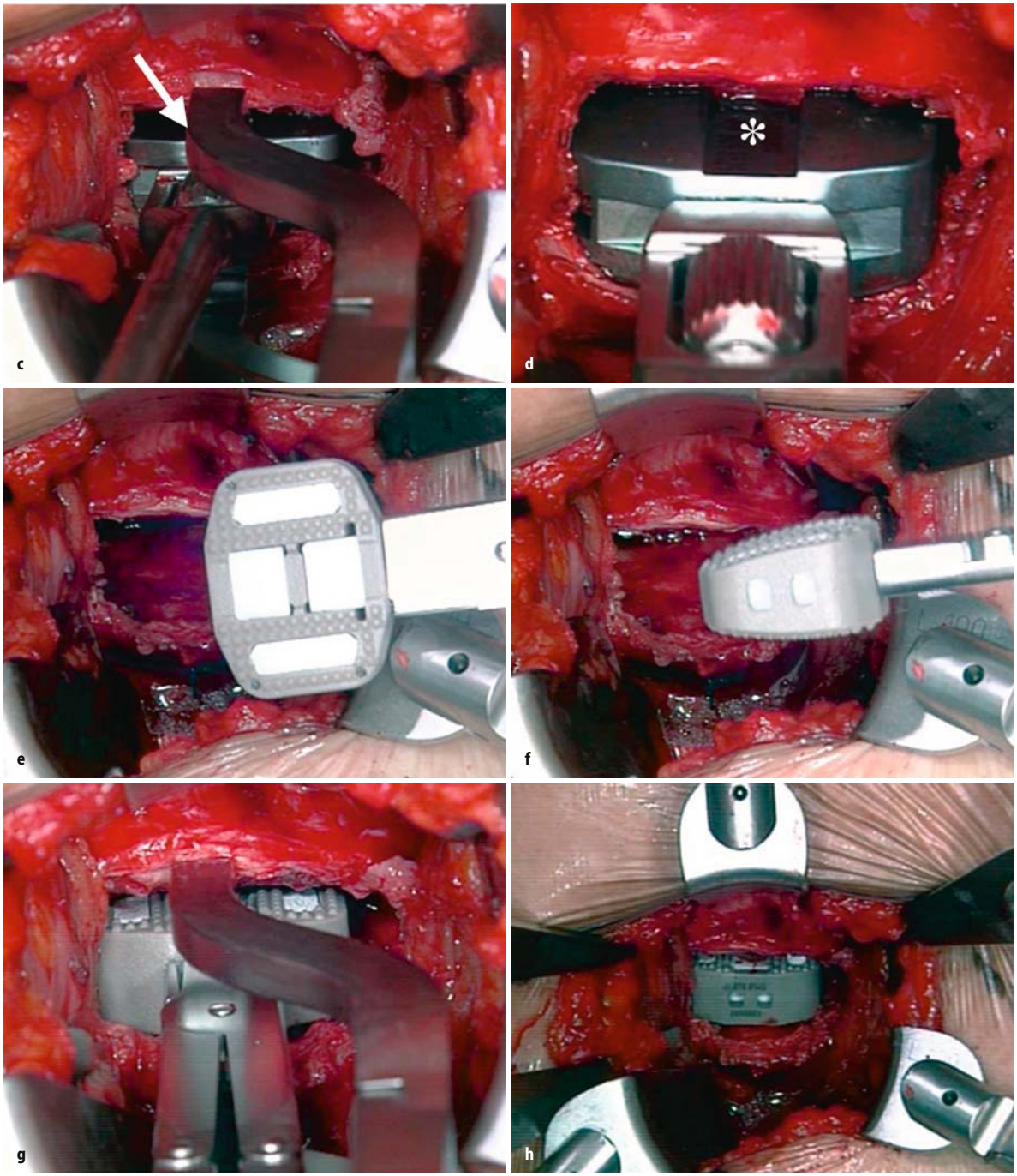


Fig. 47.4. (cont.) c Positioning of the template, guided by the spreader (*arrow*) enhancing the distraction. **d** Seated template in the disc space. **e** With Chronos (tricalcium phosphate) prefilled PEEK cage. **f** Same cage demonstrating the spherical surface. **g** Positioning of the cage. **h** Delivered locked cage after releasing the kinking of the table

(Fig. 47.5h). Once the cage is delivered through the application of the spreader (Fig. 47.4g), the latter is removed and then the table is brought back to the straight position, eliminating the hyperlordosis (Fig. 47.4h).

It is obvious that this described procedure can be applied easily for each individual or several levels at the same time from L2/3 to L5/S1. The entry point for the skin incision may change in relation to the level of the umbilicus and according to the preoperative marking with the image intensifier.

Today we do no longer use bone harvested from the iliac crest, which is a major source of persistent postop-

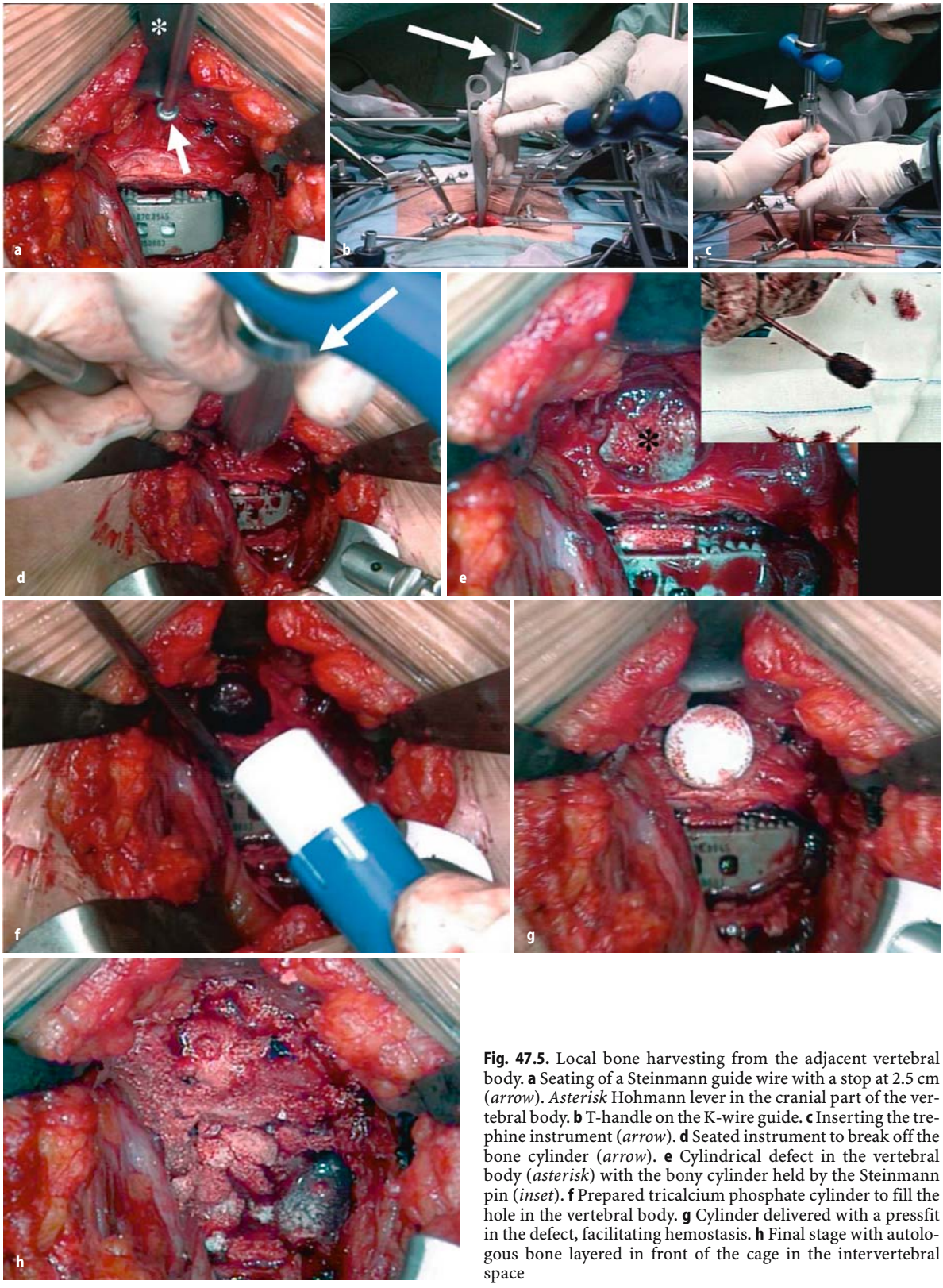


Fig. 47.5. Local bone harvesting from the adjacent vertebral body. **a** Seating of a Steinmann guide wire with a stop at 2.5 cm (*arrow*). *Asterisk* Hohmann lever in the cranial part of the vertebral body. **b** T-handle on the K-wire guide. **c** Inserting the trephine instrument (*arrow*). **d** Seated instrument to break off the bone cylinder (*arrow*). **e** Cylindrical defect in the vertebral body (*asterisk*) with the bony cylinder held by the Steinmann pin (*inset*). **f** Prepared tricalcium phosphate cylinder to fill the hole in the vertebral body. **g** Cylinder delivered with a pressfit in the defect, facilitating hemostasis. **h** Final stage with autologous bone layered in front of the cage in the intervertebral space

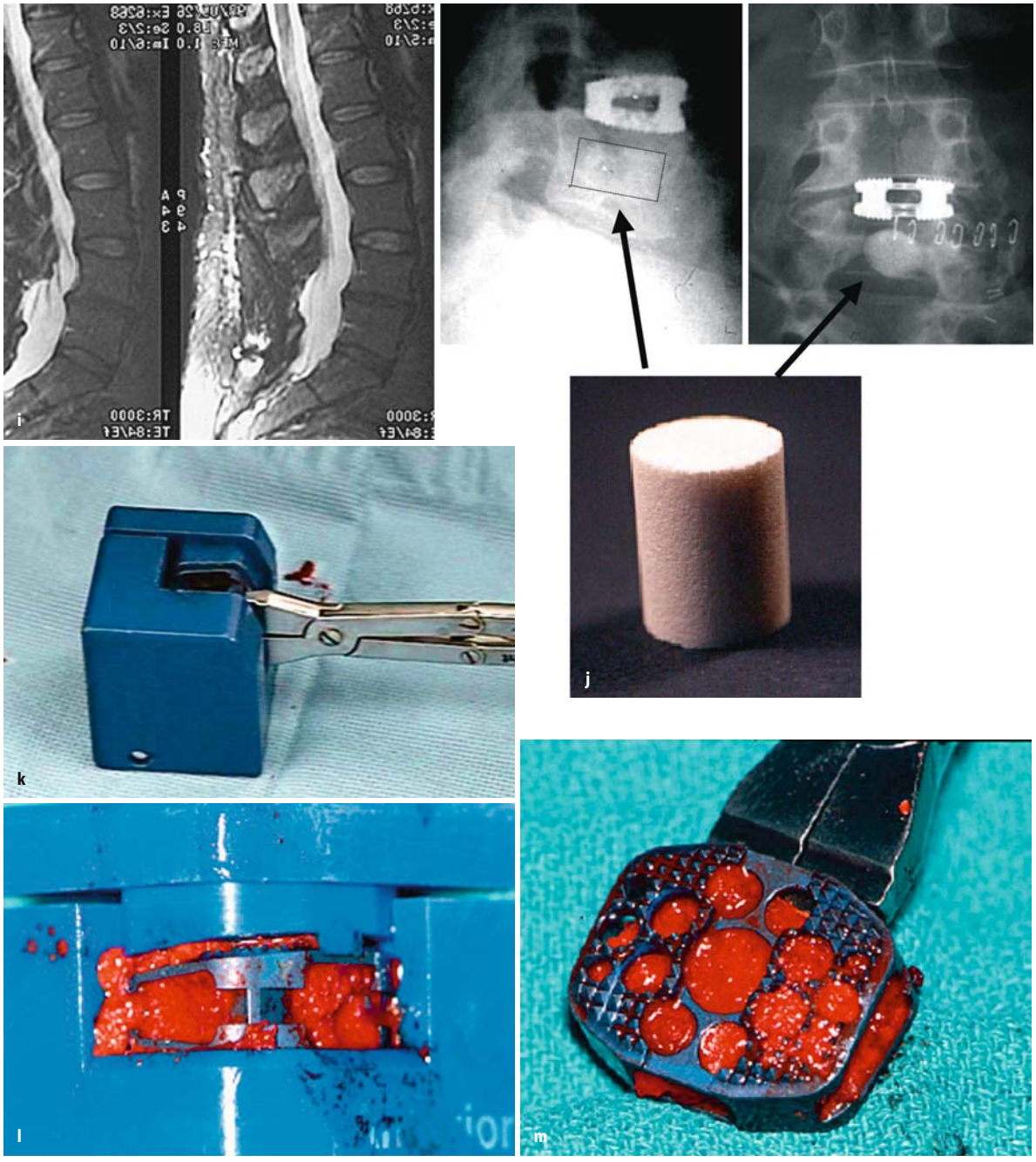


Fig. 47.5. (cont.) i Example of a case with previous decompressive posterior surgery with anterior fusion L4/5 as first step through cage and local bone harvesting. **j** Device to place the cage when filling it with bone. **k** Cage in the device filled with bone. **l** Final compression of the bone in the cage. **m** Cage filled with bone before placing it into the intervertebral space

erative pain. Instead we have developed a technique to harvest bone directly in situ from the adjacent vertebrae of the disc to be fused [11].

47.9.8 Vertebral Body Bone Harvesting

To harvest autologous bone to fill the cage, we use the vertebral body adjacent to the disc to be fused. Gentle soft tissue preparation is done either cranially or caudally. For this purpose it may be necessary to ligate or clip the pair of segmental vessels overlying the targeted

vertebral body. Usually it is sufficient to position an additional Hohmann lever in the cranial third of the vertebral body above or in the caudal third of the vertebral body below to lever all the soft tissue out of the way. A Steinmann pin with a stop at 2.5 cm penetration is inserted into the center of the vertebral body (Fig. 47.5a), aligned as parallel as possible to the adjacent endplates in order to avoid a perforation of the endplate above or below the vertebra used for bone harvesting.

A large sharp hollow cylinder (diameter 12 – 18 mm) is inserted over the K-wire which is used as a guide (Fig. 47.5b, c). The size of the cylinder depth to be removed is prefixed in this trephine instrument. The hollow sharp cylinder is inserted by hand, using rotating movements, and by a hammer. Once the determined depth is reached, the hollow cylinder is replaced by an instrument which is able to break the cylinder as a whole out of the vertebral body (Fig. 47.5d). The created cylindrical hole in the center of the vertebral body (Fig. 47.5e) is filled with a pressfit β-tricalcium phosphate cylinder (Chronos) of the measured size (Fig. 47.5f). The application of these cylinders usually leads instantly to appropriate hemostasis (Fig. 47.5g). This cylinder also restores the integrity of the vertebral body, thus iatrogenic fractures of the vertebral body do not occur and the bony defect will finally be replaced by bone in a long-term remodeling process (Fig. 47.5i). If the bone gained from the removal of the cylinder is not sufficient, further bone can be removed with a curette through the cylindrical canal, basically taking the bone from the lateral cylindrical wall, but not from the cranial or caudal part. The bone cylinder and possible additional bone is morcelized and filled sometimes together with β-tricalcium phosphate granula into the cage with the help of a special filling device (Fig. 47.5j–m). We spare some bone to deposit at the end in front of the cage for the fusion purpose (Fig. 47.5h). It is obvious that one or two simple tricortical bone grafts from the iliac crest or a femoral allograft filled with autologous bone can be used as well as a technical variant instead of cages [4, 6, 7].

47.10 Closure of the Operating Field and Postoperative Care

At the end of the procedure hemostasis has to be checked carefully. A tabotamp (Surgicel) is put in front of the disc space filled with the cage and bone chips (Fig. 47.4e). First, the Hohmanns on the contralateral side are removed to check the right-sided vessels reposition spontaneously without any unexpected bleeding. The holes in the vertebral bodies from the Hohmanns may be sealed with wax. Then the ipsilateral Hohmanns are removed. Normally the whole abdominal content falls back into position and an hemovac drain is not necessary. Depending on the original access either the two rectus sheets are closed or the abdominal muscle layers are closed with continuous sutures. The skin is closed with either intracutaneous sutures or with clips.

Since the patients have a circumferential fusion and stabilization, they are mobilized out of bed either in the same evening or the day after the surgery. A soft brace is worn which is more of psychological than mechanical support to prevent patients from uncontrolled movements. This brace is usually kept on for the first 6 weeks postoperatively. Patients have been instructed preoperatively in isometric exercises for their abdominal as well as paravertebral muscles. If there was no relevant manipulation of the prevertebral veins, no pharmacological thrombosis prophylaxis is needed, since there is no evidence for its superiority [2]; however, elastic stockings are worn while on the operating table. Patients can be discharged from the hospital between the 4th and the 8th postoperative day.

47.11 Complications, Pitfalls, and Hazards

The complications and pitfalls are separated into posterior surgery and anterior surgery.

47.11.1 Posterior Surgery

To avoid accessing the wrong level for posterior instrumentation, it is important before the fixation is performed to determine the correct level by image intensifier. Since the procedure is minimally invasive, i.e., only the tip of the spinous process of which the laminae and the joints are used for translaminar screw fixation, there is little possibility to ascertain the level of fixation digitally.

To avoid wrong positioning of the translaminar screws, the surgeon has to make sure that the screw is within the two cortices of the lamina. If there is any doubt that this can be achieved, the spinous process should be drilled in such a way that the screw exits on the contralateral side, and follows the lamina to re-enter it before the screw perforates the joint. In fact this course for the screw may be more stable than a screw that is embedded between the two cortices of the lamina. The entering, exit, and re-entering of the screws give three fixed points of cortex for stability.

It is important to mark the joint line in order to make sure that the screw passes to the center of the joint as a transfacet screw. It is recommended to measure the length of the screw to avoid root irritation by overlong screws.

In the case of the pedicle screws, minimally invasive posterior surgery follows the concept that only the en-

try point for a particular screw is exposed, and only after positioning of one screw will the next one be done in the same way. As for any pedicle screw, a perforation either of the lateral or the medial cortex or superiorly and inferiorly into the foramen is possible. The position of the pedicle screws should be ideally controlled by an AP and lateral view, especially if there is any doubt that the screws may have perforated the pedicle.

47.11.2 Anterior Surgery

The anterior incision may be too medial, especially when using the alternating spreading of the muscle layers. When going through the linea arcuata of the posterior rectus sheet, one may end up with an inability to separate the peritoneum from the transverse fascia. The peritoneal sack may tear, and it is necessary to suture those tears. Care has to be taken not to include the intestinal wall in these sutures.

Once the retroperitoneal fat tissue is separated and the surgeon is reaching the psoas, care has to be taken that the psoas muscle is not dissected in the area of the origin from the lumbar spine. The psoas muscle should be used as a landmark to find the way to the midline of the lumbar spine. While preparing the psoas muscle the genitofemoral nerve on the psoas on the medial side may be damaged. Direct injury as well as injuries through retraction of the muscle may produce discomfort and pain within the groin on the ipsilateral side as well as on the medial thigh.

When preparing the anterior surface of the lumbar spine, the table should not be kinked in a hyperlordosis, because there may be too much tension either on the abdominal muscle as well as on the psoas muscle and anterior longitudinal ligament. Only when the spine is exposed and the intervertebral disc is ready to be evacuated and prepared, a maximal hyperextension may be helpful to open the disc space.

As mentioned above usually the ureter should not be looked for, but should be mobilized with the peritoneal sack to the medial side.

At the level of L4/5 and L5/S1 one of the major problems is the bifurcation of the common iliac artery as well as the bifurcation of the vena cava. The bifurcation may be exactly in front of the disc space L4/5 or below. In such a case a decision has to be taken, once the spine is reached medially from the psoas, whether the whole left iliac artery as well as the vein are mobilized gently to the right side, or whether the left iliac artery and the left common iliac vein should be slung with a vessel loop and pulled to the left side rather than to the right. The most prominent problem when preparing the vein is that there are exiting or afferent branches dorsally which may be pulled off while preparing the common iliac vein, leading to venous bleeding. Usually tamponade of the vein will stop the bleeding. When manipulating the vena cava or the common iliac veins the patient should be treated with a thrombosis prophylaxis.

When preparing the intervertebral disc, make sure that the endplates show fresh bleeding without damaging the subchondral bone. Overdistraction should be avoided and is prevented by primary posterior translaminar screw fixation. The anterior distraction in case of posterior fixation will basically lead to a lordosis. Care has to be taken that there is no overdistraction anteriorly, especially in cases where the anterior surgery is done before the posterior surgery.

