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The Conservative Scoliosis Treatment

1st SOSORT Instructional Course Lectures Book

Edited by

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The Conservative Scoliosis Treatment
T.B. Grivas (Ed.)
IOS Press, 2008

Preface

This is the first of a series of Instructional Course Lectures (ICL) Books of the International **S**ociety **O**n **S**coliosis **O**rthopaedic and **R**ehabilitation **T**reatment (**SOSORT**). In the contents of this book the reader can find the SOSORT STATUTES and become familiar with the aims of the creation of this society. This will hopefully be the initiation of a series of books on conservative scoliosis treatment and a valuable library for SOSORT. The philosophy of the commencement of such ICL book series is the achievements of an ultimate aim, the improvement of early detection and non operative treatment of the patient care pathway for scoliosis.

For this endeavor, a number of eminent clinicians and scientists around the world, who are devoted and high-quality "students" of scoliosis, are involved and contributing with their fabulous work.

There is no doubt that this book is not able to cover every aspect of the issue. However, the future volumes of this series of books will continuously complete the latest relevant knowledge.

In this volume there are chapters reporting on various aspects of the current state of the following topics: IS aetiology, recent trends on scoliosis research, genetics, prevention-school screening, various methods of physiotherapy, various types of braces, the inclusion criteria for conservative treatment, together with the SOSORT guidelines for conservative treatment, clinical evaluation and classification, study of the surface after brace application and outcomes for each brace.

Our belief is that doctors dealing with spinal deformities and in particular with scoliosis, ought to be efficient in treating the disease from "A–Z", that is, to be familiar with all the existing therapeutic strategies.

We hope that the book, by its distribution to the attendees of the 5th International Conference on Conservative Management of Spinal Deformities at the Eugenidou Foundation, April 3–5 2008, Athens, Greece, will be disseminated around the world. Thus the important idea of proper conservative treatment of scoliosis will re-emerge, which in the past decades has been somewhat overlooked in favor of surgery, which is anyway necessary when indicated.

We would like to express our deep appreciation to all the authors and co-authors for spending their valuable time in order to share with us their profound knowledge on the issue. We would also like to express our gratitude to IOS Press publishers for making our dream a reality.

Dr Theodoros B. GRIVAS, MD
23 September 2007, Athens, Greece

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Society On Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT)

Abstract. The SOSORT was created in January 2004 in Barcelona. Specialists in orthopaedics and/or rehabilitation as well as physiotherapists and other medical professionals dealing with spinal disorders are invited to participate to the activities of the SOSORT. We encourage also patients and their families to cooperate with SOSORT.
In the following pages we are providing some more information regarding SOSORT founders, the meetings, the history and the officers of this society. The reader could have more information through the official SOSORT website www.sosort.org, about the research program, the brace study and the scoliosis study.

Keywords: Scoliosis Orthopaedic conservative Treatment, Scoliosis Rehabilitation Treatment, SOSORT, society

The founders

Figure 1. From left to right the SOSORT founders are depicted

Dr. Toru Maruyama, MD, Department of Orthopaedic Surgery, University School of MedicineTokyo, Japan

Dr. Manuel Rigo, MD, Elena Salva Institute, Barcelona, Spain,

Dr. Stefano Negrini, MD, Scientific Director of ISICO, Italian Scientific Spine Institute, Milan, Italy

Dr. Theodoros B Grivas, MD, Scoliosis Clinic, Orthopaedic Department, "Thriasio" General Hospital, Magula, Greece

Dr. Tomasz Kotwicki, MD, Orthopedic Surgeon, Spine Surgery, University Department of Pediatric Orthopedics, Poznan, Poland

Dr. Hans-Rudolf Weiss, MD, Orthopedic Surgeon, Physical Therapy and Rehabilitation, Medical Director of the, Asklepios Katharina Schroth Spinal Deformities Rehabilitation CentreBad Sobernheim, Germany

Board

Figure 2. From left to right: Tomasz Kotwicki, Elias Vasiliadis, Theodoros Grivas, Hans – Rudolf Weiss, Martha Hawes, Toru Maruyama, Manuel Rigo, Tamar Neuhous, Stefano Negrini, Joseph P. O’ Brien.

1. Meetings

After the foundation of SOSORT, four meetings were held worldwide.

1.1 1st SOSORT Founding meeting, Barcelona, January 23rd-24th,2004

Figure 3. The participants of the 1s SOSORT meeting

Program Chairman: Manuel Rigo, MD

International Faculty Members: Hans Rudolf Weiss M.D., Stefano Negrini M.D., Tomasz Kotwicki M.D., Franz Landauer M.D.,Jacques Chêneau M.D., Toru Maruyama M.D., Dror Ovadia M.D., Theodoros B. Grivas M.D.,Charles-Hilaire Rivard M.D., Renzo Aulisa M.D

Honorary Guests: Dr Christa Lehnert-Schroth,
Dr Jacques Cheneau.

1.2 2nd SOSORT Consensus meeting, Milan, January 13th- 14th

Figure 4. Snapshot of a session during the 2nd SOSORT meeting

President: Stefano Negrini

Scientific Committee: Theodoros B. Grivas ,Tomasz Kotwicki, Toru Moruyama , Manuel Rigo, Hans Rudolf Weiss

1.3 3rd SOSORT Scientific meeting, Poznan, April 7th – 8th

Figure 5. The participants of the 3rd SOSORT meeting

Honorary Presidents: Prof. Krystyna Dobosiewicz, Prof. Jacques Cheneau, Prof. Witold Marciniak

Scientific Committee: Jacek Durmala,Theodoros B. Grivas, Tomasz Kotwicki, Toru Maruyama, Stefano Negrini, Manuel Rigo, Andrzej Szulc, Hans Rudolf Weiss

1.4 4th SOSORT meeting, Boston, May 13th – 15th

Figure 6. The participants of the 4th SOSORT meeting

1.5 5th SOSORT meeting, Athens, Greece, April 3-5, 2008.

Chairman: Theodoros B. Grivas

Scientific Committee: Emanuel Rigo, Tomasz Kotwicki, Theodoros B. Grivas, Stefano Negrini, Elias Vasiliadis, Hans Rudolf Weiss, Tamar Neuhaus, Joe P. O'Brien, Toru Maruyama, Jean Claude de Mauroy

2. International Society on Scoliosis orthopaedic and rehabilitation treatment statutes

Title I Name, Registered Address

Article 1

Under the registered name of " International Society on Scoliosis Orthopaedic and Rehabilitation Treatment" (its official abbreviation will be SOSORT) was called in Barcelona (Spain 2004), started in Milan (Italy 2005) and is constituted in Poznan (Poland 2006) an international scientific society with its own legal entity , different to its members. The SOSORT will govern according to the current statutes.

Article 2

About registration

Title II Duration and Dissolution

Article 3

The life of the Society is unlimited. The Society can be dissolved according the causes written in the current statutes.

Title III Aims

Article 4

The SOSORT is a non profit organization. The general aim of the Society is: First, to foster the best conservative management – early detection, prevention, care, education and information - of scoliosis and other spinal deformities. Second, to encourage multidisciplinary team work - including scientists, medical and healthcare professionals, patients and their families -.The most specific aims of the Society are:
4.1 To offer an open forum for the exchange of knowledge and ideas on the field of conservative management of all spinal deformities and more particularly scoliosis.
4.2 To stimulate research and clinical studies in order to verify the main idea that prevention and conservative treatment are effective, efficient and valuable tools for the management of all the signs and symptoms of scoliosis and other spinal deformities.
4.3 To stimulate consensus in all the different conservative actions directed to the early detection, observation, prevention, management and orthopaedic treatment and rehabilitation of scoliosis and other spinal deformities.
4.4 To spread into the scientific community and the general population, patients and their families the idea that prevention based on education and early conservative management, avoiding under- as well as over-treatment, following generally accepted guidelines is the best approach in this field.
4.5 To promote specific education and training among professionals creating a body of specialists in this particular area, able to care efficiently for scoliosis patients.

Title IV Membership

Article 5

The society is formed by active, associated, supportive and honorary members.
5.1 Active members are medical doctors, physiotherapists, orthotists and other professionals actively involved in scientific research on conservative treatment or prevention of scoliosis and other spinal deformities.
5.2 Associated members are medical doctors, physiotherapists, orthotists and other professionals dealing with scoliosis and other spinal deformities.
5.3 Supportive members are patients, patient’s relatives or anybody dealing with scoliosis and other spinal deformities promoting the society with their donations.

5.4 Honorary members, discharged from any duty, are active members reaching retirement or becoming disabled. Any associated member or other distinguished people in the field could be also nominated for Honorary member by the Executive Committee and elected by the General Assembly for their special contribution to the Society.

Article 6

Membership rights and duties are:
6.1 Active members have the right to receive notice to attend and to vote at the business meetings of the Society, to participate in the scientific and business affairs of the society.
6.2 Associated members will be listed as members and they shall have the right to receive notice of and attend the General Assembly. They can vote for two associated members in the executive committee), or to elect a membership. They can participate in all the scientific affairs of the Society.
6.3 Active members must participate actively during the scientific meetings of the Society, they should also submit to 'Scoliosis', the official journal of the Society, and have some papers accepted. In its defective, promotion to active member can be considered by the membership committee for reasons like special contribution and/or long recognized experience in the field.
6.4 Active and Associated members must both contribute to the finances of the Society being required to pay annual dues fixed by the General Assembly.
6.5 Somebody can be supportive member by a donation of a minimum amount fixed by the General Assembly. Supportive members have the right to receive notice and to attend but not to vote at the business meeting of the society.
6.6 Active members and associated members (in its limited number of two) but not supportive or honorary members can be elected to represent the Society or to office in the Executive Committee.
6.7 Active and associate members can both be elected to office in the committee of the annual meeting.
6.8 All the members, Active, Associated, Supportive and Honorary can investigate the financial report offered by the Treasurer at each General Assembly and in its case censure the task of the Executive Committee.
6.9 Membership shall cease by death.
6.10 Membership in the Society is not transferable or inheritable under any circumstances.
6.11 Membership application. Applications for membership shall be sent to the Secretary of the SOSORT not later than three months before the Ordinary General Assembly. Applications for Active member candidate must be signed by two Active members. Applications for Associated member must be signed by two Associated members or one Active member.
6.12 The Membership Committee. The Secretary shall submit all applications for membership in the Society to the Membership Committee in order to study, investigate and report to the Executive Committee for its consideration. Majority approval by the Executive Committee shall be required prior to ratification by the Active members during the Ordinary General Assembly.
6.13 Election to membership. The Secretary - upon the recommendation by the Executive Committee – shall forward to the Active members of the Society a list of candidates to membership. The list shall show the names and qualifications of the

candidates as well as the Executive Committee recommendations. A two-thirds majority shall be required for election to membership. The Secretary shall notify each applicant of the vote result.
6.14 Membership resignation. Resignation without prejudice from the Society will occur immediately after the receipt by the Secretary of a written declaration to this effect, signed by two members of the Executive Committee. All rights and duties of membership in the Society will cease upon resignation except for dues in arrears.
6.15 Expulsion from membership. A member may be expelled from the Society, for any reason that the Executive committee consider causative to this effect, passing the two-thirds majority in an Ordinary or Extraordinary General Assembly. Expulsion shall be automatic if annual dues have not been paid for more than two years, after two warnings about repeatedly being late, separated by three months.

Title V Language

Article 7

The official language of the Society is English.

Title VI Organs of Society

The General assembly

Article 8

The General Assembly is the highest organ of the Society.
8.1 All the members of the Society will meet at least once a year during the Annual Meeting of the Society in the so called General Assembly.
8.2 All the members of the Society can express their opinions during the General Assembly but just Active, Associated and Honorary members can vote. Some restriction have considered in these statutes to Associate members and Supportive members (Article 6)

Article 9

The General Assembly can be Ordinary or Extraordinary.
9.1 Ordinary General Assembly will meet every year at the Annual Meeting of the Society. All the members will receive a written notice with the agenda at least one month before the meeting.
9.2 Ordinary General Assembly will pass the finances of the year as well as to balance the budget of the coming year, to consider and to adopt (or to reject) the conduct, the reports and resolutions of the Executive Committee and proceed, when necessary, to the renovation of its members (all of the General Assembly).
9.3 Extraordinary General Assembly will meet as often as the President thinks it necessary or by request of the Executive Committee or 20% of the Active Members.

Article 10

The General Assembly will be announced and presided by the President or the Past-president if necessary.
10.1 Quorum is formed by a simple majority of the Active Members (personally or represented by a valid proxy – maximum one per member) excluding the President of the Executive Committee. When such a quorum is not reached the General Assembly will be celebrated in any case half an hour later (second calling) one way or another.
10.2 All resolutions will be adopted or rejected by the majority of the votes, except for the following, which are also attributions of the General Assembly needing two thirds of the votes from Active members:
Ψ Modification of the current Statutes
Ψ Dissolution of the Society
Ψ Participation of the Society in other International Organizations
10.3 All votes are individual. Any member can represent another member (and just one) by a valid proxy. A proxy must be conveniently written and is just valid for the specified General Assembly (date and place must be clearly indicated).

The Executive Committee

Article 11

The Executive Committee shall administer and represent the Society.
11.1 Only Active, Associated and Honorary members may be elected for an office in the Executive Committee.

Article 12

The Executive Committee shall be composed of:
1. The President
2. The Past-President
3. The Elected-President
4. The General Secretary
5. The Treasurer
6. The Editor in Chief of 'scoliosis' (ex officio)
7. Member
8. Member
9. Member

Two members of the executive committee must be elected by the associated members.
In the Executive Committee there must be one member representative of medical doctors, one of physiotherapists, one of orthopaedic technicians and one of patients.

Article 13

The President of the Executive Committee is the President of the Society and holds the social as well as the legal representation of the Society.

Article 14

The Executive Committee shall meet at least once a year during the Annual Meeting of the Society and later convened as often as necessary by the President or by request of a minimum of two members of the Executive Committee. The President can be replaced first for the Past-President or for another member of the Executive Committee when necessary.

Article 15

The Executive Committee members shall be elected for a period of three years (Secretary and Treasurer), two years (Member) or one year (President, Past-President, Elected-President).

Article 16

A permanent Secretary will take care of all the affairs of the Society related to the office of secretary.
No remuneration shall be paid by the Society to any of the Executive Committee members. However, the permanent Secretary will be remunerated according to the Executive Committee decision.

Article 17

Just as declarative but not limitative the Executive Committee may:
17.1 Propose the nomination to the vacant offices for the Executive Committee.
17.2 Receive the applications and resignations of membership and propose the nomination of new members to the General Assembly.
17.3 Propose to the General Assembly any change of the current Statutes. The General Assembly of Active members may accept it by two thirds of the votes or reject it.
17.4 Propose to the General Assembly the Chairman, the place, the date and the topic of the next Annual Meeting. The Chairman will be automatically accepted as member of the Executive Committee for one year, without voting rights.
17.5 Elect a new member of the Executive Committee when there is a vacancy until the next General Assembly. The new member shall be ratified during the next General Assembly.

Article 18

In general the Executive Committee can take all the tasks that are not reserved to the General Assembly according to the current Statutes.

Article 19

All the decisions of the Executive Committee may be passed by the majority of the members. The President reserves for him/her self the mission to break the tie between the votes.

Title VII Finances of the Society

Article 20

The entries to cover the administration and running of the Society shall come from:
20.1 The annual dues of Active and Associated members
20.2 The donations from Supportive members.
20.3 International Organisms throughout contributions
20.4 Other incomes, grants, legacies and gifts according to the applicable international laws and deontological code.

Article 21

21.1 The Treasurer shall be in charge of the finances of the Society and may request or not the collaboration of an administrator to assist him/her.
21.2 The Treasurer shall prepare a financial report to be circulated to the members of the Society before the General Assembly at each Annual Meeting. This report shall cover the last fiscal year preceding the Annual Meeting and be considered by the General Assembly for approval.
21.3 The Treasurer shall submit an Annual Budget for the ensuing year to the Executive Committee for review and approval at least one month prior to the Annual Meeting.

Title VIII Meetings and other Activities

Article 22

To fulfil the aims and objectives of the Society the next activities are proposed:
22.1 Annual Meeting. The Annual Meeting of the society shall combine Scientific, Consensus and Education sessions.
22.2 A database to collect important information about the results of conservative management (bracing and exercises) of Scoliosis and other Spinal Deformities shall be created.
22.3 Courses, Seminaries, Workshops to inform and to teach professionals.
22.3 'Scoliosis', a new electronic scientific journal (open peer-review) has been created to be the official journal of the Society (http://www.scoliosisjournal.com).

Furthermore through the SOSORT website www.sosort.org/scoliosis_library.php [1] there is a section called "scoliosis library" where publications relevant to scoliosis can be found.

References

[1] www.sosort.org/scoliosis_library.php

Contents

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Section I

Aetiology

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The Conservative Scoliosis Treatment
T.B. Grivas (Ed.)
IOS Press, 2008

Concepts on the Pathogenesis of Adolescent Idiopathic Scoliosis. Bone Growth and Mass, Vertebral Column, Spinal Cord, Brain, Skull, Extra-Spinal Left-Right Skeletal Length Asymmetries, Disproportions and Molecular Pathogenesis

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Abstract. There is no generally accepted scientific theory for the causes of adolescent idiopathic scoliosis (AIS). Encouraging advances thought to be related to AIS pathogenesis have recently been made in several fields including anthropometry of bone growth, bone mass, spinal growth modulation, extra-spinal left-right skeletal length asymmetries and disproportions, magnetic resonance imaging of vertebral column, spinal cord, brain, skull, and molecular pathogenesis. These advances are leading to the evaluation of new treatments including attempts at minimally invasive surgery on the spine and peri-apical ribs. Several concepts of AIS are outlined indicating their clinical applications but not their research potential. The concepts, by derivation morphological, molecular and mathematical, are addressed in 15 sections: 1) initiating and progressive factors; 2) relative anterior spinal overgrowth; 3) dorsal shear forces that create axial rotational instability; 4) rotational preconstraint; 5) uncoupled, or asynchronous, spinal neuro-osseous growth; 6) brain, nervous system and skull; 7) a novel neuro-osseous escalator concept based on a putative abnormality of two normal polarized processes namely, a) increasing skeletal dimensions, and b) the *CNS body schema* - both contained within a neuro-osseous timing of maturation (*NOTOM) concept*; 8) transverse plane pelvic rotation, skeletal asymmetries and developmental theory; 9) thoraco-spinal concept; 10) origin in contracture at the hips; 11) osteopenia; 12) melatonin deficiency; 13) systemic melatonin-signaling pathway dysfunction; 14) platelet calmodulin dysfunction; and 15) biomechanical spinal growth modulation. From these concepts, a collective *model* for AIS pathogenesis is formulated. The central concept of this model includes the *body schema* of the neural systems, widely-studied in adults, that control normal posture and coordinated movements with frames of reference in the posterior parietal cortex. The *escalator concept* has implications for the normal development of upright posture, and the evolution in humans of neural control, the trunk and unique bipedal gait.
Key words. Idiopathic, scoliosis, pathogenesis, spine, spinal cord, brain, ribs, pelvis.

Introduction

Encouraging advances thought to be related to the pathogenesis of adolescent idiopathic scoliosis (AIS) have recently been made in several fields. The fields are: bone mass, bone growth, spinal growth modulation, extra-spinal left-right skeletal length asymmetries, lower limb proximo-distal and other skeletal disproportions (allometry), magnetic resonance imaging of vertebral column, spinal cord, brain and skull, and molecular pathogenesis. They are leading to new concepts of pathogenesis and to new treatments including attempts at minimally invasive surgery on the spine and peri-apical ribs. A major problem plaguing any new finding for AIS pathogenesis is whether it is primary or secondary to the deformity [1]; at present such judgments have to be made on plausibility and balance of probabilities. There is still no generally accepted scientific theory for the causes of AIS [2-16]. Concepts abound, and we restrict attention here in 15 sections to pathogenetic concepts of AIS most of which attempt to be comprehensive.

A fundamental question of AIS pathogenesis.

Is AIS a *final common pathway* that results from the production of an imbalance of forces along the spine [14] from different etiologies [17], not as one disease [18], but a deformity with a wide pathogenetic spectrum? [19]. Or, is there one, or possibly a few, mechanisms common to most types of AIS? We do not know the answer to these questions [2,7], but research on the molecular pathogenesis of AIS is beginning to identify single mechanisms [20, 21]. The current consensus is that AIS is a multi-etiological condition caused by mutations in many different genes.

Pathogenetic concepts.

The aim of a new concept or a new theory in a scientific field is to pull all the phenomena into one coherent whole [22]. In AIS pathogenesis new concepts by clarifying understanding help plan researches with the ultimate aim of basing diagnosis, prognosis and treatment on some knowledge of causation of the disease, and possibly ultimately attaining prevention. Only one of several pathogenetic concepts considered here is established - *relative anterior spinal overgrowth* and though it justifies the term theory - its mechanisms of formation, biomechanical, or biological, are uncertain. A few concepts contain discrete hypotheses i.e. they can be tested and refuted, but most are plausible and speculative. No attempt is made to weigh their strengths and weaknesses in isolation or by comparison, while indicating their clinical applications. Discrete hypotheses though common have been of limited value because until recently no single mechanism of pathogenesis had been identified and there are ethical restraints to attempts at refutation. Well-reasoned argument, the dialectic, is not the scientific method [23, 24] but it can suggest new directions in research. In a multifactorial disorder like AIS in humans, most concepts involve the interaction of several mechanisms, biological and biomechanical, many in *linear causality*, less commonly in *summation causality (Venn diagram)* [25], or in both. In relation to the sum of pathogenetic findings for AIS, there is, at present, little certainty and much doubt, but that is the nature of scientific [22, 26, 27] and particularly clinical research on the pathogenesis of idiopathic disorders.

Some undisputed facts of AIS for the concepts to explain.

Asher [28] commented that in the end, theories about the etiology(ies) of idiopathic scoliosis will have to explain:

1) the emerging dependence of the deformity upon growth and growth rate;
2) its predilection for females;
3) members of involved families; and
4) its varied progression patterns. Goldberg [29] adds
5) laterality patterns of the curves. Castelein et al [11] add
6) the 3D rotatory deformity of the spine;
7) vertebral bodies grow faster than the posterior parts of the vertebrae; and
8) AIS is exclusive to humans. The role of growth in the pathogenesis of AIS is unclear – causative, conditional, amplifying, or coincidental? [11].

Exclusions.

Not considered, or barely considered here, are:

1) research on skeletal muscles, ligaments and connective tissues;
2) research discovering susceptibility genes [16];
3) identification of environmental risk factors [30, 31];
4) skeletal bilateral symmetry of vertebrates in health and disorder, its origin and control [31];
5) developmental theory [10,32-35]; and
6) animal models of scoliosis, natural and experimental [36-40].

Animal models and their lack of unique human features.

There are limitations to animal models because of an inability in them to reproduce several unique human features, namely a) adolescent growth and maturation, b) upright posture with lumbar lordosis, and c) unique bipedal gait. Humans perceive the world in four dimensions dominated by gravity and the visual horizon. In the upright position these two environmental factors influence all voluntary movements by neuromusculoskeletal adaptations evidently modified and established during growth by a process that is likely to be actively acquired and continually adjusted until maturity. [see below 7. Collective model and neuro-osseous escalator concept for AIS pathogenesis].

Human bipedalism.

There is increasing support for the view that the unique human bipedalism and the erect posture (as an 'antigravity pole') are prerequisites for AIS pathogenesis [7, 10, 11, 38, 41-49]. In normal humans, axial rotations and counter-rotations of the trunk are carried out frequently and forcibly in activities that are not performed by quadrupeds [50]. In human evolution, alignment of the body to the gravitational vertical has been considered to be the key to human bipedalism [51] with a close link between balance and spatial cognition developed in the cerebral cortex [52]. Human bipedalism in evolution is associated with:

1) a derived lumbar curvature in the normal adult female, with reinforcement of the vertebrae to compensate for bipedal obstetric load [53].
2) decoupling of head and trunk movements [54, 55] typical of modern humans with their capability for endurance running [55,56], associated with
3) differences in semicircular canal morphology [54, 57], and the labyrinth attaining its adult size and shape long before birth [57].

According to Fitzpatrick et al [51] the semicircular canals are concerned with movement by signaling linear accelerating forces rather than by signaling gravity and vertical alignment, and they suggest that in human bipedalism the control of movement and agility is more important than the precise vertical alignment of the body.

Terminology.

In connection with *causes* three words are used, *etiology* strictly means the factor(s) causing the condition, *pathogenesis* its mode of origin, and *pathomechanism* the sequence of events in the development of the structural and functional changes resulting from the pathological process [58]. In accordance with common usage we employ the word *pathogenesis* to include *pathomechanisms.* We do not address *etiology.*

Torsion has two meanings [59]: (1) a local geometric property of the vertebral body (*geometric torsion,* or *tortuosity*); and (2) axial plane angulations between specified vertebrae (*mechanical torsion,* or *axial rotation*).

1. Initiating and progressive factors

Some workers consider that there are two types of pathogenetic factors for AIS, *initiating (or inducing) factors* and those that cause *curve progression* [7, 10, 13, 17, 60] and there is evidence to support this concept [61-66]. *Curve progression* is generally thought to involve a mechanical process (*torsion, vicious cycle*) with eccentric loading of the spine and *vertebral growth modulation* [6, 7, 10, 13, 61, 67-70], but this is questioned [71].

2. Relative anterior spinal overgrowth (RASO) (Figure 1)

Longer anterior than posterior vertebral column.

During the last 80 years anatomical studies and most recently magnetic resonance imaging (MRI) have established that in structural scoliosis the anterior components of the spine are longer than the posterior elements [6, 72-77]. This is interpreted as *relative anterior spinal overgrowth (RASO)* that results in torsion [72], possibly by an oblique deflection of growth and gravity applied to vertebral growth plates [78]. *RASO* is evident in the crankshaft phenomenon [79]. The normal adult human female has been shown to have evolved a derived lumbar curvature with reinforcement of the vertebrae to compensate for bipedal obstetric load [53]. How these sexually dimorphic features of the normal lumbar spine may or may not relate to the different predisposition of girls and boys to progressive AIS is not clear.

Sagittal, frontal and transverse planes.

Somerville [80] concluded from radiological and experimental findings that the deformity of thoracic idiopathic scoliosis consists of lordosis, axial rotation and lateral flexion and suggested that lordosis results from failure of growth of posterior elements of a segment of the spine. This concept was further developed by Roaf [72] and then by Vercauteren [81,82], and Dickson and colleagues [6, 83]. In progressive AIS Vercauteren and Dickson each ascribed *pathogenetic significance* to the sagittal plane, respectively the declive angle and a hypokyphosis. The primacy of the sagittal plane in the pathogenesis of AIS is questioned [4, 7, 10, 11, 13, 84-88] and now controversial [4, 7, 10], but the obligatory involvement of the sagittal plane of the spine as with the other planes in curve initiation, is generally accepted. Transverse plane deformity within vertebral bodies (geometric torsion, or tortuosity) and intervertebral discs (mechanical torsion, or axial rotation) in scoliosis was shown by an anatomical study [89] and confirmed by MRI [90].Transverse plane rotation affects the pelvis in major right thoracic AIS [91](see below 8.).

General skeletal and spinal overgrowth.

The current extensive research on the pathogenesis of AIS in Hong Kong is part of a series of studies [19, 76, 77, 92-98] to evaluate the hypothesis that there is a systemic disturbance of growth manifest in both the appendicular skeleton and vertebral column that points to a problem of axial skeletal growth control. Guo et al [76] used whole spine MRI to re-investigate the height of both anterior and posterior vertebral components in girls with AIS and in normal subjects (see Figure 1). They found that: (1) the scoliotic spines between T1 and T12 have longer vertebral bodies and shorter pedicles than do the normals, and the converse of that seen in Scheuermann's disease [83, 99]; (2) the ratio of anterior/posterior vertebral body components correlates significantly with a scoliosis severity score; and (3) at T6 the anteroposterior and lateral vertebral body diameters are similar in scoliotics and normals. In interpretation, they proposed *uncoupled endochondral-membranous bone formation* [76,77] consistent with histological appearances [100].

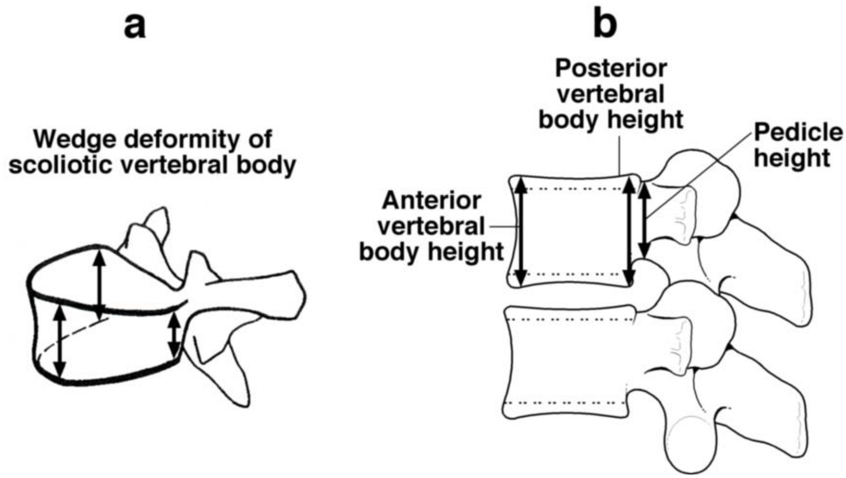

Figure 1. (a) Wedge deformity of scoliotic vertebral body. Modified from Perdriolle et al [61]. (b) Measurements made on vertebrae of MRI scans by Guo et al [76]. Modified from Guo et al [76].

In etiology, the uncoupled bone growth is viewed as one part of an *intrinsic abnormality of skeletal growth in patients with AIS which may be genetic* [77]; the other part is appendicular skeletal overgrowth [19]. This is consistent with the views of earlier workers who found a large extra-thoracic skeleton with progressive AIS and interpreted it as an intrinsic anomaly of growing bones attributed to genetic and/or environmental factors acting in pre- or post-natal life [31, 32, 101-105]. Most recently, an anthropometric comparison of AIS subjects in which those with affected first degree relatives were compared with those with sporadic AIS showed a significantly longer arm span and larger Cobb angle at maturity in the familial than in the sporadic group [97].

According to Guo et al [76, 77] *RASO* concept has two linked processes as follows:

1) General skeletal overgrowth [92, 97].
2) Relative anterior spinal overgrowth due to *uncoupled endochondral-membranous bone formation* results from *primary skeletal change* [106] as it affects the sagittal plane of the spine [76, 77]. In contrast, Castelein et al [11] hypothesize that thoracic AIS has a mechanical basis (see below 3. Dorsal shear forces).

Wever et al [7, 107] interpret the vertebral and rib deformities of structural scoliosis to bone remodeling due to a force system arising from an imbalance between forces in the anterior and posterior spinal columns; and more specifically to *lateral shear forces* created in the anterior column driving the apical vertebra out of the midline, whereas torque forces created by the posterior musculo-ligamentous structures attempt to minimize the deviations and rotations of the vertebrae.

Clinical applications.

1) Minimal anterior spinal surgery for early AIS [108-110].
2) Better surgery for severe scolioses.
3) Antioxidants may be beneficial to control the growth-related vertebral torsion of AIS [10, 111].

3. Dorsal shear forces create axial rotational instability (Figures 2 & 3)

Deacon and Dickson [112] stated that in idiopathic scoliosis the lordotic segment is the initial event and the vertebral rotation and Cobb angle are secondary. The primacy of the sagittal plane in initiating AIS is questioned [4, 7, 10]. Backward vertebral tilt (inclination or retroversion) is a normal feature of sagittal spinal shape as revealed in screening referrals (see Figure 2a) [113] and is associated with the progression of idiopathic scoliosis treated in a brace [11].

Castelein and colleagues [11, 114] hypothesize that it is not the thoracic lordosis itself, but the sagittal orientation of vertebrae in humans which, in the presence of normal axial vertebral rotation asymmetry (see Figure 2b) [115], contributes to the onset and progression of AIS. They suggest that the erect position of the human spine - relative to that of quadrupeds and non-human primates - leads to *reduced anterior shear forces* (see Figure 3a,c). Erect posture with backward vertebral tilt, gravity and muscle activity can produce *dorsally-directed (posterior) shear forces* that leave the facet joints inoperative (see Figure 3b) and cause loads which the posterior ligaments and muscles are not well-suited to counteract Such posterior-directed shear, by enhancing slight asymmetries in the transverse plane, creates internal forces (strains); these lead to asymmetric loading in the transverse plane of vertebrae, intervertebral discs, and attached ligaments. This loading induces asymmetric growth of pedicles, vertebral bodies and arches in accordance with the Hueter-Volkmann effect (see Figure 3d) [11]. This putative mechanism, involving the spine in both sagittal and transverse planes, leads to a failure of axial vertebral rotation control producing the Cobb angle and the relative anterior spinal overgrowth (*RASO*).

According to Castelein et al [11] the concept of dorsal shear forces has six linked and overlapping processes as follows (*linear and summation causality):*

1) Upright human posture.
2) Backward inclination (retroversion) of vertebrae in the sagittal plane creates -
3) dorsal shear forces that render the facet joints inoperative and introduce –
4) axial rotational instability enhancing slight asymmetries in the transverse plane which already exist [115].
5) Asymmetric loading of the posterior parts of vertebrae lead to -asymmetric growth in 3-D of pedicles, vertebral bodies and arches involving neurocentral synchondroses in accordance with the Hueter-Volkmann effect.

Clinical applications.

1) Castelein et al [11] state that their *dorsal shear concept* will lead to new options for early intervention against the development of AIS.

2) The sagittal spinal declive angle measured with a goniometer at T11/12 may provide an adjunct to screening for scoliosis with the Scoliometer [82, 116].

The role of neurocentral synchondroses in AIS pathogenesis is controversial because of lack of agreement on the exact age at which closure occurs [10, 117], and such a role is not supported by a recent finite element study [118].

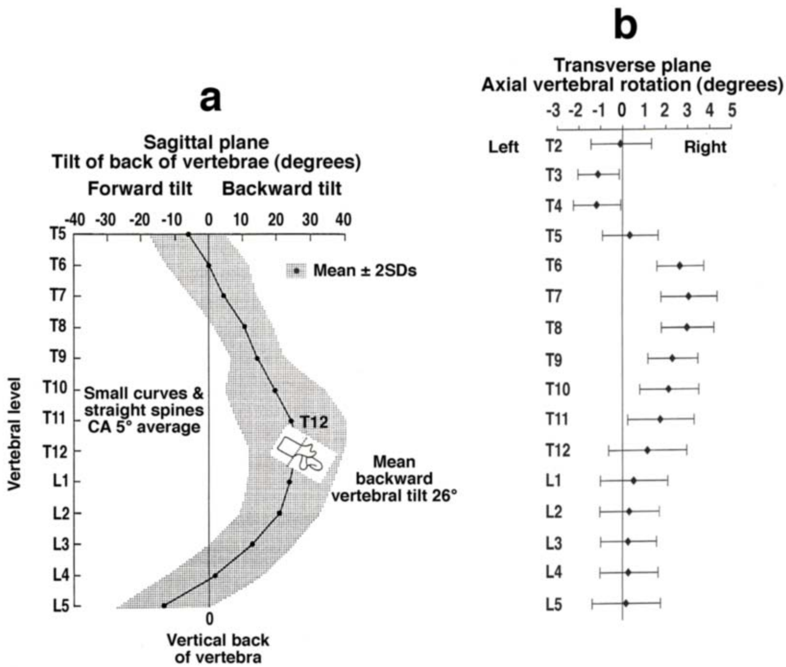

Figure 2. (a) Radiological segmental angulation of the posterior surfaces of vertebral bodies from the vertical in screening referrals with Cobb angles less than 10 degrees. Mean ±2 standard deviations (n=14). Modified from Kiel et al [113]. (b) Mean axial vertebral rotation and 95% confidence intervals in the transverse plane from CT scans of 25 males with non-scoliotic spines. Modified from Kouwenhoven et al [115].

4. Rotational preconstraint

A model to clarify the role of paravertebral muscles provides a novel concept for some scolioses [119]. The hypothesis tested is that paravertebral muscle imbalance with interference of postural reflexes and body-weight related vertical loading leads to the formation of a scoliosis.

5. Uncoupled, or asynchronous, spinal neuro-osseous growth (Figures 4 & 5)

MRI has revealed neuro-anatomical abnormalities in about 20% of younger children with putative idiopathic scoliosis and curves of 20° or more [see 120, 121].

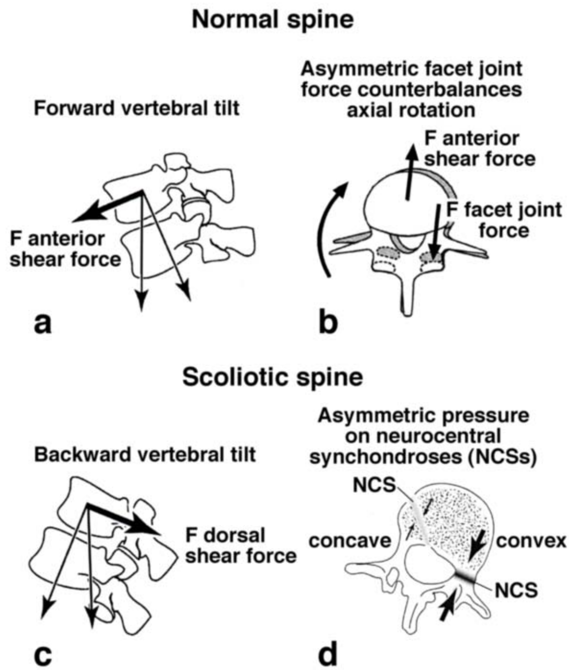

Figure 3. *Normal spine above:* (a) Anterior shear force with forward vertebral tilt. (b) How the anterior shear force in association with slight axial vertebral rotational asymmetry creates an asymmetric facet joint force. *Below scoliotic spine:* (c) Dorsal (posteriorly-directed) shear force with backward vertebral tilt. (d) How asymmetric loading in the transverse plane induces closure of the convex neurocentral synchondrosis (NCS) and continued growth of the concave NCS. Modified from Castelein et al [11].

Biomechanics of the central nervous system and pathologic axial tension (Figure 5).

From the biomechanical standpoint the *continuous axial tissue tract (neuraxis) of pons, medulla oblongata, spinal cord to conus medullaris and cauda equina* is a functional unit anchored cranially, caudally and also laterally by denticulate ligaments, nerve roots and root sleeves [122, 123]. During spinal flexion, or lateral flexion, there is a slight elastic tension with cord lengthening limited by an unyielding pia mater. Breig [122] suggested that processes which increase axial tension in the neuraxis – *changes in relative lengths of spinal canal and cord – can lead to pathologic axial tension* and cause damage to cord and spinal nerves by overstretching. Such *pathological axial tension* may arise from either [122]:

1) pathologic axial lengthening of spinal canal that stretches cord, pia and dura due to angulation of the column which can elicit neurological symptoms, or
2) shortening of cord and pia by partial, or total absence of plasticity and elasticity in parts of cord tissue.

In three cadavers, Reid [124] measured the *anterior component of force* exerted by the cord and dura at different levels (C3-T12) and with different degrees of spinal flexion. In flexion, the length of the spinal canal increased up to 18 mm at C8-T5 roots. Reid found *physiological lengthening* of cord and dura, chiefly between C2-T1 up to a maximum of 17.6%, and the anterior component of the force reached maximum values of 30-40 lb/sq inch.

Roth (Figure 4).

Roth [99,125] speculated that idiopathic scoliosis is a *disproportion of vertebro-neural growth* due either to a *short spinal cord* or a *too rapid growth spurt of the spine*. In his *spring model* Roth [99] found that shortening of the string hindered free elongation of the spring resulting in a scoliotic deformity of the model. Roth's papers were scarcely quoted until the year 2000. The complete original work of Roth on the possible causative role of neuro-osseous growth disproportion in spinal deformities is translated and reviewed [126].

Figure 4. Roth's spring model of scoliosis. White spots indicate the midline. Modified from Roth [99].

Porter.

Porter [74, 75, 127-129] addressed the problem of relative anterior spinal overgrowth in idiopathic scoliosis using anatomical specimens and found a shorter length of the vertebral canal relative to the vertebral bodies. Porter - unaware of Roth's publications - termed his speculative hypothesis *uncoupled neuro-osseous growth* in which idiopathic scoliosis is interpreted as a physical manifestation of the maladaptation of the growing immature spine to the tether created by a short spinal cord. Subsequently Porter and colleagues [130] reported that in AIS patients the *conus medullaris* position is *not* significantly different from that of the normal population.

Chu et al (Figure 5)

Chu and colleagues [19,98] re-examined the Roth-Porter concept for the pathogenesis of AIS applying *multiplanar reformat magnetic resonance imaging* to the spine of 61 AIS girls (35 moderate, 26 severe) with right thoracic curves and 36 matched normal girls with particular reference to *spinal cord-to-vertebral length ratios [19] and cross-sectional morphology of the apical spinal cord [98].* In severe AIS compared with normal subjects, a) the vertebral column is significantly longer, b) no detectable change in spinal cord length, c) anteroposterior/transverse diameter of the cord at the apex is increased (more rounded), and d) cord at the apex is displaced to the concavity. They speculate that the initiation and progression of AIS result from vertebral column overgrowth through a lordoscoliotic maladaptation of the spine to the subclinical tether of a relatively shorter spinal cord. Evidence to support a relatively shorter spinal cord was sought by determining the prevalence of cerebellar tonsillar ectopia, apical cord shape and somatosensory evoked potentials (SSEPs). There is other morphological evidence that supports Dr Chu's view that the *neuraxis* in AIS may be under *tension* in the axial direction [74, 75, 131].

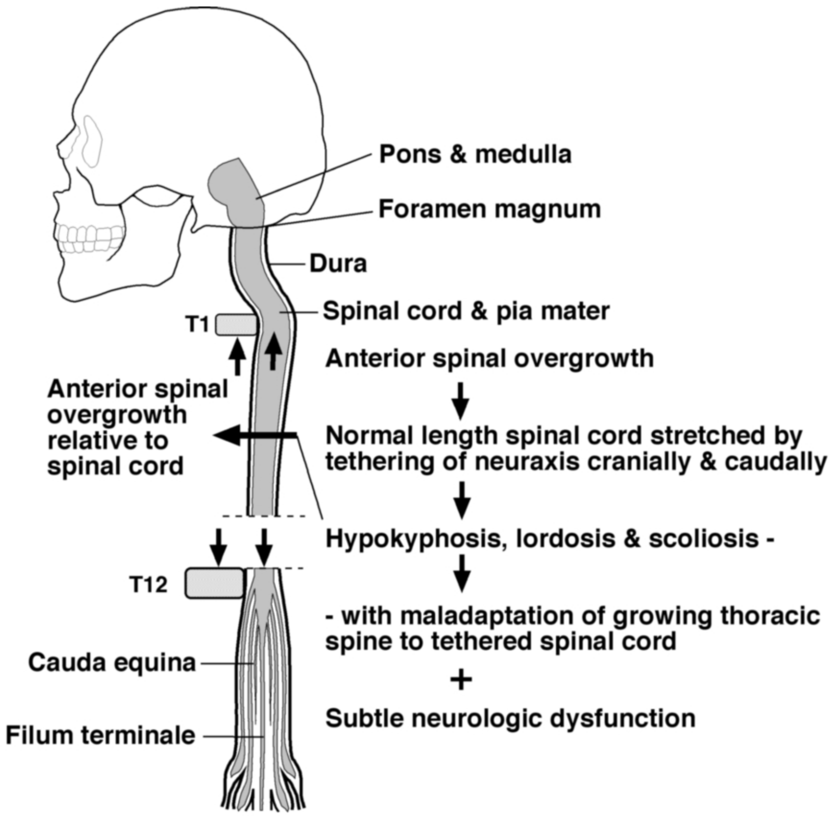

Figure 5. *Uncoupled, or asynchronous, neuro-osseous growth concept for AIS pathogenesis* involving asynchronous growth of spine and spinal cord. Diagrammatic representation from the findings of Chu et al [19]. showing how anterior spinal overgrowth (T1-T12) stretches the spinal cord and cauda equina leading to hypokyphosis (horizontal arrow ?from anterior component of force [124]) with maladaptation of the growing thoracic spine to the tethered spinal cord which, with subtle neurologic dysfunction, forms a scoliosis. Diagram modified from Breig et al [122].

The *uncoupled, or asynchronous, neuro-osseous growth concept* according to Chu et al [19, 98] has six linked processes that initiate the scoliosis deformity as follows *(linear causality) (see Figure 5):*

1) General skeletal overgrowth [92].
2) Anterior spinal overgrowth relative to spinal cord as causes -
3) stretching of normal length spinal cord with tethering force cranially and caudally causing –

4) changes in apical spinal cord shape, and
5) hypokyphosis, lordosis and scoliosis by maladaptation of growing immature thoracic spine to relatively short spinal cord tether, coupled with -
6) subtle neurological dysfunction.

Clinical application.

The findings are consistent with the trial of melatonin and combinations of other radical antioxidant scavengers [111] as preventive measures against spinal cord damage during any overstretching [127].

Non-idiopathic scoliosis.

The relation of column to spinal cord length in non-idiopathic scoliosis has not been examined.

The brain.

The uncoupled, or asynchronous, neuro-osseous growth concept as it affects the spinal cord does not account for AIS being triggered by abnormalities arising within the brain: a) infra-tentorially in brain stem [19, 98, 120, 132], any scoliosis driven by the vestibular apparatus [133-137]; and b) supra-tentorially from higher centres [138, 139]. To accommodate this knowledge it is necessary to postulate either, that AIS may arise from different causes as a disorder of wide spectrum [19], or that both brain and vestibular factors are unrelated to the expression of AIS.

A common etiology for idiopathic scoliosis, syringomyelia and Arnold-Chiari malformations?

Royo-Salvador [140] proposed a common pathology for idiopathic scoliosis, syringomyelia and Arnold-Chiari malformations predicated on abnormal asynchrony in growth of the *notochord* and the *spinal cord.*

A neuro-anatomical spectrum?

Taylor [23] asked the question: Does AIS resulting from occult brain stem dysfunction possibly lie at one end of a spectrum, wherein myelomeningocoele with hydrocephalus, cerebellar ectopia, syringomyelia and distal cord tethering is at the other extreme?

6. Brain, nervous system and skull - concepts of Herman, Veldhuizen and colleagues

Several workers consider that the etiology of AIS involves undetected neuromuscular dysfunction [4]. Lowe et al [4] concluded that:
"The current thinking is that there is a defect of central control or processing by the central nervous system that affects the growing spine and that the spine's susceptibility to deformation varies from one individual to another." Moreover, that the most consistent clinical studies point to the pontine and hindbrain regions as the most likely sites of primary pathology.

Motor control problem.

Herman et al [134] considered that idiopathic scoliosis is a motor control problem. They implicated a higher level *CNS* disturbance producing visuo-spatial perceptual impairment, motor adaptation and learning deficits which lead to faulty recalibration of proprioceptive signals from axial musculature causing idiopathic scoliosis. In AIS subjects they found that the processing of vestibular signals within the *CNS* yielded the highest correlation with curve magnitude.

Similar pathogenetic mechanisms for AIS curve initiation are proposed by Veldhuizen et al [7].

The neuromuscular concept of Veldhuizen and colleagues.

Veldhuizen et al [7] write:
".....the most likely cause of idiopathic scoliosis includes a neuromuscular condition and an asymmetry of the transversospinalis muscles, produced by alteration of the motor drive at the spinal cord level, either from altered sensory input at the same level or from a central mechanism, which may produce enough lateral deviation and axial rotation to embarrass the delicate balance of forces in the region, so producing an idiopathic scoliosis." (See also below 7. *Body-spatial orientation concept of Veldhuizen et al).*

Postural and balance control.

Studies over many years support the concept of an abnormality in visual, vestibular, proprioceptive and postural control in AIS [see 7, 120, 141-144] and involving the *brain stem* [7, 120, 132]. In a re-evaluation of balance control in AIS patients with abnormal somatosensory evoked potentials (SSEPs), a significant effect was found when subjects had to rely on somatosensory input for their balance control [145].

Vestibular apparatus and basicranium asymmetry and CNS body schema.

In patients with idiopathic scoliosis, Wiener-Vacher and Mazda [135] found 67% had significantly greater values of directional preponderance in off-vertical axis rotation compared with controls including congenital scoliosis, suggesting that *central otolith* *vestibular disorders* lead to a vestibulospinal system imbalance, which may be a factor in the cause of AIS. Rousié and colleagues [133] in patients with scoliosis and craniofacial asymmetries [136, 137] found disorders of vestibular function, basicranium asymmetry and semicircular canal malformations which they suggest *creates a distortion in the CNS body schema* [137]. These studies need evaluation in patients with AIS referred to orthopaedic surgeons in the usual way.

Cranio-cervical junction, cerebellar tonsillar position and SSEPs (Figure 5).

In subjects with Chiari I malformation – a developmental disorder of paraxial mesoderm - the size of the posterior fossa is, abnormally small [146]. In AIS subjects the size of the posterior fossa has not yet been reported but there is evidence to suggest that it might be abnormally small.

Research in Hong Kong introduced a redefined MRI reference level at the foramen magnum (at and below the *basion-opisthion line*) to diagnose asymptomatic Chiari I malformation [147, see 146]. In 135 patients with AIS, *tonsillar ectopia* was found in 33% of patients with abnormal somatosensory evoked potentials (SSEPs) and 2.9% of patients with normal SSEPs [148] pointing to a *neural origin of AIS*. Abnormal SSEPs were found in 17/147 (11%) of AIS patients [149, see 150]. SSEPs show functional delay above the cervical level in most patients [151]. According to Guo et al [145] SSEPs reflect the presence of disturbed standing balance control when the subject relies on somatosensory input.

Skull base and vault.

Recent evidence from Hong Kong suggests that the skull base and vault in AIS girls are abnormal. Chu et al [96] in 69 AIS subjects and 36 controls found a larger foramen magnum, 42% with cerebellar tonsillar tips 1 mm or more below the foramen magnum (basion-opisthion line), and normal cerebro-spinal fluid velocities through the foramen.

Yeung et al [93,94] reported:

"The length of the hypophyseal fossa was significantly shorter while the length between the dorsum sellae and basion was significantly longer in 28 AIS girls when compared to 18 age-matched controls based on midline sagittal MR image of the brain, indicating that abnormal growth probably affects the skull base."

Shi et al [95] examined MRI data from the skull vault in 10 AIS girls and 10 controls and found that the posterior region is smaller while the left part is larger.

Left-right brain asymmetries.

Dichotic listening tests for perceptual asymmetry in 31 AIS subjects were significantly more lateralized for linguistic processing than in 20 controls indicating a greater degree of left-right asymmetry throughout their cortical organization [152]. Chu and her colleagues [138,139] used MRI to investigate whether there is any difference in regional brain volumes between 20 AIS patients and 20 age- and sex-matched controls. They found [138]:

"....significant unilateral regional differences in the following: left thalamus and left postcentral gyrus of AIS patients were significantly larger than the control subjects.