Lastly the sympathetic hypogastric chain as well as the sympathetic nerve fibers in front of the lumbosacral spine can be injured leading to either temperature differences in the legs, subjectively remarked, or ending up with an impotentia coeundi.

47.12 Results

A combined anterior as well as posterior instrumentation with anterior cage and interbody fusion and posterior translaminar screw fixation or pedicular fixation together with a minimally invasive access with the help of the Synframe concept have been done in a series of 74 patients. There were 42 female and 32 male patients, and fusions were done at one level in 48 patients and at two or more levels in 26 patients, totaling 105 levels. The majority of cases were done with translaminar screw fixation and 18 patients with pedicular systems. The average time for surgery was 25 – 40 minutes for posterior translaminar screw fixation and 45 – 75 minutes in pedicular systems. The turning of the patient took between 20 and 30 minutes, before the patient was ready for the anterior surgery The anterior approach surgery lasted from 55 to 130 minutes. In the vast majority of cases the blood loss for the anterior surgery was less than 150 ml, and less than 200 ml for the posterior surgery. None of the patients received foreign blood. Either they had cell saver blood harvesting, own predonated blood, or the surgery was managed by hemodilution and lowering of the blood pressure alone. The average hospitalization time was between 4 and 9 days. These patients have not yet been followed for at least 2 years to make a final statement of their outcome. The preliminary results are very satisfying with more than 80 % of the patients returning to their primary occupation. Complications in the anterior approach were in two cases a lesion of the wall of the common iliac vein, which needed a suture. In five cases the patients had, with great probability, an irritation of the genitofemoral nerve. There is no established non-union, no established loosening of instrumentation, and no migration of the cages. There was one patient with a deep vein thrombosis.

47.13 Critical Evaluation

The combined posterior/anterior surgery described in this chapter has been well established for many years. The specific characteristics of this proposed surgery is the minimally invasive anterior access, made possible by a specific retractor system and the application of an atraumatic bone harvesting tool in combination with the use of cages, and minimal access surgery for the posterior instrumentation. This minimally invasive procedure has definitively reduced the average number of hospitalization days, the surgical time is no longer than in open surgery, and in fact after a learning curve of approximately the first 15 cases became faster than the average normal or regular open surgery. A concise evaluation of the economic benefits of this surgery [technology versus use of hospital services and infrastructure (OR occupation, hospitalization)] is still outstanding.

Unlike other techniques described for mini-retroperitoneal approaches, the technique presented here can be used from at least L2/3 to L5/S1. In fact even L1/T12 and L1/2 can be achieved by splitting the diaphragm from below. Although the risk of vessel damage was considered to be high when starting this technique, this has not been substantiated. In fact, there were very few vascular hazards in this surgery.

There are major advantages of this surgery:

- Access to the whole lumbar spine
- Assistants are no longer necessary, in fact this surgery can be done alone or with a maximum of one assistant
- Minimal exposure, less surgical pain, reduction of hospitalization and rehabilitation

  One other important advantage compared to other ALIF methodology is that there is no longer any bone harvesting from the iliac crest and the iliac crest as a pain source is excluded. Therefore, generally speaking the donor site complications are almost excluded. The removal of the cylindrical plug from the vertebral body adjacent to the disc space under consideration has not shown any relevant complications when the rules of the direction of the bone harvesting tools are respected.

  This technique is reproducible, has little postoperative and perioperative morbidity, and the patient can be mobilized early with a soft brace. It is not necessary to learn this technique completely from scratch because the surgical techniques are very similar to those usually used in macroscopic approaches and so are familiar to surgeons. This technique is independent of a microscope, works well with loupes only, and has optimal illumination with the fiberoptic light.

  Obviously the interbody fusion can be done with different cage types. There is no prospective study to compare the individual cages against each other. Also the posterior surgery can be done with different techniques either with translaminar screw fixation, as long as the posterior elements are intact, or as a pedicle fixation system.

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48 The Anterior Extraperitoneal Video-assisted Approach to the Lumbar Spine

M. Onimus, H. Chataigner

48.1 Terminology

The technique described is an open, mini-invasive approach to the anterior lumbar spine which can be performed with the help of "open" endoscopy.

48.2 Surgical Principle

The anterior lumbar spine is approached through a small anterior midline skin incision via an extraperitoneal (retroperitoneal) route: right-sided for L5-S1 approach, left-sided for lumbar discs approach. Illumination and magnification of the surgical field is provided by an "open" endoscopic technique. The optical system (stab lens) may be introduced toward the target area through the same skin incision or through a second, separate skin incision.

48.3 History

Endoscopic lumbar surgery has developed in two different directions:

1. Transperitoneal laparoscopic surgery was developed for laparoscopic discectomy and fusion, the advantage of which being to give an approach to the anterior aspect of the disc through a natural cavity. But there are several disadvantages to the transperitoneal approach: the need for gas insufflation, the risk of peritoneal complications, and the difficulty to access the L4-5 level. Moreover, true laparoscopic surgery is demanding and special training is necessary.
2. Extraperitoneal laparoscopic surgery was initially proposed for lumbar sympathectomy. The lateral extraperitoneal approach is not subject to peritoneal complications, and this approach makes it possible to perform lateral osteosynthesis. However, the exposition is provided to the lateral part of the disc, making it more difficult than an anterior exposure for the strict midline placement of any reconstructive device, such as cages, grafts, etc. Moreover, the lateral extraperitoneal access to the lumbosacral disc is difficult and is very infrequently performed.

The minimally invasive technique of the video-assisted approach described here has the advantages of both an anterior midline and an extraperitoneal approach, without the specific disadvantages of laparoscopic surgery. This approach is related more to a microsurgical open approach than to true "closed" endoscopic surgery. Disc exposition is facilitated by a specially designed self-retaining retractor. The technique was reported in 1996 [14].

48.4 Advantages

The anterior extraperitoneal video-assisted approach is conventional surgery performed with ordinary instruments. The advantages of this technique include the following:

- An extraperitoneal approach
- A wide anterior midline access to the disc
- An optimization with video assistance

The advantages of an extraperitoneal approach are:

- Previous abdominal surgery and bowel adhesions do not make the procedure more difficult.
- During surgery, the bowel is withheld by the peritoneum and does not invade the operative area. The risk of vascular and peritoneal complications is reduced, as well as the risk of postoperative septic complications.
- The postoperative course is safer and uneventful with an early return to normal transit. The classic risk of late bowel obstruction is completely eliminated.

The advantages of an anterior midline approach are:

- To give a direct access to the anterior aspect of the disc and adjacent vertebral bodies, allowing grafting in an optimal midline situation

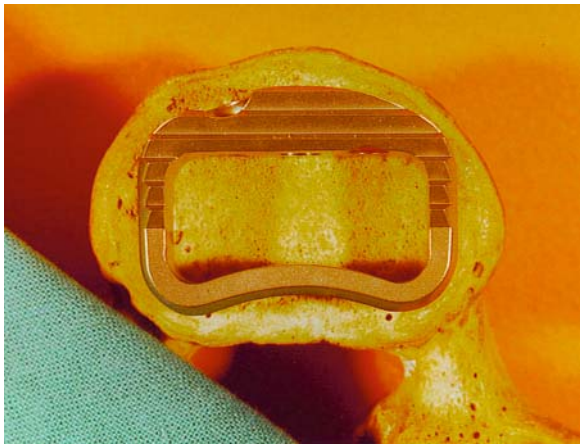


Fig. 48.1. A massive cage, providing a large surface for fusion, may be inserted through the midline approach

- To give access to all discs from L2 down to S1, using a similar dissection for each level, even if the more commonly approached levels are L4-5 and L5-S1
- To allow insertion of a unique ring cage, providing more stability and a wider surface of fusion between graft and vertebral plates than conventional twin cages (Fig. 48.1)

The advantages of video assistance are:

- To make the procedure a minimally invasive one through a keyhole incision.
- To improve the lighting of the operating area.
- To provide a better visualization to the presacral area, allowing an easier and more acute dissection.
- Good visualization of the vertebral end plates with an angulated endoscope gives assurance of a better decortication up to the subchondral bone, thus increasing the fusion rate.
- Compared with transperitoneal or extraperitoneal closed laparoscopic surgery, open surgery with video assistance has the advantage that there is no need for CO_2 insufflation.
- A last advantage is that no specific training is necessary. The approach is a conventional one which can be performed without video assistance or through a wider incision. A wider midline incision does not transect any muscular fibers and has no specific disadvantages. This gives the surgeon the possibility of learning the technique and progressively reducing the length of the incision as he/she becomes more skilful with the technique.

48.5 Disadvantages

No obvious disadvantages can be described with the extraperitoneal approach. Special attention must be given to the cleavage of the peritoneum. Cleavage of the anterior peritoneum close to the midline is difficult because the peritoneum is thin and can be torn, especially in women. This is avoided by dissecting not between the posterior sheath of the rectus and the peritoneum, but anteriorly to the posterior sheath of the rectus, between the sheath and the muscle. The peritoneum is more resistant on the lateral wall of the abdomen and cleavage is easier, making peritoneal tears infrequent. The cleavage is considerably facilitated by the use of an inflatable balloon.

The anterior midline approach to L4-5 may be difficult in obese patients and an anterolateral approach may be preferred (see Section 48.11.1)

The main disadvantage of the anterior approach is that a rigid osteosynthesis is usually contraindicated because of the proximity of the great vessels, except if a very low profile system is used. As a result, a posterior additional osteosynthesis may be necessary when a solid stabilization is required.

When a scoliotic deformity is present, an anterior midline approach does not give direct access to the anterior aspect of the vertebral bodies which face more laterally because of the vertebral rotation. In such circumstances, an anterolateral pararectal approach may be preferable, giving access to the anterior aspect of the vertebral bodies. Furthermore in this situation the great vessels remain more medially and are not troublesome.

There are no specific disadvantages to the use of video assistance. The endoscope can be introduced through the midline incision, avoiding an additional port and giving better endoscopic vision to the disc than through a lateral port. However, video assistance is not necessary and a headlight may provide effective lighting. The main advantage of video assistance is to give the assistants the possibility to observe the surgery.

48.6 Indications and Contraindications

This technique can be used from L2 to S1 in all situations requiring an anterior approach to the lumbar spine, such as open biopsy, vertebral reconstruction, or segmental interbody fusion.

The technique can be used for open biopsy of the lumbar vertebral bodies. However, isolated open biopsy is not frequently indicated and in many cases a more complex vertebral resection and reconstruction has to be performed. This approach is not routinely considered for vertebral reconstruction in traumatic lesions nor for

corporectomy in tumoral lesions because the proximity of the great vessels makes hazardous a stabilization by an anterior aggressive osteosynthesis. In selected cases, graft fixation can be performed using embedded screws.

The selective indication for the anterior extraperitoneal video-assisted approach is anterior interbody fusion (ALIF) which can be considered in two main situations, both concerned with disc degeneration: painful progressive spondylolisthesis and low back pain due to degenerative disc disease.

48.6.1 Progressive Spondylolisthesis

Progression of spondylolisthesis in adults is related to disc degeneration. In L4-5 an obvious instability may be observed, suggested by a major hypermobility occurring in flexion and in extension. In L5-S1 the instability is latent and is suggested by the slip progression with tilting of the upper vertebra in a segmental kyphosis, and progressive disc collapse. In such situations, posterior stabilization may be insufficient to provide correction and stability and an additional anterior fusion may be considered. The anterior fusion can be performed during the posterior surgery (PLIF procedure). However, the PLIF procedure is more aggressive for posterior structures than an ALIF procedure performed by a mini-invasive technique. Moreover, correction of the slip and the disc collapse is easier by an anterior approach. The anterior approach is performed in a first surgical step, then the patient is turned into a prone position and an additional posterior fixation is performed during the same operative procedure.

48.6.2 Degenerative Disc Disease

Indications for surgery in low back pain by degenerative disc disease are still a challenging problem, as no unquestionable predictive criteria are available to indicate fusion. Stabilization by anterior fusion may be successful in relieving a discogenic pain. The aspects of disc degeneration on discogram are common and not specific; equally the pain reproduction test is not specific as it is patient- and operator-dependent. The disc changes on MRI [12] (decreased signal on T2-weighted image) are also non-specific. More attention should be given to vertebral plates and adjacent bone marrow changes on MRI. Modic type I changes (inflammatory changes with decreased signal on T1 and increased signal on T2-weighted images) have been correlated with low back pain [18]. We observed the best results after anterior fusion when inflammatory changes were present on adjacent vertebral plates [2]. The exact source of the pain, disc or vertebral plates, is unknown; however, Moore et al. [13] observed an intraosseous hyperpressure associated with Modic I changes, similar to that present in painful peripheral joint osteoarthritis, and suggesting that the recommended treatment should be stabilization by fusion (or disc prosthesis). Anterior fusion can be performed by a posterior approach, but preferably by an anterior approach, as posterior elements are intact and posterior stabilization is not indispensable. Furthermore, a canal exploration is unnecessary.

48.7 Patient's Informed Consent

No specific patient's informed consent is required because this is conventional surgery, performed with ordinary instruments. Preoperative routine information must be given to the patient with special reference to the specific complications of the anterior approach to the lumbar spine.

48.8 Surgical Technique

48.8.1 Patient Positioning

The patient is placed in a routine supine position with a pillow under the knees to have a good relaxation of the vessels. Bending the table in lordosis after exposure of the disc will widen the intervertebral space. No specific preoperative bowel preparation is used, and no nasogastric tube is placed. A urinary catheter is inserted after general anesthesia.

48.8.2 Surgical Steps

48.8.2.1 Approach to L5-S1

The surgeon stands on the left side of the patient, with one assistant standing on the right side and an additional assistant standing beside the surgeon who will have to hold a peritoneal retractor before insertion of the self-retaining retractor. A short 5-cm vertical skin incision is made half way between umbilicus and pubis (Fig. 48.2a). In female patients, a more cosmetic horizontal suprapubic incision is possible for approaching the lumbosacral disc. Checking the right localization of the incision by imaging amplifier may be necessary, as the incision must be exactly situated in the direction of the disc.

The lumbosacral disc should be preferentially approached from the right side, because the common iliac vein lies vertically on the lateral aspect of the disc; conversely the left iliac vein lies obliquely on the disc and it has to be laterally retracted should a left approach be

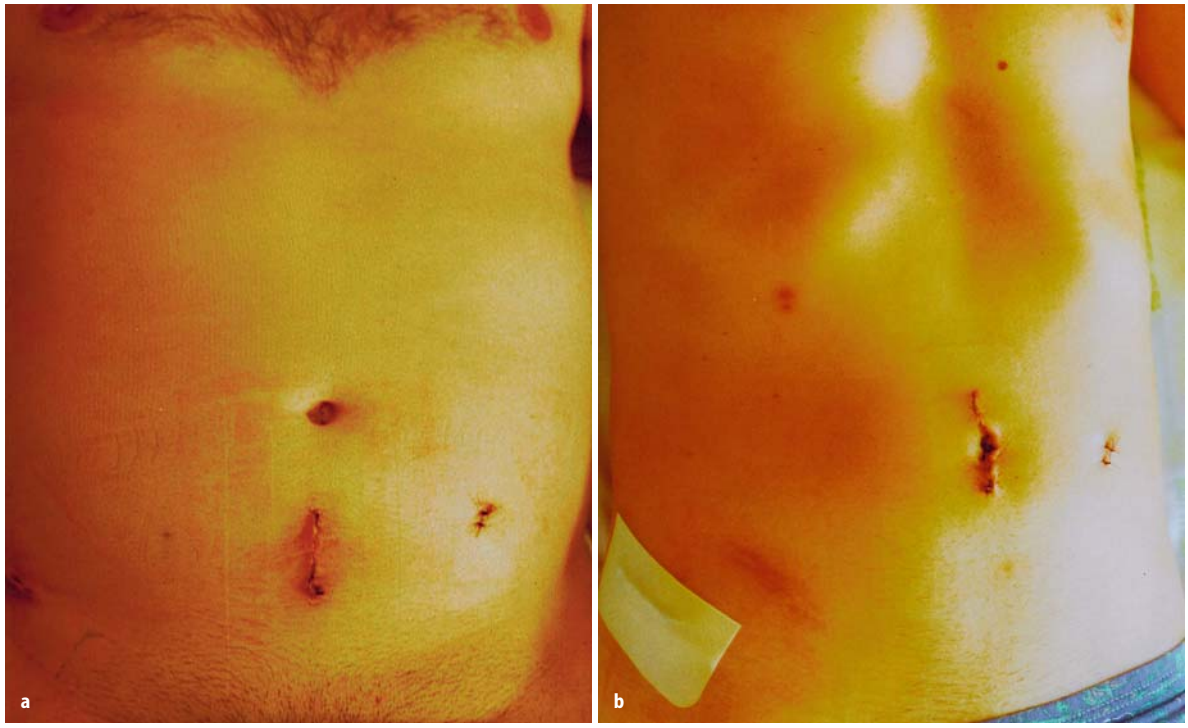
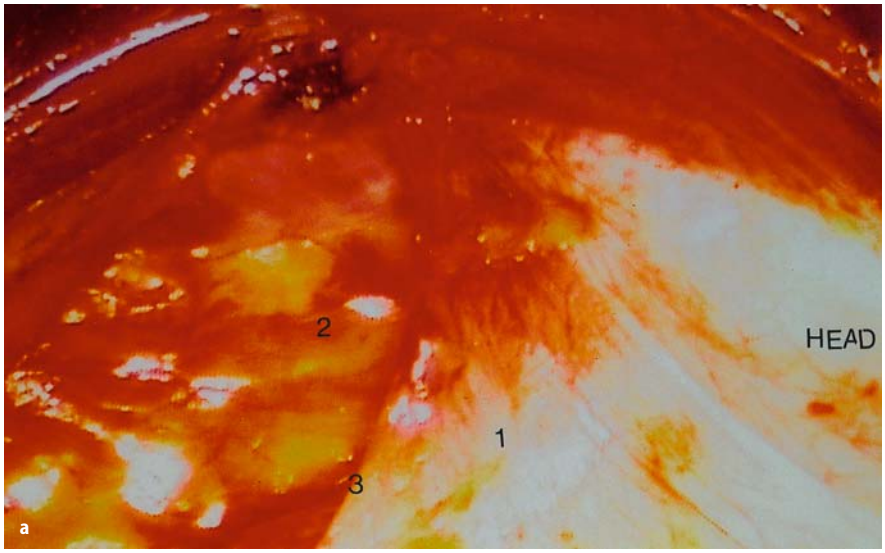


Fig. 48.2. a Postoperative aspect of the vertical midline skin incision for approach to the L5-S1 disc. **b** Postoperative aspect of the skin incision after L4-5 approach

performed; furthermore the right iliac vein is protected by the common iliac artery and is nearly not seen during the procedure. The anterior sheath of the right rectus abdominis is opened, and the muscle is gently pulled up, allowing it to be cleaved from its posterior sheath. Adhesions of the muscle to the posterior sheath are not observed and the cleavage is easy. Epigastric vessels are pulled up together with the rectus abdominis muscle. The posterior sheath of the rectus is a barrier in front of the peritoneum but it does not extend below the linea arcuata (Fig. 48.3a) and is often not necessary to be open. Occasionally an upward 1- to 2-cm incision of the posterior sheath from the linea arcuata is sufficient to give a wide exposure on the peritoneum. The dissection is continued in the extraperitoneal fascia, with progressive cleavage of the peritoneum from the lateral abdominal wall and the iliac muscle. The cleavage of the peritoneum may be difficult in cases where there has been a previous appendectomy and the peritoneal adherences should be gently released. The peritoneum is then medially retracted with a large retractor and the extraperitoneal cavity is progressively enlarged A 10-mm endoscope can be inserted either through a lateral port situated at the level of the disc or through the midline incision. The introduction of the endoscope gives good illumination and visualization to the operative field, and allows the operation to be continued through the midline incision, under both endoscopic and direct vision. The next landmark is the prominent psoas muscle and then the lateral iliac artery lying on the medial side of the muscle is identified. By backward dissection of the artery, the iliac bifurcation is exposed. The right iliac vein is covered by the iliac artery and is usually not seen. The lumbosacral disc is medial to the bifurcation and it can be identified by palpation as the first prominent structure above the sacral concavity (Fig. 48.3b). Its anterior aspect is still covered by the fibrous and nervous tissue constituting the presacral network. These have to be progressively dissected and retracted by blunt dissection with peanut swabs until the disc exposure is sufficient. Cauterization should be avoided because of the risk of damage to the hypogastric nerves supplying the bladder, eventually resulting in retrograde ejaculation. The only vascular structures to be divided are the midsacral vessels. They should be hemoclipped and cut, giving a wide exposure to the disc. The ureter is usually identified; it is adherent to the peritoneum and is medially retracted together with it. A specific self-retaining retractor is inserted, providing a medial retraction of the peritoneum and a lateral retraction of the iliac vessels. This retractor is held in place with Steinmann pins inserted in adjacent vertebral bodies. It is made up of two expandable blades allowing intervertebral distraction (Fig. 48.4a). The medial blade is first inserted and secured to the vertebral bodies of L5 and S1. Then the lateral blade is inserted and secured. Both blades are joined together with a half ring giving definitive stability to the construct (Fig. 48.4b). The procedure is then



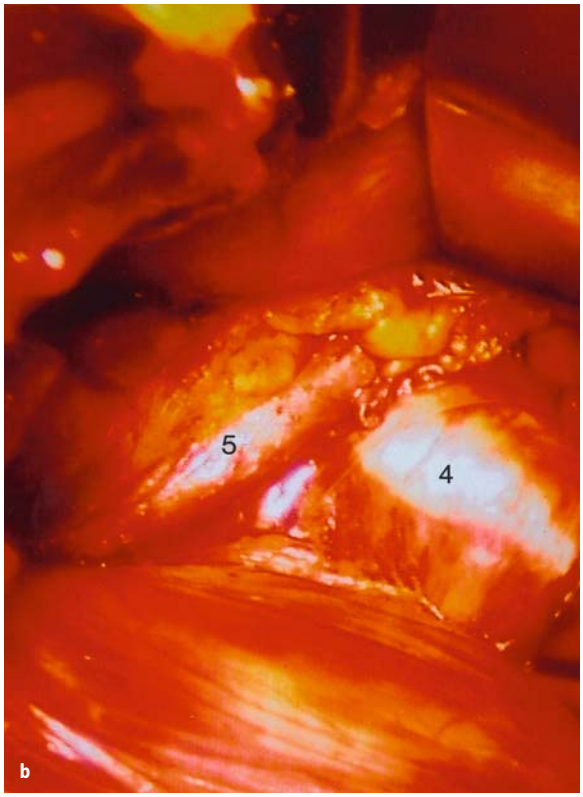


Fig. 48.3. a Perioperative aspect of L5-S1 extraperitoneal approach. The posterior sheath of the rectus abdominis (*1*) is present in the upper part of the operative field; the peritoneum (*2*) can be seen below the linea arcuata (*3*). **b** Perioperative aspect of the lumbosacral disc, after exposition and division of the midsacral vessels. The disc (*4*) is medial to the iliac bifurcation and prominent above the sacral concavity. Iliac artery (*5*)



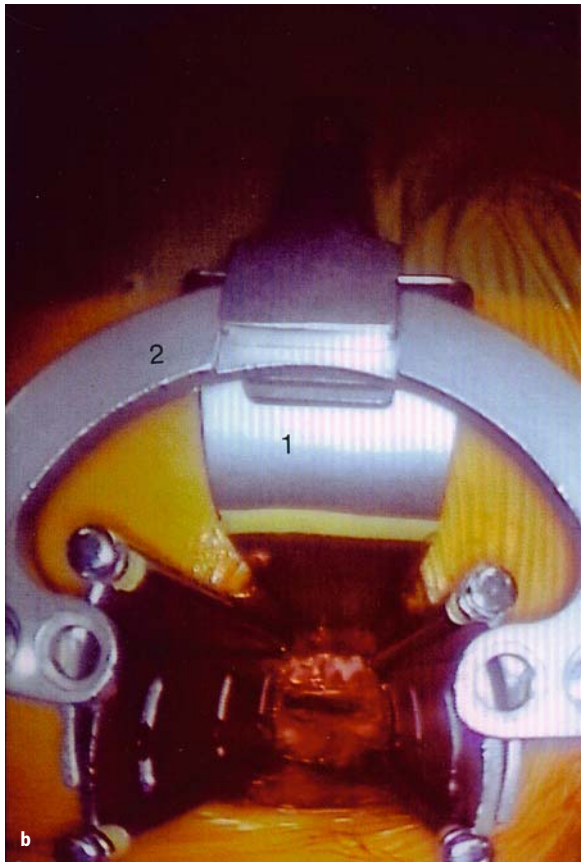


Fig. 48.4. a The self-retaining retractor is made up of two adjustable lateral blades linked by a half ring and secured to the adjacent vertebral bodies by pins. **b** The retractor in place during an L5-S1 approach. An additional third blade (*1*) is secured to the half ring (*2*) and can be inserted for cranial retraction of the peritoneum if needed

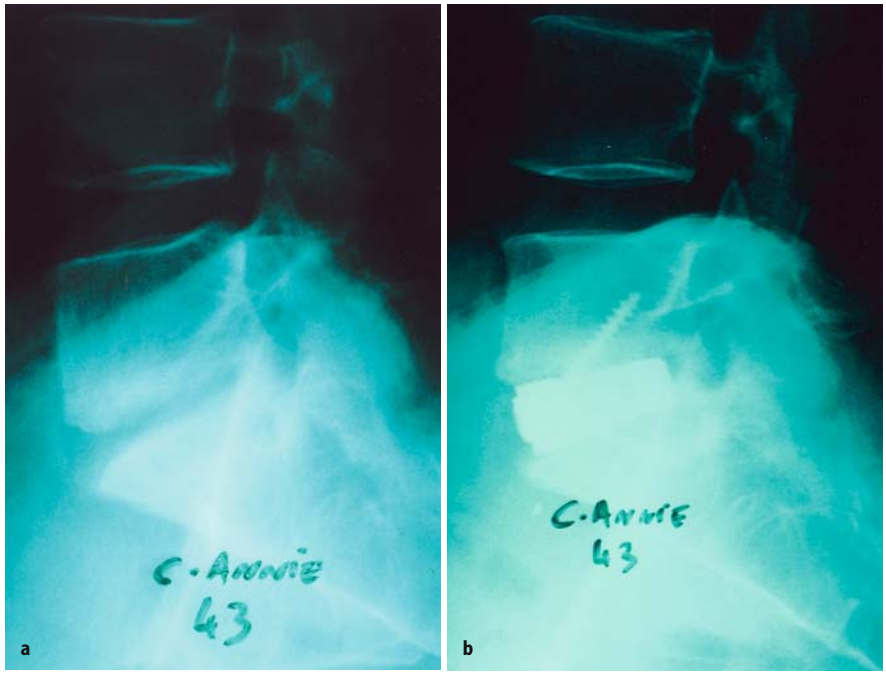


Fig. 48.5. a Preoperative radiograph of a patient presenting with a degenerative painful lumbosacral disc. **b** Postoperative radiograph after anterior extraperitoneal approach and insertion of a massive ring cage filled with iliac graft. The cage is screwed to the adjacent vertebral bodies. Screwing provides primary stability making a posterior fixation unnecessary

carried on, still under endoscopic illumination and still through the midline incision, with disc excision and vertebral plates decortication. A powerful intervertebral distraction is performed with a long-arm spreader, giving a normal intervertebral height and widening the foramen. Then fusion can be performed. A ring cage filled with cancellous iliac graft is inserted and screwed into the adjacent vertebral bodies (Fig. 48.5a, b).

The wound is closed after insertion of a retroperitoneal suction tube; the only structures to be sutured are the anterior sheath of the rectus abdominis muscle, the subcutaneous fascia, and the skin.

48.8.2.2 Approach to Lumbar Discs

The routine approach to lumbar discs is left sided. The surgeon stands on the right side of the patient, with an assistant standing on the left side and an additional assistant beside the surgeon on his left. It is important to have both hips of the patient slightly flexed during the approach in order to have relaxation of the iliac vessels, making it easier for their dissection and retraction. The operating room table will be curved in lordosis after the disc exposure.

For the approach to L4-5, a 5-cm vertical incision is centered on the umbilicus (Fig. 48.2b); for the approach to L2-3 and L3-4 the incision is made above the umbilicus; fluoroscopic control may be necessary to ensure the right alignment of the incision in the axis of the disc. The approach is similar to the L5-S1 approach, with incision of the left rectus anterior sheath and retraction of the muscle together with its anterior sheath. The approach is performed above the linea arcuata and the posterior sheath is a continuous barrier which has to be divided at the lateral side of the rectus in order to enter the extraperitoneal space. A small orifice is opened in the posterior sheath of the rectus and an inflatable balloon is introduced in the extraperitoneal fascia and pushed down in the lateral lumbar area. The insufflation of the balloon provides complete cleavage of the peritoneum from the posterior sheath and from the lateral abdominal wall. After removal of the balloon, the posterior sheath is easily divided and the extraperitoneal cavity can be progressively enlarged with medial retraction of the peritoneum. The ureter is retracted together with the peritoneum. The endoscope is introduced through a lateral port or through the midline incision. The next landmark is the psoas muscle, which is identified as the first prominent structure on the posterior area. The muscle is progressively exposed; the dissection becomes more superficial on the anterior aspect of the psoas muscle and it should not be carried on deeply at the lateral side of the muscle where the lumbar roots can be injured. The approach to the lumbar discs is lateral to the great vessels; these have to be gently dissected and medially retracted until disc exposure is sufficient. Then the retractor is inserted and secured.

48.9 Postoperative Care

Liquid alimentation is allowed on the first postoperative day, with progressive return to normal alimentation after bowel evacuation (usually by the third postoperative day). The patient is allowed to stand up on the second postoperative day. A lumbosacral orthosis is prescribed for 2 months and should be worn during daily activities, being removed at night. Sitting in a deep arm chair is restricted; patients are advised to sit on a stool or on the edge of a chair, keeping a straight lumbar spine.

48.10 Hazards and Complications

The complications observed were listed from a series of 90 patients, all of them operated on with the technique.

48.10.1 Perioperative Complications

Only vascular complications have been observed: five perioperative iliac vein injuries occurred during the L4-5 (three cases) and L5-S1 (two cases) approaches. In one case, a lumbar vein avulsion occurred during the disc exposure. In four cases the operation was uneventful; the vein injury probably occurred during the exposure and the bleeding occurred at the end of the procedure, at removal of the retractor. In all cases the bleeding was controlled by suture or hemoclip without enlarging the approach. Perioperative injury to the great vessels is a well-known complication reported in conventional anterior surgery: the 15% rate in Baker et al.'s series [1] is consistent with the 5% incidence observed in our review. Venous injuries are more frequent than arterial injuries. According to the literature, most of the injuries are small tears, easily treated by a clip or a stitch. According to some investigators, venous repair often results in secondary thrombosis; however, we did not observe this complication. No perioperative peritoneal, gastrointestinal, neurologic or urologic complications were observed. The overall incidence of perioperative severe complications after conventional extraperitoneal approach is equally low; the 38% incidence in Rajamaran et al.'s review [15] included many minor complications. Most of the complications in Escobar et al.'s review [5] occurred during the transperitoneal approach.

48.10.2 Postoperative Complications

The main complication to avoid at the L5-S1 level is postoperative retrograde ejaculation due to presacral nerve injury. The reported incidence is highly variable: 1 case out of 55 in Flynn and Price's series [6]; 2 cases out of 50 in Christensen and Bunger's series [4]; 9 cases out of 40 (17%) in Tiusanen et al.'s series [17]; 6 cases out of 146 (4%) in Sasso et al.'s review [16]; and 4 cases out of 50 (8%) in Escobar et al.'s series [5]. We observed 2 cases out of 20 (10%), one of them resolving at the sixth postoperative month. The exact incidence of this complication is still controversial, as the published series often do not separate the material by gender nor by the operated levels. It should occur specifically after approach to the lumbosacral disc where the dissection of the presacral area may damage the sympathetic fibers supplying the bladder. There is no unanimously accepted consensus regarding the prevention; the left and transperitoneal approaches should be more aggressive than the extraperitoneal and right approaches [6, 7, 16, 17]. According to the literature, it is important to perform a gentle and bloodless dissection, without electrocauterization, and with careful retraction of any vertical structure lying in front of the lumbosacral disc. However, some fibers are extremely tight against the disc and difficult to retract, and the risk should be seriously taken in account when considering a lumbosacral fusion in young male patients and a posterior approach may be preferable. Postoperative arterial obstruction has been described [8, 9, 11], especially in the elderly, but was not observed in our series. Such a complication may occur in cases of pre-existing vascular disease, and, in patients with increased risk, a vascular work-up should be performed before surgery as well as perioperative monitoring of lower limbs flow. A sympathectomy syndrome was observed in 3 cases after an L4-5 approach.

48.11 Critical Evaluation

48.11.1 Level of Approach

The approach can be performed for access to lumbar discs from L2 to S1. Disc surgery on L2-3 or L3-4 is infrequently indicated. The skin incision is made above the umbilicus. Care must be taken of the peritoneum which is very thin and can be entered. The balloon insufflation makes the cleavage easier and peritoneal tears are unlikely to occur. When approaching the L2-3 disc, retraction of the peritoneum must be made cautiously to avoid damage to the spleen. For both levels, the anterior aspect of the disc is easy to palpate; the aorta must be medially retracted and it is necessary to divide at least one of the adjacent segmental vessels.

At the L4-5 level, the iliac vessels obliquely cross the anterior aspect of the disc. They must be dissected and retracted caudally and medially. Dissection must be carried out carefully; the common iliac artery is the

first element to be identified along the medial border of the psoas muscle; the iliac vein is more deeply situated and is seen after retraction of the artery. It should also be gently dissected and retracted toward the midline. A complete exposure of the anterior aspect of the disc is possible but that requires an extensive dissection and retraction of the iliac vessels. Adhesions of the vein to the disc may be present, making the dissection more difficult. The L4 lumbar segmental vessels may be divided to facilitate the retraction of the iliac vessels. Distal dissection of the iliac artery and vein must be performed as far as necessary to allow sufficient retraction of the vessels. The division of the iliolumbar vein is not usually necessary. The sympathetic chain lies more laterally on the anterolateral side of the disc, along the psoas muscle, and is normally not injured during the procedure.

The L4-5 anterior approach may be difficult in overweight patients and a wider skin incision may be necessary. The fat is mainly present in subcutaneous tissues and as soon as the extraperitoneal space has been reached the procedure can usually be performed in the usual way without specific difficulties. Dissection and mobilization of the great vessels is even easier in fatter people. In very obese patients, rather than risk an iliac vein injury, it may be preferable to perform an anterolateral approach by splitting the muscular fibers. This provides access to the anterolateral part of the L4-5 disc. After disinsertion and retraction of the anterior attachments of the psoas muscle, the anterolateral part of the disc is exposed and the self-retaining retractor can be inserted and secured to the adjacent vertebral bodies. It is then possible to perform a complete disc resection and vertebral plates decortication, working under the iliac vessels still protected by the remaining anterior longitudinal ligament and the superficial fibers of the annulus fibrosus. However, using this approach often results in injury to the sympathetic chain with postoperative temperature difference in lower limbs, which does not always resolve.

The L5-S1 approach is made below the aortic bifurcation; the iliac vessels are laterally situated and have to be only slightly retracted. Using a right-sided approach, the oblique left common iliac vessels are usually not seen; however, the dissection should not be performed too far to the left. A left-sided approach may be necessary, for instance in case of a combined L4-5 and L5-S1 approach; the left common iliac vein should be then dissected and laterally retracted. The anterior aspect of the disc is always easily identified. Use of cauterization should be strictly avoided. The presacral network is not as mobile in the areolar retroperitoneal tissue as reported in the literature and it may be difficult to retract together with the peritoneum.

The L5-S1 disc may be deeply situated, especially when a spondylolisthesis is present; care must be taken not to dissect right down into the sacral concavity, and the dissection must be carried on in an upward direction corresponding to the direction of the disc.

48.11.2 Intervertebral Distraction

Intervertebral distraction is very effective for correction of existing preoperative radicular pain, by increasing the foraminal volume [3]. The use of a large spreader allows distraction even in stiff and collapsed discs. In our experience, anterior distraction has never induced neurologic complications, probably because the distraction is anteriorly applied, far from the neural canal. Intervertebral distraction has the advantage of improving the sagittal alignment of the lumbar and lumbosacral spine, thus protecting the adjacent non-fused levels.

48.11.3 Video Assistance

The operation can be performed without video assistance. Illumination of the surgical field is improved by the use of a headlight. The main advantage of video assistance is to provide a better illumination and to allow the assistants to see the procedure. By using a 30° angulated endoscope, a careful visualization of the vertebral plates is possible, thus controlling their decortication.

48.11.4 Disc Reconstruction

The large exposure provided on the anterior aspect of the disc allows the possibility of reconstruction using a ring cage filled with bone graft. We use a titanium cage screwed into the adjacent vertebral bodies. Screwing does not increase the stability in flexion, in torsion, or in lateral bending, but it does increase the stability in extension as far as 31 % [10]. An additional posterior fixation may be useful in cases of posterior instability (Fig. 48.6).

48.11.5 General Criticism

As the approach is being performed through the abdomen, knowledge of abdominal and vascular surgery should have been acquired. As for any other anterior approach to the lumbar spine, the most striking perioperative complication is vascular injury; bleeding may occur during the exposure and is then easily identified; in some circumstances the insertion of the retractor may collapse the injured vessel and bleeding then will occur after the procedure has been completed, when the retractor is removed. The surgeon should

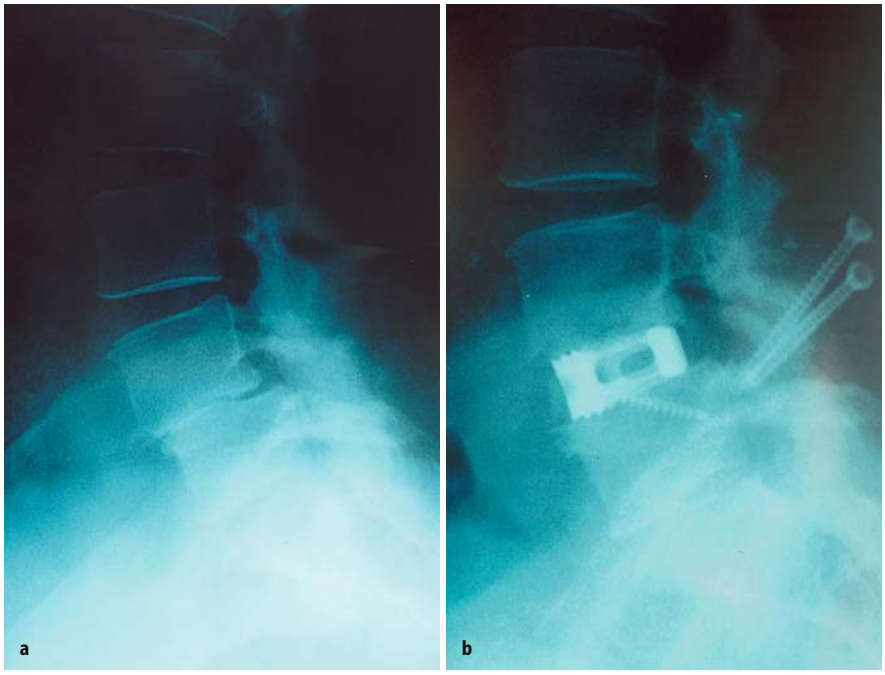


Fig. 48.6. a Painful degenerative spondylolisthesis treated by a combined mini-invasive procedure, including an anterior fusion performed through the anterior extraperitoneal approach and a posterior recalibration with translaminoarticular screwing. **b** Postoperative X-Ray showing the restoration of the intervertebral height and the sagittal alignment of the spine

maintain great attention until the retractor has been removed and a last look in the operative field after removal should be made. For these reasons, a mini-invasive technique should not consist only of a small keyhole incision, but more reasonably in a well-conducted and atraumatic surgery performed through the necessary skin incision.

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Minimally Invasive Dynamic Stabilization of the Lumbar Motion Segment with an Interspinous Implant

49

J. Sénégas

49.1 Terminology

The principle of dynamic stabilization consists in both increasing the stiffness of the intervertebral segment and limiting the amplitude of mobility to stop the otherwise inexorable course of degenerative disc disease, and possibly, in some cases, to foster the healing of the least severe lesions.

As in any dynamic system, a mobile intervertebral segment undergoes acceleration inversely proportional to the moment of inertia when it is submitted to a force. The rigidity of the system limits the displacement. This braking action preserves a margin of security and helps protect against tissue lesions involving the disc or the intervertebral ligaments. "Rigidity" is a mechanical parameter defined in terms of load for a given displacement. It corresponds to the slope of the load/deformity curve.

Laxity or a diminution in the rigidity of an intervertebral segment is constant in the degenerative process, as demonstrated by Ebara et al. [1] and Mimura et al. [7]. This is true regardless of the stage of degeneration. At the beginning of the degenerative process, before alteration of the disc height, an increase in the range of motion is observed on bending studies because of the greater laxity. When the disc lesions are more severe, intervertebral mobility is reduced because of the narrowing of the disc space. However, mechanical testing shows that the system is still less rigid than normally observed, the decrease being reflected by an increase in the neutral zone.