The anterior and posterior limb of the right internal capsule, right caudate nucleus, right cuneus and left middle occipital gyrus of AIS patients were significantly smaller than the controls. Some regions were bilaterally involved. Perirhinal and hippocampus regions were larger in AIS while the inferior occipital gyrus and precuneus were smaller than the corresponding regions in the control subjects. In the midline, the volumes of corpus callosum and brain stem in AIS patients were significantly larger than the control subjects. It was concluded that: 1) there might be abnormal asymmetrical development of the brain in AIS; and 2) the findings might help to explain the reported poor performance in the combined visual and proprioceptive test, spatial orientation test, abnormal nystagmus response to caloric stimulation, and the impaired postural balance in AIS patients."

To explain progressive AIS Chu et al [139] propose a concept with six linked and overlapping processes as follows (*linear and summaton causality):*

1) Longer latency SSEPs, and
2) impaired balance control, with -
3) low-lying cerebellar tonsils, together with -
4) other intracerabral structural abnormalities that could contribute to -
5) inappropriate postural adjustment during -
6) the adolescent growth spurt that leads to -
7) progressive spinal deformity.

Clinical applications.

Chu et al [139] state that their findings may help to explain for AIS patients the reported poor performance on combined visual and proprioceptive testing and spatial orientation testing, as well as reports of abnormal nystagmus response to caloric testing and impaired postural balance. The relation of brain abnormalities to prognosis needs to be included in the evaluation.

7. A collective model involving abnormality of the escalators of a normal neuro-osseous timing of maturation (*NOTOM*) system of central control (Figures 6-9).

Summary.

The central concept of this collective model is a normal *NOTOM* system operating in a child's internal world during growth and maturation by which dynamic physiological balance is continuously renewed between two synchronous, polarized processes (escalators) linked through sensory input and motor output, namely:

1) *increasing skeletal size and relative segmental mass*, *and*
2) *the CNS body schema.*

The latter system is recalibrated continuously as the body adjusts to biomechanical changes resulting from skeletal enlargement, enabling it to coordinate motor actions. We suggest that AIS progression results from abnormality of the neural and/or osseous components of these normal *escalators* in time and/or space – as asynchrony and/or asymmetries – which cause a failure of neural systems to control asymmetric growth of a rapidly enlarging and actively moving adolescent spine [153].

Some of the evidence and reasoning that led to the formulation of this neuro-osseous escalator concept for AIS pathogenesis [153] will now be outlined.

Neuro-osseous timing of maturation (NOTOM) and female susceptibility to progressive AIS (Figure 6).

The term *neuro-osseous timing of maturation* (*NOTOM*) was coined by Burwell and Dangerfield [154-156] for a concept articulated by Nachemson in 1996 based on the researches of Sahlstrand and Lidström [10,111]; this research suggested that the maturation of postural mechanisms in the *CNS* may be complete about the same time in boys and girls. Nachemson [157] stated that the higher prevalence of progressive AIS curves in girls may result from their entering their adolescent skeletal growth spurt in postural immaturity, compared with boys who enter their adolescent growth spurt in postural *maturity (see Figure 6).* The *NOTOM* concept suggested a medical treatment for AIS, by using a neuroendocrine method to delay the adolescent growth and slow curve progression [154,156,158].

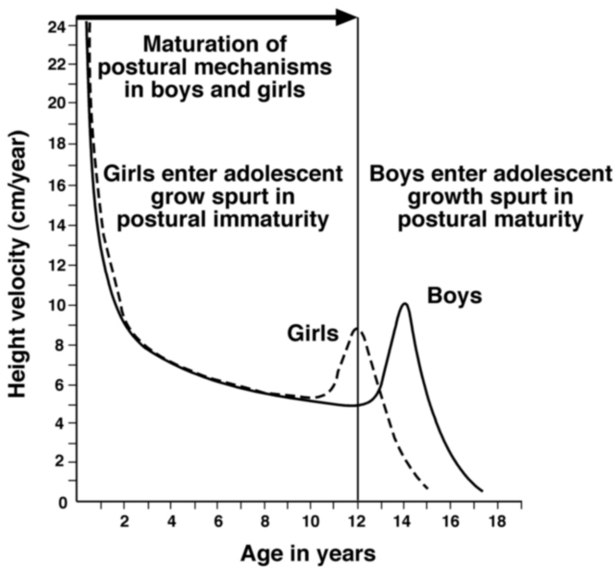

Figure 6. Neuro-osseous timing of maturation (*NOTOM*) concept to explain the female susceptibility to progressive AIS. Height velocity (cm/year) is plotted against age in relation to putative postural maturation at 12 years of age. Diagram from Burwell and Dangerfield [154-156].

Neuro-osseous timing of maturation (NOTOM) in normal development.

Growth is more than an increase in size and involves maturational processes in the child [10]. In normal health the skeletal system and nervous system evidently grow and mature together in harmonious development of a normal neuro-osseous timing of growth and maturation (*NOTOM*). Such normal neuro-osseous development occurs in the limbs, spine and trunk [19, 74, 75, 98, 99, 125], and between the body as a whole and the brain for sensory/motor control of posture and coordinated movements. In the latter case, the key theoretical issue is how the changes in brain circuitry controlling muscles and joints become matched to the developmental biomechanical changes simultaneously occurring at the periphery [159]. These considerations of the *NOTOM* concept led to a novel hypothesis, termed here the *NOTOM system escalators.* We suggest that AIS pathogenesis results from *abnormality of these normal NOTOM system escalators* in the spinal column and *CNS*, *with asynchrony and asymmetric scoliogenic triggers in the spine [33,170,171] and possibly the brain [138,139](see Figures 7-9).* Figure 7 provides an outline of the concept for normal growth and maturation. Figure 8 provides an outline of the concept for AIS pathogenesis.

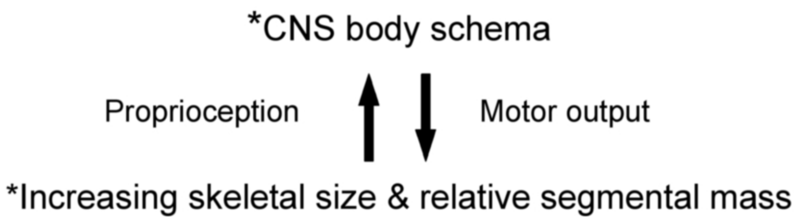

Figure 7. Normality. *Neuro-osseous timing of maturation (NOTOM) system escalators.* * = two polarized processes of the *NOTOM system escalators* [153].

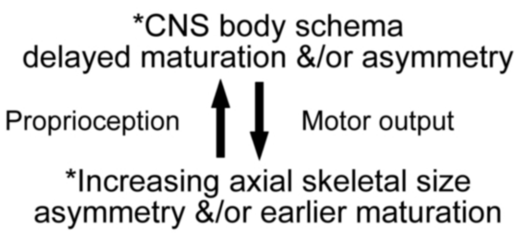

Figure 8. *AIS pathogeness. Abnormal neuro-osseous timing of maturation (NOTOM) system escalators as applied to the spine.* .* = two polarized processes of the *NOTOM system escalators [153].*

CNS body schema ('body-in-the-brain') and the NOTOM system escalators in normal growth and maturation.

Definition. The CNS body schema in the adult is defined as a *".....system of sensory-motor processes that continually regulate posture and movement – processes that function without reflective awareness or the necessity of perpetual monitoring."* [160]. This control involves frames of reference in the posterior parietal cortex which participate in the dynamic representation of the *body schema* integrated with other cortical areas [160,161,163,164].

The presence of an *internal representation* - *CNS body schema ('body-in-the-brain', 'unconscious body awareness')* is considered here for simplicity in the traditional proprioceptive modality. It is an important component of interpreting senses and coordinating actions for normal motor control by providing *frames of reference* for posture, balance, verticality (uprightness) updated with movement in feedback [7, 25, 51, 52, 111, 160-164].

During postnatal growth and maturation, motor control by the *CNS* during growth evidently needs continuous, or continual, updating unique for each individual as changes of body size, shape and segmental mass occur. We postulate that during normal growth and maturation, a physiological balance is continuously renewed between two synchronous polarized processes that we term escalators, namely (see Figure 7):

1) *Osseous escalator:* increasing skeletal size, changing skeletal shape and relative mass of the different body segments which through posture and motion of the body by producing developmental biomechanical changes at the periphery create developmentally altering proprioceptive inputs including balance, to the brain that result in –
2) *Neural escalator:* postural maturation with the *CNS body schema* being recalibrated as it continuously adjusts to skeletal enlargement, shape and relative mass changes to enable it to coordinate motor actions. The *posterior parietal cortex* in human clinical and experimental studies has been shown to participate in the dynamic representation of the body schema [160-164].

The term escalators are applicable only during growth termed *the NOTOM system escalators*. Muscles are not included in this terminology because they do not drive skeletal growth, but have key roles in sensory and motor function and contribute to segmental masses. Similar mechanisms are being evaluated in robotics and specifically the learning in and from brain-based devices [165, 166].

Earlier skeletal maturation in AIS girl and relative postural maturational delay.

Recently we speculated that AIS natural history is contributed to by a postural maturational delay involving the *CNS* body schema, absolute or relative, to skeletal maturation [25,111,162]. While there is no direct evidence of constitutional *CNS* maturational delay of postural mechanisms in AIS subjects, there is evidence of *earlier skeletal maturation* in AIS girls; this may upset the neuro-osseous balance of the *escalators* and create a *relative* postural maturational delay. In this concept of AIS pathogenesis, any such delay in the *CNS* may arise from an abnormality in afferent, central, or motor mechanisms [25], or be *relative to earlier skeletal maturation*.

In AIS girls, Hagglund et al [167] reported a) above average height two years before the onset of the pubertal growth spurt, b) earlier age at peak height velocity and c) low pubertal gain in height, so that their values at maturity are only slightly higher than the reference mean; these features were attributed to increased growth hormone activity. Much evidence is consistent with earlier skeletal maturation of AIS girls and explains their early skeletal overgrowth [104, 168, 169] to which a normal *CNS body schema* has to adjust. This overgrowth is greater in familial than in sporadic AIS [97].

Skeletal overgrowth, extra-spinal skeletal length asymmetries, disproportions and lower limb torsional abnormalities (Figure 9).

In AIS subjects the authors and their colleagues found widespread skeletal overgrowth [32,103,104], extra-spinal skeletal length asymmetries [32, 33, 103, 104, 170-174], proximo-distal lower limb skeletal disproportions [66, 172] and torsional abnormalities. [169, 173-175], and other skeletal disproportions [102].

The findings of Guo et al [76, 77] and Chu et al [19] show that the skeletal overgrowth of AIS also affects the vertebral column. It is not known whether the extra-spinal left-right skeletal length asymmetries, skeletal disproportions and torsions signify any local involvement in the spine. We speculate that they do [25, 170-174]. In this connection there is indirect evidence from neurogenic scolioses suggesting that in *idiopathic* scoliosis both the *hypokyphotic* and *axial rotation components* about the apex of the deformity may de determined by local processes in the spine [176-178].

Indirect evidence that AIS may be initiated by triggering arising within the spine.

In presumed AIS, Davids et al [176] found that the most valuable single MRI indicator for abnormal central nervous system findings was the *absence of a thoracic apical segment lordosis*. Similarly, in an MRI study of 1232 patients undergoing surgery for idiopathic scoliosis Diab et al [177] found that thoracic *hyperkyphosis* was the greatest risk factor for *neural anomaly*, most frequently syrinx or Chiari malformation. Brockmeyer et al [178] found *very little axial vertebral rotation* in scolioses associated with Chiari I malformation, often with a significant curve. All these findings suggest that in adolescent *idiopathic* scoliosis, each of the *lordotic* and *axial rotation components* of the deformity may be determined, at least in part, by *local, rather than neural, processes.* In addition to vertebrae, these processes may affect discs, muscles and/or nervous tissue about the curve apex. A recent speculation suggests *vertebral symphyseal dysplasia* involving type IX collagen may initiate the development of progressive AIS [13].

Body-spatial orientation concept of Veldhuizen et al.

Veldhuizen et al [7] in their model of AIS pathogenesis also invoke a *CNS body-spatial orientation concept* without considering how the *CNS* may adapt with age (see below). Their model of AIS pathogenesis invoking the *CNS body schema concept* is termed a *cortical model*. Veldhuizen et al write [7]:
"Faulty sensory information from visual, vestibular and somatic sensors or faulty interpretation within the central nervous system results in an altered body-spatial orientation, leading to sensory rearrangement to restore perceptual dysfunction. Motor adaptation of the axial motor system ensues when the subject maintains modified perceptual analysis of proprioceptive information describing an erect spine. A new motor control strategy is adopted, resulting in the structural deformity."

Collective model and neuro-osseous escalator concept for AIS pathogenesis.

Our novel neuro-osseous escalator concept, previously termed neurodevelopmental [23,111,162], evolved from the *Nottingham* [43,44,111] and *NOTOM concepts* [10,154-156]. In 2006, four requirements were identified [25] (see Figure 9):

1. Curve initiation process.
2. Rapid spinal elongation in the adolescent growth spurt.
3. Maturational delay of *CNS body schema*.
4 Upright posture and movements.

Putative abnormalities of the two polarized components of the *NOTOM system escalators* – with asynchrony and asymmetry(ies) - provide the central concept of a *neuro-osseous developmental concept* for AIS pathogenesis (see Figure 9):

1) in the *spine* (growing rapidly with asymmetry(ies), and
2) in the *CNS body schema, mainly maturational delay*, absolute or relative to the skeletal system, possibly with brain asymmetries [see 137-139].

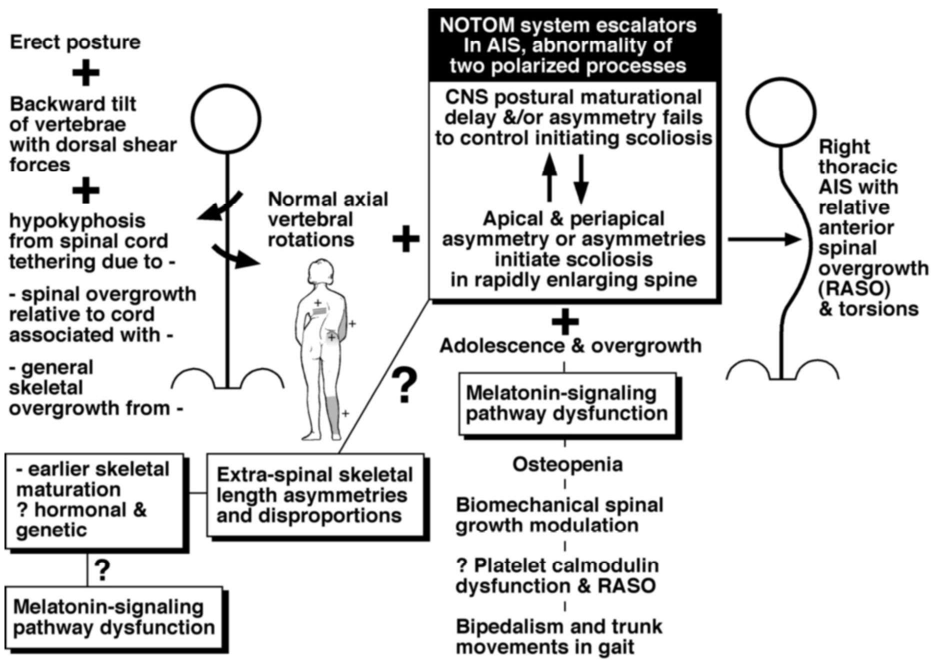

Figure 9. A collective *model* for AIS pathogenesis involving abnormality of the *escalators of a normal neuro-osseous timing of maturation (NOTOM) system* as the central concept. In normal growth and maturation, the two polarized processes are synchronous and symmetric linked through sensory input and motor output. In AIS pathogenesis, the polarized processes are asynchronous with asymmetry in one or both of the processes. In the diagram of the AIS girl the + signs indicate some skeletal length asymmetries [103,104] including ribs [87,88] with relative overgrowth on that side, correlating significantly with scoliosis severity in upper arm [32,33,101,170] and ilia [171] but not tibiae [66,172]; skeletal disproportions [66,102,172] and lower limb torsions [169,173-175] are not shown. *NOTOM*=neuro-osseous timing of maturation [154-156]. *RASO* = relative anterior spinal overgrowth [6,72-77]. Developed from Burwell et al [25, 33].

The fate of early AIS – to progress, become static or resolve (rarely) - according to this concept depends mainly on the degree of failure in postural control of a rapidly enlarging and actively moving adolescent spine and trunk; progression may occur in some curves because of strong spinal asymmetries. Some concepts of other workers are added to this central concept to formulate a *collective model for AIS pathogenesi*s which has 13 linked and overlapping processes as follows *(linear and summaton causality)*(see Figure 9):

1) Upright human posture, bipedalism and trunk axial rotations and counter-rotations as in the Nottingham concept of pathogenesis [10, 41-44, 179].
2) Backward tilt of vertebrae with dorsal shear forces and normal axial rotations (see Figures 2 & 3) [11].
3) General skeletal overgrowth with earlier skeletal maturation, left-right asymmetries [32, 33, 103, 104, 170-174], disproportions [66, 102, 172] and lower limb torsions [169.173-175].
4) Anterior spinal overgrowth relative to spinal cord (see Figure 5) [19, 73-75, 98, 99,127] leads to -
5) Axial tension in the spinal cord (see Figures 4 & 5) [19, 74, 75, 98, 99, 122, 125, 131].
6) Spinal cord and dura exert an *anterior component of force* [124] on the thoracic kyphosis to create a *hypokyphosis* that leads to -
7) dorsally-directed shear forces (see Figure 3) which enhance slight normal lateral spinal curves [180] and normal axial rotation asymmetries [115] (see Figure 2b).
8) Putative abnormal growth asymmetry(ies) developing postnatally in the spine (? 1D, 2D and/or 3D, left-right, A-P, and/or torsional, from end-plate physes, osseous, discal, or neuromuscular tissues) [7] and/or periapical ribs [87, 88] that further enhance axial rotational instability [11] to create a trigger for scoliosis initiation [25]. Urban [181] points out, as scoliosis occurs during the growth spurt, it is likely that the growth plate is a major factor in the development of a scoliotic deformity.
9) *CNS body schema* maturational delay relative to skeletal size with or without neural asymmetries leads to postural mechanisms failing to control asymmetrical growth (*growth kinematics*) developing in a rapidly enlarging and actively moving adolescent spine and trunk in the adolescent growth spurt with upright posture and bipedal gait [179] leading to curve progression [25]. If the putative *CNS body schema* maturational delay corrects, curve progression will abort, unless the spinal asymmetry(ies) is(are) strong.
10) Vertebral axial rotation, having moved from the normal anterior centre to a posterior centre of axial rotation [74, 182] during progression of a thoracic AIS deformity, is associated with lateral spinal curve formation and relative anterior spinal overgrowth *(RASO)* with leg-arm proportions and movements during gait contributing a dynamic pathomechanism to early AIS [179]. Whether the *RASO* is determined primarily by biological [6,7,10,68,69,71,183,184], or mainly biomechanical [6,7,10,13,15,61,67-70,72,107,183] mechanisms secondary to eccentric loading of vertebral bodies during linear growth [item 13], is unknown.
11) Platelet-skeletal concept (see Figures 9 & 11) [184].

12) Thoracic AIS laterality is determined by the laterality of pre-existing slight physiological axial vertebral rotation (see Figure 2b) [115] and any anomaly of the binary asymmetry switch in embryonic life [185,186].
13) Biomechanical spinal growth modulation involving the Hueter-Volkmann and Pauwels' effects [13, 61,68,69]. Pauwels' effect is where intermittent pressure within the limits of physiological stress and strain stimulates the growth plates of a healthy bone [see 13].

Some undisputed facts explained (11, 28, 29).

1) The dependence of AIS progression on growth is explained by rapid skeletal enlargement beyond the capacity of the postural mechanisms to control the deformity rather than by the velocity of growth, i.e. the role of growth is conditional [11].
2) In girls the higher prevalence of progressive AIS is explained by the putative *CNS* postural delay magnifying the effect of girls' postural immaturity to control an initiating scoliosis of a enlarging adolescent spine relative to the postural maturity of boys.
3) The varied curve progression patterns are explained by the interaction of factors in the polarized processes of the *NOTOM system escalator*s and how factors outside the escalators are involved.
4) The relative anterior spinal overgrowth *(RASO)* with curve progression is explained by postural maturational delay failing to control each of a) axial vertebral rotation [11], and b) putative vertebral growth asymmetries [170,171] including torsion [169,173,174], and to spinal growth modulation [13,107].
5) The mechanism of the RASO in the *uncoupled endochondral-membranous bone formation concept* relates to asymmetry in the sagittal plane [76,77].
6) The restriction of AIS to humans is explained by several factors relating to erect posture and bipedalism (see below, Implications for human evolution).

Axial vertebral rotation and Cobb angle.

Each AIS curve may progress differently [187] and be accounted for by the putative initiating spinal asymmetries developing differently in the three cardinal planes – sagittal, transverse and frontal. Any *CNS* asymmetry involving postural mechanisms would be expected to compound the relationship (correlation) of axial rotation with Cobb angle.

Curve laterality.

The mechanisms that determine curve laterality in AIS are ill-understood [10]. The common right thoracic AIS has been explained by the presence of a physiological slight right thoracic curve [180] and pre-existing axial vertebral rotation [115] as follows. If the precarious balance of normal thoracic motion is disturbed, vertebrae in the slight curve may somehow move into the convexity of the curve [165]. The pre-existing axial vertebral rotation has been accounted for by the asymmetrical anatomy of thoracic organs [115]; the latter has been explained by a normal developmental process in early prenatal life – the breaking of the initial bilateral symmetry by a *binary asymmetry switch mechanism* [185]. An anomaly of the latter mechanism has been suggested as a reason for the occurrence and preponderance of right thoracic AIS [186]. This embryonic hypothesis for right thoracic AIS does not explain left thoracic AIS, or the distribution of laterality in lower spine scolioses [171,186]. Most recently, Moreau et al [188] have reported that left-right asymmetry gene expression domains are reversed in AIS and in scoliotic bipedal mice.

Clinical applications.

1) Concave peri-apical rib resection (from the thoracospinal concept [87, 88]).
2) Early stapling of vertebral bodies (from the *RASO* concept)[108-109].
3) Consideration of new neuroendocrinologic medical treatments to delay the adolescent growth spurt and the increase in skeletal size [154, 156, 158].
4) Should neuronal lipid peroxidation [10, 111] be detected in AIS subjects and be a factor causing brain maturation delay [25], there is the possibility of new safe dietary treatments for early AIS including antioxidants (α-tocopherol, vitamin E), selenium-containing enzyme glutathione peroxidase, melatonin and fatty acids, exhibited in the initial stages of spinal deformation.
5) Antioxidants may be beneficial to control the growth-related torsion of AIS (as in the *RASO* concept).
6) Possible prediction of curve progression in the future from brain [138,139], and perhaps vertebral [184] imaging studies.

8. Transverse plane pelvic rotation, skeletal length asymmetries and developmental theory (Figure 10): timing of maturation from 'top-down' to 'bottom-up' organization of posture control

Several studies have suggested that the pelvis is involved in the etiology or pathogenesis of AIS [10,41-45,189,]. Gum et al [91] studied pelvic transverse plane rotation in patients with scoliosis (AIS and congenital), Scheuermann's kyphosis and isthmic spondylolisthesis on postero-anterior radiographs using a new method [190]. They tested the hypothesis that the direction of transverse plane pelvic rotation is the same as that for a thoracic scoliosis. When divided into six Lenke curve patterns this was true for the groups with a major thoracic curve (see Figure 10). All congenital scoliosis patients studied had main thoracic curves and significant transverse plane pelvic rotation in the same direction as the thoracic curve. There was no transverse plane pelvic rotation in the Scheuermann's kyphosis and isthmic spondylolisthesis patients.

The transverse plane pelvic rotation accompanying the major thoracic curve is interpreted as a fourth transverse plane rotation; the four axial rotations are shown in Figure 10 for a major thoracic curve: T8 clockwise, T4 & L2 counterclockwise and the pelvis clockwise.

Gum et al [91] discuss some skeletal asymmetries associated with AIS [103, 170,171,189,191-193]. They conclude: "An appealing, unifying explanation of these many anthropometric variations from normal is the concept of developmental instability proposed by Goldberg et al" [35]. In this paradigm scoliosis is viewed as a loss of symmetry "when the developmental program coded in the genome fails to run properly, due to the timing and severity of any number of stress factors".

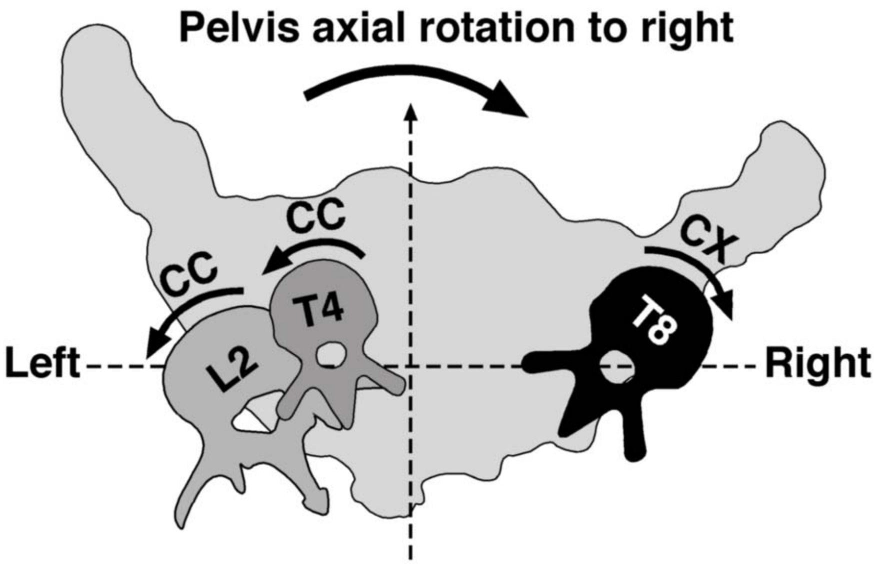

Figure 10. Diagram of top view of right thoracic AIS to show clockwise apical vertebral rotation to the right at T8, compensated by counterclockwise rotation above (T4) and below (L2) with clockwise pelvis axial rotation to the right as the next compensation in the same direction as the major thoracic scoliosis. Modified from Gum et al [91].

Females are considered vulnerable to progressive AIS because [91]:

1) they have more directional asymmetry than males [194], and
2) their trunk muscle strength per lean body weight decreases from their juvenile to adolescent years whereas in males it increases [195].

The feet, pelvis and 'bottom-up' organization of posture control. During postnatal growth and development postural functions adapt sequentially. With the maturation of posture and locomotion a 'bottom-up' organization of posture emerges from the supported feet providing reference values for calculation of pelvic position in space before postural control is reorganized about 7 years of age. There are possible implications of this *timing of maturation* from "top-down" (vestibular and visual) to "bottom-up" (feet) organization of posture control for the initiation and progression of AIS. (see below *Implications for control of posture and coordinated movements*).

9. Thoracospinal concept – girls with right thoracic adolescent scoliosis

Sevastik's thoracospinal concept [87, 88] based on experimental, anatomical and clinical evidence, applies only to right thoracic adolescent idiopathic scoliosis in girls. There are six sequential processes as follows *(linear causality):*

1) Dysfunction of the autonomic nervous system [196].
2) Increased vascularity of left anterior hemithorax.
3) Overgrowth of left peri-apical ribs which -
4) disturbs the equilibrium of the forces that determine the normal alignment of the thoracic spine, in a putative growth conflict [31] that –
5) triggers the thoracospinal deformity simultaneously in the three cardinal planes.
6) Biomechanical spinal growth modulation [13].

A 2-year longitudinal study of the anterior chest wall blood supply of girls with progressive right thoracic (RT) AIS [197] led to the suggestion that right thoracic AIS may result from asymmetry of blood supply to the anterior chest, characterized by decreasing blood supply to the right anterior hemithorax with simultaneous maintenance of blood supply to the left anterior hemithorax. This combined abnormality may result in a relative increase in blood supply to the left anterior chest wall, increased temperature on the left sternocostal cartilaginous junction, and subsequent elongation of left ribs. These findings support the concept in RT AIS of a disturbance in the autonomic nervous system regulating blood flow to the anterior chest wall [197].

In a recent paper Sevastik [198] proposes that right thoracic adolescent scoliosis in girls "…is a disparate *nosological entity* rather than a mere orthopaedic deformity of the spine." In view of the knowledge about this type of scoliosis, Sevastik states that the use of the word *'idiopathic'* is obsolete.

Clinical applications [199].

With experience of three patients who had peri-apical concave rib resection, Sevastik [87] writes: "….the results of these studies provide evidence that mini-invasive operations on the ribs based in these pathophysiological concepts is a feasible approach for the surgical treatment of thoracic curves, thus opening new possibilities of treatment for young patients with early progressive thoracic curves."

10. Origin in contracture at the hips

Karski [45,200-205] provided the following account of his concept for AIS pathogenesis in which there are three sequential processes as follows *(linear causality):*

1) Hip abduction contracture, in reality a limitation of adduction, mostly of the right hip.
2) Disturbance in growth of the pelvi-sacral lumbar region with the development of a left lumbar scoliosis.

3) Development of a right thoracic scoliosis.

In a recent paper Karski [204] describes Ist, IInd and III etiopathological groups.

Ist group. These comprise children with an abduction contracture of the right hip. The group has an S-shaped double curve with rib hump on the right. The scoliosis is viewed as a secondary compensation for deformities in pelvis and spine.

IInd group. These have only limited adduction of the right hip. The group has a C-shaped lumbar, sacro-lumbar, or lumbo-thoracic left convex scoliosis. It is linked to a permanent standing posture maintained on a free right leg during the first years of life.

IIIrd group. These show either no or a minimal curve on X-ray with either no rib hump or a very minor one but have a 'stiffness' of the spine.

Karski [205] links the right hip abduction contracture, or differences in adduction to the *'syndrome of contractures'* in infants (Mau). This view is supported by Trivedi [206].

Clinical applications.

According to Karski [204]: "This classification establishes a clear therapeutic approach to every etiopathological group of scoliosis and allows for the possibility of introducing causative prophylaxis."

11. Osteopenia – a risk factor for curve progression (Figure 9)

Lowe et al [4] concluded that they were not aware of any evidence that inferior bone quality was an important factor in the etiology of idiopathic scoliosis. Studies have shown that 27% to 38% of girls with AIS have osteopenia [207-209]. An association of osteopenia with curve severity in AIS has been reported [210]. In a recent study of 324 girls with AIS, Hung et al [209] measured bone mineral density in spine and both hips at diagnosis using dual-energy x-ray absorptiometry. Curve progression of 6° or more occurred in 50%. The prevalence of osteopenia at the spine and hips was 27.5% and 23.1% respectively. Risk factors for progression included: larger initial Cobb angle (>30°), lower Risser grade, premenarcheal status, younger age at diagnosis and osteopenia in the femoral neck of the hip on the convexity of the scoliosis. The lower bone mineral density of the convex-side hip confirms an earlier finding [211], explained by more loading on the concave side hip in AIS.

In a subsequent study of 621 girls with AIS, Cheung et al [212] found that lower bone mass in AIS compared with controls could be explained by faster anthropometric growth, higher bone turnover, and lower calcium intake The calcium intake in AIS patients was found to be very low with low consumption of dairy products, and likely to be insufficient for normal bone mineralization [213]. We suggest that a contributory factor to the osteopenia of some AIS girls may be maturational abnormalities in cell differentiation, recently suggested by studying calcium channel isoforms in the membranes of platelets and osteoblasts from patients with AIS [214]. This may explain why the control girls in the study of Cheung et al [212] had the same low calcium intake as the AIS girls. Most recently, *decreased circulating leptin levels* have been found to be associated with lower body and bone mass in girls with AIS [215].

Clinical applications.

Hung et al [209] recommend weight-bearing activity, programmed exercise, and calcium supplements for osteopenic AIS patients. While brace treatment has not been found to affect bone mass in children with idiopathic scoliosis, Hung and colleagues call for further study of bracing in relation to osteopenia.

12. Melatonin deficiency

Machida and colleagues [46, 47, 216] having found lower plasma melatonin levels through 24 hours only in progressive AIS curved (n=12) concluded that melatonin disturbance has more of a role in progression than in the cause of AIS. They postulate that in the development of progressive AIS, melatonin acts through the nervous system. After experiments on pinealectomized bipedal rats, Dubousset and Machida [47], suggested that idiopathic scoliosis results from four processes, or requirements, as follows *(linear and summaton causality)*:

1) A inherited disorder of neurotransmitters from neuro-hormonal origin affecting melatonin,
2) associated with the bipedal condition, and
3) a horizontal localized neuromuscular imbalance with torsion produces (compare above Section 6. *Neuromuscular concept of Veldhuizen and colleagues* and Section 7 *Collective model and neuro-osseous escalator concept for AIS pathogenesis*, item 8) -
4) a scoliotic deformity of the fibro-elastic and bony structures of the spine.

The hypothesis that melatonin deficiency is a causative factor of AIS was confirmed by some workers but not by others [217, see 16]. Reinker [218] concluded that it seems unlikely that idiopathic scoliosis results from a simple absence of melatonin. Rather, scoliosis could result from alteration in the control of melatonin production, with direct or indirect consequences upon growth mechanisms. Cheung et al [16] reviewing melatonin and AIS pathogenesis state: "…the possible aetiological factors producing scoliosis in lower animals…..cannot necessarily be extrapolated to human beings."

Melatonin-calmodulin interaction may represent a major mechanism for regulation and synchronization of cell physiology [219].

Clinical applications.

The findings are consistent with a trial of melatonin and combinations of other radical antioxidant scavengers [10, 25, 111, 127] as preventive measures against the progression of AIS.

13. Systemic melatonin-signaling pathway dysfunction (Figure 9)

In progressive AIS, Moreau et al [20] reported *melatonin-signaling transduction* to be impaired in osteoblasts, myoblasts and lymphocytes caused by the inactivation of Gi proteins. In 2006, their presentations showed this to be associated with high levels of a circulating protein P factor that appears essential for the initiation and progression of AIS through a specific signaling action during a postnatal window [220-222]. The melatonin-signaling pathway dysfunction is thought to be a biological marker with potential for prognosis, curve classification and medical treatment. A novel mechanism in the pathogenesis of AIS is proposed namely, a systemic abnormality of cell differentiation [214].

In 2007, Moreau et al [21] reported the use of lymphocytes for the development of a functional blood assay for the identification of children at risk of progression. This test can be performed without any prior knowledge of mutations in any defective genes causing AIS.

The finding that promoter polymorphisms of the gene for melatonin receptor 1B is associated with the occurrence of AIS, but not directly with curve severity, supports the hypothesis of melatonin-signaling pathway dysfunction in AIS [65].

Clinical applications.

The findings are consistent with:

1) Clinical validation of a functional blood test for AIS [19].
2) A molecular classification for AIS [214, 221].
3) Tailored pharmacological approaches to a melatonin-signaling defect in progressive AIS [221].

14. Platelet calmodulin dysfunction (Figures 9 & 11)

Background.

In the early 1980s abnormalities in the structure and function of thrombocytes (platelets) were noted in patients with AIS [60,219,223]. The subsequent research of Lowe was predicated on the view that the platelets can be considered as a 'mini' skeletal muscle with a similar protein contractile system (actin and myosin), so that both would be affected if a systemic cellular defect was present. Calmodulin regulates the contractile properties of muscle and platelets through its interaction with actin and myosin and regulation of calcium fluxes from the sarcoplasmic reticulum of muscle fibres. Melatonin functions may include modulating calcium-activated calmodulin [219].

Findings.

Increased calmodulin levels in platelets were shown to be associated with progression of AIS [223].

Platelet-muscle concept.

Lowe et al [223] suggested that altered paraspinal muscle activity explained the relationship between platelet calmodulin level changes and Cobb angle changes in AIS with calmodulin acting as a systemic mediator of tissues having a contractile system (actin and myosin).

Platelet-skeletal concept (Figure 11).

An alternative speculative concept to explain the findings of Lowe et al [219,223] has been formulated [184]. It has five sequential processes, or requirements, as follows *(linear causality):*

1) A small scoliosis curve.
2) Axial loads transmitted directly to vertebral body growth plates (end-plate physes) as axial inward bulges that create mechanical micro-insults.

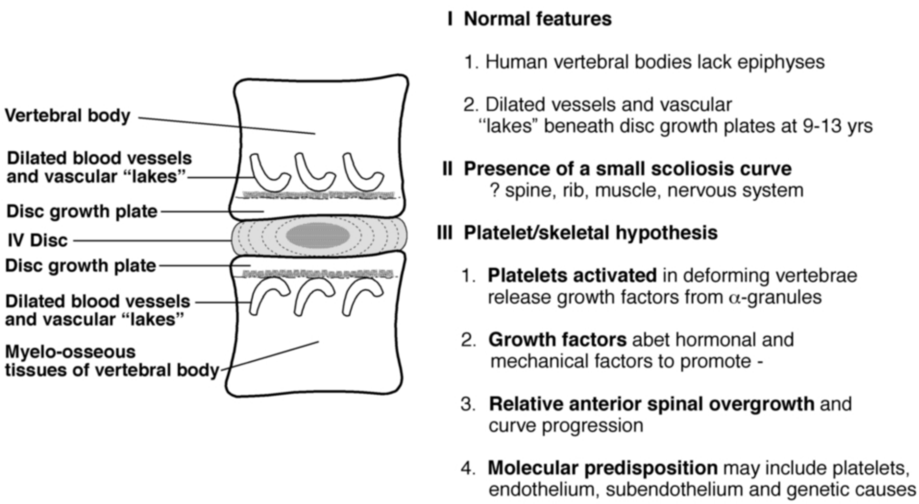

Figure 11. Diagram to show the *platelet-skeletal concept* for progressive AIS involving immature vertebrae, intervertebral discs, growth plates, dilated blood vessels, vascular 'lakes' and platelets. From Burwell & Dangerfield [184] with permission of the Editor of Acta Orthop Belg.

3) The latter cause dilatation of juxta-physeal vessels and, in deforming vertebrae vascular damage with exposure of subendothelial collagen and other agonist proteins.
4) Subject to predisposition, platelet activation with calmodulin changes occurs with dilated vessels of deforming vertebral bodies.
5) The activated platelets in juxta-physeal vessels release growth factors which, after extravasation, abet the hormone-driven growth of the already mechanically-compromised vertebral endplate physes to promote the relative anterior spinal overgrowth *(RASO)* and curve progression of AIS.

This concept links several fields in each of which research within ethical restraints is suggested to refute it. In articular processes excised at surgery [224] significantly lower calmodulin in bone cells without left-right asymmetry was found in 9 AIS compared with 10 congenital scoliosis subjects, suggesting a role for calmodulin in the development and progression of AIS.

Clinical applications.

The *platelet-skeletal concept* is consistent with:

1) The trial of melatonin and combinations of other radical antioxidant scavengers [184] as preventive measures against the progression of AIS.
2) Tailored pharmacological approaches to a melatonin-signaling defect in progressive AIS [221].

15. Biomechanical spinal growth modulation – its testing and mechano-transduction (Figures 1, 9 & 11)

Roaf [225] suggested that spinal imbalance through gravity and continuous muscle action leads to asymmetric loading of vertebral growth plates, and hence to asymmetric growth in accordance with the Hueter-Volkmann Law or Delpech effect [13, 68, 69]. Perdriolle et al [61] reported that the onset of scoliosis occurred as a result of intervertebral motion but worsening was caused by deformation of vertebral bodies (see Figure 1a); they hypothesized that scoliosis from its outset was determined by a mechanical process termed *torsion*, with *geometric torsion, or tortuosity*, of vertebral bodies [59, 89, 90]. The mechanical modulation of vertebral growth in the presumed asymmetrically loaded spine is supported by most [6, 10, 13, 15, 61, 67-70] but not all [7, 71] workers. It was described by Stokes as a *'vicious cycle'* and interpreted by his *vicious cycle hypothesis of pathogenesis* [13]. In a two-dimensional mathematical simulation of the hypothesis in vertebrae (not discs) of the lumbar spine, Stokes [13] *tested whether the calculated loading asymmetry created by muscles in a spine with scoliosis could explain the observed rate of scoliosis*. He obtained results consistent with the vicious cycle hypothesis, namely that in progressive AIS, frontal plane vertebral body wedging during growth results from asymmetric neuromuscular loading.

Stokes' [13,15,68,69] *vicious cycle concept* for AIS pathogenesis has four sequential processes as follows *(linear causality)*:

1) Pre-existing scoliosis curve of unknown etiology.
2) Physiologically plausible *neuromuscular activation strategies* – i.e. putative neuromuscular dysfunction with the most physiological strategy causing loads more on the concavity at the curve apex.
3) Neuromuscular-determined *left-right asymmetric loading of vertebral bodies* sustained over a substantial proportion of the day.
4) *Vertebral body growth plates (endplate physes)* sensitive to altered asymmetric compression with mechanically modulated alteration of growth leads to worsening of the scoliosis. The endochondral bone growth of vertebral endplate physes is modulated by sustained, but not transient, loading.

Different individuals may adopt differing neuromuscular activation strategies, with consequences for spinal loading that could explain why some individuals have more progressive scoliosis curves than others. The forces on vertebrae due to muscle activation are generally of greater magnitude than forces due to superimposed bodyweight [226].

Mechano-transduction.

Mechano-transduction is the process by which force-induced changes in cells [227] convert mechanical energy into electrical or chemical signals [228]. It lies within the field of *mechano-biology* that in the skeleton includes the three effects of Hueter-Volkmann, Pauwels and Wolff [13]. Little is known about how mechanical forces delivered to a cell result in a repertoire of output physiological responses [228], though recently force-transducing molecules – *mechano-sensitive ion channels* – have been identified in cell membranes with lipids [228] and calcium channels in osteoblasts [229] intimately involved. In certain connective tissues, mechano-transduction appears to involve cyclical mechanical strain up-regulating extracellular matrix genes suggesting that such genes are possible targets for therapeutic intervention [230].

Clinical applications.

1) Biomechanical modulation of vertebral growth provides a scientific basis for brace treatment of AIS [13, 69].
2) Extracellular matrix genes may be possible targets for therapeutic intervention [230].

Conclusions

1. Encouraging advances thought to be related to the pathogenesis of adolescent idiopathic scoliosis (AIS) have been made recently in several fields.
2. Current thinking is that there is a *defect of central control or processing by the central nervous system (CNS)* that affects the growing spine with the pontine and hind brain as the most likely sites of primary pathology.
3. Evidence suggests that factors which predispose and *initiate* AIS are separate from those that cause curve *progression*.
4. The core concept of *relative anterior spinal overgrowth (RASO*) for progressive AIS is established.
5. The consensus is that *RASO* results largely from biomechanical spinal growth modulation, tested mathematically, but the concept is questioned.
6. Morphological pathogenic concepts for AIS curve initiation are focusing on the sagittal and now the transverse plane of the spine, the ribcage and hips, and the relation of skeletal growth to neural growth and maturation.
7. In normal health the skeletal system and nervous system evidently grow and mature together in harmonious development within a normal *neuro-osseous timing of growth and maturation* (*NOTOM*). Such normal neuro-osseous development occurs a) in the limbs, b) spine and trunk, and c) between the body

as a whole and the brain for sensory/motor control of posture and coordinated movements.

8. One concept of vertebral-to-spinal-cord growth in AIS has three names: *1) disproportion of vertebro-neural growth (Roth), 2) uncoupled neuro-osseous growth (Porter and Chu), and 3) asynchronous neuro-osseous growth (Chu*). The putative mechanisms are similar. The concept can be construed as an abnormality in the spine and spinal cord of the *neuro-osseous timing of maturation (NOTOM).*
9. The *NOTOM concept* was formulated to explain why adolescent girls are more susceptible than boys to curve progression. It is based on the timing of adolescent growth spurts (earlier in girls) in relation to the timing of postural maturity (possibly similar in girls and boys).
10. The *NOTOM concept* led to a neuro-osseous body-brain developmental concept for which the term *NOTOM system escalators* is coined.
11. The *NOTOM system escalators* is the term we give to the normal system operating within a child's internal world [160,161,231-235] during growth and maturation by which a dynamic physiological balance is continuously renewed between two synchronous and polarized processes, or escalators, namely:

   a) Osseous escalator: increasing skeletal size, changing skeletal shape and relative mass of the different body segments which through posture and motion of the body by producing developmental biomechanical changes at the periphery create developmentally altering proprioceptive inputs including balance, to the brain that result in –

   b) Neural escalator: postural maturation with the *CNS body schema* being recalibrated - considered here for simplicity in the traditional proprioceptive modality - as it continuously adjusts to skeletal enlargement, shape and relative mass changes to enable it to coordinate motor actions.
12. Putative abnormalities of the *NOTOM system escalators,* involving asynchrony and/or asymmetry(ies) of one or both of its polarized processes, provide a theoretical basis *for AIS pathogenesis*. In this concept, delay in the *CNS body schema may be absolute* - arising from an abnormality in afferent, central, or motor mechanisms - or *relative to earlier skeletal maturation.*
13. *Abnormalities of skeletal growth, bone formation/resorption (osteopenia), and of skeletal symmetry and proportions* in the trunk, upper and lower limbs, are found in AIS girls.
14. Experiments have revealed *two systemic molecular disorders* in AIS, possibly interrelated:

a) *platelet calmodulin dysfunction*, and

b) *melatonin-signaling pathway dysfunction* in osteoblasts, skeletal myoblasts and lymphocytes. The melatonin-signaling pathway dysfunction is thought to be a biological marker with potential for prognosis, curve classification and medical treatment.

15. Whether or not neural tissue is affected by these molecular dysfunctions associated with AIS is unknown, but likely.
16. Like atheroma, the systemic melatonin-signaling pathway dysfunction phenotypically may be expressed differently in various tissues and regions of the body and depending on how these are biochemically affected, will determine what functions are disturbed.

17. Whether AIS has one cause, or is a final common pathway disease arising from different etiologies, it is beginning to look as if AIS may be a systemic molecular disorder(s) affecting neuro-musculo-skeletal structures in growth and development.
18. The concepts outlined here make it possible to formulate a *collective model for AIS pathogenesis* which involves theory, hypothesis and speculation.
19. The central concept of this collective model is the *neuro-osseous escalator concept for AIS pathogenesis*.
20. The *NOTOM system escalator*s have implications in health for –

a) control of posture and coordinated movements,
b) development of human upright posture and locomotion, and
c) human evolution – neural control, decoupling of head and trunk and unique bipedal gait.
d) b) & c) provide an *evo-devo* perspective for AIS pathogenesis.

Implications for control of posture and coordinated movements

1. A sense of how the body is orientated in space and how its component members are aligned is fundamental to any behavioral act [236].
2. In the 1960s and 1970's the basic question, now known as *Bernstein's problem* [159,237-239], was how the brain regulates the incredible number of motions of the many mechanical linkages of the body and the activities of the associated muscle groups [237]. Bernstein hypothesized that the nervous system organizes movement in a hierarchical manner for which there is now support with the *body schema high in the hierarchy* [160,161,163,240].
3. During development there is overwhelming evidence that the emergence of coordinated movements is intimately tied to the growth of the musculoskeletal system and to the development of the brain [159].
4. In neurodevelopment, the key theoretical issue is how the changes in brain circuitry controlling muscles and joints become matched to the developmental biomechanical changes simultaneously occurring at the periphery [159].
5. *Body schema, or postural body schema,* has been frequently used to refer to long-term organized knowledge about the spatial characteristics of human bodies [163].
6. In the adult, the *body schema* is a long-term dynamic physiological construct distinct from both the *somatotopic body maps* in the brain, and the *body image or body percept* with its immediate body perception that depends on immediate sensory input [163].
7. Some suggest that the *body schema* may be best understood as a multimodal spatial representation of the body that contains input from somatosensory, proprioceptive, and vestibular systems as well as visual input about body dynamics [241] and possibly body graviceptors [237]. On this view the schema is supramodal in that it exists independent of modality-specific processing [163].
8. Gallagher [160] defines the body schema as, *"... a system of sensory-motor processes that continually regulate posture and movement – processes that function without reflective awareness or the necessity of perceptual monitoring."*
9. Melzack [242,243] thought the *body schema* concept was improbable. He proposed the concept of a *neuromatrix* as a network of neurons extending

throughout the brain whose spatial distribution and synaptic links are initially determined genetically and are later sculpted by sensory inputs from experience.

10. The genetic origin of the *body schema* is supported by observations that *neonates imitate movements* [163,244-246] suggesting either implicit knowledge of body structure antedates the adult body schema [246], or innate mapping between observation and execution [245]. It is hypothesized that the *body schema, or internal representation of body posture,* is partly genetically determined and partly acquired in learning [237].
11. Each animal is thought to have a reference posture, or stance, which is genetically determined [237].
12. Postural or equilibrium control is generally presumed to be a precondition for the development of motor skills [247].
13. According to Massion and colleagues [234,237] posture provides:

a) antigravity function including balance;
b) body segment orientation with respect to gravity;
c) adaptation of antigravity posture to ongoing movements including the head and trunk by providing reference frames for organizing movements.

14. Postural functions adapt sequentially during postnatal growth and development [233,237]:

a) the first part of the body to develop a postural organization is the head with its visual and vestibular sensors;
b) head posture in space contributes importantly to the posture of the lower body segments with a 'top-down' mode of postural organization;
c) with the maturation of posture and locomotion a 'bottom-up' organization of posture emerges from the supported feet providing reference values for calculation of pelvic position in space before -
d) postural control is reorganized about 7 years of age.
e) There are possible implications of this *timing of maturation* from "top-down" (vestibular and visual) to "bottom-up" (feet) organization of posture control for the initiation and progression of AIS.

15. Many posturo-kinetic activities involve mastering the composite head-trunk unit [233].
16. In the *NOTOM system escalators*, the skeletal changes are evidently determined by mechanisms intrinsic to bones and by hormones. We suggest that the changes in the *CNS body schema* with growth and development may be determined by proprioceptive inputs, arising from learning and/or voluntary motor activity driving neuronal changes [248] and brain plasticity. i.e. the brain's ability to change its structure and function for which the major stimulant is experience [249-251]. Similar mechanisms are being evaluated in robotics and specifically the learning in and from brain-based devices [165,166].
17. The *posterior parietal cortex* in human clinical and experimental studies has been shown to participate in the dynamic representation of the *body schema* [160,161,163,164,252-256]. The body schema has been studied in relation to peripersonal space including haptic perception (touch – extrinsic and intrinsic, and proprioception - intrinsic) [257] and visual input (extrinsic) [258].
18. These studies have revealed two categories of *frames of reference* in the posterior parietal cortex in which spatial coordinates are thought to be defined with reference to both the body (egocentric) and external space (allocentric) including

gravity with hypothesized interaction between these frames of reference [258, 259].