49.2 Surgical Principle

Depending on the indication, the Wallis implant is placed either subsequent to a conventional decompressive procedure or in isolated fashion through a midline incision. The supraspinous ligament is detached from the two spinous processes of the degenerative lumbar segment and retracted intact with the underlying paravertebral muscles. The interspinous ligament is removed and, if necessary, a decompressive procedure is performed. After determining the size with a trial implant, a spacer is placed in the interspinous space. Two attached tension bands are then secured and tightened around the spinous processes on both sides of the spacer stiffening the segment. The supraspinous ligament is reattached by single sutures through a hole in each spinous process and the wound is closed over a suction drain.

49.3 History

Prompted by progress achieved in similar techniques in other joints of the locomotor system, we began studying and developing dynamic stabilization of lumbar segments. Research in this field had been hindered by the fact that the multiarticular spinal system compensates relatively well for damage to a single segment, regardless of whether such lesions result from a degenerative process or surgical fusion.

The stretching of the elements of articular union leads to a force resisting the displacement. The dissipation of kinetic energy in the form of heat is mediated by the viscoelastic properties of the connective tissue (passive damping). This damping phenomenon would, in fact, be quite insufficient to protect the disc if it were not constantly supplemented by a much more effective active damping provided by the reflex contraction of the powerful paravertebral muscles. Although the dynamic equilibrium of the intervertebral articular system is dependent on a combination of muscle activity and tension of the passive elements of union, the active system constantly protects the passive elements, which consequently are never submitted to the limits of their elasticity under normal conditions.

Under these specific mechanical conditions, the intervertebral disc cells that produce the extracellular matrix exhibit normal activity. These cells are, in fact, mechanodependent, as demonstrated by Lotz and Chin [6]. They function normally only under a precise range of mechanical loading. Outside of this range, they initiate apoptosis. When loading is excessive or the active

system of damping is deficient, the passive system represented by the disc and intervertebral ligaments can be overloaded and rupture. If these lesions are not excessively severe, or if the lesional process takes place over time analogously to stress fractures, cell activity can repair the damage, as is the case in any connective tissue. However, when the stresses persist, the reparative process can be overwhelmed, and irreversible degenerative lesions develop if the loss of rigidity persists.

Nonetheless, the disc tissue, notably the annulus, has healing capacity, as do all connective tissues. In fact, an indisputable healing process can be observed in the intervertebral disc, with a fibroelastic reaction and neovascularization, at least at the beginning of degenerative lesions. However, the persistence of excessive mechanical loading leads to the failure of this healing process, similar to that observed in pseudarthrosis of long bones or in meniscal lesions.

We performed animal studies to test this hypothetical healing capacity of the intervertebral segment under propitious mechanical conditions. Encouraged by these preliminary unpublished results, we carried out biomechanical cadaver studies, mechanically testing various dynamic systems of stabilization of lumbar intervertebral segments, from 1984 to 1986. The system that we developed and first implanted in 1986 included a titanium interspinous blocker and a woven polyester cord. The results of an initial observational study were published in 1988 [12, 14]. This was followed by a prospective controlled study from 1988 to 1993 [15]. The results of these studies were quite promising.

Subsequently, more than 300 patients were treated for degenerative lesions with the first generation implant, with clinical and radiological follow-up. Assured of the complete innocuousness of the technique by the absence of serious complications in the latter patients over a 10-year period and after careful analysis of the points that could be improved, we developed a second generation implant called the "Wallis" system (Figs. 49.1, 49.2), which was marketed in 2002 [13].

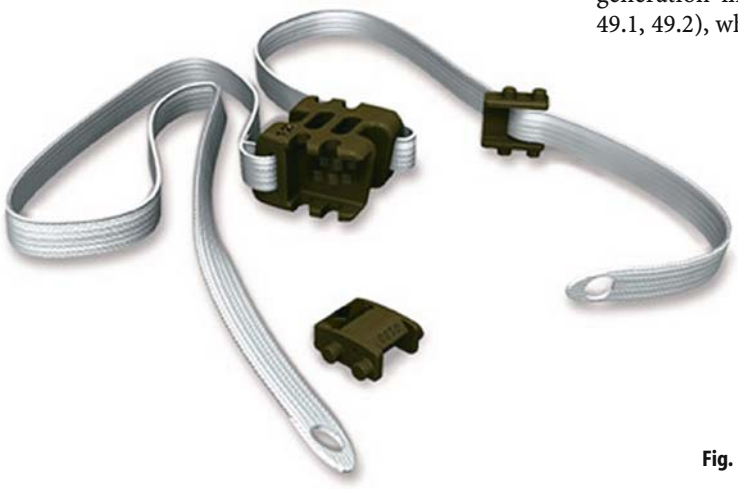


Fig. 49.1. The Wallis dynamic stabilization implant

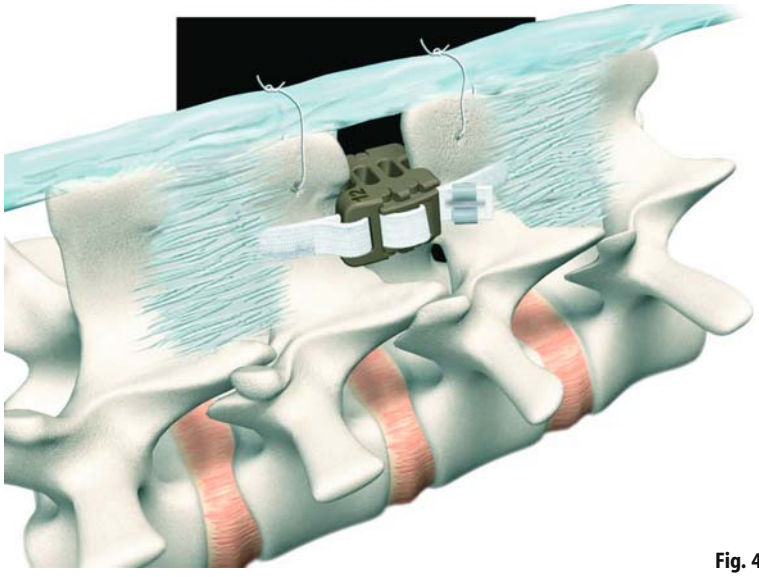


Fig. 49.2. A Wallis implant in place

49.4 Advantages

49.4.1 Technical Advantages

- No bony fixation, as we think it is illusory to hope for durable purchase of bone screws in a dynamic intervertebral construct.
- Due to its shape and its composition in polyetheretherketone (PEEK), the interspinous spacer is 30 times more elastic than the first generation (titanium) spacer to reduce the risk of spinous process stress fractures.
- Flat bands of woven polyester replace the former woven polyester cord to avoid stress concentration on the spinous processes and thus reduce the risk of osteolysis.
- Anatomical angles of the grooves for better fit in the interspinous process space.
- New system of attachment between the spacer and the bands eliminating the torque present in the former system at final tightening.
- The established long-term biocompatibility of PEEK and woven polyester.
- Completely radiolucent materials compatible with MRI.
- Radiodense markers for convenient radiographic follow-up.
- Reduced number of dedicated instruments for rapid placement of the implant.

49.4.2 Clinical Advantages

- Increases stiffness and restores stability to the treated segment relieving low back pain due to degenerative instability.
- Limits but does not eliminate movement in the treated segment (Fig. 49.3).
- Based on finite element analysis modeling the implant's effect on an uninjured lumbar segment and the intradiscal pressure, Wallis appears not to alter the mechanical behavior of the adjacent segment, possibly limiting the domino effect of degenerative disc disease.
- An interspinous spacer displaces mechanical loading dorsally reducing the load upon the disc and facet joints (by as much as 50% for a spacer 12 mm in thickness [8]).
- With the exception of the interspinous ligament and occasional slight trimming of the spinous processes, preservation of the vertebral and intervertebral structures.
- No pedicle screws, meaning less invasive procedure with fewer complications.
- Blood loss involving implant placement is negligible.
- Rapid placement reducing operative duration.
- The procedure is fully reversible, leaving all subsequent surgical options open, including fusion, disc replacement, and potential future cell therapeutic interventions [3].

49.5 Disadvantages

The disadvantages of the first generation implant have been identified and taken into account when developing the second generation implant (see above).

We believe that it is not possible to rigidify all joint elements of the intervertebral segment with a simple system. In our system of dynamic stabilization, only flexion/extension and rotation are damped.

To avoid problems involving screw fixation in a dynamic construct, the Wallis system is not provided with implants for the L5-S1 segment.

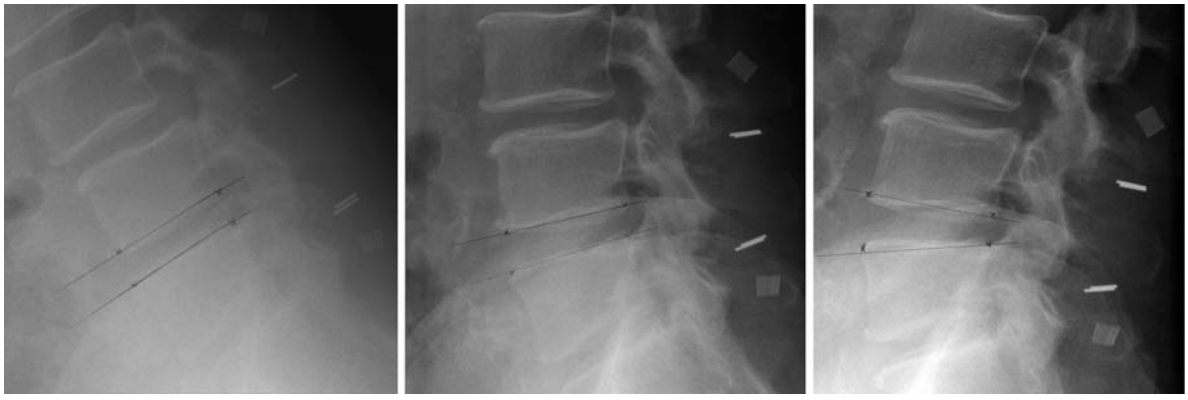


Fig. 49.3. Lateral films showing flexion (*left*), neutral position (*middle*), and extension (*right*). As shown by the lines drawn for the second level of this two-level procedure, extension appears to retain a larger range of motion than flexion in this patient. The radiodense markers of both implants are visible as are the clipping rings added to prevent fraying of the bands at each extremity

49.6 Indications

The Wallis mechanical normalization system treats low back pain that accompanies degenerative lesions of grades II, III, and IV (among the five grades in the MRI classification proposed by Pfirrmann et al. [10]) in lumbar segments down to L4-5 in the following indications:

- Voluminous herniated disc in young adults
- Recurrent herniated disc
- Herniated disc accompanying an L5 sacralization transitional anomaly
- Degenerative disc disease at a segment adjacent to fusion
- Modic I degenerative lesions
- Lumbar canal stenosis treated by undercutting ("recalibrage" in French).

49.7 Contraindications

- Grade V degenerative lesions in the MRI classification of Pfirrmann
- Spondylolisthesis
- Osteoporosis
- Non-specific low back pain
- Patent constitutional or acquired spinous process insufficiency
- L5-S1
- Litigation
- Patent psychological disorders

49.8 Patient's Informed Consent

It is important for surgeons to inform patients of the inherent complications of the spinal procedures performed under the same anesthesia as the implant. Regarding the Wallis dynamic stabilization procedure itself, the surgeon need only provide information on potential complications of anesthesia and spine surgery, in general (e.g., allergy to anesthesia, infection, deep venous thrombosis, pulmonary embolism).

It is just as important to inform the patient of the possibility of persistent low back pain due to concomitant degenerative lesions in other discs or facet joints, unless this possibility has been eliminated by methodical diagnostic procedures performed over several days prior to the operation [9, 11].

49.9 Surgical Technique

The procedure to insert a Wallis implant is typically associated with minimally invasive unilateral decompression consisting in discectomy, undercutting to enlarge the spinal canal, or both. Only the implant placement will be described here. The decompressive procedures will not be addressed.

49.9.1 Preoperative Planning and Preparation of the Patient

- Plain films
- Bending films
- MRI

49.9.2 Anesthesia

The operation is performed with the patient under general anesthesia, but with no precautions specific to the Wallis procedure alone.

49.9.3 Positioning

The patient is placed in the prone position on a frame of foam padding. A neutral position of physiological lumbar lordosis is best to optimize the effect of the implant. All efforts should be made to avoid subsequent lumbar kyphosis.

49.9.4 Surgical Steps

49.9.4.1 Localization

Carefully locate the segment requiring the implant with an image intensifier.

49.9.4.2 Skin to Interspinous Space

After a short midline incision, the supraspinous ligament is detached from the two spinous processes at the level involved and retracted laterally without sectioning.

After the initial incision, it is recommended to temporarily suture a small sterile surgical drape over the wound edge on both sides to prevent contact between the skin and the implant.

The interspinous ligament is resected. Rough edges of the inferior aspect of the upper spinous process and of the superior aspect of the lower spinous process are

trimmed, if necessary, to facilitate insertion of the interspinous spacer.

The bony junction between the laminae and spinous processes may also be trimmed to position the implant as anteriorly as possible and ensure a stable fit against the laminae. *Note*: If the procedure includes enlargement of a stenotic lumbar canal by resection of the upper portion of the laminae, make sure to preserve sufficient spinous process thickness.

49.9.4.3 Placement and Securing of the Implant

To preserve physiological lordosis, when hesitating between two implant sizes, the surgeon should choose the smaller implant. Given the prone position of the patient during the operation, substantial primary implant stability is not necessary.

The spacer is positioned in the interspinous space and the bands are passed through the interspinous ligament as close as possible to the instrumented spinous process. On each side, the system is secured by positioning and snapping onto the spacer a clip, through which the band is inserted. The bands are then tightened and a ring is crimped onto each band to avoid fraying after cutting off the excess band.

49.9.4.4 Reinsertion of the Supraspinous Ligament

The supraspinous ligament is returned to its original position and reinserted onto each spinous process with a single silk passed through a hole made in the spinous process using a Backhaus towel clamp.

49.9.4.5 Final Operative Procedures

To permit proper drainage of possible postoperative epidural bleeding related to a decompressive procedure, the operative wound should be closed over a suction drain on one side of the spacer.

49.10 Postoperative Care

- The suction drain is removed the following day in the absence of abnormal discharge.
- External lumbar support is recommended for 1 month.
- Patients should refrain from rehabilitation exercises for 1 month.

49.11 Results

A prospective single-arm open study of the second generation Wallis implant is underway, in which to date 220 patients (37 % women, 63 % men; age range 18 – 82 years; average age 44 years) have been included. Thirty-six percent of the patients presented with degenerative disc disease without disc herniation, 30 % with voluminous disc herniation, 18 % with canal stenosis, and 16 % with recurrent disc herniation.

The mean operating time for implant placement was 19 minutes and the mean time for surgery skin to skin was 79 minutes. The average blood loss was 190 cc. Forty-eight percent of the patients received a 12-mm Wallis implant and 38 % received a 10-mm Wallis implant. The most frequently operated level was L4-5 (92 % of the patients).

Among the 220 patients, there were six (2.72 %) postoperative complications. Three patients developed deep infection leading to removal of the implants. One patient with psychological problems had the implant removed by another surgeon 10 months after the intervention. Two implants were replaced by a second Wallis implant, one after immediate recurrence of herniated disc and the other after implant displacement. Although these were considered as adverse events, they confirmed the straightforwardness of Wallis implant replacement and that all options remained for other surgical solutions.

Preliminary, 12-month results have been obtained for 52 patients involved in the ongoing multicenter international study.

Preoperative evaluation of the functional and pain status of the patients was performed using the Japanese Orthopedic Association assessment of lumbar pain management (JOA score) [16], a visual analog scale for lumbar pain (VAS), and two quality-of-life questionnaires, the first version of the medical outcomes score short form 36 (SF-36) [4] and the Oswestry low back pain disability questionnaire [2].

In the preoperative period, 65 % of the patients had pain scores between 70 and 100 on the VAS and 90 % of the patients had pain scores between 0 and 30 1 year after surgery.

The result of the straight leg raising test was negative in 92 % of the patients. Sensory and motor disturbances were present in 75 % and 61.5 % of the patients before surgery and in 10 % and 4 % of the patients after 1 year, respectively.

The therapeutic success as assessed by Odom's criterion at 1 year follow-up found 89.6 % of the patients with excellent or good clinical results, 6.25 % with satisfactory results, and 4.15 % with poor results.

49.12 Critical Evaluations

The Wallis system is only applicable above L5 and does not include L5-S1. Although much work has been done and solutions have been found, none have been sufficiently satisfactory. Consequently, we have intentionally limited the application not to include the lumbosacral junction. A bilateral approach is necessary for the moment in order to secure the implant with the bands, but work is in progress to develop an implant that can be inserted through a unilateral approach. There is also a small risk of recurrent disc herniation due to the reduced, but persistent mobility of the segment.

Next to these points of criticism, the present system has many substantial advantages. It is technically simple and straightforward, with a short learning curve and reduced perioperative and postoperative morbidity. The early mobilization and rehabilitation of operated patients are also appreciable. One of the major incentives prompting the development of dynamic stabilization was its potential protective effect against accelerated changes in adjacent discs seen after fusion. Years of follow-up will be necessary to establish whether this theoretical advantage is actually achieved. Furthermore, although it is still too early to determine whether the treated disc tissue actually heals or undergoes scarring, there is MRI evidence of disc rehydration at follow-up. Many initially black discs are coming back with normal, white signal. Examples are shown in Figs. 49.4 and 49.5.

Among the notions to retain concerning dynamic lumbar stabilization, foremost are the good clinical results being observed. Follow-up evidence has convinced us that, to date, the efficacy of the new implant is at least as good as that of fusion.

Wallis is an operative alternative for many young patients with degenerative disc disease who suffer, but for whom fusion, or even a disc prosthesis, might seem too radical. Surgery rarely affords definitive solutions, and spinal surgery is no different. If the threshold of surgery is low and if a surgical procedure leaves other options open, a step-by-step strategy to treat low back pain without compromising future solutions should be considered. Through the Internet, more and more patients are aware of the advent of biological methods of treating degenerative discs with the patients' own stem cells or fibroblasts [3]. This perspective is at our doorstep. Stem cell therapy has already begun for tendon and ligament lesions [5]. For patients and surgeons, Wallis is a failsafe solution because the procedure is completely reversible. If relief from low back pain is not achieved or if, after years of relief, the degenerative process regains the upper hand, surgeons will still have all the original options to treat their patient. Consequently, this method should rapidly assume a specific role along with total disc prostheses in the new stepwise surgical strategy for early forms of degenerative disc disease.



Fig. 49.4. Patient with MRI evidence of disc rehydration at follow-up

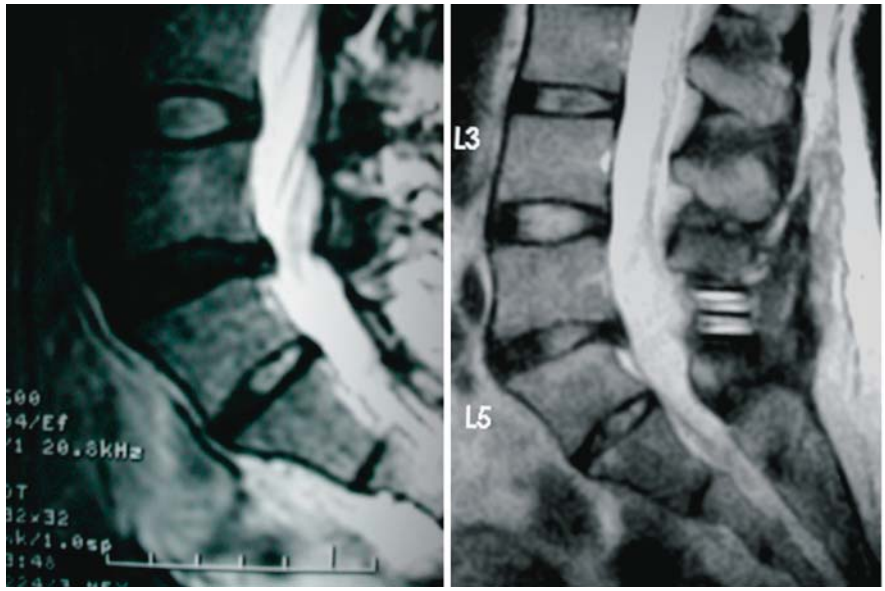


Fig. 49.5. Another patient with MRI evidence of disc rehydration at follow-up

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50 Technical and Anatomical Considerations for the Placement of a Posterior Interspinous Stabilizer

J. Taylor, S. Ritland

50.1 Terminology

Interspinous spacers/stabilizers are implants which are introduced between the spinous processes of the lumbar spine to achieve a segmental distraction.

50.2 Surgical Principles

The behavior of a functional spinal unit is related to the displacement of the center of rotation, making it possible to balance the moments and thus control the transferred loads. When a lordotic posture is used, the downward transmission of forces results in redistribution of loads which tend to be transferred posteriorly to the facet joints. The facet joints have an absorbing and a stabilizing role. Their impairment results from an ongoing aging process.

The Device for Intervertebral Assisted Motion (DIAM) acts as a shock absorber and displays a non-linear behavior. This implant is a silicone "bumper" that is inserted between the spinous processes. Both the height of the implant and the load applied to the implant influence the degree of mobility. It is used in various indications.

50.3 History, Advantages, and Disadvantages (see also Chapter 45)

Ligamentoplasty is an alternative technique to posterior arthrodesis. Ligamentoplasty devices can be classified into two groups: pedicle screw-based devices and interspinous ligamentoplasty implants. The interspinous implant is comprised of a silicone core wrapped into a polyester sheath connected to artificial ligaments of the same material. The DIAM is an interspinous stabilizer designed to assist the degenerated segment in both flexion and extension through its novel dynamic ability to stretch and compress in synchronization with the normal movement of the functional spinal unit.

50.4 Indications

50.4.1 Disc Herniation

This indication mainly interests the L4-5 level which is often unstable. The device is used to prevent pain resulting from overloading of the facets following a discectomy. Image analysis and intraoperative observation are most important because they may reveal hypertrophy of the posterior facets, synovial cyst, and stretching of the posterior supraspinous ligament with abnormal approximation of the spinous processes (Fig. 50.1). It is important to note that the consequences of the posterior transfer of loads are evidenced by indirect signs which need to be identified. These include:

- Retrolisthesis
- Discal hyperlordosis
- Disc tilt (often clearly visible with the patient under general anesthesia in the prone position)



Fig. 50.1. Combined dehydration of the disc and interspinous ligament

Note: The posterior interspinous stabilizer restores the vertical component of the posterior moment arm, which helps reestablish ligamentotaxis.

50.4.2 Lumbar Spinal Stenosis

Acquired spinal stenosis (Fig. 50.2) is by far the most frequent cause of neurogenic claudication (sciatica resulting from effort). A retrolisthesis worsens the stenosis and requires its reduction. Implantation of the device is always associated with nerve root decompression. There are three anatomical diagnoses (with a possible combination of two or all of them): foraminal stenosis, soft stenosis (disco-ligamentous; Figs. 50.3–50.5), and kissing spines. The implant acts on the foraminal bony elements to change local conditions (reducing venous congestion and traction on the spinal ganglion).

50.4.3 Facet Syndrome and Black Disc

In these cases, the device is implanted at one or several levels to assist in unloading the disc and the posterior articular columns which are subjected to excessive loads due to the degenerative process. A block-test helps identify the source of pain. In such cases, the conservative technique is valuable because it allows insertion of the implant with minimal tissue disruption, staying away from the nerve structures, and it is a time-saving procedure. One or more levels can be addressed with combinations of stand-alone implants and/or implants associated with decompression procedures.



Fig. 50.3. Soft stenosis



Fig. 50.2. Dynamic stenosis according Fuentes definition



Fig. 50.4. L4 retrolisthesis



Fig. 50.5. Postoperative X-ray

50.4.4 Topping-off

This indication addresses the adjacent segment after lumbar fusion. Degeneration of the adjacent segment results from stress concentration above or below the fusion. A posterior translation with hyperlordosis results in a foraminal narrowing due to a "pinch" effect. Therefore, this device should prove useful when used in association with fusion in cases where decompression and/or instrumentation may compromise the adjacent facets. This procedure can be used for both the cranial and caudal segments adjacent to a fusion. It might be used above/below a multiple-level fusion to delay degeneration of the segments adjacent to a fused level.

50.4.5 Precautions

- In osteoporotic bone, it is important to properly position the distractor which must rest on the junction between the spinous process and the lamina.
- Stable degenerative spondylolisthesis (grade I): this borderline indication is a matter of surgical experience.

50.5 Contraindications

- Unstable spondylolisthesis
- Neoplasia
- Fracture
- Isthmic Spondylolysis
- Idiopathic scoliosis

50.6 Patient's Informed Consent

This is a minimally invasive procedure which does not involve neural structures directly. A specific complication may be a dislocation of the implant and lack of efficiency.

50.7 Surgical Technique

50.7.1 Anatomical Considerations

The DIAM is a dynamic stabilization device (Fig. 50.6). To the extent that we disrupt the normal segmental musculature we damage the inherent dynamic stabilization of the spine and degrade our surgical outcome. The implant conforms to the interspinous anatomy and allows placement with minimal disturbance to the segmental muscles. While a simple midline approach with dissection of muscles from the spinous process is possible, attention to the details of segmental anatomy can preserve the neuromuscular integrity of the back.



Fig. 50.6. DIAM positioning between the posterior arches

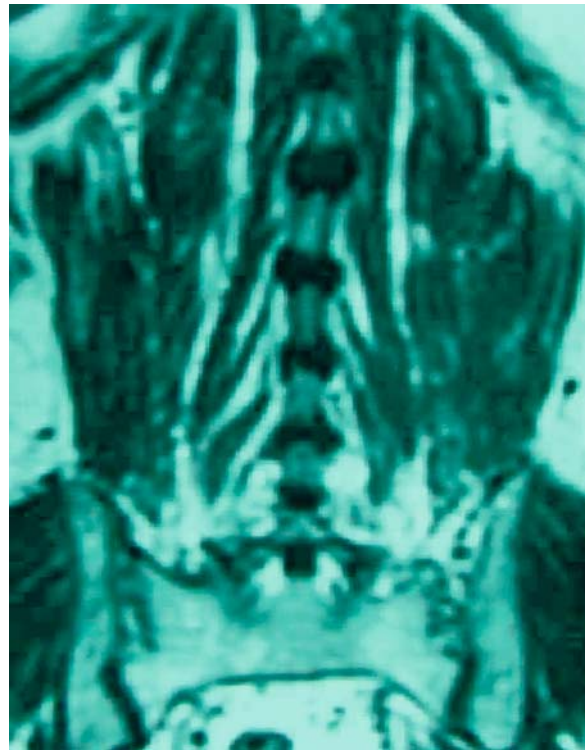
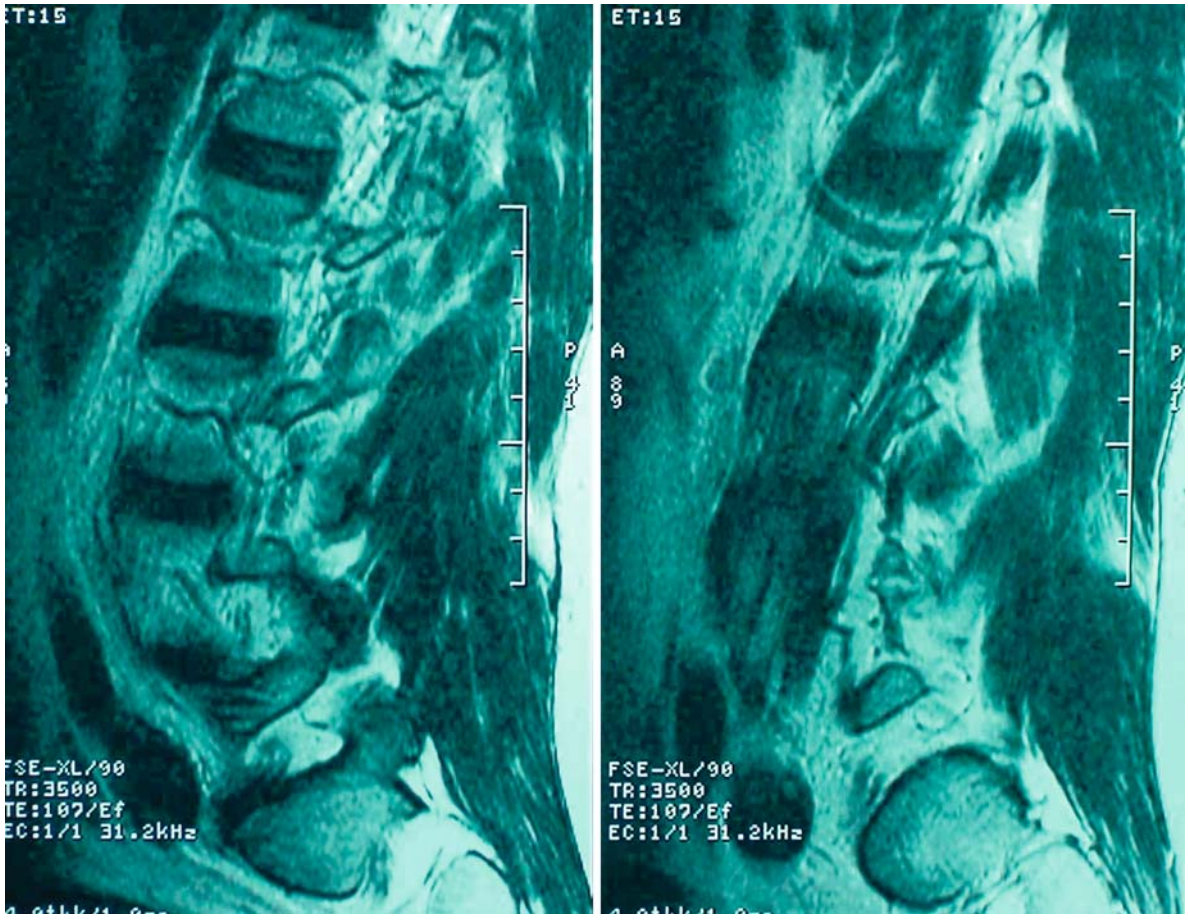


Fig. 50.7. MRI view of the multifidus muscle

The midline muscle group in the back is the multifidus (Fig. 50.7). This is a series of muscles, with each arising from its spinous process and developing insertions to more caudal articular processes and to the sacrum. As seen on MRI images (Fig. 50.8) there is a relatively robust pair of tendons originating from the caudal aspect of each spinous process. The major portion of the tendon arises from the dorsal two thirds of the caudal spinous process. The more ventral aspect of the tendon thins out dramatically as it continues to the medial aspect of the caudal lamina. As the sagittal image demonstrates, there is a plane along the spinous process and over the lamina free of any attachments. Entry in this plane allows retraction of the cephalic fascicles of the multifidus with preservation of the origin of the caudal segment.

The segmental neurovascular supply to the multifidus is the medial branch of the dorsal ramus and the accompanying artery of the pars interarticularis

Fig. 50.8. MRI image of the tendons' origin



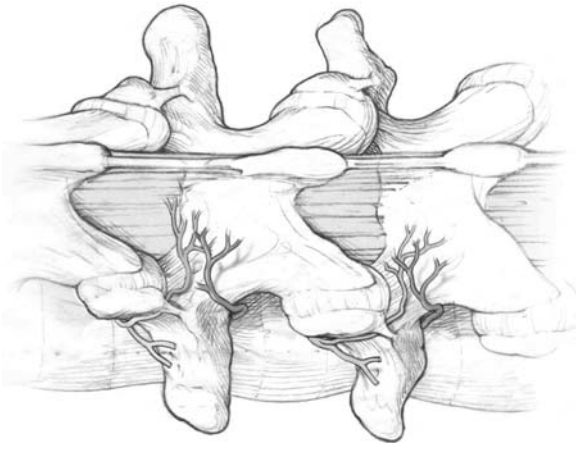


Fig. 50.9. Segmental neurovascularization



Fig. 50.10. Origin of multifidus

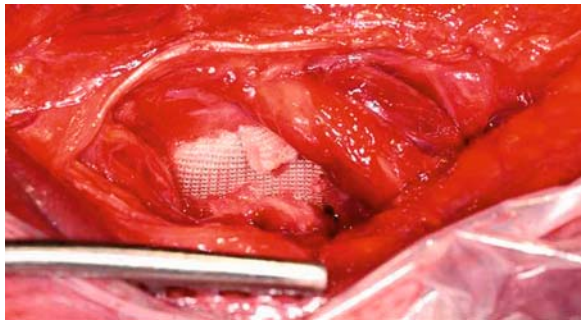


Fig. 50.11. Preserving implantation

(Fig. 50.9). The neurovascular complex penetrates the muscle from the ventral and ventromedial aspect of the fascicle. If one respects this plane with careful retraction of the muscle, the neurovascular supply is generally not compromised. As long as the insertion of the multifidus to the superior articular process is maintained and retraction kept against the bone or facet capsule, the cephalic artery is unlikely to be injured. If exposure in this plane is continued caudal to the joint to the dorsal lamina of the level below there is potential to injure the vessel below; however, this exposure is not typically necessary for foraminal decompression or discectomy. It is a very simple matter to perform a segmental exposure with preservation of the tendon at each level.

The erector spinae is a broad flat tendon covering the back muscles. It is the tendon of the pars thoracis of the erector spinae complex. When viewed from the back the fibers are seen to converge from cephalic to caudal. This tendon has a stout insertion developed at each level to the spinous process. This insertion is to the upper aspect of the spinous process and continues along the dorsolateral margin of the process. When viewed in surgery it is seen as a broad flat tendon. It frequently is appreciated as having a banded appearance with thinned areas allowing visualization of the underlying muscle. It is important to appreciate what happens with flexion and extension of the back. In a young person the disc segment will flex in the order of 15°. With this flexion the spinous processes will separate in the range of 15 – 20 mm. The banding seen in the aponeurosis allows for a relative shearing motion of the segments of the tendon to deal with changes occurring with flexion.

Approaching the spine from an approach 10 mm or thereabouts from the midline allows preservation of the integrity of the erector spinae insertion while making an approach along the spinous process. One needs to be far enough lateral to the midline to divide the aponeurosis and retract the portion inserting to distal spinous processes adequately for the desired approach to the spine.

The superficial layer of the dorsal lumbar fascia is the aponeurosis of the latissimus. For a discreet approach a medial lateral orientation to open this layer works well or a vertical opening provides as much exposure as desired.

Once retraction of the cephalic fascicle of the multifidus is accomplished the lateral aspect of the origin of the multifidus from the spinous process is seen (Fig. 50.10). This is a well-developed robust tendon arising from the caudal margin of the spinous process. An instrument may be passed deep to the ligament across the midline through the interspinous space. This may entail penetrating the most ventral portion of the tendon as it sweeps to the caudal margin of the lamina, however, this is generally a very thinned out and relatively minor portion of the tendon. Some detachment of the ventral portion of the tendon may be required in some cases for comfortable placement of the device. This places the device in a ventral location on the lamina with preservation of tendon dorsal to preserve the natural dynamic stability of the spine and to help naturally secure the device in its most appropriate location (Fig. 50.11).

50.7.2 Surgical Procedure

General anesthesia is most commonly used for this type of procedure. However, local lumbar anesthesia may also be utilized: spinal or epidural anesthesia. Spinal anesthesia and postoperative epidural analgesia is the recommended protocol for implantation of an interspinous stabilizer:

1. Preparation of the patient.
2. Placement of a peridural catheter (creation of a 5-cm tunnel); the lumbar puncture site is located two levels above the theoretical superior dissected level.
3. Spinal anesthesia is performed one level above the catheter space by infusion of:
   - Bupivacaine chlorhydrate, 15 mg
   - Sufentanyl citrate, 5 µg
   - Clonidine chlorhydrate, 20 µg
   Supine position for 2 – 3 minutes.
4. Prone position.
5. Cutaneous pain may occur (in rare cases) during incision, due to lack of sensitive block (early prone position) and prevalent motor block.
6. Intraoperatively, systolic arterial pressure is maintained between 90 and 110 mm Hg using:
   - Nicardipine chlorhydrate
   - Ephedrine chlorhydrate
7. Infiltration of muscular compartments is performed prior to closure with ropivacaine chlorhydrate monohydrate. Thus, analgesia is optimized during the first 6 postoperative hours.
8. Postoperatively, continuous infusion of morphine (2 – 3 mg/day) is performed through the peridural catheter, together with oxymetric monitoring.

50.7.3 Patient Positioning

Preoperative standing lateral radiographs should be carefully evaluated to assess the sagittal balance prior to performing the stabilization procedure. Patient positioning is critical to proper implant sizing and restoration of the proper segmental lumbar lordosis. The patient is positioned prone on the operating table. The use of an adjustable spine frame is recommended to avoid abdominal pressure and vena cava compression. The knee-sitting position can be used, but in this case, the lumbosacral lordosis is lost.

50.7.4 Incision and Preparation of the Implant Site

The most frequently involved level is L4-5. Mean length of the incision is approximately 4 – 5 cm. Patient size, pathology, and number of levels involved should be taken into account when planning the surgical approach. The incision should be long enough to ensure adequate exposure. The surgical approach is performed using a standard midline incision or a slightly lateral incision (10 mm).

First, anatomical lesions are assessed. The use of a unilateral approach allows decompression of the nerve roots, which is highly recommended in the presence of positive symptoms. It can be a discectomy and/or a foraminotomy (or even a resizing). At this stage, the placement of a contralateral distractor facilitates decompression.

A counterincision is necessary for insertion of the device. A 3- to 4-cm incision is sufficient. It allows preparation for insertion and seating of the device. Whenever possible, care must be taken to maintain continuity of the supraspinous ligament by preserving a band at least 10 mm wide and as thick as possible. After identification of the interspinous space, resection of the remnants of the interspinous ligament is carried out down to the ligamentum flavum. A window is created in the interspinous space using a scalpel that is ideally curved upwards, and then enlarged with curved Kerrison forceps and a Sicard rongeur (modified), taking care to preserve cortical bone. This step is critical and requires extreme caution; using excessive force due to tissue entrapment may result in fracture of the spinous processes. In cases of overlapping and hypertrophic laminae (kissing laminae), trimming is recommended. Similarly, in cases of a kissing spine involving the spinous processes, trimming of their lateral hypertrophic aspect is necessary. At this stage, the interlaminar distractor can be inserted as far anteriorly as possible, at the junction between the base of the spinous process and the laminae.

Note: during mechanical distraction achieved by spreading the laminae, care should be taken to apply loads that do not exceed the bony stiffness. If resistance is felt, the interlaminar bony bridges must be resected. Otherwise, fracture of the base of the spinous processes may occur, which will make implantation of a prosthesis impossible.

The distractor is used to spread the overlapping laminae. It is important to rely on:

1. Retensioning of the supraspinous ligament.
2. Realignment of the facets and articular capsules.
3. Excessive distraction might result in excessive pressure on the anterior aspect of the disc. In case of doubt, interlaminar distraction must be readjusted under fluoroscopic guidance. Parallel alignment of the endplates can be used as a reference for retensioning of the posterior longitudinal ligament.

Note:
1. An optimal interlaminar space is maintained at all times thanks to the flexibility of the device, which provides pain relief.
2. Weight bearing results in preloading of the prosthesis; this, combined with posterior tension banding, provides restoration of local lordosis.

50.7.5 Implant Insertion

50.7.5.1 Implant Selection

The appropriate trial (sizes available in 2-mm increments, from 8 to 14 mm) is positioned between the grooves of the distractor to determine the appropriate implant size.

50.7.5.2 Inserter

The implant is positioned on the claw of the inserter. The tips of two lateral wings are grasped within the spatulated jaws. Approximation of the jaws results in folding of half of the implant (Fig. 50.12). Thus, the implant can be easily inserted into the space previously created with the distractor. The spatulated jaws can be readjusted to tightly hold the folded implant and prevent anterior bulging of the device.

At this stage, the distractor may be used to temporarily slightly overdistract the interlaminar space, and thus facilitate insertion of the implant. Then, while firmly holding the implant, the inserter is positioned in the interspinous space. First, the opposite ligament is passed beneath the supraspinous ligament. Then, the implant is inserted and driven to the opposite side with the claw. Pressing the trigger of the inserter both activates the claw and pulls back the arms of the inserter, which allows unfolding of the wings, bringing them into contact with the spinous processes (Fig. 50.13). Then, the inserter can be removed.

Note: In case of central stenosis (Fig. 50.14), partial laminectomy requires a midline approach, and the supraspinous ligament is sacrificed. In this case, the implant is inserted from posterior to anterior without using the inserter.