19. Poucet [260] has proposed that the parietal cortex and hippocampus play different roles in the storage of cognitive spatial maps. The hippocampus codes *topological information* (arrangement of space, eg proximity), while the posterior parietal cortex provides *metric representation* (vectorial, eg angles and distances) of allocentric space. Hypothetically, frontal cortical areas then convert this allocentric spatial information into spatially-directed locomotor movements in the egocentric frame [261].
20. Prime candidates for mediating learning and memory [262] are long-term potentiation and long-term depression of excitatory synaptic transmission - which may underlie the learning deficits of AIS subjects [134].
21. New insights are being gained into the molecular pathology of the synapse [262]. In this connection, neural plasticity may involve a family of postsynaptic transmembrane cell-adhesion proteins, *neuroligins* in dendrites [263, 264] which are required for proper synapse maturation and brain function [265].
22. Synaptic plasticity underlies cortical map reorganization [266] which is known to occur after amputations [163,241,267] and limb lengthening [268].

Implications for development of human upright posture and locomotion

1. Balance control of posture and locomotion is acquired in successive developmental periods as the body's biomechanical constraints evolve continuously [233,234,237,269,270].
2. At 18 months to 3 years children rely primarily on visual information
3. Between 4 and 6 years the child begins to integrate visual, vestibular and somatosensory inputs [231].
4. Vestibular input becomes particularly prominent from 7 years of age when there is a return to an articulated mode of head-trunk control as a means of stabilizing the head in space [233].
5. The timing of this latter development in juveniles suggests a relationship with the evolutionary decoupling of head and torso in humans.

Implications for human evolution – neural control, decoupling of head and trunk and unique bipedal gait

1. In terms of human evolution [271-276] evidence is consistent with the concept that the *NOTOM system escalators* and the *collective model for AIS pathogenesis* are each associated with genes altering neural function, mostly unidentified, which enabled the human lineage to adopt their uniquely human features including large brain, speech, higher-order cognitive function, erect posture, bipedalism [52] and capability for endurance running [56, see 276].
2. The *FOXP2* gene is associated with language development, mutation of which causes problems in articulating speech (developmental verbal dyspraxia) accompanied by linguistic and grammatical impairment [276-279]. It is speculated that the *FOXP2* gene, critical to the evolution of human speech, has been the target of selection that enabled the fine control of larynx and oro-facial

movements essential to speech [277]. Many more genes are likely to involved in the cognition and motor skills needed for speech [280].

3. The *MYH16* gene, encoding a sarcomeric myosin heavy chain expressed in nonhuman primate masticatory muscles, is inactivated in humans. Stedman et al [281] hypothesized that the decrement in masticatory muscle size caused by the inactivation of MYH16 removed an evolutionary constraint on encephalization in early man. This hypothesis is controversial.
4. The neural changes associated with locomotion were likely to be associated with musculoskeletal changes producing dimensional biomechanical changes to the body.
5. The biomechanical changes include *decoupling of head and pectoral girdle* facilitating counter-rotations of the pectoral girdle and arms necessary to counter-balance the legs in running and eliminate axial rotations of the head in bipedal gait and running [56]. Such trunk movements feature in the model of AIS pathogenesis (see Figure 9)[10, 179].

Summary

This interdisciplinary approach to concepts of AIS pathogenesis is based on evidence found in spinal research of scoliosis, control of posture and coordinated movements in relation to the *CNS body schema,* development of human upright posture and locomotion, and human evolution of neural control of movements, decoupling of head and trunk and unique bipedal gait trunk.

The concepts make it possible to formulate a collective model for AIS pathogenesis involving theory, hypothesis and speculation. The central concept of this model includes the widely-studied neurodevelopmental hierarchical system involving the *body schema, or neuromatrix,* controlling normal posture and coordinated movements. This control involves frames of reference in the posterior parietal cortex which participate in the dynamic representation of the *body schema* integrated with other cortical areas.

In normal postnatal growth, *NOTOM system escalators* is the term we give to a system operating within a child's internal world during growth and maturation by which a dynamic physiological balance is continuously renewed between two synchronous and polarized processes, involving increasing skeletal size and the maturing *body schema.*

The *escalators* comprise *neural and osseous components*. The latter changes dimensionally and in segmental mass during human development. In theory, the growing musculoskeletal system and the biomechanical changes to the body that it causes, through sensory feedback from experience during posture and movement, epigenetically sculpt the maturing *body schema* which may in part be genetically-determined.

It is suggested that AIS progression results from abnormality of the neural and/or osseous components of these normal *NOTOM system escalators* in time and/or space – as asynchrony and/or asymmetries – which cause a failure of neural systems to control asymmetric growth of a rapidly enlarging and actively moving adolescent spine.

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Idiopathic Scoliosis and Chaos

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Abstract. At growing ages, the progression of the idiopathic scoliosis with a curve under 25° outlines many features related to the chaos theory. The image of the scoliosis calls to mind the "strange attractors" of the chaotic spine. We describe the 7 main characteristics of the dynamical scoliotic system classified as chaotic. It is an open set system, unpredictable, multi-factorial complex, discontinuous with thresholds that you can model, and it is an inter-phase between childhood and adult time. The chaotic model enables us to understand more the progression of the idiopathic scoliosis. It positively modifies the speech with the patient and its family as well as the therapeutic treatment.

Keywords: Scoliosis, Idiopathic, Chaos, Progression

Introduction

According to SRS definition, we are talking about scoliosis when Cobb angle is more than 10o. We know the linear progression of the curves of more than 25°, thanks to Madame Duval Beaupère and the vicious circle of the scoliosis at this curve rate described by Ian Stokes.

For more than 50 years, the scoliosis specialized physicians from the entire world focalized on etiologic elements, predicting the evolution of the scoliosis between 10° and 25°. Despite the computing progress, the result is a failure. We are still unable to predict the progression of a scoliosis between 10° and 25°.

The deterministic chaos theory [1,3,11] enables us to explain easily to the patient our ignorance about the evolutivity of the scoliosis under 25B°, and the necessity of regular medical visits until the moment the evolution is going to become linear according to Mrs Duval Beaupere's laws. That kind of scoliosis will be the one we will refer to as "chaotic scoliosis".

We explain it to the patient insisting on the necessity to watch after the scoliosis. The different treatments proposed and especially physiotherapy cannot avoid the "earthquake" resulting the progressive chaotic scoliosis, but are indeed an "anti seismic" building in a risky zone. The objective is to realize an early conservative orthopedic treatment, as painless as possible for progressive scoliosis.

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1. Definition of the chaos and the "strange attractors"

The chaos described by Edward Lorentz in 1963, is an unpredictable behavior appearing in a deterministic system [4,5,6]. It is very sensitive to the initial conditions and only a slight variation of those conditions leads to unpredictable effects upsetting the system. The strange attractor, discovered in 1971 by David Ruelle and Floris Takens, was a geometrical object coming from a chaotic system [9,10]. It is a fractal system that constitutes a figure in the space standing for the behavior of a dynamic system. It is the case of trajectories subjected to a chaotic movement [2]. It stands for a multi periodic system outlining two independent oscillation frequencies [8].

The scoliotic deviation can be considered as the representation of the strange attractor of the spine.

2. The seven elements of the chaotic scoliosis.

The structural idiopathic scoliosis of less than 25° is a characteristic of the chaotic system and this explains the big diversity of scoliotic curves according to many parameters inherent to the system.

2.1. Open set system

The idiopathic scoliosis is not a reality for four-legged vertebrate. The verticalisation of the vertebrate leads to the loss of the pressure point on the ground of the superior members, that is to say the transition from a closed kinetic chain to an open kinetic chain. The head is in balance with the spine which gets closer to the gravity line. The dynamic system has become open and balanced, like a pen resting on its head, just like in Maxwell's image.

2.2. Unpredictable system

We have to admit that even thought we know relatively well the laws of bony growth, the nerves and muscular physiology, the vertebral biomechanic, the experimental factors reproducing a scoliosis, the pejorative clinical elements…we are unable to predict the progression of a scoliosis of less than 25°. In 1989, when Duval-Beaupère was looking for all the criteria useful to predict the progression of a scoliosis during growth age, she could withhold only one factor and trust it by 95%; it is a curve of a scoliosis above 35°, that is to say a scoliosis with the posterior wall of the apical vertebra which has collapsed. This unpredictability comes from the extreme sensitivity of the initial conditions. We can foresee where the apple is going to fall down, but not where the tree leaf is.

2.3. Complex system

The experimental study of scoliosis and the etiologic research about scoliosis demonstrate that many factors can provoke a scoliosis: bony factor, muscular, ligament, neurologic, metabolic, chemical and postural…

We admit that a scoliosis is a multi-factorial disease, but we have never demonstrated that the accumulation of lots of those factors can lead to a scoliosis. The linear transposition is deceiving. The chaotic transposition is logical.

2.4. Discontinuous system

With Stagnata [7] we described the discontinuity system or threshold. Let's quote two characteristic examples.

2.4.1. The easiest threshold to understand is the biomechanic one:

Let's imagine a movement of the anterior flexion of the trunk and let's look at what is happening at the level of the apical vertebra of the scoliosis. For a rotation less than 25°, the lever arms of the concave and convex muscles are around the Instant Rotation Center of the vertebral body and enable the stability of the spine. At this step all the muscular activity leads to a correction of the scoliosis.

For a rotation above 25°, the lever arms of the concave and convex muscles are on the same side in regards of the Instant Rotation Center of the vertebral body. Their contractions lead to a worsening of the scoliosis (See Figure 1).

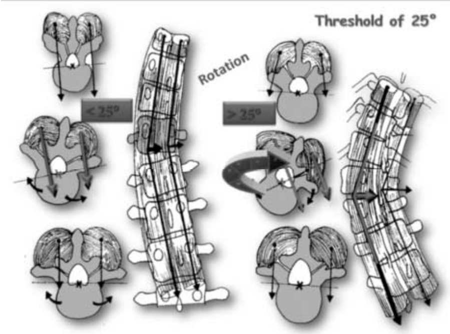

Figure 1. Biomechanic threshold

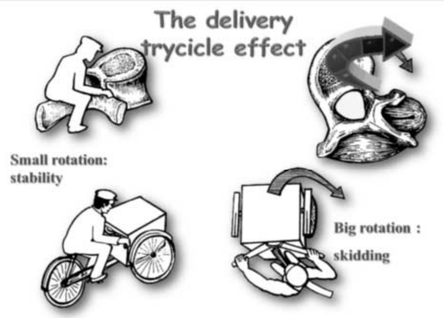

Figure 2. Threshold of slithering

2.4.2. The speed factor or "threshold of slithering":

We can schematize this apical vertebra body seen from above like a delivery tricycle heavily loaded. The load goes through the vertebral body; the driving is made thanks to the muscles acting on the transverses which stand for the handlebars. For the same rotation, that is to say a turn, the delivery tricycle is going to slither if it goes too fast (See Figure 2).

2.5. Deterministic system

Scoliosis is not a lottery. It can be considered in fact as deterministic in what seems random. Although we can not rely on any characteristic of the progressive idiopathic scoliosis when they are used to predict the progression, we later find some characteristic disturbances:

- Late maturation of the postural system,
- Dysplasia signs of the abnormal laxity of the tissues…

We cannot, therefore, use the model of the stochastic mechanic.

2.6. A system that we can model

With the development of the 3D many models have been described using bony elements and then muscular and ligaments…

Many classifications such as the one of Stagnara, SRS, King, Lenke enable to group the different scoliosis according to different criteria (See Figure3).

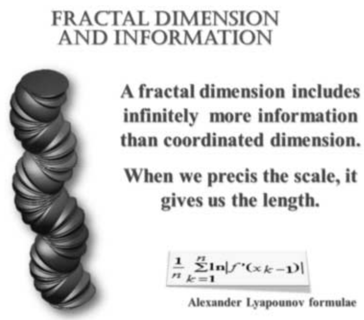

Figure 3. Modeling system

Figure 4. Practical Consequence

2.7. A system with inter phase

The chaotic system is observed during a transition between a solid and liquid phase, such as snow, or intestinal villosity and a transition between liquid and gaze such as tree leaves or pulmonary alveolus. Most of the idiopathic scoliosis evolves during the adolescence, which is the transition between childhood and adulthood.

This time of adolescence, with a growth of 25 cm at the level of the spine, varies a lot according to the child and is a chaotic time well described at the physiologic and social level. We have to notice that this non linear puberty growth is a characteristic of the homo-sapiens and does not exist for other vertebrates which have a linear growth.

3. The other chaotic vertebral symptoms.

The rotatory dislocation of the lumbar adult scoliosis shows as well the characteristic of a chaotic system. Most low back pains are also chaotic.

4. The practical consequences for the therapist

The etiologic treatment of the scoliosis does not make any more sense than going to hunt a butterfly in Brazil in order to prevent a tornado in Texas. Some amazing results are described and are the basis of some methods which are usually impossible to accomplish. (See Figure 4)

The preventive treatment of the scoliosis makes no sense and explains the failure of some school screenings, braces which were useless to treat non progressive scoliosis, and the failure of the percentage of operated scoliosis identical to some other states which did not use the school screening. In Europe, the failure of stretching orthesis can be explained in the same way.

We have to repeatedly observe scoliosis in order to screen early for the progressive scoliosis. The screening makes some sense only if it is repeated.

The role of the physiotherapy is often argued and many English speaking countries do not use those techniques in the treatment of idiopathic scoliosis. It is true, in fact, that physiotherapy cannot avoid the "earthquake" of the progressive idiopathic scoliosis, but it stands as an "antiseismic building", limiting statistically the progression of the scoliosis of 1,5° a year.

Conclusion

The chaotic geometry produces an angulous image of the spine and not a round or a smooth one as the Euclidian geometry does. The chaotic geometry corresponds to the bend and the dislocation, it applies perfectly well to the scoliosis.

The image of the scoliosis stands for the strange attractors of the chaotic spine. The idiopathic scoliosis of less than 25° has the 7 principal characteristics of a dynamic chaotic system.

The children's' screening, their observation, the communication with the parents and the therapeutic indications are therefore modified. . The children's screening, their observation, the communication with the parents and also the therapeutic indications are therefore modified.

The progressive chaotic scoliosis is opposed to the linear progressive scoliosis and this explains the confusions and contradictions of this symptom.

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Section II

Recent Trends on Scoliosis Research

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How Can We Achieve Success in Understanding the Aetiology of AIS?

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Abstract. A cure to prevent scoliosis from developing does not seem to be available in the near future. Primarily this is because of a lack of understanding of the aetiology of this devastating disease or cosmetic deformity. While extensive research has been performed in this area over the past 100 years many experiments have been poorly designed because they have been developed on the premise that patients with AIS all have the same, single underlying cause despite much evidence to the contrary. Consequently, much of the data in the literature can be challenged and perhaps explains the lack of significant progress. Certainly, the results from this previous research suggest strongly that a new approach needs to be adopted or the same confusing results will continue to be collected and little progress will be made. There are certain areas of research that hold the greatest potential for success in finding a cure. These are identified in this paper and included in a theoretical research laboratory. It is suggested that this laboratory need not be theoretical if modern, cheap communication systems were readily adopted throughout the world and if people were willing to share ideas readily and contact each other regularly. In perhaps an unconventional way, the emphasis of this paper is on finding a cure to prevent scoliosis from developing and uses the area of research into the aetiology of scoliosis as the platform for discussion.

Keywords. Adolescent idiopathic scoliosis, aetiology, cure

Introduction

Scoliosis, with its lateral curvature of the spine and vertebral rotation, has been a recognized problem for literally thousands of years with records describing the deformity dating back to Hippocrates. It is not hard to imagine that recognition dates back even further as the changes that occur to the spine are significant, easily recognized and cannot be ignored. By definition, scoliosis is a disease but is more often referred to as a cosmetic deformity because it does not appear to affect function unless the curve is sufficiently large to impinge on the lungs and heart in particular and affect cardiovascular function. In this way, treatment becomes an ‘elective’ issue. The cosmetic aspect of the deformity though has led to the somewhat derogatory term of ‘hunchback’ and patients (and many parents) wish for the curve to be corrected.

The most common type of scoliosis is adolescent idiopathic scoliosis (AIS) and affects 80% of the patients. The spinal curves associated with AIS become sufficiently large to be first observed at adolescence (at the time of the growth spurt) and the assumption is that it has been developing for just a short period of time and has not been present since birth. The classification that it is ‘idiopathic’ literally means that there is no known cause and so becomes a diagnosis by exclusion of the known causes of scoliosis which constitute the other 20% of scoliosis patients. Interestingly, many people suggest that cases of AIS have very similar appearance which suggests a common underlying cause but this is just an observation that has yet to be proved.

Research into the possible cause of AIS has been extensive and all encompassing but to no avail. Despite this extensive research, particularly in the past 100 years in all areas of concern, very little has actually been learned. In particular, although we have made some progress in general knowledge, information that can be applied to specific patients is significant by its absence. There is at least one recorded case where a concerned, insightful mother who, as a teenager, had herself undergone the trauma of spinal surgery to correct her significant scoliosis, recognized that her pre-pubescent daughter was developing in her exact image and was a probable candidate to develop AIS. Fearful of the possibility of surgery for her daughter, the mother was determined to do everything possible to prevent this and insisted that her daughter be examined and followed closely. Initial examination (age ~8 years) showed no scoliosis but subsequent examination in the following years showed rapid progression which eventually resulted in spinal surgery – despite the best, current techniques of prevention and treatment being applied. This is not good and reflects the lack of applicable knowledge that has been uncovered over the years. This case should also act as motivation to continue the search for mechanisms underlying the development of scoliosis so that more practical and successful approaches can be developed to stop spinal curves from developing and to treat them more successfully when they do arise.

Lee Iacocca, the former CEO of Chrysler, has created the Iacocca Foundation in his retirement years whose mission is to find a cure for diabetes. Apparently this was Iacocca’s first foray into the world of medical research and was a real education for him. In his typical, blunt style Iacocca, a very successful business man, concluded that this research was much like government – kind of a self-generating bureaucracy. Cynically, he noted that people do research so that they can write papers to get more funding to do more research to write more papers. After he had finally figured out what was happening, he asked: ’Hey, isn’t anyone trying to find a cure?’ Is that what is happening with research into AIS? (Iacocca also has advice on how to live to be 100 years old, given to him by the comedian Bob Hope: get a massage every day, start each day with fruit, and have sex every day. Perhaps with just two out of those three, we will be still alive when a cure for AIS is found and can find something else to do with our lives.)

This paper focuses on identifying the problems with current research into AIS that are possibly preventing progress and also those areas of research that have the most potential for success. The concept of creating a research laboratory where people involved in these research areas can reside for progress to accelerate is also developed.

A typical patient

The progress of a typical patient with AIS must be considered (see Figure 1):

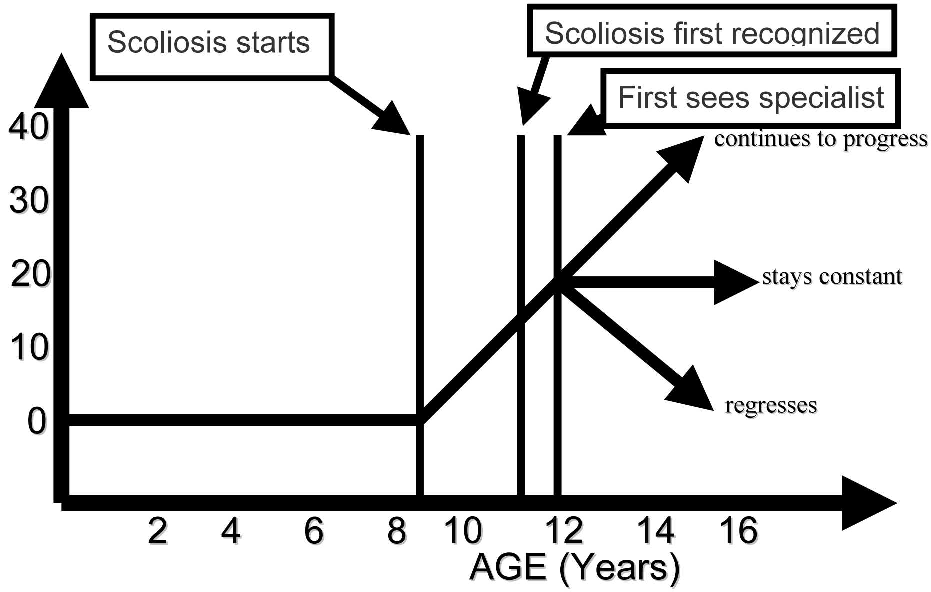

Figure 1. Hypothetical progress of spinal curve development in a typical patient with AIS.

It is assumed that a child who is going to appear in a clinic with AIS at the time of puberty has not had the spinal curvature since birth or else it would presumably have been noticed if it was sufficiently large to be significant. Therefore, between the ages of childbirth and (in the example shown in Figure 1) 8 years old, the spine was straight. At this age, a spinal curve started to develop slowly for whatever reason and becomes noticeable to relatives and friends (e.g. shopping for clothes, at the swimming pool etc.) when it has reached a Cobb angle of ~15° but by now ~1-2 years have gone by and the patient is 11 years old. At this time it is interesting to note that the patients themselves are usually unaware of the curve which is an interesting fact on its own. Usually, the family physician is the first professional who sees the patient and recommends specialist evaluation – which can sometimes be 6 months or more into the future. By the time the patient sees a specialist, the curve has been developing quite possibly for several years and the patient, in the scenario above (see Figure 1), is now 11 years old. At this time, the curve, with appropriate treatment, can continue to progress in unfortunate cases, remain stable or regress. Using this model as a base, the following are the most important areas for AIS research accompanied by the most important questions associated with each:

- before the curve starts to develop – the aetiology of AIS – Can a marker be found to identify those children who have the potential to develop scoliosis in the future?

- when the curves are small (>25°) – Can a method be found to correct small curves?
- when the curves are large (>25º) – Can a method be found to correct large curves that is less invasive and extensive than the current traumatic method involving insertion of metal rods?
- treat the societal aspects of the patient – Can methods be developed to help these unfortunate patients (80% female) who are undergoing such trauma at a very influential period of their overall development especially in regards to their confidence and personality in these fragile, formative year of adolescences.
- treat the families of patients – Can methods be found to inform adequately and appropriately how to help their affected relatives overcome some of the issues associated with this problem in a family environment.

Even within these areas, it should be clear that while all are important, the most important area for research is the aetiology of scoliosis because if that problem is solved, then the other areas disappear of their own accord.

Figure 1 also highlights a major problem associated with research into AIS: the curve is not recognized until it has reached approximately 15° when the patient first visits the family physician and then formal records are probably not started until the patient is evaluated by the specialist. By this time, the curve might have been developing for 2 years but most significantly the underlying cause for the curve might well have gone. Adolescence is a very turbulent time of development and many changes, especially hormonal, must occur in synchrony for puberty to continue successfully. The initial stages of puberty, when all these changes are appearing, might take a short period of time to become coordinated and harmonious. This short period of disharmony might be sufficient time for any cause that produces a spinal curve to have done its initial damage and then disappear as the necessary changes within the adolescent becomes harmonized. In the meantime, sufficient changes in the spine have occurred because of the development of this initial curve, especially morphological changes such as vertebral and intervertebral disc wedging, that even with the removal of the underlying cause, the body is unable to straighten the spine. Further development of the spinal curve now becomes purely a biomechanical phenomenon. The major point being that when the specialist finally gets to examine and evaluate the patient with AIS, the cause of the spinal curvature that has developed has gone and the patient is entirely normal other than having a continuing biomechanical problem of curve progression. In such a case, all measurements of a suspected contributing factor will result in normal values.

The hypothetical situation shown in Figure 1 also highlights another major problem in regards to research. If the spinal curve starts to develop at 8 years of age but does not become recognized until 2 years later, there is a vacuum for data during this period of time. The initial stages of development are perhaps the most important as the underlying cause should be most recognizable during this time but no data can be collected because the patient has not yet been identified! Screening studies of large numbers of children have proved to be poor in terms of cost effectiveness and have been discontinued in most communities making it impossible to collect data prior to curve development. Attempts to identify a population for study in which the predicted incidence of AIS would be greater than that for the normal population (by studying children or relations of former and current patients) have not proved successful. Consequently, research into AIS is restricted because any differences found between patients with AIS and normal controls cannot be separated from the effects of scoliosis itself and its effect on curve development. Several years ago studies of calmodulin levels in platelets showed significant differences between patients with AIS and matched-controls. This was very encouraging because it was difficult to see how curve development could affect such levels. Disappointingly, subsequent work showed that calmodulin levels reverted to normal after treatment with bracing, indicating that such changes were indeed the result of curve development in some unexplained way.

To obtain data from inside the time period between curve initiation and recognition, some researchers have tried to extrapolate backwards from data obtained later but the patient is undergoing treatment when these later data points are being collected and the extrapolation becomes very difficult if not impossible and its predictive usefulness is very limited

It might be thought that the childhood period of time when there are no data points collected for patients with AIS is a time out of reach to the researcher. However, photographs are available from family collections and while probably not having been taken professionally or scientifically, these images might contain much-needed information. Similarly, questions to the patient themselves asking if there are other problems that appear to have developed in parallel with the scoliosis might bring some reward as might simple questions to the parents and support staff in the clinic that have close contact with the patient and might be an as yet untapped source of valuable information.

Confounding the whole issue, however, might be the simple fact that spinal curves such as are found in AIS might just be the extreme at one end of a normal distribution of curve development compounded by biomechanical involvement that increases curve size exponentially. In this case, there would be nothing fundamentally wrong with these patients and ultimately no abnormality to be found.