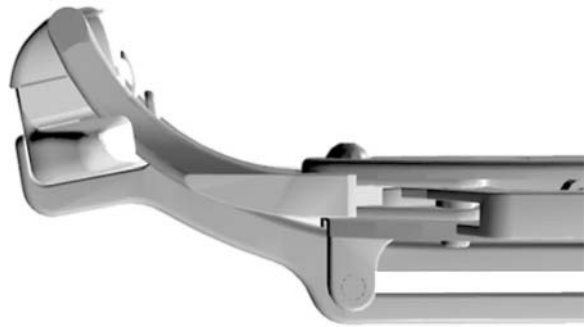


Fig. 50.12. Jaws folding the implant's wings

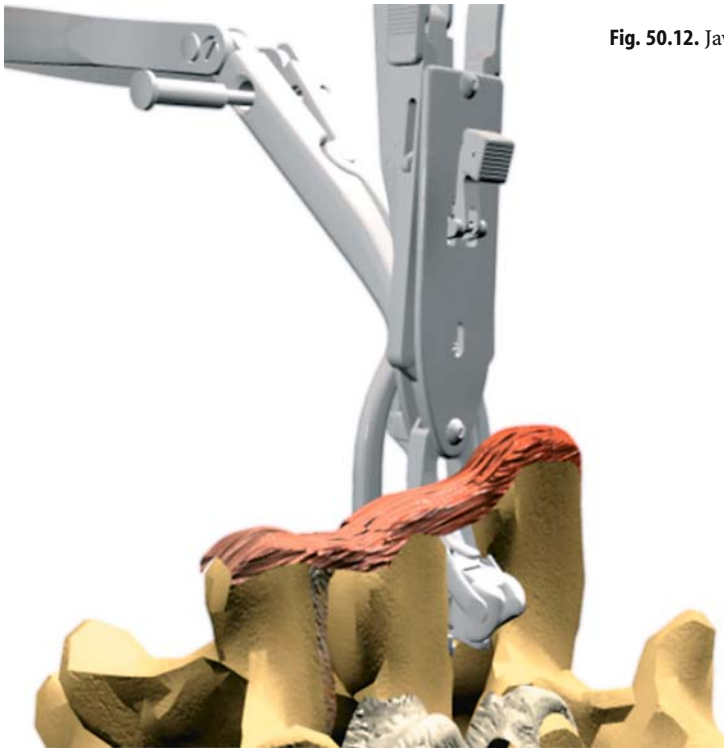


Fig. 50.13. Introduction of the implant



Fig. 50.14. Alternative indication of midline approach

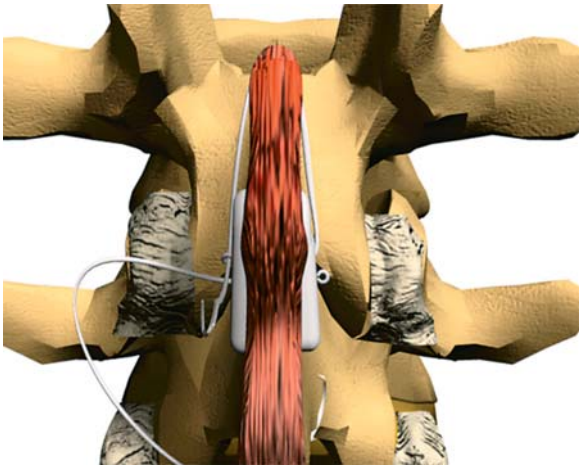


Fig. 50.15. Fixation of the independent ligaments

50.7.6 Final Positioning

The impactor is placed on the top of the implant and the DIAM is pushed down using a few mallet blows, until it reaches the distractor legs. Then the distractor is removed, and the device is optimally seated as far anteriorly as possible, close to the facet joints. The wings of the device must rest on the laminae. The tag is sutured to the supraspinous ligament.

50.7.7 Ligament Fixation

The posterior interspinous stabilizer is packaged with two independent ligaments that attach to each adjacent spinous process. Each ligament is inserted into the adjacent overlying and underlying interspinous spaces and passed through the loop. The ligament is cut below the needle (at the rigid segment). This stiff portion must be carefully sectioned obliquely with a scalpel to facilitate insertion of the titanium rivet. Then the rivet is brought down to the loop (Fig. 50.15). The ligament is tensioned and secured with the crimper. The rest of the ligament is cut off and removed.

50.8 Postoperative Care

No special postoperative measures are necessary. The patient is allowed to mobilize within the first hours after surgery.

50.9 Hazards and Complications

Careful sizing of the implant will ensure the outcome of the procedure. Too small an implant may not provide adequate decompression and over sizing may create undesired discal kyphosis.

50.10 Conclusion

A posterior interspinous stabilizer is effective in reducing the increased segmental flexion–extension motion that is observed after a discectomy or partial facetectomy. Realignment of the facet interface restores the facet congruity. Distraction of the neural arch results in enlargement of the neural foramen, relieving neural compression.

Two retrospective studies have been performed by independent observers according to the Dallas Pain Questionnaire (DPQ) self-assessment protocol designed by Lawlis, McCoy, and Seldy. These studies involved 125 patients with 36 month follow-up, and 104 patients with 18 month follow-up, respectively. The mean age of the patients was approximately 50 years. Level L4-5 was the most frequently instrumented. Two in three patients had improvement in function. The failure rate was 10%, whereas the satisfaction rate exceeded 80%. Interestingly, in each study, results on pain kept improving for at least 18 months, and then diagrams showed progressive inversion of the curves.

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51 Elastic Microsurgical Stabilization with a Posterior Shock Absorber

S. Caserta, G.A. La Maida, B. Misaggi

51.1 Terminology and Surgical Principle

See Chapters 49 and 50.

51.2 History

Lumbar disc degeneration is the most common cause of back and leg pain. It is a multifaceted syndrome and it could be part of a more complex syndrome in which all three columns are involved with consequent instability.

One of the biggest problems in spinal surgery is the diagnosis and treatment of vertebral instability. The diagnostic instruments we have to recognize instability are standard and dynamic X-rays, and MRI with its Modic signs [25], which allows the identification of early disc degeneration. Discography is the only investigational device that, with its provocative test, can identify the pain source (memory pain). CT scan is important for detecting bone diseases and to analyze facet joint status [5].

Disc arthrosis, segmental instability, and spondylolisthesis are the principal indications for spinal fusion. However, there is a lack of precision concerning the definition of certain pathologies and the relation between degenerative lesions, actual low back pain, and the need for fusion is, at best, open to debate [31]. Up to now the surgical treatment is based on rigid lumbar arthrodesis with instrumentation, reported by different authors as a safe procedure [27].

Many different surgical techniques are employed to treat lumbar instability: posterolateral fusion (PLF), intersomatic fusion (ALIF or PLIF), and posterior instrumented fusion alone (screws fixation) or combined with intersomatic fusion (circumferential fusion). All these procedures may achieve the goal of fusion, with good radiological results, but at the same time they could create a pathology concerning the levels adjacent to the fused area.

Although it has been considered for a lot of years as the gold standard in the treatment of vertebral instability, arthrodesis is reported by many spine surgeons to have a series of complications and failures [7]. The most important complications are: infection reported in 2–6% of cases [8]; implant failures in 5–31% [2, 10]; pseudoarthrosis in 4–5% [13], and symptomatic or asymptomatic degeneration of the disc adjacent to a fused area in 5–100% [1, 24].

During recent years the interest in the "so-called" non-fusion technology has grown up and new stabilization systems have been introduced in spinal surgery, identifying a new kind of treatment philosophy. This new kind of surgical treatment is based on the principle of the preservation of the functional spinal unit (FSU), leaving the arthrodesis technique to a very few selected cases. The non-fusion surgical procedures include the disc arthroplasty and the dynamic posterior stabilization systems. The former include the nucleus pulposus replacement and the total disc replacement while the latter group can be divided into interspinous devices and dynamic stabilization systems by using pedicular screws.

Nucleus pulposus replacement can be performed with a conventional PLIF approach, with risk of extrusions into the spinal canal, or through an anterior retroperitoneal approach [22]. Among the different design proposals for intervertebral disc replacement, two key principles can be differentiated: the first is to reproduce the viscoelastic properties of the disc while the second is to reproduce the motion characteristics of the disc [31].

There are a number of ligamentoplasty systems on the market, such as the posterior dynamic stabilization systems that include the Graf ligamentoplasty and the Dynesys implant, and the interspinous systems that include the Wallis implant and the DIAM shock absorber.

Graf in 1992 proposed a new surgical treatment of vertebral instability by using pedicular implants which were linked together by a polyester threaded band, maintaining the two vertebrae in extension [17, 18]. Graf ligamentoplasty may be described as a stabilizing and splinting procedure, designed to substantially immobilize a symptomatic and presumably damaged motion segment, made vulnerable by the degenerative process or injury. Other authors reported their experience with





▷
Fig. 51.1. A 50-year-old man affected by chronic low back pain. Lateral X-ray view at 10 years follow-up. The patient is pain free

▷▷
Fig. 51.2. Anteroposterior X-ray view of the patient presented in Fig. 51.1. The combination of the Bronsard ligament with the Graf stabilization system can be seen

the Graf system in the treatment of symptomatic degenerative disc disease with good results [14, 15, 19]. In 1994 Guigui and Chopin reported the results of a retrospective study on 26 patients affected by lumbar stenosis and treated with the Graf system. They found that the low back pain did not improve and that the system did not avoid slipping of the most instable levels [20].

We began our experience in 1991 with the Bronsard ligament and, one year later, with the Graf stabilization system. Our clinical results in a few cases using the Graf system were bad, with worsening of the back pain and one case developed sciatica pain. We thought that the problem was in the overloading of the facet joints and in the decreasing of the neuroforamen size caused by the system. So, starting with the previous experience with the Bronsard ligament, we thought to combine, in the same patient, the Bronsard ligament with the Graf stabilization system. The interspinous system contrasts the compression stresses caused by the Graf system, creating a kind of stabilization that could be considered the precursor of the Dynesys system. The clinical result was very encouraging and we obtain an improvement of the back pain. At 10 years follow-up the patient is still pain free (Figs. 51.1, 51.2).

Dubois introduced dynamic neutralization as a new concept for restabilization of the spine. The Dynesys system seems to allow a real stabilization with a controlled range of motion throughout a dynamic neutralization absorbing the non-physiological loads in compression and flexion-extension. With the system the spinal segments can be repositioned in an anatomically subnormal situation in which the pain is relieved [9]. Other authors reported their experience with the system and they concluded that the dynamic neutralization system reduces the bulging of the posterior anulus [12]. In a multicenter study recently published the authors found that the Dynesys system is a safe and efficient procedure for the stabilization of unstable conditions of the lumbar spine presenting with neurocompression. The system is less invasive than a fusion procedure and it theoretically produces less degeneration of adjacent segments in the long term [30].

51.2.1 Shock Absorbers

With the term shock absorbers we identified all the interspinous systems whose purpose is to reestablish the stability of the posterior spinal ligament complex. Interspinous devices were designed in order to restore the posterior stability normally done by the ligamentous complex and to restrict abnormal flexion-extension movement of the spine.

Sénégas in 1988 introduced the concept of the interspinous device for the treatment of vertebral instability. The system principles are: reduction of the instability, fixation of the mean instantaneous axes of rotation (IAR), discharging facet joints, and opening the neuroforamen [28]. Since 1988 a number of interspinous systems were designed and different materials were combined in order to improve the shock absorber function. One of the latest systems to be designed is the Loop sys-

tem [16]. They confer substantial mechanical advantages and when the spinal column is submitted to loading, the interspinous blocker displaces the mechanical constraints dorsally and reduces the load upon the disc and the facet joints [29].

Since 1991 we began to use the interspinous shock absorbers, using first the Bronsard ligament and later the DIAM system. The good preliminary results obtained with the shock absorber led us to perform a biomechanical study, in collaboration with bioengineers of the Politecnico of Milano. The aim of the study was to understand better the efficacy of the Bronsard ligament when applied to a model simulating the lumbar spine.

51.2.2 Biomechanical Model

We conceived a schematic representation of lumbar spine (Fig. 51.3) composed of contiguous segments representing the spine in a sagittal plane. To simplify the scheme we decided to consider the spine as formed by elastic discs, with a circular hollow section, interposed by rigid bodies with a solid circular section. We did not consider the nucleus pulposus properties. All data about mechanical and geometrical characteristics were deduced from other mechanical models reported in the literature [6, 21].

We examined the lumbar spine in a standing position; our purpose was to value stress and deformation of the intervertebral disc during flexion. We decided to consider only flexion at first to simplify the valuation which could be very complex for other movements owing to the different components involved. During forward flexion some torsion components were present, but their entity was so slight that we can consider the flexion movement as a pure one, completely contained in the median plane of the subject.

The lumbar spine was charged by a system of loads due to body weight, muscles and ligament actions, maintaining the trunk's balance in all degrees of flexion. In Fig. 51.4 we see a schematic representation of a vertebral motion segment during flexion: we call C and M the forces which come from the trunk's weight, and muscle actions are indicated as LIS, LIT, and LLP. By means of a classic technique normally used in engineering for hyperstatic structures, we have analyzed the internal actions and the main stresses and deformations of intervertebral discs which are developed at different degrees of flexion up to 40°.

The simulations carried out concerned the physiological movement, the movement in one- or two-level rigid stabilization, and finally the movement in one-level rigid stabilization combined with elastic stabilization above, using a Bronsard ligament.

51.2.2.1 Results

In Fig. 51.5 we report the results of the simulation. We consider maximal stress in the L3-4 disc, and these values are set on the ordinate. The angles of lumbar flexion up to 40° are on the abscissa.

We see that maximal stress in the disc adjacent to a fused area increases more than the values calculated in physiological conditions and much more if there is a two-level fixation. If we put an elastic stabilization on the disc above, this value reduces but only if lumbar flexion is less than 28°. For higher grades of flexion, this value increases.

Elastic stabilization seems to reduce the concentration of stresses applied to the adjacent disc, during flexion up to about 30° [5]. The increasing of stresses for

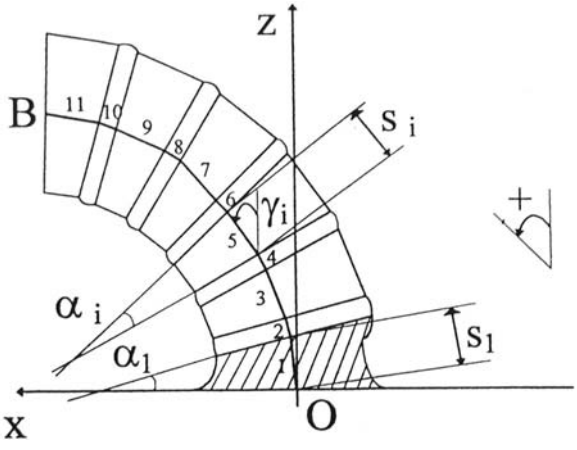


Fig. 51.3. Schematic representation of the lumbar spine. α_i *Angle between two adjacent discs,* γ_i *angle of inclination of each vertebral body,* S_i height of the vertebral body

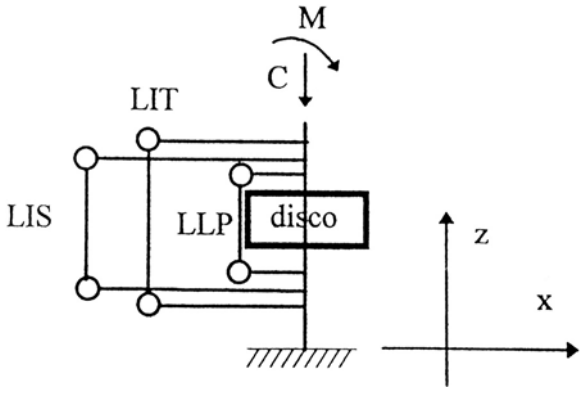


Fig. 51.4. Scheme of a vertebral body unit during anterior flexion. *C* and *M* represent the weight and muscular forces. *LLP* represents the posterior longitudinal ligament, *LIT* the ligamentum flavum and the intertransverse ligament, and *LIS* the interspinous and supraspinous ligaments

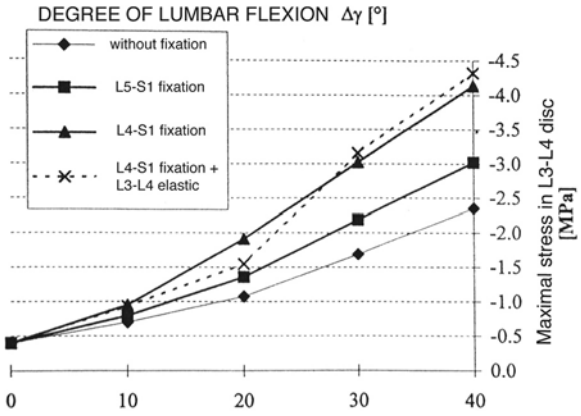


Fig. 51.5. Results of biomechanical model. On the *y*-axis there is the maximum strain of L3-4 intervertebral disc while on the *x*-axis there is the angle of lumbar flexion

higher grades of flexion is probably due to the mechanical properties of the Bronsard ligament. This could mean that the artificial ligament we used is probably too stiff.

51.3 Indications

The main indications for elastic stabilization are:

- Initial disc degeneration with very low grade instability in young people affected by chronic low back pain
- Discectomy for voluminous herniated disc leading to substantial loss of disc material
- Recurrent disc herniation with or without scar tissue formation
- Degenerative disc disease at a level adjacent to a previous fusion
- Neuroforamen stenosis

51.4 Contraindications

See Chapters 49 and 50.

51.5 Surgical Technique

The surgical technique is very simple (Fig. 51.6) and it is possible to perform the procedure through a small skin incision. Once the paravertebral muscles are divided, it is necessary to detach the supraspinous ligament (that has to be left in place) and in doing so it is possible to remove the degenerated interspinous ligament (Fig. 51.6a). Using the appropriate instrument it is possible to perform a small distraction of the level (Fig. 51.6b); at this point is very important to do an intraoperative X-ray in order to check the distraction thus avoiding kyphosis. Now is possible to put in place the interspinous device (Fig. 51.6c) that is held in place with two tension bands wrapped around the spinous processes of the two vertebrae. The device we use has a very simple blocking system (Fig. 51.6d).

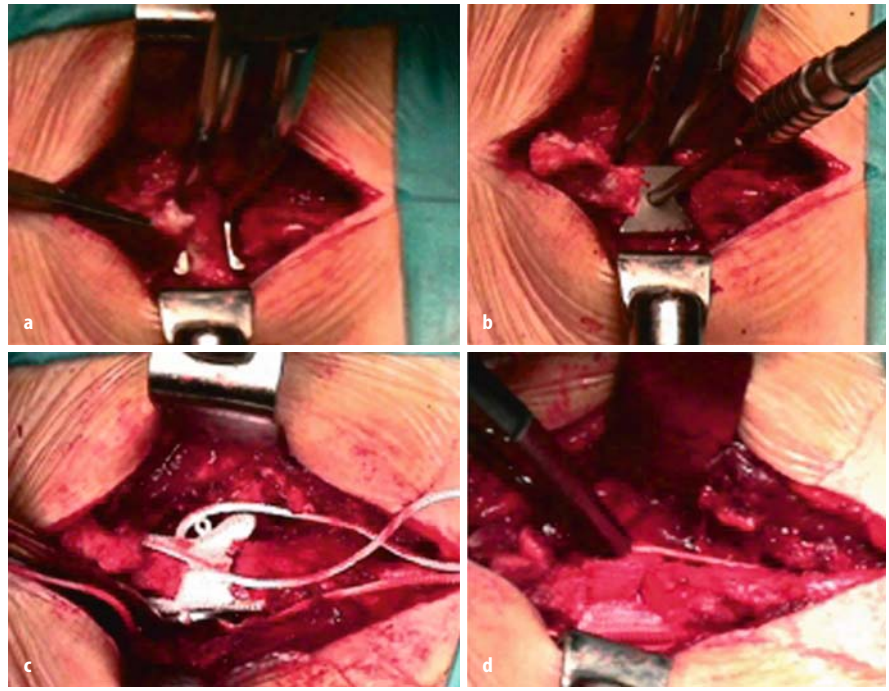


Fig. 51.6a–d. Stages of the surgical technique

51.6 Results

We started using the system in 1991 but our results are reported from January 1994 to December 2001. We performed 82 surgical procedures, 57 elastic stabilization alone and 25 associated with instrumentation and fusion (combined stabilization). The mean age was 43 years and the admission diagnosis was degenerative disc disease in 50% of the cases, disc herniation in 25.6%, recurrent disc herniation in 11%, and other diagnosis in 13.4% of the cases (Table 51.1). Two patients were affected by L5 spondylolisthesis. We performed reduction and a combined stabilization in both cases. Fusion was done from L4 to S1 and it was associated with an elastic stabilization in L3-4 because of initial degeneration of the disc. Four patients suffered from a lumbar stenosis. We performed a one- or two-level laminectomy associated with elastic stabilization.

Fifty-seven patients (57/82) underwent elastic stabilization alone (Table 51.2). In 61.4% of these cases we performed a one-level L4-5 elastic stabilization. Six patients underwent a two-level procedure; four of them had an L3-4 and L4-5 stabilization. In one case we did an L5-S1 stabilization using the Dynesys system with an L4-5 interspinous device, the DIAM.

In Fig. 51.7 we present the case of a 35-year-old woman affected by L4-5 degenerative disc disease. The MRI demonstrates the presence of a bulging disc. She suffered from a persistent back pain and we decided to perform an L4-5 elastic stabilization. The dynamic X-rays taken at 1 year follow-up (Fig. 51.8) demonstrate the good position of the device and increased stability of the segment. The patient is pain free.

Table 51.1. Admission diagnosis

Admission diagnosis	Number
degenerative disc disease	41
Disc herniation	21
Recurrent disc herniation	9
Lumbar instability	5
Spondylolisthesis	2
Lumbar stenosis	4
Total	**82**

Table 51.2. Elastic stabilization alone. Levels stabilized

Level	Number
L2-3	6
L3-4	10
L4-5	35
L1-2 and L2-3	1
L3-4 and L4-5	4
L4-5 and L5-S1	1
Total	**57**

In 25 patients (25/82) we performed a combined stabilization (Table 51.3). L4-S1 rigid stabilization with fusion associated with an L3-4 elastic stabilization was done in 44% of these cases. Three patients underwent spinal fusion associated with two-level elastic stabilization; in one of them we performed a one-level fusion with interspinous devices on the levels above and below.

We reviewed 61 patients (61/82) with a mean follow-up of 20 months (minimum 12 months; maximum 6 years). Clinical results are very satisfactory especially in the group of patients affected by recurrent disc herniation in whom the elastic device was used alone.



Fig. 51.7. MRI of a 35-year-old woman affected by L4-5 degenerative disc disease

Table 51.3. Elastic stabilization combined with fusion (mixed stabilization)

Fused area	Elastic stabilization	Number
L5-S1	L4-5	6
L4-S1	L3-4	11
L4-5	L3-4	4
L4-5	L2-3 and L3-4	1
L3-4	L2-3	1
L3-4	L2-3 and L4-5	1
L5-S1	L3-4 and L4-5	1
Total		**25**



Fig. 51.8. Lateral dynamic X-ray views at 1 year follow-up. Good position of the interspinous device and the stability of the segment can be seen

The best indication is a single-level elastic stabilization positioned at L4-5. No differences in results were observed if two devices were placed one above the other. The L5-S1 level should be avoided because of the poor quality of the S1 spinous process.

51.7 Hazards and Complications

No complications related to the material were detected.

Although elastic stabilization with an interspinous device seems able to prevent the recurrence of disc herniation [32], in our series we reported a patient who developed a recurrence after 2 years from the intervention of elastic stabilization. Our mean follow-up is too short to arrive a conclusion about it.

51.8 Conclusions

The elastic stabilization systems are now considered differently from the way they were considered in the past. They are no longer designed simply to control rotational motion of the bridged segment, but also to change particular features of the internal mechanical environment of the disc itself, for example to off-load the whole disc or modify the loading of the posterior anulus [23]. For example the use of an interspinous blocker confers substantial mechanical advantages. When the spinal column is submitted to loading, the interspinous shock absorber displaces the mechanical constraints dorsally and reduces the load upon the disc and the facet joint system [29].

Butler et al. [3] performed a study in order to determine the relationship between facet joint osteoarthritis and disc degeneration in subjects in whom both MRI and CT scans had been obtained. The MRI scans were used to determine disc degeneration, and the CT scans to determine facet joint osteoarthritis. They hypothesized that disc degeneration would sometimes occur without the presence of facet joint osteoarthritis, but that facet joint osteoarthritis would only occur in the presence of disc degeneration. The authors concluded that disc degeneration occurs before facet joint osteoarthritis, which might be secondary to mechanical changes in loading of the facet joints. If this concept is true for a non-instrumented spine, imagine applying this to a functional spinal unit near a fused area, in which stresses are more concentrated.

Freudiger et al. [12] published an in vitro study about dynamic neutralization of the lumbar spine. They concluded that the dynamic neutralization system they used reduces bending angles and horizontal translations but it increases vertical translations. They concluded also that the bulging of the posterior anulus was reduced.

Some authors [11, 17] used elastic stabilization for the treatment of initial lumbar instability with satisfactory results, while Dubois et al. [9] classified the dynamic destabilization phases in order to recognize early signs and symptoms of lumbar instability. Based on their classification they operated on 57 consecutive patients with the Dynesys system. They concluded that their dynamic stabilization system is applicable to a wide range of non-structural lumbar instabilities.

The Dynesys system seems to restrict the range of movement and it may also unload the disc if the patient achieves a position of lordosis, so that the plastic cylinder becomes weight bearing [26]. Non-rigid fixation

clearly appears to be a useful technique in the management of initial forms of degenerative intervertebral lumbar disc disease [29]. Flexible stabilization systems were based on the concept that they permitted only restricted movement within the range of normal movement. They work because they restrict movement to a zone or a range where normal loading may occur, or they prevent the spine adopting a position where abnormal loading may occur [26]. Dynesys is a pedicle system providing mobile stabilization controlling motion in any plane [30], while the shock absorber systems seem to work and stabilize the spine in flexion-extension only. They can be considered as two different systems to be used in different degrees of spine instability. In our hands the Dynesys system seems to work very well if applied on one or two levels, with less good results for more levels. Nevertheless elastic stabilization could be a good alternative to fusion in cases in which arthrodesis is an excessive procedure. Furthermore, it should be used in addition to lumbar stabilization-fusion in cases in which the disc adjacent to the fused area is initially degenerated.



Fig. 51.9. MRI of a 55-year-old man affected by multiple-level disc disease

Following this new treatment philosophy we are now working on a new kind of lumbar stabilization that we call "hybrid and modular." In Fig. 51.9 we show the case of a 55-year-old man with multiple-level disc disease of the lumbar spine. He suffered from a disabling chronic low back pain with no response to conservative treatment. We believed that a fusion extending from L3 to the sacrum would be too much for him and so we adopted an "hybrid modular" stabilization using a rigid stabilization with fusion at L5-S1 associated with a dynamic neutralization system from L3 to L5 (Fig. 51.10). In this way we obtained a modularity in the stabilization system with the preservation of the movement in the upper lumbar spine, avoiding a longer fusion with its consequences.

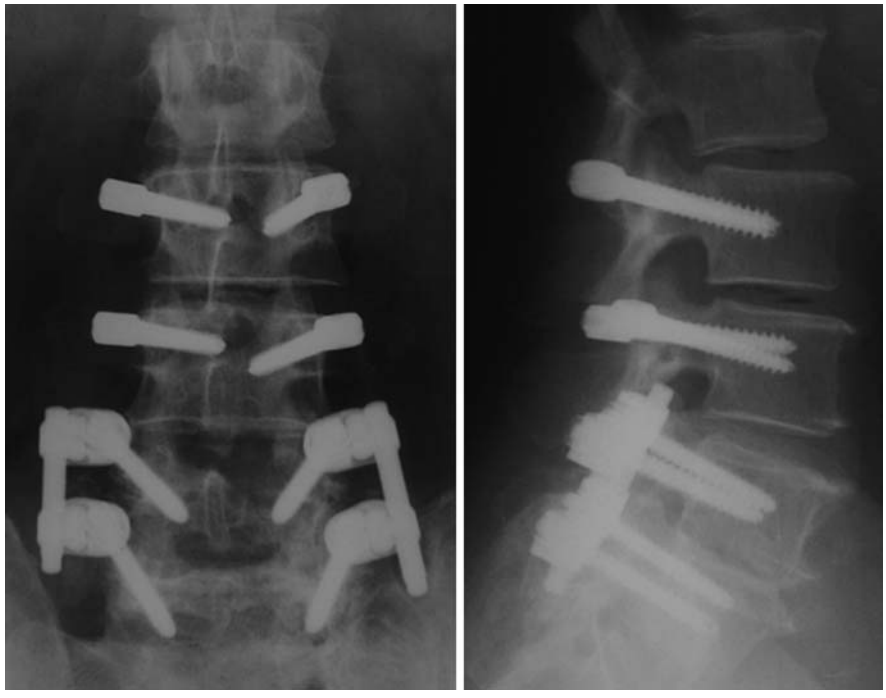


Fig. 51.10. Hybrid modular stabilization: combination of a stabilization fusion at L5-S1 with a dynamic neutralization system from L3 to L5

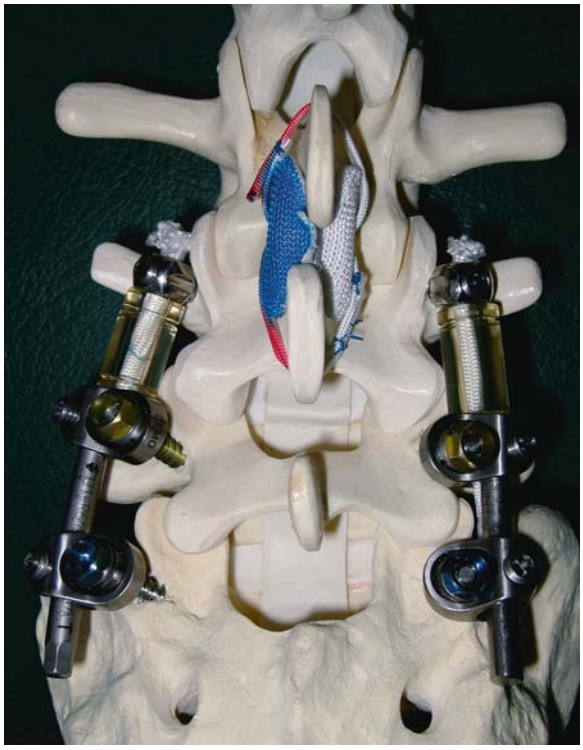


Fig. 51.11. Spine model in which there is the association of a rigid stabilization system with a dynamic neutralization system and a shock absorber system

In our experience we believe that elastic stabilization with an interspinous shock absorber is a safe procedure with good clinical results especially in patients affected by recurrent disc herniation. It should also be used with good results in patients affected by degenerative disc disease, lumbar stenosis, and in very low grade instability. When used in association with lumbar stabilization-arthrodesis we think that the elastic stabilization reduces the mechanical stresses applied on the disc above. In such a way the bordering area should be protected from accelerated degenerative process [4, 5]. A further step that we are working on is an association of a rigid stabilization system, a dynamic neutralization system, and a shock absorber system (Fig. 51.11). By doing so we are trying to obtain a "system modularity" which aims to preserve function and prevent early degeneration of the discs adjacent to a fused area.

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Subject Index

abdominal hernia 386
access
– biportal 339
– midline 35
– surgery 3
ACD, *see* anterior cervical discectomy
ACF, *see* anterior cervical (interbody) fusion
ACT, *see* autologous chondrocyte transplantation
acute respiratory insufficiency 130
ADCT, *see* autologous disc chondrocyte transplantation
adhesiolysis, epidural 255
ADI, *see* atlanto-dental interval
adolescent idiopathic scoliosis 178
air embolism 109, 116
alar ligament 39
allostrut 68
ALPA, *see* anterolateral transpsoatic approach
altlanto-dental interval (ADI) 44
AMD, *see* arthroscopic microdiscectomy
anesthesia, endotracheal 45
angiography 63
ankylosing spondylitis 386
annular
– delamination 260
– fenestration 334
annuloplasty, thermal 268
annulotomy 336
annulus fibrosis 187
anterior
– axillary line 168
– cervical (interbody) fusion (ACF) 54
– cervical discectomy (ACD) 54
– – conventional 82
– cervical foraminotomy 82
– circumference of the dura 20
– longitudinal ligament 39, 187
– lumbar interbody fusion 6, 380
– plating 54
anterolateral transpsoatic approach (ALPA) 379
anterolisthesis 386
antibiotic coverage 39
anulotomy 382
anulus
– flap 383
– incision 382
AO classification 204
aorta 394
aortic arch 187
apex 186
apical ligament 39
apochromatic optics 8
apophyseal joint 110
approach
– anterolateral transpsoatic 379
– endoscopic interlaminar 346
– intercostal 129, 132, 203
– interlaminar 283
– intradiscal bilateral 339
– intraspinal 307
– Mini-ALIF 380
– mini-retroperitoneal open 216
– over-the-top 397
– paramedian 283
– paramuscular 306
– paraspinal 307
– periannular foraminal 339, 340
– posterior 55
– posterolateral 315
– retroperitoneal 307
– transforaminal 315, 317
– translaminar 297
– transmaxillary 36
– transoral 35
– transpalatal 36
– transperitoneal 423
– transthoracic (TTA) 129
Aquarelle 379
arachnoiditis 406
arcuate ligament 204
– medial 204
arterial
– line 108
– thrombosis 386
arteriovenous fistula 120
artery
– common carotid 102
– common iliac 420
– intercostal 145
– segmental 110, 394
– vertebral 119
– – ectatic 120
– – injury 120
arthrodesis 92
arthroplasty 92
arthroscopic microdiscectomy (AMD) 149, 331
arthrosis of the facet joint 83
artificial
– disc 93
– endplate 94
– nucleus 94
atelectasis 130, 204
atlantoaxial
– instability 43, 118
– transarticular screw 118
atlanto-dental
– complex 119
– interval (ADI) 119
atlas 42, 118
audio-visual equipment 24
autofocus system 9
autologous
– bone 188
– – graft 54
– chondrocyte transplantation (ACT) 364, 374
– disc chondrocyte transplantation (ADCT) 368, 374
axial back pain 255
axillary line 145
– anterior 168
– middle 168
– posterior 189
axis 42, 118
azygos
– arch 187
– vein 148

beta tricalcium phosphate (b-TCP) 435
Betadine solution 37
bifid root 115
binocular tube 8
bioceramics 72
biocompatibility 94
bioconductive osteoconductive polymer (BOP) 71
biocortical screw 191
biopsy 232
bipolar coagulation 21
biportal access 339
bladder dysfunction 198
bleeding
– epidural 6, 283
– intraspinal 21
– retroperitoneal 130
– tissue 21
BMI, *see* body mass index
BMP, *see* bone morphogenic protein
body mass index (BMI) 369
bone
– cement 161
– – high-viscosity 233
– dowel 383
– graft 209

– – tricortical iliac 430
– morphogenic protein (BMP) 72
– strut 54
BOP, *see* bioconductive osteoconductive polymer
bowel dysfunction 198
Bozzini 149
brachial plexus 185
– injury 76, 216
brachiocephalic vein 148
Bristol prosthesis 93
bronchial tear 183
Brooks 118
Bryan cervical disc prosthesis 92
burst fracture 231

C1 36
– transarticular screw fixation 43
– tubercle 37
C3 vertebra 35
calcibon 241
calcium phosphate 70, 72
– cement (CPC) 239, 242
camera
– 3CCD 9
– digital 9
cancer pain 256
carbon sliding surface 93
Caspar
– distractor system 66
– Micro Lumbar discectomy Retractor 17
– microdissector 20
– retractor 20
– – blades 46
caudal epidural steroid injection 253
cell
– culture 365
– saver 438
– transplantation 365
cement leakage 232
central
– gap effect 68, 69
– venous line 108
cerebral ischemia 116
cerebrospinal fluid (CSF) 36
– cyst 83
– fistula 83, 386
– leakage 40
cervical
– brace 105
– collar 45, 120
– column 84
– myelopathy 54, 57
– prostheses 92
– spine
– – blocking plate 73
– – fracture 43
– – injury 43
– spondylodiscitis 54
– traction device 84
cervicomedullary junction 36
chest tube 136, 188
chondrocyte 365
– chondrocyte-specific marker 365
chromium 101
chromo-discography 272
chronic fresh fracture 223
chylothorax 130, 193, 216
cisternae chyli 193
clivus 35
Cloward 55, 86
coagulopathy 217
coaxial illumination 10
cobalt 101
Cobb
– elevator 183
– periosteal elevator 17
collagen
– contraction 261
– fibril 260
– type I/II 261
color temperature 9
common
– carotid artery 102
– iliac artery 420
– iliac vein 390, 420
computed tomography (CT)
– color-coded angiography 388
– CT-based navigation 28
– fine-cut 120
– high resolution (hrCT) 83
– quantitative (qCT) 78
– three dimensional scans 5
computer-assisted surgery 26, 28
congenital
– anomaly 166
– deformity 197
contained disc herniation 292
controlled hypotension 438
coordinate system (COR) 27
cord encroachment 62
corneal damage 116
corpectomy 54
corporectomy 159, 165
cosmetic alteration 16
costal
– arch 166
– head 169
costodiaphragmatic recess 205
costotransverse joint 147
costovertebral joint 147
CPS, *see* calcium phosphate cement
craniovertebral junction 35
crankshaft deformity 164, 178
Crohn's disease 432
CSF, *see* cerebrospinal fluid
CT, *see* computed tomography
cultured autologous chondrocyte 365
Cummins artificial cervical joint 93
curette 21, 183
cutting burr 39
cystoscope 165
cytomegaly virus 204

da Vinci position 387
Dallas Pain Questionnaire (DPQ) 473
death 40
decompression
– over the top 21
– procedure 6
deep chest infection 193
deep venous thrombosis 40, 124, 217, 386
deformity
– congenital 197
– crankshaft 164
– developmental 197
– kyphotic 55, 222
– Swan neck 108
degenerative lumbar scoliosis 386, 397
dens 39, 118
depth guard 20
developmental deformity 197
device for intervertebral assisted motion (DIAM) 466
DEXA 101
diabetes mellitus 76
DIAM, *see* device for intervertebral assisted motion
diaphragm 204
– hernia 130, 204
– insertion 204
– splitting 156
digital camera 9
disc
– chondrocyte 365
– fragment
– – epidural 85
– – herniated 85
– herniation
– – contained 292
– – extracanalicular 304
– – extraforaminal 278, 304
– – foraminal 307
– – intraforaminal 317
– – recurrent 326
– prosthesis 55
– protrusion 292
– shaver 187
discectomy
– anterior cervical 54
– laser-assisted 55
– lumbar 6
– microsurgical 278, 283
– outpatient microsurgical 357
– percutaneous 55
– transforaminal endoscopic 315
discitis 251
discogenic low back pain 260
discography 149, 255
discoligamentous instability 204
discoscopy 316
discotomy 356
dissector
– Caspar microdissector 20
– Freer 20
– Penfield 20
disturbed senses
– smell 36
– swallowing 36
– taste 36
dorsal
– fascia 122
– rast ganglion (DRG) 260
double-block technique 250
down lung syndrome 178
Down's syndrome 119
DPQ, *see* Dallas Pain Questionnaire
DRB, *see* dynamic reference base
DRG, *see* dorsal rast ganglion
drill guide tube 122
dura
– anterior circumference 20

– patching 40
– tear 76
dynamic
– plate 73
– reference base (DRB) 27
– reference frame 27
Dynesys implant 476
dysphagia 39, 45
– postoperative 76

ectatic vertebral artery 120
EFR score 421
endo-scissors 207
endoscope 6
endoscopic
– interlaminar approach 346
– microdiscectomy 334
Endostitch device 188
endothoracic fascia 146
endotracheal
– anesthesia 45
– tube 37, 40
endplate-fins 100
enteral nutrition 40
epidural
– abscess 40, 58, 251
– adhesiolysis 255
– adipose tissue 338
– bleeding 6, 283
– disc fragment 85
– fat 283
– fragment 292
– hematoma 326
– injection 253
– scar 406
– vein 283
– venous plexus 224
– vessel 21
epiduroscopy 149
epigastric vessel 453
erector spinae 470
EuroDisc Study 369
European Myelopathy Score 78
evoked-potential monitoring 63
exploration hook 20
external
– oblique muscle 442
– occipital protuberance 109
– orthosis 45
extradural compressive pathology 35
extraforaminal disc herniation 278, 304
extramedullary procedure 63
extrapedicular method 241
extravasation 224
extrusion 292
eye–ocular distance 23

facet
– capsule 60
– denervation 252
– joint 250
– – injection 251
– – osteoarthritis 101, 386
facetectomy 107, 306
failed back surgery syndrome 270
failed disc syndrome 357
fan retractor 189
fascial patch 39
Fernstrom prosthesis 92
FEV-1, *see* forced expiratory volume in 1 second
fiberoptic intubation 62
fibrin glue 39
fiducial marker 28
flavectomy 289
– open door 289
Floseal 102
fluoroscopy 122
– fluoroscopy-based navigation 26, 28
– intraoperative 26, 63
Foley catheter 205
foot control panel 9
foramen magnum 36, 121
foraminal
– disc 108
– – herniation 307
– stenosis 83, 85, 318
foraminoplasty 315
foraminotomy, anterior cervical 82
forced
– expiratory volume in 1 second (FEV-1) 183
– vital capacity (FVC) 183
fracture
– cervical spine 43
– chronic fresh 223
– Jefferson 44
– odontoid 42
– osteoporotic vertebral compression (VCF) 222
– posterior apophyseal ring 105
– thoracic spine 164
– thoracolumbar 203
– transpedicular 56
– type B 241
– vertebral 56, 231
Freer dissector 20
Frenchay prosthesis 93
FVC, *see* forced vital capacity

galvanocautery 165
ganglionectomy 307
Gelfoam 87, 187
genitofemoral nerve 410, 420
genupectoral position 308
German Drug Law (Arzneimittelgesetz) 371
GPS satellite navigation system 26
Graf ligamentoplasty 476
graft failure 76
groin pain 410
guide
– tube 122
– wire 189

haemothorax 216
halo vest 120
hardware failure 76
harmonic scalpel 178
Harms basket 71
hematoma, postoperative 36
hemiazygos vein 148
hemilaminectomy 399
hemivertebrae 164, 197, 200
– excision 197
– fully segmented 197
– non-segmented 197
– semisegmented 197
hemodilution 438
hepatitis B 204
herniation
– disc fragment 85
– perforated 292
heterotopic ossification 98
high-speed
– burr 6, 18
– drill 18, 20
HIV 204
hoarseness, postoperative 60, 76
Hohmann lever 439
holmium:YAG laser 349
Horner's syndrome 216
hydrogen bond 261
hydroxyapatite
– block 71
– cylindrical core 70
– porous 72
hypogastric plexus 423
hypotension 438