After 100 years of research what do we know?

For a comprehensive review of the aetiology of AIS, the reader is directed to Robin (1990). From this excellent review, it is clear that there has been intensive research into the aetiology of AIS in many separate areas for almost 100 years. However, in each separate area the results from different projects are often contradictory. For every experiment that produces a positive result for the topic or parameter under discussion there is often an equally effective study that does not support the initial findings and often suggests entirely the opposite. This is very confusing and even more frustrating when subsequent authors are selective in finding only those data which support their ideas and exclude equally valuable but unsupportive data from consideration. In fact, despite this extensive research over the past 100 years, there are very few confirmed facts related to AIS:

- the development of the spinal curve requires a growth spurt
- the spinal curves appear to be more progressive and severe in females
- there is a wide variety of deformities
- AIS can be familial

Unfortunately, each of these facts could be obtained simply by being observant over a 20 min period at a scoliosis clinic. The patients are adolescents, mostly female, with a variety of curves (double, single, left, right etc.) and one of the accompanying adults often exhibits a similar curve. This lack of information is very frustrating because it indicates a lack of progress despite enormous efforts. However, the very fact that there have been no major advances can be very useful because it indicates something very important – we need to use a different approach if a solution to AIS is to be achieved. One definition of stupidity is said to be continuing to do the same thing and expecting different results. The results from research so far might be very informative if it is interpreted as encouraging us to try something different if we wish to make real progress.

A fundamental question and its consequences in experimental design

If you can imagine Hippocrates in his medical clinic 2000 years ago, then he will have had patients who exhibited curved spines – which he called scoliosis. He probably knew nothing else about them and simply placed them in a single category. When the group got sufficiently large, perhaps he noticed that some of these patients exhibited other symptoms and subgroups were able to be identified. For example, patients with Friedrich Ataxia, neurofibromatosis or poliomyelitis all develop scoliosis and over the years (but probably not in the days of Hippocrates) these patients have been culled from the main group of patients with AIS as their cause has been identified. Unfortunately, only 20% of the overall group of patients has been able to be removed in this way and the vast majority of scoliosis patients (80%) remain with their cause unknown – designated 'idiopathic'. Following this possible evolution of the characterization of AIS, it becomes difficult to believe that a single cause for AIS remains to be found within this group. Perhaps a better conclusion might be that several separate causes still exist but that they are less obvious and will be more difficult to identify. In fact, this culling from the group of patients with AIS continues today with male patients diagnosed with AIS having scoliosis curves to the left being more frequently recognized as having syringo-myelia. This begs the question 'What evidence is there to suggest that all the remaining cases of AIS have just a single cause?' This is a fundamental question in this area of research and has yet to be answered in any meaningful way – but its impact is enormous and far reaching as it influences so much of the experimental design and basic thinking. For example, if you saw a young girl with her leg in a cast you might ask 'How did you hurt your leg?' Her response might be 'Playing football'. Then if you saw six more young girls all of whom also had their leg in a cast identical to the first girl and asked the same question, the responses might vary considerably - 'Playing volleyball, falling off my bike, fell down some stairs etc.'. In other words, the end result looks very similar and yet the underlying cause might be entirely different in each case. If you substitute a curved spine (scoliosis) for the broken leg in each case then, again, the underlying cause might well vary considerably – muscle imbalance, unequal bone growth, deficiency in muscle spindles etc. which would indicate that scoliosis has multiple underlying causes all resulting in a similar curved spine. To emphasize further the concept of multiple different causes for AIS, scoliosis is manifested by a wide variety of different types of spinal curve with no single example being predominant.

While the question 'Does AIS have a single cause or multiple causes all with the same end result?' is basic to this area of research, it must be realized that the answer people select has consequences regarding experimental design. This is particularly important as most people would answer that AIS has many different, separate causes but this is not often reflected in the design of experiments. For example, imagine that you believe that the cause of scoliosis is a reduced number of muscle spindles in vertebral muscle. With such a hypothesis the obvious experimental design would be to collect vertebral muscle samples from 20 patients with AIS and 20 age-matched controls. The muscle samples would be sectioned and stained so that the muscle spindles could be identified and counted within a specified area. Imagine that the normal value for the number of muscle spindles in a specified area is 10. Consequently, you would expect your control samples to give values all of ~10 with a small S.D. Now imagine that AIS actually has multiple causes (which most people believe) and that in 20% of cases the underlying cause actually is a reduced number of muscle spindles – exactly as you are predicting. However, when you observe the data from the 20 patients with AIS only 4 of them (20%) will have reduced levels, possibly in the range of 2 or 3, but clearly showing a deficiency. When statistical analysis is applied to the data and the mean and S.D. values for the two populations are compared, the low values for the four AIS patients who have reduced numbers of muscle spindles will be 'hidden/swamped' by the higher, more normal values of the sixteen patients whose cause is not represented by reduced numbers of muscle spindles. Consequently, no significant difference in average values between the two groups will be seen. The conclusion would be that reduced numbers of muscle spindles in vertebral muscle is not a cause of AIS (because there was not a significant difference between the means of the two groups) and yet the theory was actually correct! An experimental design such as described has a single cause for scoliosis as its base and a review of the literature shows that it is full of research with this design. If AIS has several separate and different causes, then selection of a group of patients with AIS and comparing the average value of a parameter between these patients and that of a matched control group will not usually reveal a significant result – and yet many experiments have been designed this way. Ironically, most people would say that AIS has many different causes! This lack of ability to obtain significance with this type of experimental design perhaps goes a long way to explaining the range of differing results in the literature – mostly non-significant but occasionally significant.

At research meetings and in submitted manuscripts where experimental designs similar to that described have been used, the authors should be required to explain why they believe that AIS has a single cause to support their design. The evolution of AIS aetiology suggests strongly that patients diagnosed with AIS, which is a diagnosis by exclusion and not a positive diagnosis, have multiple different causes which still need to be identified. There is little evidence to suggest that patients with AIS all have just one, common underlying cause – and yet that is the premise on which many experiments have been designed.

At this point it is important to clarify the concept of AIS having multiple underlying causes as this is an area of possible confusion. It is entirely possible that each of the remaining causes of AIS remaining to be identified consists of several different factors that interact to produce a single cause. For example, it might be that an underlying cause (hypothetical) of scoliosis is a reduced number of muscle spindles in vertebral muscle BUT scoliosis only develops if this anomaly is accompanied by ligamentous laxity. Similarly, an entirely different underlying cause might be an inherent muscle imbalance between the two sides of the spine BUT scoliosis develops in such cases only if there has also been unequal vertebral growth. Both these hypothetical causes represent entirely separate causes of scoliosis but consist of several factors. This is often a difficult concept to convey clearly but emphasizes the possible complexity of scoliosis development and the daunting task that continues to await people in this area. However, it is important to base thoughts and experiments on a model which can be tested and modified. Currently, many experiments related to aetiology have adopted a model of a single cause which is difficult to justify. More progress might be made with adoption of a different model along the lines of AIS having multiple, different causes each of which might also have several, interlocking contributing factors.

Members of a potentially successful research laboratory.

Having reviewed the available literature, it is an extravagance to dream about the members to be recruited for a research laboratory focusing on the causes of scoliosis and which would have the best chance for success and make significant and faster progress than is currently being made. Nevertheless, such a laboratory might recruit the following people:

A masochist:

There is an enormous amount of literature available related to the aetiology of scoliosis. As described above, much of this is based on experiments with questionable experimental design (i.e. select a group of patients with AIS and compare a single parameter with a control group.) While the conclusions from such experiments might be misleading, nevertheless there is an abundance of data that could be useful. However, it might be buried in the 'outliers' of the experimental data and individual data might no longer be available. Progress might be made by going through the literature and evaluating the data already available based on experimental design and eliminating those data which have been obtained and analyzed in a poor fashion. No literature should be eliminated outright because it has all been collected honestly and with good intentions but it needs to be analyzed in a different way to be useful. This would involve long, tedious and possibly unrewarding work and so a masochist (who would sacrifice himself for the benefit of the group as a whole) would be a valuable member of the group.

Basic scientist with ideas for a specific cause:

There is a place in the hypothetical laboratory for a basic scientist who has developed educated ideas about a specific, separate cause for scoliosis. However, the approach would have to be along these lines:

- develop a feasible and plausible theory
- show that it is applicable in an animal model (which is a problem in itself outside the scope of this paper)
- identify the symptoms or characteristics that would be demonstrated by a scoliosis patient
- find patients who demonstrate these symptoms and verify the theory

Such an approach might be labeled 'needle in a haystack' but selection and development of an appropriate theory might not be too difficult. The creation of an animal model, however, presents a huge hurdle as Man is the only truly bipedal animal and an upright posture appears to be another prerequisite for scoliosis development (for examples see references related to pinealectomy experiments in bipedal rats).

Recently, Talib Rajwani at the University of Alberta used the concept of unequal growth of the neurocentral junctions (NCJs) in vertebrae as a possible cause and utilized such an approach. While it was a very plausible concept he was only able to demonstrate that the NCJs do not contribute sufficiently to vertebral growth to initiate a spinal curve if growth between the two sides of the vertebra is unequal. While this was a disappointment he was at least able to eliminate the NCJ as a possible cause of scoliosis. Other possible causes might be examined in a similar way but it would be very time consuming and expensive.

Two geneticists:

Mendelian geneticist: This would be a person interested in family lineages and determining whether or not scoliosis is genetically transferred from generation to generation. Clearly, there are some families where scoliosis is common and others where scoliosis appears to have emerged randomly in just one person. Is this further evidence to suggest that multiple, separate causes for scoliosis exist? This area of the literature appears to be incomplete but has tremendous influence on the model that can be used while designing experiments as well as in selecting patients for study. There are some aspects of this area which prompt immediate questions. For example:

- It is difficult to understand why only 70% of identical twins both develop scoliosis.
  - o What has happened to the other 30%?
  - o How much influence has the environment in scoliosis development – 30%?
  - o Are there people walking around with identical DNA (identical twins), one of whom has scoliosis and the other not? How does this affect genetic screening experiments?
  - o In cases where both identical twins develop scoliosis, are the curve characteristics identical?
- In only 37% of cases do non-identical twins both develop scoliosis. In contrast siblings, who are not twins, both develop scoliosis only in 7% of cases.
  - o what influence does life in *uterus* have if non-identical twins are considered simply as siblings?

A mendelian geneticist would have much to offer the group because there are many questions whose answers have significant consequences in many areas.

Molecular geneticist: this would be a person who is interested in genetic screening and who has interest in identifying those gene anomalies peculiar only to patients with scoliosis. Currently this is a common research approach in many areas of medicine. It involves selecting patients who have been diagnosed with a specific disease and comparing their genetic profiles with normal to identify important differences. At the moment, a shotgun approach is being used simply to identify those particular genes where differences from normal exist and it is anticipated that these results will direct future research into function of these genes and an understanding of specific underlying mechanisms. Sometimes seemingly unrelated genes have been identified which has been very surprising. This is the area where most success is expected in the short term (in association with many diseases) and the results are eagerly awaited.

If AIS has multiple causes AND each of those separate causes consists of several factors (as described above) AND if there is a complex relationship between those factors (which need to be present at specific times and maybe not all need to be present for scoliosis development to be activated) AND if there are people walking around (identical twins) with identical DNA but not with both having scoliosis etc. what model can be used in such gene screening experiments? A prediction from the current model would be that many differences in genotype will be found and this seems to be the case. Headings similar to ‘Spina Bifida gene identified’ or ‘Gene for Cystic fibrosis identified’ (actual examples) do not seem to be immediately forthcoming for AIS as the model seems to be much more complex but significant progress is being made and results will come – hopefully quickly and sooner rather than later.

Cell biologist: Having determined a specific cause for the development of scoliosis, a cell biologist would be required to describe the sequence of events which are necessary to occur between the identified cause and the development of an actual spinal curve. For example, pinealectomy in young chickens regularly produces scoliosis and can be identified as the underlying cause. The pathway between removal of the pineal gland with the presumed reduction in serum melatonin levels and the development of a spinal curve remains to be determined. There is no doubt that the model produces scoliosis but it is a long way from the pineal gland and its products, to the production of vertebral and spinal malformations. A cell biologist would be required to plot this path and provide the necessary explanations for each of the steps. Significant progress is being made in this area in regards to the involvement of the pineal gland in the development of scoliosis with findings that melatonin has significant effects on osteoblast and osteoclast behavior.

Engineer specializing in 3-D column structure:

The Cobb method for measuring the degree of lateral curvature of a scoliosis curve has been very useful particularly to the surgeons. A scoliosis curve though is not 2-dimensional as represented on a radiograph and by the Cobb method. A scoliosis curve is a 3-dimensional spiral and, as such, should be measured in three dimensions and not two dimensions. To understand fully the nature of a three-dimensional scoliosis curve it should be measured and analyzed in its true form and so methods need to be developed by which three-dimensional curves can be easily, quickly and usefully measured. It has been said that ‘if you measure in 2-D, you think in 2-D; if you measure in 3-D, then you think in 3-D’. Scoliosis curves are three dimensional and continued measurement in two dimensions is limiting our understanding. To make progress, scoliosis curves need to be measured and thought of in three dimensions and not just two.

A radiograph is an image of a three-dimensional structure compressed into two dimensions. Measurement from the radiograph of the lateral curve using the Cobb method is attractive because it allows for an easy assessment – ‘Your curve was 25º last time and it is now 15º. You are much better’ but a two-dimensional measurement does not help the researcher and his three-dimensional concepts.

Figure 2 shows an 8’ tall metal bar in a children’s playground that is attached to swivels at both top and bottom. The bar consists of a fixed spiral and goes through 360º between its attachments. The bar is designed so that the children can spin the bar around on its two swivels at the two ends. Judicious positioning of the bar and imagining it to represent the spine on a radiograph allows 4 images to be captured which show all the different types of common scoliosis as seen using the Cobb method with radiographs where three-dimensional spines are compressed into two-dimensional radiographs. All these images of the metal bar are of the same curve (the fixed bar) and illustrate that simple positioning of a three-dimensional structure can affect two-dimensional interpretation. For progress to occur in the understanding of scoliosis, methods for measuring three-dimensional representation must be a priority.

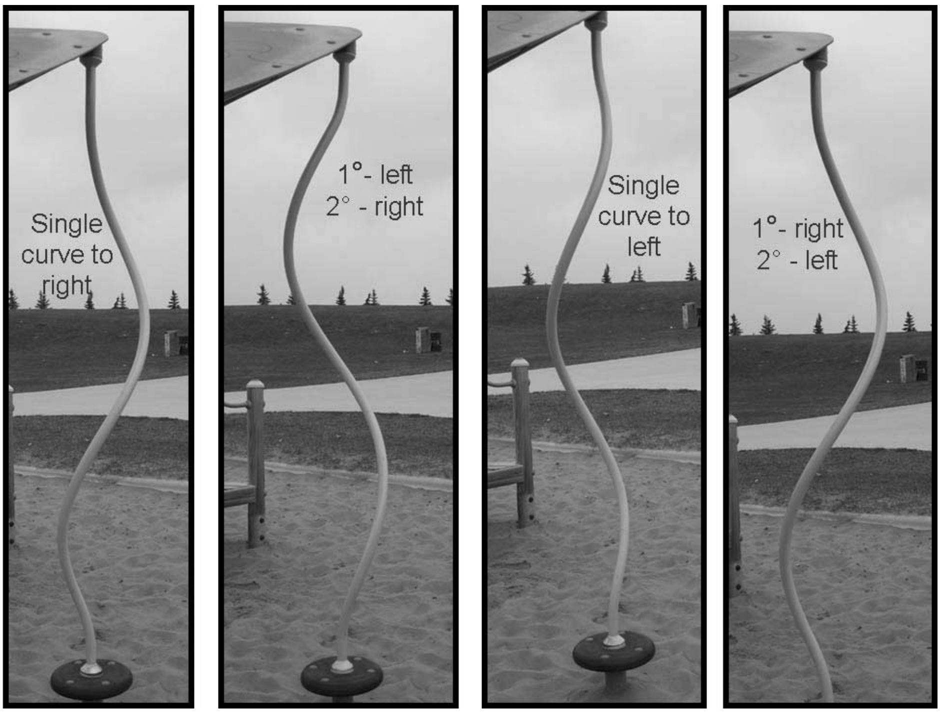

Figure 2. Images of an 8' high metal bar in a children's playground. The bar is a spiral that passes through 360º from top to bottom attachment and is a fixed structure designed so that it can be spun around by the children. In these pictures, the bar has been stopped at 4 specific points of rotation and the images show four forms of scoliosis curve that are described by evaluation using the Cobb method – all from the same curved bar!

Measurement of a three-dimensional curve might possibly involve an equation describing the curve e.g. (hypothetical):

$$y=ax^2+bxy+c^3x3z^3-dy^3z+ez^4$$

This equation might well best represent the overall shape of the three-dimensional spinal curve at a visit of a patient and clearly is difficult to interpret. The next time the same patient is evaluated, the curve might have changed along with the descriptive equation e.g.

$$y=fx^3+gx^2y+hx^3z^5-iy^2z+jz^3$$

Again, this is a difficult equation with which to relate and becomes even more difficult when trying to compare it to the equation obtained from the last visit. Clinically, a comparison of numbers that are easy to comprehend and communicate to others is essential - 'last time, you were 6/10; this time, you are 3/10 – and you are so much better.' Simplification of complex equations and their comparison for communication purposes is probably just one of the complicated issues awaiting the 3-D engineer.

Another important issue that would occupy the mind of an engineer is the 'point of no return'. Whatever the initial cause for development of a spinal curve, the patient should be able to straighten the spine given appropriate guidance as long as there have not been any morphological changes made to the vertebrae and surrounding structures. Straightening the spine after it has been curved is an everyday process for normal people after any activity and so should be possible (to a certain degree) for people with scoliosis curves devoid of morphological changes. However, there is possibly a point in severity of the curve after which it can no longer be straightened even with appropriate guidance. This point is significant because from this position on, the biomechanics of the spine become an even more important problem. At this point, the spine has become so curved that even with removal of the underlying mechanism, the spine remains curved and obeys biomechanical laws resulting in further progression of the curve but by additional biomechanical means. Coupled with the underlying cause, the addition of the biomechanical forces would accelerate curve development. Presumably, treatment to remove the underlying cause before reaching this 'point of no return' would have more benefit than treatment after reaching the same point.

There is much for the engineer to do in the research laboratory in applying her engineering skills and techniques to this three-dimensional problem.

Universal Research Laboratory

The discussion above has focused on creation and description of a theoretical laboratory which would have the potential for making the most progress in finding a cure for AIS. Development of such a laboratory would be very expensive and the cost would probably be prohibitive. However, in this day and age, communication world-wide is becoming cheaper and easier each month. In fact, the purchase of a video-cam for <$50 (for H-R W. - some of the more advanced computers now have them already built-in) and the use of message systems such as MSN and SKYPE which are easily available on the internet for free should allow for ready access to anybody anywhere in the world to communicate visually and inexpensively with anybody else at any time. The theoretical laboratory described above already exists if people would adopt new technologies and were willing to share ideas and suggestions. If a research laboratory has access to the internet and a video-cam, then it takes only a few minutes to set up the equipment and appropriate software to establish contact with each other. (Advice - the most appropriate person to set this up is the youngest person in the laboratory, certainly not the older P.I.) If we are truly committed to finding a cure for AIS, then this system of communication and ready sharing of ideas should be adopted immediately. A consequence would be an acceleration of the rate of progress towards a solution and should be actively encouraged by all interested parties.

Another disease where similar research has been more successful

Scoliosis and AIS have proved to be complex diseases that involve interactions between genetics and the environment and which are multifactorial in their underlying causes. In contrast, spina bifida is a simple (?) failure of the neural tube to close which has been shown to be related to low levels of folic acid during early pregnancy. The mandatory addition of folic acid to the diet in North America (in wheat and rice) has reduced the incidence of neural tube defects by 72% (as well as significant reductions in some other diseases). Unfortunately, the development of abnormal spinal curves seems to be a much more complicated problem. Nevertheless, the appropriate model for the cause of scoliosis is not unique and a comparison of the models being used to tackle the problems associated with an understanding of other diseases such as cancer and autism suggests that research into scoliosis might benefit from adoption of similar models. Research into these other diseases in general seems to be further along than that associated with scoliosis and a comparison with these other models and possible adoption of similar research strategies might allow scoliosis research to stand taller on the shoulders of the work already completed in these other areas and avoid having to reinvent the wheel.

Summary

This paper has approached the topic of the aetiology of AIS in an unconventional way. It has focused deliberately on those areas of research where the most progress towards a cure will be made in the near future. There are other areas of research that were initially considered (such as computer modeling) but it was felt that they need more development before they can make a significant impact. Readers might agree or disagree with the selections made but if any discussion of the issues ensues, then the paper will have reached its goal. Hopefully even more discussion will be stimulated if the following questions are also asked:

- if you had access to $50M to disperse at your own discretion among scoliosis researchers, what areas would you select and to which specific laboratories would you allocate the money?
- conversely, and perhaps a better question, if you had access to $50M to disperse at your own discretion among scoliosis researchers, what areas would you NOT select and to which specific laboratories would you NOT allocate the money?

These are questions that can be asked privately or publicly at research meetings and have the potential to focus people's attention on making progress and finding a cure and would serve to show Lee Iacocca that his assumption is wrong in regards to medical research, at least with respect to scoliosis.

Similarly, another question which might encourage discussion would be:

- if the work you are currently completing is successful, how will it affect a patient who has scoliosis?

Surely, there can be nothing more dispiriting than spending a life-time studying scoliosis and completing enormous amounts of research that has not influenced in any way the outcome or treatment of a single patient who has scoliosis.

It would be delightful if a cure for scoliosis was to be found tomorrow and simply involved, say, the sprinkling of small amounts of melatonin on the breakfast of young children each day while they are going through the developmental stages associated with puberty. It is probable that the cure will not be that simple but, if a one were to be found soon then perhaps other dreams could be followed and the real purpose of life achieved which, while I am still in my prime, is to ………. …

Mechanical Modulation of Spinal Growth and Progression of Adolescent Scoliosis

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Abstract. It is unclear why some children with a small magnitude scoliosis at the onset of the adolescent growth spurt develop a progressive curve. Normally the skeleton grows symmetrically, presumably because genetic and epigenetic factors regulating growth to maintain growth symmetry despite activities and environmental factors causing asymmetrical loading of the spine. This chapter reviews the recently published data relating to the notion that progression of scoliosis is a result of biomechanical factors modulating spinal growth ('vicious cycle' theory). Quantitative data exist for the key variables in an analysis of scoliosis curve progression. In a predictive model of the evolution of scoliosis simulating the 'vicious cycle' theory, and using these published data, a small lateral curvature of the spine can produce asymmetrical spinal loading that causes asymmetrical growth and a self-perpetuating progressive deformity during skeletal growth. This can occur if the neuromuscular control of muscle activation is directed at minimizing the muscular stress (force per unit cross section), although other activation strategies may produce differing spinal growth patterns. Mechanical modulation of vertebral growth is a significant contributor to the progression of an established scoliosis deformity. Quantitative simulation of this mechanism demonstrates how therapeutic interventions to alter neuromuscular control of trunk muscles or otherwise modify spinal loading may alter the natural history of progression.

Keywords. Scoliosis, Progression, Biomechanics, Growth

1. Introduction

The idea that progression of scoliosis deformity could be predicted and prevented is attractive. However, both the identification of individuals at risk for progression, and prevention of progression of the deformity present challenges because of the unknown etiology of idiopathic scoliosis, and unknown mode of progression. The similarity between natural history of progressive scoliosis of different causes (idiopathic, congenital and neuromuscular) which all progress rapidly during rapid growth [1] points to similar mechanism of progression, despite differing initial causes. Progressive post-natal skeletal growth deformities including scoliosis are often attributed to the 'Hueter-Volkmann Law' of mechanically modulated endochondral growth (increased compression slows growth and vice versa). According to this concept, a lateral curvature of the spine causes it to be habitually loaded asymmetrically, which produces asymmetrical growth and consequent increased deformity in a 'vicious cycle' (See Figure 1) [2,3,4].

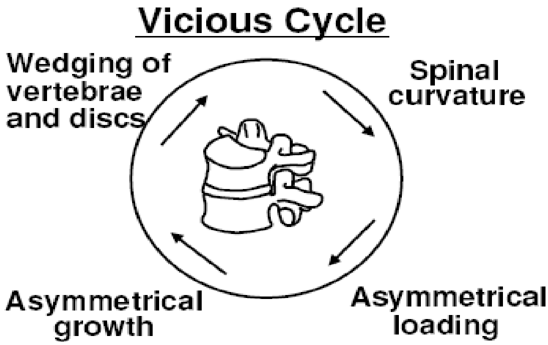

Figure 1. The vicious cycle that represents the widely accepted qualitative explanation for the mechanism of scoliosis progression by mechanical modulation of growth (Hueter-Volkmann 'law'). (from Stokes *et al.* [10]). The asymmetrical spinal loading associated with a scoliosis causes growth modifications that lead to increased vertebral and discal wedging and curve progression.