IAR, *see* instantaneous axis of rotation
IBT, *see* inflatable bone tamp
IDET, *see* intradiscal electrothermal therapy
ileum 427
iliac
– crest 209
– – autograft 121
– vein injury 456
iliocostal nerve 386, 410
iliohypogastric nerve 219
ilioinguinal nerve 219
iliolumbar vein 151
illumination 9
– coaxial 10
– xenon 9
impaired swallowing 60
implant
– bed 100
– failure 212
– subsiding 100
index curve 200
infection rate 16
inflammatory enzyme 260
inflatable
– balloon 455
– bone tamp (IBT) 239
informed consent 36
infrared
– light-emitting diode (IRED) 27
– light-reflecting markers 27
inion 121
instantaneous axis of rotation (IAR) 42, 477
instrument
– for spinal microsurgery 16
– for wound opening 16
– microsurgical 21
interbody fusion 54, 68
intercostal
– approach 129, 132, 203
– artery 145
– nerve 145
– – neuralgia 212

– neuralgia 220
– space 168
– vein 145
interlaminar
– approach 283
– epidural steroid injection 253
– space 110
– window 17, 283
interleukin (IL) 1 260
internal
– disc derangement 260
– laminoplasty 397
– oblique muscle 442
interpupillary distance 8
interscapular pain 60
interspinous
– blocker 460
– ligament 459
– ligamentous complex 110
– stabilizer 466
intervertebral disc abscess 150
intra-abdominal fibrosis 423
intraarticular ligament 147
intradiscal
– bilateral approach 339
– electrothermal therapy (IDET) 260
intraforaminal disc herniation 317
intramedullary tumor 63
intraoperative
– fluoroscopy 26, 63
– navigation 123
– ultrasound 29
intraosseous injection 222
intraspinal
– approach 307
– bleeding 21
intrathecal opioid pump 255
intrathoracic adhesion 211
inverted L 168
IRED, *see* infrared light-emitting diode
irritation 36
isometric exercise 295

Jacobaeus 149, 165
Jamshidi cannula 241
Jefferson fracture 44
Jenny score 368
JOA score 463
jugular vein 102
junction
– cervicomedullary 36
– craniovertebral 35
– thoracolumbar 203

Kerrison
– punch 18
– rongeur 39, 09
keyhole 107
knee–chest position 6
kneeling position 308
K-wire 46
kyphoplasty (KP) 31, 230
– balloon 232
kyphosis 386
– Scheuermann 164
– segmental 101, 197
– thoracic 186
kyphotic deformity 55, 222

laceration of the spinal cord 60
lag screw 47
laminectomy 231
– lumbar 92
– posterior 107
lamino-foraminotomy 92
laminoplasty 107, 356
– internal 397
laminotomy 111, 289
Langenbeck
– hook 427
– retractor 17
Langer's line 65
laparoscopic lumbar discectomy 150
laparoscopy
– retroperitoneal 151
– transperitoneal 151
laser disc decompression (LDD) 268
laser-assisted discectomy 55
lateral decubitus position 150, 197, 412
lateral mass 120
– articulation 118
LDD, *see* laser disc decompression 268
Lenke 180
lesion to the tongue 36
Lhermitte's sign 62
ligament
– alar 39
– anterior longitudinal 39, 187
– apical 39
– arcuate medial 204
– interspinous 459
– intraarticular 147
– laxity 119
– posterior longitudinal 20
– radiate 147
– supraspinous 459
– transverse 39, 42, 119
ligamentoplasty 466
– Graf 476
ligamentum nuchae 109
lighting 25
linea
– alba 390, 423
– arcuata 442
longus colli muscle 84
Love retractor 20
lower brain stem 35
lumbar
– discectomy 6
– drain 39
– laminectomy 92
– plexus 380
– scoliosis 386, 436
– – degenerative 386, 397
360° lumbar fusion 435
lung
– contusion 217
– fan retractor 178
– herniation 216
– tidal volume 186
luxation 56
lymph fluid 193

MACS TL, *see* modular anterior construct system thoracic lumbar

magnification 15, 25
– three dimensional 15
malleable-blade retractor 37
mammary gland 144
mandibulotomy 36
MAPN, *see* microscopically assisted percutaneous nucleotomy
Mayfield clamp 36
Mecca position 286
mechanoreceptor 260
MED, *see* microendoscopic discectomy
medial axillary line 168
median
– glossotomy 36
– raphé 39
mediastinitis 130
meningitis 40, 83
meningocele 116
MEP monitoring 78
mesenterium 427
MET, *see* microsurgical endoscopic technique
metalloproteinase 260
metastasis 231
Metzenbaum scissors 17
micro needle holder 21
Micro Speed EC 19
microdiscectomy 283, 362
microendoscopic discectomy (MED) 86, 149
microforaminotomy 92
microforceps 21
microinstrument 21
microknife 20
microlaminoplasty 362
microprocessor-controlled coagulation forceps 21
microscissors 21
microscope
– eyepiece 8
– handling 24
microstaple 21
microsurgery 12
– approach track 15
– hand–eye coordination 15
– instruments 16
microsurgical
– discectomy 278, 283
– endoscopic technique (MET) 165
– instrument 21
microtherapy 267
microscopically assisted percutaneous nucleotomy (MAPN) 322
middle axillary line 168
midline access 35
military tuck position 120
Minerva brace 120
Mini-ALIF approach 380
mini-laparotomy 387
minimal-invasive reference array (MIRA) 225
minimally invasive spine surgery (MISS)
– computer-assisted 26
– muscle-splitting techniques 6
– optical aids 6
mini-retroperitoneal open approach 216

mini-thoracotomy 139, 216, 439
MIRA, *see* minimal-invasive reference array
MISS, *see* minimally invasive spine surgery
modic type I change 452
modular anterior construct system thoracic lumbar (MACS TL) 157, 207
molybdenum 101
monitoring
– MEP 78
– SSEP 78
monocortical screw 73
monolayer culture 365
Morquio's syndrome 119
motorized fluoroscope 31
MRI 44
– artifacts 74
multifidus muscle 469
Murphy needle 224
muscle 283
– external oblique 442
– internal oblique 442
– longus colli 84
– multifidus 469
– pectoralis major 185
– pharyngeal 39
– psoas major 204
– rectus 386
– sternocleidomastoid 49, 84
– transverse 442
– – abdominal 413
muscle-splitting technique 409
musculus
– iliocostalis 311
– intervertebralis 311
– longissimus 311
– multifidus 311
– psoas major 311
– sacrospinalis 311
myelopathy 54
myeloscope 149
myocardial infarction 40

nasal tone of voice 39
NASCI
– II 62
– III protocol 218
NASS, *see* North American Spine Society Instrumentarium
navigation
– CT-based 28
– fluoroscopy-based 26, 28
– intraoperative 123
– stereotactic 39
– system 225
NDI, *see* neck disability index
neck
– disability index (NDI) 89
– exercise program 116
neoneurogenesis 268
neoplastic lesion 233
neovascularization 260
nerve
– common iliac 420
– genitofemoral 410
– hook 349
– iliocostal 386, 410
– iliohypogastric 219
– ilioinguinal 219
– intercostal 145
– recurrent laryngeal 60
– retractor 311
– root 224, 283
– injection 253, 254
– traversing 338
– sinovertebral 334
– splanchnic 136, 148
neural encroachment 231
neuralgia of intercostal nerve 212, 220
neurofibromatosis 188
neuroforamen 251
NeuroPilot 86
neurotomy 251
neurovascular supply 470
Newcleus 379
nickel 101
nitrous oxide 260
nociceptive tissue 260
nociceptor 260
non-ionic contrast dye 250
North American Spine Society Instrumentarium (NASS) 351
nucleoscope 149
nucleus
– excision 382
– prosthetic device 382
– replacement 380

occiput 42
ocular tilt 24
Odom's criteria 78
odontoid 39
– fracture 42
– process 36, 42, 43
– – of C2 118
– screw 44
– tip 47
odontoidectomy 119
– transoral 40
open-door technique 129
operated back 286
operating room setup 23
OPMI Vario 8
OPPL, *see* ossification of the posterior longitudinal ligament
optical
– aids 6, 16
– system 8
oral cavity 35
oropharyngeal
– incision 40
– mucosa 37
oropharynx 37
orotracheal tube 36
Orozco 55
orthosis 119
– external 45, 120
os odontoideum 44
osseous incorporation 93
ossification of the posterior longitudinal ligament (OPPL) 56
osteolytic lesion 222
Osteopal 161
osteopenia 386
osteophytic root compression 108
osteoporosis 76, 217, 386
osteoporotic
– fracture 222
– vertebral compression fracture (VCF) 222
osteotome 21
Oswestry Low Back Pain Disability Questionnaire 351
Ott 149
outpatient microsurgical discectomy 357
overstretching 60
oxygen saturation 391

PADI, *see* posterior atlanto-dental interval
pain generator 250
paradox cerebral embolism 232
paramedian approach 283
paramuscular approach 306
paraplegia 60, 116
paraspinal approach 307
– muscle splitting 307
parietal pleura 187
pars
– interarticularis 118
– intermedia 118
partial facetectomy 107
patient
– informed consent 36
– map 26
– patient-controlled analgesia (PCA) 136
PDN device 379
peanut dissector 46
pectoralis major muscle 185
pedicle screw placement 31
pedicular notch 336
PEEK, *see* polyetheretherketone
Penfield dissector 20
percutaneous
– discectomy 55
– nucleotomy 149
perforated herniation 292
periannular foraminal approach 339, 340
perioperative antibiotics 36
periosteal elevator 39, 110
peritoneum 430
peritonitis 130
pharyngeal
– flap 37
– muscle 39
phospholipase A2 260
pipeline view 189
pituitary rongeur 169, 183
plaster
– brace 200
– cast 200
plastic portal 178
platelet-rich plasma 72
platysma 45, 84, 102
– muscles 49
pleura 169
– parietalis 134
pleural
– cavity 204
– closure 188

– drain 165
– effusion 198, 204
– empyema 130, 217
pleuritis 130
PLIF, *see* posterior lumbar interbody fusion
PLL, *see* posterior longitudinal ligament
PLLA, *see* poly-l-lactic acid
PMMA, *see* polymethylmethacrylate
pneumonia 40, 124
pneumothorax 198
poly-l-lactic acid cage 72
Polyaxial-screw XL 161
polyetheretherketone (PEEK) 461
– cage 61, 70
– – lumbar 443
polyethylene 101
polymeric
– particles 95
– sheath 94
polymethylmethacrylate (PMMA) 71, 224
– cement 224
– extrusion 232
– high-viscosity 230
– leakage 232
porous
– coating 95
– hydroxyapatite 72
positioning 6
– da Vinci 387
– genupectoral 308
– kneeling 308
– lateral decubitus 197, 412
– military tuck 120
– prone 197, 308
– Trendelenburg 37, 109, 151, 168, 430
posterior
– apophyseal ring fracture 105
– approach 55
– atlanto-dental interval (PADI) 119
– axillary line 189
– hairline 121
– laminectomy 107
– longitudinal ligament (PLL) 20, 85
– lumbar interbody fusion (PLIF) 72, 435
– microlaminotomy-foraminotomy 107
– shock absorber 476
posterolateral
– approach 315
– disc herniation 85
postlaminectomy 101, 386
postoperative
– dysphagia 76
– hoarseness 60, 76
post-thoracotomy pain 220
pressure transducer 241
Prestige cervical disc system 93
prevertebral fascia 84
Prodisc C 100
programmable handgrip 9
prone position 197, 308
prosthesis
– Bristol 93
– Bryan cervical disc prosthesis 92
– cervical 92
– Fernstrom 92
– Frenchay 93
– viscoelastic-jacketed hydrogel 93
prosthetic joint 92
proteoglycan 367
pseudarthrosis 198, 204, 420
psoas major muscle 204
psychosocial factor 386
pulmonary
– collapse 169
– embolism 40, 217, 232
– toilet 40
punch 18

quadriplegia 60, 116

radiate ligament 147
radiculopathy 82
radiofrequency
– coagulator 342
– denervation 249
– laser 342
ramp effect 68
real time tracking 26
rectus
– muscle 386
– sheath 423
recurrent
– disc
– – herniation 326
– – prolapse 347
– laryngeal nerve 60
reflex symptomatic dystrophy 116
registration method 28
– non-invasive 29
regurgitation 39
respiratory
– arrest 40
– distress 40
retainer screw 102
retractor
– Caspar 20
– fan 189
– Langenbeck 17
– Love 20
– low-profile self-retaining transoral system 36
– lung fan 178
– malleable blade 37
– systems 17
– tooth-bladed 37
retrograde ejaculation 456
retrolisthesis 45
retroperitoneal
– approach 307
– bleeding 130
– laparoscopy 151
rheumatoid arthritis 36, 76, 119
rib head 147
rigid scoliosis 166
Risser 178
Roland Morris scale 264
rongeur 20
– down-biting angulated 20
– Kerrison 39, 209
– pituitary 169, 183
– up-biting angulated 20
root paralysis 115
rotation 166
rule of Spence 44

sacroiliac joint injection 254
sacrum 205
sagittal profile 166
scapula 205
Scheuermann
– disease 166
– kyphosis 150, 164
SCIWORET, *see* spinal cord injury without radiographic evidence of trauma
scoop
– angled 21
– straight 21
Scottie dog view 249
screw
– atlantoaxial transarticular 118
– biocortical 191
– lag 47
– monocortical 73
– odontoid 44
– pull-out 50
– retainer 102
– transarticular 43
– translaminar 435
SED, *see* selective endoscopic discectomy
segmental
– artery 110, 394
– kyphosis 101, 197
selective
– endoscopic discectomy (SED) 267
– nerve root injection 253
self-retaining wound retractor 16
– Weitlaner 16
semi-invasive procedure 249
sensory deficit in the oral cavity 36
sequestrectomy 376
SF-36 375
Shaw scalpel 39
sigmoid colon 423
single-lung ventilation 130, 166
sinovertebral nerve 334
skeletal immaturity 166
skin
– incision 16
– retractor 16
sliding technique 129
Smith-Robinson type interbody cage 60
smoking 76, 368
soft
– cervical collar 105
– disc
– – herniation 101, 108
– – sequestration 114
– palate 37
speculum-retractor system 308
spherical intercorporeal endoprosthesis 92
spinal
– alignment 40
– anesthesia 358
– claudication 398
– cord 224
– – contusion 116

– – injury 116
– – injury without radiographic evidence of trauma (SCIWORET) 56
– – laceration 60
– – stimulation 255
– – upper cervical 35
– instability 40
– instrumentation 31
– navigation system 27
SpineCATH 260
splanchnic nerve 136
– greater 148
– lesser 148
spondylectomy 436
spondylitis 129, 386
spondylodiscitis 54, 129
spondylolisthesis 56, 101
– isthmic type 431
spondylosis 56, 101
spontaneous fusion 99
spur compression 108
SSEP monitoring 78
stab incision 122
stereo bridge 8
stereotactic
– guidance 123
– navigation 39
sternocleidomastoid muscle 49, 84
subclavian vessel 146
subluxation 56, 101
subsidence 93
substance P 260
suction tip 20
suction–irrigation cannula 19
supraspinous
– ligament 459
– ligamentous complex 110
surgery time 16
surgical microscope 8
Surgicel 87, 187
suspension system 9
suture pusher 21
Swan neck deformity 108
sympathectomy syndrome 456
sympathetic
– chain 136, 219, 381
– trunk 148, 410
symphysis 205
Syncage 443
Synex 210
SynFrame 218, 436
systemic risk factor 76

T score 101
Tachocomb 89
tactile feedback 165
target surgery 3
b-TCP, *see* beta tricalcium phosphate
tectorial membrane 39
telemetry 256
tension pneumothorax 152, 190
tetraplegia 116
thecal sac 209
thermal
– annuloplasty 268
– damage 230
– cavity 129, 210
– disc herniation 129
– duct 136, 193, 204
– kyphosis 186
– lordosis 186
– spine fracture 164
thoracolumbar
– fracture 203
– junction 203
– transition 203
thoracolumbophrenotomy 216
thoracotomy 129, 166
– open 213
– postoperative pain 220
three-dimensional magnification 10
three-stage surgery 185
thyroid blood vessel 102
thyromegaly 60
tissue
– adhesion 21
– bleeding 21
titanium
– endplate 94
– mesh cylinder 71
TLA, *see* translaminar approach
tooth-bladed retractor 37
total disc replacement 100
total parenteral nutrition (TPN) 193
touchscreen 9
TPN, *see* total parenteral nutrition
tracheal tear 183
tracheostomy 36
transarticular screw 43
transforaminal
– approach 315, 317
– endoscopic discectomy 315
– epidural steroid injection 253, 254
transitional vertebra 118
translaminar
– approach (TLA) 297
– screw 435
transmaxillary approach 36
transmuscular dilatation 322
transoral
– approach 35
– odontoidectomy 40
– surgery 40
transpalatal approach 36
transpedicular
– fracture 56
– method 241
transperitoneal
– approach 423
– laparoscopy 151
– route 394
transthoracic approach (TTA)
– mini-TTA 129
transverse
– abdominal muscle 413
– fascia 442
– ligament 39, 42, 119
– muscle 442
– process 147
trapezial plate 55
traversing nerve root 338
Trendelenburg position 37, 109, 51, 168, 430
trial implant 103
triangular working zone 149, 316
tricortical iliac bone graft 430
TTA, *see* transthoracic approach
tumor
– disease 54
– intramedullary 63
– vertebral 231, 233
tunnel view 249

ultrasonography
– A-mode 29
– B-mode 29
ultrasound, intraoperative 29
uncinate process 55, 82
uncoforaminectomy 55
Unitrac 86
upper cervical spinal cord 35
ureter 390
– injury 198
urethral catheter 108
urinary tract infection 40
uvula 37

VAS, *see* visual analogue scale
vascular
– bifurcation 423
– injury 386
– topography 5, 386
VATS, *see* video-assisted thoracic surgery
VCF, *see* osteoporotic vertebral compression fracture
VectorVision system 225
vein
– azygos 148
– brachiocephalic 148
– common iliac 390
– epidural 283
– genitofemoral 420
– hemiazygos 148
– iliolumbar 151
– intercostal 145
– jugular 102
vena cava inferior 394
venous plexus 283
Ventrofix 159
vertebral
– artery 82, 119
– body
– – fracture 56
– – screw 191
– fracture 231
– hemangioma 222
– tumor 231, 233
vertebrectomy 54, 209
vertebrobasilar occlusion 40
vertebroplasty (VP) 222
– open 230
video
– endoscopy 409
– recorder 9
video-assisted thoracic surgery (VATS) 157, 164, 203
– anterior spinal release and fusion (VATS-RF) 176
– anterior spinal fusion and instrumentation (VATS-ASFI) 176
virgin back 286
visceral
– injury 183

– pleura 132
viscoelastic property 459
viscoelastic-jacketed hydrogel prosthesis 93
visual analogue scale (VAS) 89, 239, 351
visual axis 15, 16

Wallis implant 459
Weitlaner self-retaining wound retractor 16
window technique 129
wine bottle cork 45
Worker's Compensation 357
working channel 17
wound
– closure 16
– dehiscence 40

xenon
– illumination 9
– light source 86
xenostrut 68
xiphoid process 204

zoom 25
– system 8
Z-plate 157
zygapophyseal joint 232
– injection 251