Recently, advances have been made in understanding the regulation of skeletal growth including genetic, epigenetic and environmental factors [5], and mechanical factors in regulation of growth [6,7,8]. Also, control of muscle activation patterns in trunk muscles and alterations in the muscle forces in the presence of spinal altered curvature are now better understood [9]. These advances have permitted analytical modelling of the process of scoliosis progression by mechanical modulation of growth [10]. Villemure et al.[11] modelled spinal growth and deformity progression in an analytical simulation, using estimated spinal asymmetrical loading based on gravity (bodyweight) forces in the standing posture and heuristic estimates growth sensitivity to load. They used this model to investigate different theories as to mechanical causes development of scoliosis [12]. The predicted amount of curve progression supported the 'vicious cycle' hypothesis. Stokes [10] presented an analysis of scoliosis progression based on the ‘vicious cycle’ concept, using published data for spinal loading and for growth sensitivity to alteration in loading. The simulated spinal geometry represented a lumbar scoliosis of different initial magnitudes, averaged and scaled from measurements of fifteen patients' radiographs. Level-specific stresses acting on the vertebrae were estimated for each of 11 external loading directions (‘efforts’) from published values of spinal loading asymmetry [9]. These calculations assumed a physiologically plausible muscle activation strategy (minimization of the muscle stress, summed over all active muscles, which corresponds to minimum energy utilization). The rate of vertebral growth was obtained from published reports of growth of the spine. The distribution of growth across vertebrae was estimated as a function of stress, according to published values of growth sensitivity to stress. These analyses predicted that a substantial component of scoliosis progression during growth is biomechanically mediated.

2. Methods

A search of Medline in September 2007 using the keywords 'scoliosis', 'biomechanics', 'growth', 'progression' yielded 34 citations. These papers were reviewed and 9 are cited in this paper. A further 16 pertinent papers identified by other means are also cited.2.2. How a brace works

3. Results

3.1 *Spinal growth - vertebral and discal contributions*

While both the vertebrae and the discs are wedged in a spine with scoliosis (Figure 2) [13], it has been found that there is little growth in height of the discs in the adolescent spine - most of the growth occurs in the vertebrae [14]. Therefore, the mechanism by which these structures become wedged in the immature skeleton presumably differs between these two structures. Vertebral wedging could in principle result from asymmetrical growth plate activity, or from remodelling of the vertebral body. This second mechanism (diaphyseal remodelling) could be important after skeletal maturity, but is probably of minor importance during growth [15]. Within the disc, the wedging could result from modelling, remodelling , or a combination of both (See Figure 3). Some evidence points to degeneration of the disc on its concave side, as a result of mechanical stress and impaired nutrition [16,17].

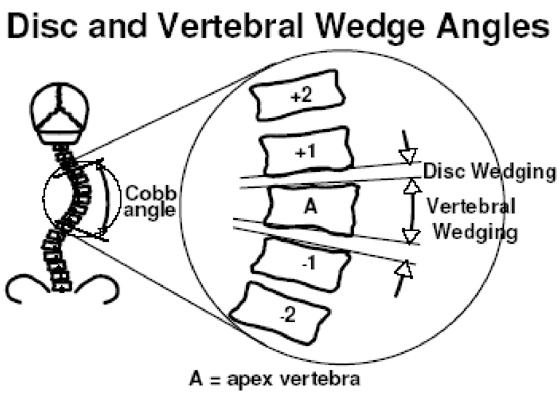

Figure 2. Cobb angle provides a measure of the overall scoliosis curve, but does not distinguish between the two components of the deformity - vertebral and discal wedging

It is not well understood whether the wedging of intervertebral discs precedes that of the vertebrae during progression of a scoliosis (as suggested by Perdriolle et al. [18] and by Grivas et al., [19]), or whether both the bony and soft tissue components develop synchronously (as indicated by the longitudinal study of Stokes and Aronsson [13]).

3.2. Bone growth sensitivity to mechanical loading

While it has been known qualitatively that sustained compressive stress retards growth and vice versa, this relationship has only recently been quantified. Stokes et al. [6] reported a very consistent relationship between stress applied and proportional alteration in growth in a wide range of growth plates (different species and anatomical locations) growing at very different rates. Akyus et al. [20] reported that dynamic (i.e. time-varying at one cycle per second) stress applied to the tail vertebrae of rats produced at least as much growth modulation as a constant, sustained compression force. This observation seems surprising since in growing children the level of activity, and hence the prevailing levels of cyclic stress, do not apparently influence the amount of longitudinal growth of bones.

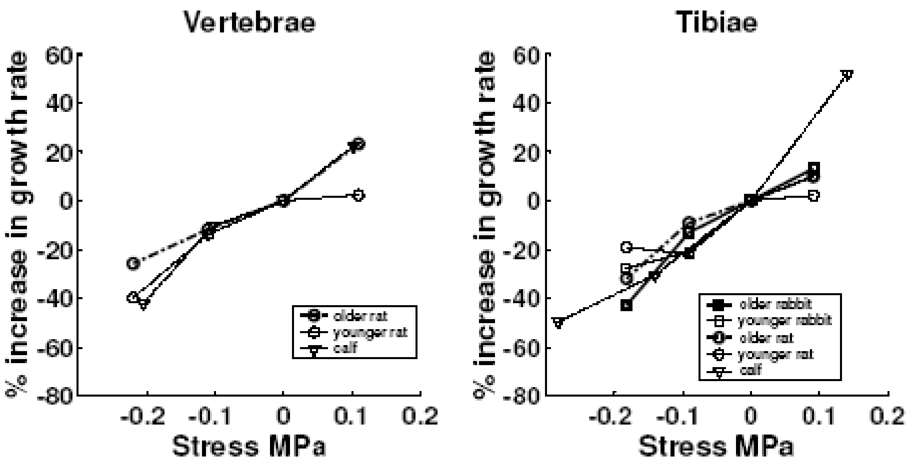

Figure 3. Similar stress-growth relationship for several different growth plates. These data were obtained from experiments in which vertebral and tail vertebral growth plates were subjected to sustained compression (negative stress) or tension (positive stress) during growth. The alteration in growth as a percentage of that measured in control (unloaded) growth plates is plotted. Also, in each case, the values were subtracted from those obtained for 'sham' growth plates (loading apparatus attached across the growth plate, but no forces applied - plotted as 0 MPa). From Stokes et al. [6].

3.3. Mechanical loading of the spine - dependence on muscle control strategy

The importance of trunk muscle control strategy in scoliosis progression was demonstrated by use of biomechanical analysis by Haderspeck and Schultz [21]. Wynarsky et al. [22]. used an analytical method to determine whether muscles could be preferentially activated to produce a straightening of the spine. This was especially interesting at that time, because selective muscle electrical stimulation had been proposed as a method to prevent progression of scoliosis. They reported that both brace (passive forces) and active muscle forces should be capable of substantial correction of a thoracic scoliosis.

3.4. Forces acting on a spine with scoliosis

There are no suitable methods to measure the stress distribution across the spine during in vivo activities, hence mathematical modelling has been used to make estimates of how scoliosis alters spinal loading. Estimates of the degree of asymmetrical loading at different levels of a lumbar scoliosis with increasing degrees of scoliosis were reported by Stokes and Gardner-Morse [9]. The analyses were performed for external loading ('efforts') expressed as each of three pure moments or forces acting at T12, with each of two magnitudes of effort: either 50% or 75% of those corresponding to maximum voluntary effort. Since there is a 'redundant' number of muscles in the trunk to achieve any specified task, mathematical models obtain a solution for the muscle force distribution by assuming that the muscles are recruited in a way that is somehow optimal according to a physiological 'cost' function. In the analyses, for each external loading, the muscle activation patterns were determined with each of three different muscle activation strategies in an optimization model. The optimization was based on 'cost functions' either (1) to minimize the sum of cubed muscle stresses, or (2) to minimize spinal asymmetrical load (i.e. 'follower load') or (3) to reverse the spinal load asymmetry (increased compression on convex side) at the level of the apex.

The first strategy produced loading that tended to increase the curve magnitude, with the resultant force acting at up to 15 mm lateral to the intervertebral disc center. Both Strategies 2 and 3 achieved their objective to eliminate or reverse the asymmetrical loading, but at the cost of increased muscle stress on average between 42 and 75%. These findings indicate that individuals with scoliosis can adopt different muscle activation strategies, and that these strategies may determine whether or not the spinal loading causes scoliosis progression during growth. Muscle activation patterns generating spinal loadings that do not promote curve progression during growth have greater physiological costs.

3.5. A predictive model of scoliosis progression in the coronal plane

An analytical simulation of scoliosis progression as a consequence of biomechanically modulated growth was published by Stokes [10]. The simulated spinal geometry represented a lumbar scoliosis of different initial magnitudes, averaged and scaled from measurements of fifteen patients' radiographs. Level specific stresses acting on the vertebrae were estimated for each of 11 external loading directions ('efforts') from published values [9] of spinal loading asymmetry. These calculations assumed a physiologically plausible muscle activation strategy in which the sum of cubed muscle stresses was minimized. The rate of vertebral growth was obtained from published reports of growth of the spine. The distribution of growth across vertebrae was modulated according to published values [6] of growth sensitivity to stress.

These analyses predicted that mechanically modulated growth of a spine having an initial 13 degrees Cobb scoliosis at age 11 years with the spine subjected to an unweighted combination of eleven loading conditions (different effort direction and magnitude) was predicted to progress during growth. The overall shape of the curve was retained. For this initial curve, the averaged final lumbar spinal curve magnitude was 32 degrees Cobb at age 16 years for the lower magnitude of effort (that produced compressive stress averaging 0.48 MPa at the curve apex) and it was 38 degrees Cobb when the higher magnitudes of efforts (that produced compressive stress averaging

0.81 MPa at the apex). A larger initial curve of 26 degrees progressed to 46 degrees and 56 degrees respectively. (See Figure 4) The calculated stresses on growth plates were within the range of those measured by intradiscal pressures in typical daily activities.

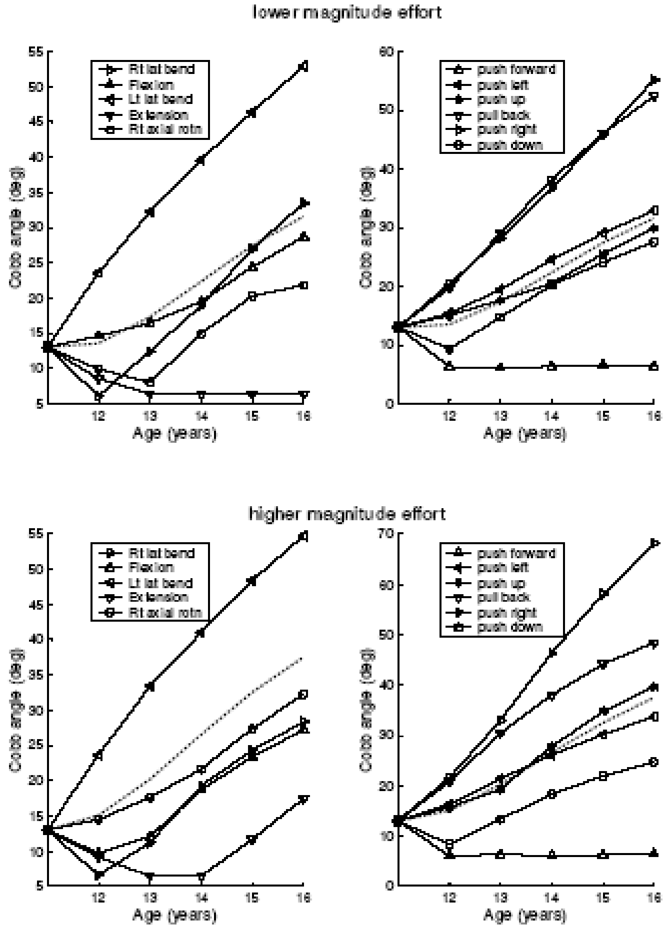

Figure 4. Progression of a scoliosis curve as predicted by a biomechanical model [10]. Starting from an initial scoliosis of 14 degrees Cobb, the Cobb angle was estimated, assuming stress-modulated growth. Analyses were performed for each of 11 external effort directions, and for two different magnitudes of effort - Upper panels: the effort magnitude at the lower effort magnitudes; lower panels: the higher effort magnitudes. Left panels: for each of five pure moment efforts generated about the thorax; Right panels: for each of six pure force efforts generated at T-12. In each case the dotted line shows the average of the 11 solid lines. (From Stokes et al. [10])

3.6. Axial rotation component of scoliosis

The reasons why a spine with scoliosis (lateral curvature) is also rotated axially, and is associated with rib cage deformity is unclear. The apical vertebra in a curve is typically the most rotated axially, but the greatest vertebral torsion (relative rotation between endplates) occurs in the inflectional regions [23]. The rib cage deformity typically reaches a maximum just below the apex (i.e. in the ribs that attach to the apical vertebra and descend from it) [24]. It is not immediately clear which biomechanical factors and associated growth modulation might explain the rotational deformity, although force and associated torques due to 'tethering' of the spine by soft tissue structures on the concave side has been proposed. The magnitude of the rotational torques, and their likely effect on growth are not known quantitatively. Moreland [25] applied torques to femoral growth plates of growing rabbits and found that large magnitudes of torque (close to those that caused growth plate failure) were required to produce rotational deformities. These were associated with alteration of the angulation of the columns of growth plate chondrocytes from their normal alignment parallel to the longitudinal axis of the bone. Human vertebral growth plates may be more susceptible to altered growth produced by shear forces and torsion, since they are more flat, in comparison to the more ‘wavy’ form of the femoral growth plate.

4. Discussion

It is commonly assumed that a laterally-curved spine is more heavily loaded on the concave side, and that this asymmetry of the stress acting on vertebral growth plates is responsible for curve progression. While this mechanism of deformity progression is intuitively attractive and plausible, it can now be supported by objective data and quantitative analyses. These analyses demonstrate how curve progression depends on an individual’s neuromuscular control of the trunk muscles. However, of note was the additional physiological cost, in terms of muscle activity, that was required to equalize the stress distribution on the spine, and 'straighten' the spine.

One can speculate that different muscle activation patterns, and hence different patterns of spinal loading, may be responsible for the differing patterns of scoliosis progression between patients. If so, this would have implications for identification of patients with deformity at risk for progression. Equally, if it were possible to reeducate muscle activation patterns, or muscle strength and resting tension, it might be possible to develop new treatments to prevent progression of deformity.

It is important to know how significant the biomechanical factors are in progression of scoliosis, relative to other factors. In the case of neuromuscular and congenital scoliosis, there are known changes that are responsible for initiating the scoliosis, and they remain present during its progression. In the case of idiopathic scoliosis, the initiating cause or causes are unknown, may differ between individuals, and may or may not remain as substantial contributors during subsequent curve progression. Not all small curves in patients at the onset of adolescent growth do in fact progress. The biomechanical modulation of growth provides an explanation for accelerated progression of a small pre-existing lateral asymmetry of the spine. However, it does not explain how an inherited genetic anomaly or other systemic anomaly such as a circulating growth factor or alteration in melatonin receptors might produce the initial curvature.

The relative importance and contributions of the discal and vertebral components of the lateral curvature deformity are not well understood. These are respectively the flexible (discal) and rigid (vertebral) components of the lateral spinal deformity. The effects of asymmetrical stress on the development of wedging of discs is unclear. Also, the rotational component and rib cage deformity remain as very poorly understood aspects of scoliosis progression. Priorities for future research work in this area include the mechanics of growth, development and degeneration in the wedging of the intervertebral discs, as well as the origins of the axial rotation component of the spinal and rib cage deformity in scoliosis. Finally, there are many challenges in bringing the insights from biomechanics into use in the management of these deformities in children.

5. Conclusions

Mechanical modulation of the asymmetrical growth in height of vertebrae provides a plausible explanation of the mechanisms of scoliosis progression during adolescent growth. These insights might be translated into clinical practice by the design of better braces, muscle and postural 're-education' programs, or selective (unilateral) growth arrest or acceleration. Also, they may help to identify individual spinal shapes and muscle activation patterns that predispose to scoliosis progression, thereby eventually addressing the challenge of accurate and early identification of patients at risk for progressive scoliosis curves, who might then benefit from early therapeutic intervention. Improved treatments of scoliosis require early interventions that are less destructive than multi-level spinal arthrodesis, so the ability to improve prognosis of progressive curves is key to their introduction, to avoid treating non-progressive curves.

Acknowledgements

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The Conservative Scoliosis Treatment
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School Screening as a Research Tool in Epidemiology, Natural History and Aetiology of Idiopathic Scoliosis

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Abstract. The aim of school screening is to identify most or all the individuals with unrecognized idiopathic scoliosis (IS) at an early stage when a less invasive treatment is more effective. However like other medical screening programs it has not escaped controversy about its value. The present study summarises the contribution of school screening in research of IS epidemiology, natural history and aetiology. Such contribution is beyond the original aim of school screening but is very important to expand our knowledge and adequately understand the pathogenesis of IS. The role of biological factors such as the menarche, the lateralization of the brain, the handedness, the thoracic cage, the intervertebral disc, the melatonin secretion, as well as the role of environmental factors such as the light and the impact of the geographical latitude in IS prevalence were studied in children referred from school screening. The present study provides evidence to support that school screening programs should be continued not only for early detection of IS but also as a basis for epidemiological surveys until we learn much more about the aetiology of IS.

Keywords. Idiopathic scoliosis, school screening, epidemiology of idiopathic scoliosis, natural history of idiopathic scoliosis, aetiology of idiopathic scoliosis

Introduction

The goal of scoliosis school screening (SSS) is to detect scoliosis at an early stage when deformity is likely to go unnoticed [1] and a less invasive treatment is more effective [2], although it is not a diagnostic process.

There is skepticism and the worth of SSS programs for the purposes of health care has been challenged. Unfortunately this is the view of epidemiologists and public policymakers who view SSS at a macro level [1]. They consider the scoliosis impact in total health care to be low, the prevalence low, the specificity of the screening test low, the false-positive rate high, and the cost of screening excessive. For them, screening for scoliosis is not indicated [3, 4, 5].

On the other hand there is evidence that SSS provide valuable data regarding the prevalence and the natural history of IS [1, 2, 6]. Considering that there are no sufficient epidemiological data in the literature for the prevalence of IS in several geographical areas and the natural history is not yet accurately predictable, we can assume that the SSS is not only an issue of early detection and decrease in the number of adolescents that will eventually experience operative treatment, but is also a priceless tool for research on IS aetiology [7, 8, 9, 10, 11, 12, 13, 14, 15]. Even the opponents of SSS agree that it has a role and should be carried out as a basis for epidemiological surveys until we know much more about the aetiology and factors likely to determine the natural history of late-onset IS [16].

The present study summarises the contribution of our SSS program in research of IS epidemiology, natural history and aetiology.

Material-Method

We reviewed all the relative publications which originated from the results of the Thriasio school screening program [17] regarding the epidemiology, natural history and research of IS aetiology. The data is categorized as follows;

1. Epidemiology
2. Natural History
3. Research of IS aetiology
   - 3a. Study of the influence of environmental factors in IS prevalence
   - 3b. IS prevalence in girls with visual deficiency
   - 3c. the role of melatonin in IS pathogenesis
   - 3d. age at menarche in IS girls and its relation to laterality of the curve
   - 3e. the role of the brain in trunk asymmetry and IS pathogenesis
   - 3f. the role of the thoracic cage in IS pathogenesis
   - 3g. the impact of the lateral spinal profile
   - 3h. the role of the intervertebral discs in IS pathogenesis
   - 3i. association of cavus foot with IS
   - 3j. anthropometric data in IS patients

Results

1. Epidemiology

After examining 3039 children (1506 boys, 1533 girls) aged between 5.5 to 17.5 years in a total population of approximately 20000 pupils and using as a cut-off point for referral and radiological examination the angle of trunk inclination above 7 degrees, 262 pupils were referred to the hospital and 118 underwent radiological examination and diagnosed with IS. This number represents 3.9 % of the examined population [18].

SSS has been performed by many authors at different geographical areas of Greece. After reviewing the results of 17 Greek SSS programs we found that the IS prevalence in Greece is 2.9%. Taking into consideration that the population of children aged between 8 and 14 years old is 751000 (data from 1998 census), we estimate that 21781 children will have IS. Based on curve size, and following indications for treatment, 980 (4 %) IS children will need conservative treatment, while 41 (1.9%) IS children will require surgery [19].

2. Natural History

In a 5-year prospective study on idiopathic scoliosis, an attempt was made to elucidate the natural history of the disease and to determine which factors contribute to curve progression. A total of 85,622 children were examined for scoliosis in a prospective school screening study carried out in north-western and central Greece. Curve progression was studied in 839 of the 1,436 children with IS detected from the school screening program. Each child was followed clinically and radiographically for one to four follow-up visits for a mean of 3.2 years. Progression of the scoliotic curve was recorded in 14.7% of the children. Spontaneous improvement of at least 5 degrees was observed in 27.4% of them, with 80 children (9.5%) demonstrating complete spontaneous resolution. Eighteen percent of the patients remained stable, while the remaining patients demonstrated no significant changes of less than 5 degrees in curve magnitude. The following factors were associated with a high risk of curve progression: sex (girls); curve pattern (right thoracic and double curves in girls, and right lumbar curves in boys); maturity (girls before the onset of menses); age (time of pubertal growth spurt); and curve magnitude (> or = 30 degrees). On the other hand, left thoracic curves showed a weak tendency for progression. In conclusion, the findings of the study strongly suggested that only a small percentage of scoliotic curves will undergo progression. The pattern of the curve according to curve direction and sex of the child was found to be a key indicator of which curves will progress [20].

3. Research of IS aetiology

3.1 Study of the influence of environmental factors in IS prevalence

The screened area of Thriasio Pedio is a heavily industrialized area which has experienced considerable environmental pollution over the past decades. It is interesting that the IS prevalence which is found in this area is similar to the prevalence reported in other non-industrialized areas of Greece. This implies that industrial environmental factors do not play any role for a possible difference in IS prevalence [18].

IS prevalence has been reported to be different in various geographic latitudes and demonstrates higher values in northern countries. This observation could be related to the influence of the geography of a specific region on human biology and could be determined by socioeconomic and environmental factors such as temperature, humidity and light. [21]

In a different study on epidemiological reports from the literature we investigated a possible association between prevalence of IS and age at menarche among normal girls in various geographic latitudes. The regression of prevalence of IS and age at menarche by geographical latitude was found statistically significant ($p < 0.001$) and both they were following a parallel declining course of their regression curves, especially in latitudes northern than 25 degrees, which means that late age at menarche was parallel with higher prevalence of IS. We hypothesized that the amount of light which is different in different geographical latitudes influences melatonin secretion and alters age at menarche. Delayed puberty results in a prolonged period of spine vulnerability when other aetiological factors are contributing to the development of IS [22]. Furthermore, we found that this positive association between prevalence of IS and geographic latitude is present only in girls and not in boys. This contradictory association implicates that the possible role of environmental factors acts in a different way between boys and girls [21].

3.2 IS prevalence in girls with visual deficiency

In order to test our hypothesis that the environmental light influences IS prevalence we examined IS prevalence in blind girls. Blind girls were found to have a delayed age at menarche (13 years old versus 12.58 years of controls) and surprisingly the prevalence of IS in blind girls was found to be 42.3%! This finding is strongly supporting our hypothesis that the in blind girls, the luck of light through the increased levels of melatonin delays sexual maturation and exposes for longer period the growing immature spine to detrimental causative factors of IS, which results in increased IS prevalence[23].

3.3 The role of melatonin in IS pathogenesis

The role of melatonin deficiency in IS pathogenesis has been proposed after production of scoliosis similar to those of human IS in pinealectomized chickens. There is a controversy whether chickens are appropriate models for studying scoliosis, because they present extrapineal sites of melatonin production that contribute to circulating melatonin levels, in contrast to humans that no extrapineal sources affect the circadian rhythm of melatonin. Melatonin's actions appear to differ between humans, other mammals, and other vertebrates. In the majority of studies on melatonin circadian secretion in humans no significant decrease in circulating melatonin level has been observed. Pinealectomy in bipedal nonhuman primates did not produce scoliosis in any of the 18 monkeys examined in a mean follow up period of 28 months. Furthermore, no increased IS prevalence has been observed in children after pinealectomy or pineal irradiation because of pineal neoplasias, although they have a lack of serum melatonin in the majority of studies [22].

Melatonin acts in gonads indirectly, reducing the secretion of gonadotropines and mainly of LH. The menarche is related with episodic secretion of LH during the night. The melatonin levels are decreasing after a peak at the age of 3 years old and reach a critical level in adolescence when they inhibit LH and consequently initiate the menarche. The age at menarche when regressed by northern geographical latitude shows a statistically significant correlation (p < 0,001), with girls in northern areas present with a delayed age at menarche. We hypothesized that the increased levels of melatonin in northern countries with poor light environmental conditions are reducing the secretion of LH and causes delayed age at menarche. In addition, the regression curves of prevalence of IS by latitude and age at menarche by latitude are of similar pattern. This hypothesis implicates increased melatonin levels in the pathogenesis of IS [22, 24].

3.4 Age at menarche in IS girls and its relation to laterality of the curve

It is reported in the literature that age at menarche in IS girls is delayed, comparing to non-scoliotic girls. This generalized statement questions the accuracy of reported figures for age at menarche which are found different at different geographical latitudes. In an observational study derived from our SSS referrals, there was not statistically significant difference of the age at menarche between scoliotic and non scoliotic girls [8]. When analyzing the laterality of the curve in relation to age at menarche we found that pre-menarche girls presented predominantly with a left primary scoliotic curve, while post-menarche girls presented predominately with a right primary scoliotic curve [24]. This observation which associates the age of IS onset with the laterality of the curve requires further investigation and could not be figured out without running a SSS program.

3.5 The role of the brain in trunk asymmetry and IS pathogenesis

We conducted a study in order to detect a possible correlation between trunk asymmetry assessed with a scoliometer and lateralization of the brain as expressed by handedness in a school aged population. We recorded a) the handedness and b) the trunk asymmetry by using the Pruijs scoliometer in the standing forward bending position in 8245 children (4173 girls and 4072 boys), 6–18 years of age, who were examined during our SSS. The examined children were divided into three groups for each of the three examined regions (mid-thoracic, thoracolumbar and lumbar) according to the recorded asymmetry (no asymmetry, 2–7 degrees and more than 7 degrees). Ninety-one per cent of children were right-handed, while 9% were left-handed. A significant statistical correlation of trunk asymmetry and handedness was found both in boys and girls in the group of asymmetry 2–7 degrees at mid-thoracic ($p < 0.038$) but not at thoracolumbar and at lumbar region, suggesting that there is a significant correlation of mild mid-thoracic asymmetry and the dominant brain hemisphere in terms of handedness, in children who are entitled at risk to develope IS. These findings are implicating the possible aetiopathogenic role of cerebral cortex function in the determination of the thoracic surface morphology of the trunk [25, 26].

3.6 The role of the thoracic cage in IS pathogenesis

In all lateral spinal radiographs in IS the outline of the convex side ribs overlies the outline of the concave side ribs, showing a double rib contour (DRC) sign of the thoracic cage, which is the radiographic appearance of the rib hump. A study of the

DRC sign was conducted in order to test the hypothesis that in IS, the deformity of the thorax precedes that of the spine. The radiographs of 133 children (47 boys and 86 girls), with a mean age of 13.28 and 13.39 years respectively, who were referred to hospital from our SSS program were examined. Children were divided in 5 groups (straight spines, curves <10°, thoracic, thoracolumbar and lumbar curves 10°-20°). The radiological lateral spinal profile (LSP) was assessed by an angle of the posterior surface of each vertebral body (T1-L5) in relation to a vertical line. DRC sign was quantified by the introduction of the "rib index", which was defined as d1/d2 ratio, were d1 is the distance from the most extended point of the most projecting rib contour to the posterior margin of the corresponding to that point vertebra and d2 the distance from the posterior margin of the same vertebra to the most protruding point of the least projecting rib contour. In a symmetric and non-deformed thorax these two RC lines are superimposed and the "rib index" is 1. There were no sex differences of the "rib index" which was measured 1.45, 1.51, 1.56, 1.59, 1.47 for the 5 above mentioned groups respectively. No correlation was found between the Cobb angle and the "rib index" of thoracic, thoracolumbar and lumbar curves. A positive correlation of the "rib index" with each of T2, T3, T4, T5, T6 and T7 LSP in girls with lumbar curves was found. The mean age of non-scoliotics was 1.5-2 years younger than scoliotics. The DRC sign is the expression of rib deformity and secondarily of vertebral rotation and was approximately 1.5 in all SSS referrals who presented with an already developed deformity of the thorax. 70% of them were scoliotics, 10% had a curve < 9° and 20% had straight spines, as confirmed by an x-ray. This observation supports the hypothesis that in idiopathic scoliosis the deformity of the thorax precedes the deformity of the spine [9].

In a different study of rib vertebra angles (RVAs) we showed that scoliotic children with small curves had under developed thoracic cage compared to non scoliotic counterparts. It has been reported that rib vertebra angles (RVAs) is an expression of the resultant muscle forces, which act on each rib and that RVA asymmetries by weakening of the spinal rotation defending system are contributing in IS pathogenesis. These differences were more apparent in the scoliotic children with thoracic curves. It was suggested that the differences of the RVAs between right and left side were the expression of asymmetric muscle forces acting on the thoracic cage, which deforms early and possibly transfers the deforming forces to the spine [10].

Based on an observation that in some younger referred children from our SSS there is a discrepancy between the thoracic scoliometer readings and the morphology of their spine, we hypothesized that in scoliotics the correlation between the rib cage deformity and the deformity of the spine is weak in younger children and vice versa. We studied the correlation between the Cobb angle and rib cage deformity (rib index) with and without the effect of the variable age in 83 girls, with a mean age of 13.4 years (range 7-18) who were referred from our SSS program. Twenty five per cent of patients with an ATI ≥7° had a spinal curve under 10° or had a straight spine. Linear regressions between the dependent variable "Thoracic Cobb angle" with the independent variable "rib-index" without the effect of the variable "age" is not statistical significant. After sample split, the linear relationship is statistically significant in the age group 14-18 years old ($p<0.03$). Growth has a significant effect in the correlation between the thoracic and the spinal deformity in girls with idiopathic scoliosis. Therefore it should be taken into consideration when trying to assess the spinal deformity from surface measurements. The findings of the present study implicate the role of the thorax, as it shows that the rib cage deformity precedes the spinal deformity in the pathogenesis of idiopathic scoliosis [27].

3.7 The impact of the lateral spinal profile

In a study of the LSP of mild (10°-20°) scoliotic curves, we demonstrated that hypokyphosis of the thoracic spine is not a predisposing factor for the initiation of mild scoliotic curves because LSP of these curves was found to be similar to the LSP to the spines of their healthy controls [11]. This study provides evidence that thoracic hypokyphosis, by alleviating axial rotation, is rather a compensatory mechanism than am aetiological factor of IS pathogenesis.

3.8 The role of the intervertebral discs in IS pathogenesis

We observed that in mild scoliotic curves, the deformity appears first at the level of the intervertebral disc (IVD), which is found wedged. The deformity of the vertebral body or of the spinal column follows. In order to test this hypothesis we designed a radiological study to investigate the deformation of the IVD in mild scoliotic curves from SSS referrals. In 92 standing posteroanterior spinal x-rays we measured Cobb angle (CA), apical vertebral rotation (AVR), apical vertebral wedging (AVW) and the adjacent to the apical vertebra Upper (UIVDW) and Lower (LIVDW) InterVertebral Discs Wedging. The mean thoracic CA was 13.4°, lumbar CA 13.8°, thoracic AVR 5.3°, lumbar AVR 4.7°, thoracic AVW 1.4°, lumbar AVW 1.5°, thoracic UIVDW 1.6°, thoracic LIVDW 1°, lumbar UIVDW 1.3° and lumbar LIVDW 2°. Both thoracic and lumbar CA regressed statistically significant with lumbar LIVDW, lumbar UIVDW, thoracic LIVDW and thoracic AVW. Lumbar LIVDW correlates statistically significant with thoracic CA, lumbar CA and thoracic LIVDW. The statistical analysis revealed that AVW appears later when already CA increases, the IVDW is more important than AVW and the LIVDW, which is greater than UIVDW, is the most frequent correlated radiographic parameter. The spine is deformed first at the level of the IVD, due to the increased plasticity of the IVD, in the way of either torsion or wedging. The eccentric intervertebral disc in the scoliotic spine, through variation in its water concentration, produces asymmetrically cyclical load during the 24-hour period and an asymmetrical growth of the vertebral body (Hueter-Volkman’s law). The deformation of the apical IVD seems to be an important progressive factor in IS pathogenesis [28].

3.9 Association of cavus foot with IS

It is well known, that in a number of certain neuromuscular diseases cavus foot and scoliosis are presented together. Such diseases are muscular dystrophy, cerebral palsy, Friedrich’s ataxia, Charcot-Marie-Tooth disease, poliomyelitis, syringomyelia, spinal cord tumours. Having in mind this observation many authors studied the relationship between foot morphology (especially pes cavus) and scoliosis, as it is thought these pathologic conditions may share a common cause. We investigated if there is such a relationship in a large Greek children population derived from the SSS. The significant correlation between IS and cavus foot as it has been elsewhere reported was not verified in our study. In the contrary it is emphasized that the percentage of cavus foot was traced higher in the general healthy population than in children with small and moderate scoliotic curves. The existence of a similar correlation between flat foot and IS was also investigated as it has been reported that scoliotic patients present increased joint laxity, which may predispose in flat foot rather than cavus foot deformity. No positive correlation was found between IS and flat foot in our study [7].

3.10 Anthropometric data in IS patients

A variety of findings regarding the stature and weight of IS children has been published. In a study in Mediterranean population, the somatometric parameters of height and weight in children with scoliosis, regardless of curve type and site, are not statistically different from their non scoliotic counterparts [12].

Discussion

The early detection of IS has been a major and growing commitment of Orthopaedists since the early 1960s. Early detection implies early treatment and by that less surgery. SSS which had initially adopted as a tool for early detection of IS in the community, has been criticized mainly because of low specificity, high false positive referral rate and increased financial cost.

As a screening test which relies on the identification of surface deformity, SSS cannot predict accurately the spinal deformity, especially in younger children [27]. Bunnell characteristically is stating that in typical screening settings where the prevalence and positive predictive value are relatively low, for every curve >10° detected, there are 1-5 false positives; and for every curve >20° detected, there are 3-24 false positives [1]. Consequently, the role of SSS is not only to detect children with an already established spinal deformity but to identify younger individuals who are at risk for IS development. All those referrals with a significant surface deformity but without a severe scoliotic curve, who need to be kept under observation for IS development.

Although SSS's aim is prevention and it should be regarded as a criterion of welfare of our civilization, it has been criticized for its negative cost-effectiveness. It is clear that a realistic evaluation of the cost is not feasible and could result in inaccurate overestimation of the total cost as it might take into consideration many qualitative and subjective factors. On the other hand the financial profit from research of IS epidemiology, prevalence and aetiology, which was analyzed in the present study cannot be estimated. Therefore, any financial analysis of SSS programs should measure only the direct cost of such programs, which is significantly low and cost-effective [17].

The present study provides evidence to support that school screening programs should be continued not only for early detection of IS but also as a basis for epidemiological surveys until we learn much more about the aetiology of IS.

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Section III

Genetics

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Scoliosis and the Human Genome Project

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Abstract. Understanding the cause of a disease or disorder is key to developing effective and humane strategies for early intervention and treatment. School screening programs have made it possible to demonstrate the high prevalence of childhood scoliosis, worldwide, and to reliably identify spinal curvatures early in the disease process before progression to a fixed structural deformity. Unfortunately, effective early interventions have not been established. Developing strategies to prevent scoliosis has been compromised, in general, by lack of understanding of its causes on a case by case basis. Information about genetic loci associated with disorders including scoliosis is emerging rapidly, since completion of the human genome sequence in 2003. These data can be used to identify children at high risk for developing spinal deformities and to design strategies for prevention.

Keywords. Scoliosis, spinal deformity

Introduction

Scoliosis, a common disorder among human populations, has a prevalence of 3000-5000 per 100,000 individuals by the age of eight to ten years [1]. For every 100 patients in whom scoliosis is detected, up to ninety percent are given a diagnosis of 'scoliosis of unknown origin' or 'idiopathic scoliosis' (IS). Paradoxically, this nonspecific diagnosis stems not from a lack of knowledge about factors that cause scoliosis but at least in part because, as Hippocrates noted two millennia ago, so many different factors can cause spinal deformities [2]. Scoliosis ranging from mild to severe occurs in children in response to environmental factors as diverse as psychological distress [3], trauma [4], back injuries [5,6], surgery [7], cancer treatments including radiation and chemotherapy [8,9], infection [10], tumors [11,12], birth injury [13] and fetal alcohol syndrome [14].

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Establishing the link between a specific injury or illness can be complicated by obscure or unrecognized symptoms, the passage of time, and inadequate appreciation of a patient's clinical history. In one remarkable example, a female patient developed progressive scoliosis during adolescence and received spine surgery for her deformity at age thirty-seven years [15]. In response to unrelieved pain, additional tests finally revealed the presence of instraspinal glass fragments from an injury sustained at age nine years, prior to her diagnosis of 'idiopathic' scoliosis. In a second example, a female adolescent with moderate scoliosis did not complain of pain and was diagnosed with idiopathic scoliosis [10]. Only after increasing pain during a six week period of orthotic treatment did diagnostic tests reveal the presence of a spinal infection. The scoliosis resolved after treatment with antibiotics and bed rest.

Complicating diagnosis further is that in some cases, a genetic mutation or variant may predispose individuals to a higher likelihood of developing scoliosis, either spontaneously for unknown reasons or in response to the same factors known to cause spinal curvatures in anyone. Such 'familial idiopathic scoliosis' can be inherited in autosomal dominant, autosomal recessive, or X-linked manner [16].

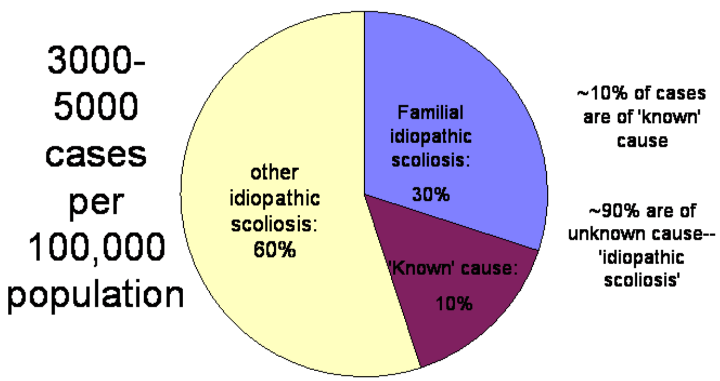

Figure 1. Prevalence of scoliosis

For a minority of patients, spinal curvatures occur in association with heritable syndromes like Duchenne muscular dystrophy with easily identifiable signs and symptoms including scoliosis. For most individuals, however, the cause is unknown and clear evidence for an inherited disorder is absent [17,18]. As an example, one study evaluated the possible role of genetics in 114 patients with idiopathic scoliosis [18]. A radiological survey of family members revealed that thirty-one (twenty-seven percent) of the patients had one or more relatives, ranging in age from infancy through adulthood, with a detectable curvature. This supported the possibility that the scoliosis resulted from an inherited trait that was expressed in family members. The remaining eighty-three patients (seventy-three percent) did not have relatives with a detectable curvature. This majority of patients whose family members are unaffected could have scoliosis in response to an undiagnosed injury or infection, in which early diagnosis and treatment (i.e. antibiotics to eliminate a spinal infection) could result in spontaneous resolution of a potentially dangerous curvature with lifelong morbidity. Alternatively, they might suffer from the effects of spontaneous genome changes rather than particular genotypes inherited from their parents, or a previously undiagnosed family history may have been overlooked.

Current clinical strategies for all 'idiopathic' scoliosis in the United States involve 'watching and waiting' until curvatures either stabilize spontaneously or progress to a moderately severe deformity. At this point patients are treated with orthosis or spinal fusion surgery in an effort to prevent further progression [www.nih.gov]. For children with curvatures ≤25 degrees (Cobb angle) no treatment is offered and diagnostic efforts are limited to follow-up radiological examinations every four to six months to assess rate of progression ('Observation Only'). Minimal effort is made to provide early intervention of underlying causes which, when identified and treated, can resolve the resulting scoliosis even when a structural deformity is present. Some U.S. spine surgery clinics, in the interest of 'clinical efficiency,' even argue against the use of diagnostic tools such as magnetic resonance imaging [19]. Furthermore, the 2004 recommendation against scoliosis screening by the U.S. Preventive Services Task Force is predicted to cause a lag in the diagnosis of the deformity until the child has a moderate or severe curvature thus limiting the opportunity for early intervention and increasing the number of scoliosis surgeries.

The human genome project (genome.gov) is a public resource that increasingly will provide tools to identify or rule out the presence, within an individual patient's genome, of genotypic variation correlated with symptoms including scoliosis. Since the full human genome was sequenced, in April 2003, progress in defining the molecular and biochemical nature of specific genotypic variations associated with clinical syndromes has been very rapid. As a result, as summarized in the Program Overview (http://www.genome.gov/10000331), "*..clinical researchers at the National Human Genome Research Institute (NHGRI) are poised to inaugurate a new era in medicine - one where a more profound understanding of the biological basis of disease will pave the way for more effective ways to diagnose, treat and prevent illness*." Scientists and clinicians throughout the world can access the tools of the genome project in the interest of providing accurate diagnosis and improved patient care.

The goal of this study was to provide an outline of all genetically based syndromes identified to date, which have been reported to occur in association with scoliosis.

Methods

Medline, PubMed, and Science Citation Index were used to search for articles on the genetics of scoliosis using 'scoliosis' and 'gene, genetics, genome, genomics' and related key words. Full text articles were accessed through the Arizona Health Sciences Library system to identify syndromes in which scoliosis has been reported as case reports or case series in children or adults in the context of diagnosis (including genetic mapping, molecular biology or biochemical analysis), symptoms, natural history, follow-up, and/or treatment. Studies in which animal model systems were used for genetic analysis also were included. The National Center for Biotechnology Information (NCBI) database (www.ncbi.nlm.nih.gov) was used as a resource to identify alternative, redundant, or outdated names for syndromes identified in articles from the original literature.

Results

More than 400 original articles on 'genetics of scoliosis,' of which most have been published since completion of the first draft of the human genome sequence were identified. The full list can be accessed at www.sosort.org/scoliosis_library.php.

More than 100 genetic loci were found to be represented among syndromes in which scoliosis has been reported in one or more patients (see Table 1). The genetic loci were mapped to all twenty-two autosomes as well as the X chromosome. The syndromes range from complex multi-system disorders that are obvious from birth and can result in perinatal lethality [48, 49], to relatively benign familial systems in which the diagnosis of the syndrome occurred secondary to the diagnosis of childhood or adolescent scoliosis [121]. Indeed, in some cases a diagnosis of 'idiopathic scoliosis' was used until additional tests revealed the underlying genetic association and allowed appropriate treatment to correct the symptoms [122].

Additional syndromes which appear to be heritable have been reported in association with scoliosis, but to date the underlying genetic loci have not been mapped (see Table 2).

Table 1. Syndromes in which scoliosis has been documented in one or more patients, and predicted chromosome location of associated genetic variation

Chromosome Number	Syndrome Frequency[1]	Scoliosis[2]
Chromosome 1		
Charcot-Marie-Tooth 1B, 2A, 2B1 [20-32]	1/2000	'common'
Hutchinson-Gilford syndrome [33-36]	<1/1,000,000	
Hypophosphatasia [37]	1/100,000	2 siblings
Multiple pterygium syndrome [38]		
Thrombocytopenia-absent radius syndrome [39]	<1/100,000	1/34
Chromosome 2		
Alstrom syndrome [40-42]	<1/100,000	30%
Ehlers-Danlos syndrome, type I [43]	2-5/100,000	
Fibrodysplasia ossificans progressiva [44, 45]	1/2,000,000	
Joubert's syndrome [46]		
Leigh's syndrome [47]	1/32,000	
Lethal multiple pterygium syndrome type II [48, 49]		
Majewski osteodysplastic primordial dwarfism [50]		
Neurofibromatosis [51, 52]	1/4000	10-30%
Schimke immuno-osseous dysplasia [53]		
Ullrich syndrome [54]		
Chromosome 3		
Charcot-Marie-Tooth 2B [20-32]	2/100,000	'common'
Enchondromatosis, multiple		
Larsen syndrome [55]	1/100,000	
Seckel syndrome [56]		
Spondylocarpotarsal synostosis syndrome [57]		
Synspondylism, familial [58]		
Chromosome 4		
Achondroplasia [59]	1/100,000	35-50%
Hurler syndrome (mucopolysaccharidosis I) [60]	1/150,000	
Hyper IgE recurrent infection syndrome [61]	5/100,000	76%

Chromosome 5		
Beals syndrome [62]	5/100,000	'common'
Brachmann-de Lange syndrome [63]	1/10,000	4/26
Brachydactyly, Type A1 [64]		5/9
Cri-du-chat syndrome [65]	1/20-50,000	
Diastrophic dysplasia [66]	1/30,000	40-90%
Leigh's syndrome [47]		
Stuve-Wiedemann syndrome [67]		
Chromosome 6		
Chondrodysplasia [68]	1/100,000	
Cleidocranial dysostosis [69, 70]		
Joubert's syndrome [46, 71]		
Chromosome 7		
Cystic fibrosis [71]	5-50/100,00	10-20%
Leigh's syndrome [47]		
Neurofibromatosis [51, 52]		
Osteogenesis imperfecta, Type I, II, III [43, 72-77]		
Williams syndrome [78, 79]	1/8-10,000	
Wolff-Parkinson-White syndrome [80]		
Chromosome 8		
CHARGE syndrome [81]	1/12,000	'common'
Cohen syndrome [82]		
Duane anomaly [83]		
Familial idiopathic scoliosis [84]		
Kallmann syndrome [85]		
Klippel-Feil [86]		
Trichorhinophalangeal syndrome, type I [87]		
Chromosome 9		
Cartilage-hair hypoplasia [88]	5/100,000	25%
Ehlers-Danlos syndrome, Type I, II [43, 90]	2-5/100,000	'common'
Familial dysautonomia [90]		90%
Friedreich's ataxia [91, 92]	1/50,000	100%
Joubert's syndrome [46, 71]		
Leigh's syndrome [47]		
Nail patella syndrome [93]		
Primary ciliary dyskinesia syndrome [94]		
Robinow syndrome [95, 96]		
Torsion dystonia (early onset) [97]		
Tuberous sclerosis complex [98]	<1/10,000	
Chromosome 10		
Cerebro-oculo-facio-skeletal syndrome [99]	<1/100,000	
Charcot-Marie-Tooth D1D [20-32]	<1/100,000	'common'
Leigh's syndrome [47]		
Chromosome 11		
Hemi-3 syndrome [100]	1/86,000	
Horizontal gaze palsy with progressive scoliosis [101,102]		100%
Joubert's syndrome [46, 71]		
Leigh's syndrome [47]		
Russell-Silver syndrome [103,104]		
Beta-thalassemia [105]	0.1-16%	20%
Chromosome 12		
Bardet-Biedl syndrome 1 [106]	<1/5000	4/26
Cardio-facio-cutaneous syndrome [107]		
Charcot-Marie-Tooth 2C [20-32]	<1/100,000	'common'
Costello syndrome [108-110]		
Noonan syndrome [111-113]	1/1-2500	
Joubert's syndrome [46, 71]		
Lipomatosis, multiple [114]		
Hypophosphatemic osteomalacia [115]		
Short-chain acyl-CoA dehydrogenase deficiency [116]	1/50,000	

Stickler's syndrome [117,118]	1/10,000	'common'
Tuberous sclerosis complex [97]		
Chromosome 13		
Leigh's syndrome [47]	<1/200,000	
Chromosome 14		
Dopa-responsive dystonia [120-122]		40%
Goldenhar sequence (oculo-auriculo-vertebral dysplasia) [123]		72%
Maternal uniparental disomy for human chromosome-14 [124]		
Chromosome 15		
Angelman syndrome [125,126]	1/12-20,000	10-90%
Marfan syndrome	1/5000	50-70%
Prader Willi [127-131]	1/10-20,000	40-50%
Shprintzen-Goldberg syndrome [132]		
Chromosome 16		
Bardet-Biedl syndrome 2 [106]		10-20%
beta-thalassemia [105]	0.1-16%	20%
Charcot-Marie-Tooth 1C [20-32]	1/100,000	
Fanconi anemia [133]	1/20,000	
Jaeken's syndrome [134]	1/80,000	'common'
Mitral valve prolapse syndrome [135]		
Mucolipidosis [136]		
Tuberous sclerosis complex [98]		
Chromosome 17		
Andersen syndrome [137,138]	5/100,000	4/36
Bruck syndrome [139]		
Camptomelic dysplasia [140-143]	1/300,000	100% (8/8, 5/5)
Charcot-Marie-Tooth 1A [20-32]	30/100,000	
Desbuquois dysplasia [144-146]		
Ehlers-Danlos syndrome, Type I [43, 90]	2-5/100,000	'common'
Distal arthrogryposis type 2A [147]		85%
Gordon's syndrome [148]	1/200,000	14/50
Neurofibromatosis [51, 52]	1/3000	12%
Osteogenesis imperfecta type I [43, 72-77]		
Smith-Magenis [149-154]		
Chromosome 18		
Dyggve-Melchior-Clausen [155,156]		
Idiopathic torsion dystonia [157]	3/100,000	
Chromosome 19		
Jarcho-Levin syndrome [158,159]		
King-Denborough syndrome [160,161]		
Leigh's syndrome [47]		
Multiple epiphyseal dysplasia [162]		
Ryanodine receptor type 1 mutation [163]		
Steinert syndrome [164]	1/10,000	
Chromosome 20		
Alagille syndrome [165,166]	1/100,000	26/50
Fibrous dysplasia in the spine [167]		40-50%
Chromosome 21		
Down syndrome [168]	1/600	10%
Ullrich syndrome [54]		
Chromosome 22		
Velo-cardio-facial syndrome [169]		
X chromosome		
Allan-Herndon-Dudley syndrome [170]	25 families	8/8
Anhidrotic ectodermal dysplasia [171]		
Clasped-thumb mental retardation syndrome [172]		
Charcot-Marie-Tooth X1,2, 3 [20-32]	3/100,000	40-50%
Coffin-Lowry syndrome [173]	1/40-50,000	20-30%
Duchenne muscular dystrophy [174]	1/3000	60-90+%
Fragile X [175]	1/4000 (M)-1/8000F	'frequent'
Frontometaphyseal dysplasia [176]		

Kallman's syndrome [85]		
Lesch-Nyhan Syndrome [177]		
Pelizaeus-Merzbacher disease [178]		
Rett syndrome [179,180]	1/10-15,000	50-60%
SHOX deficiency (pseudoautosomal region) [181]	1/3000	
Turner syndrome [182]	1/2500 females	10-12%
Uruguay facio-cardio-musculo-skeletal syndrome [183]		6/6

[1]Values are given as 'frequency' rather than prevalence or incidence to emphasize that with the exception of relatively common and readily diagnosed syndromes like trisomy 21, these estimates are based on very small samples and should be considered general approximations.
[2]Values for scoliosis frequency are from one or more clinical surveys, cited herein; when 'common' or 'frequent' is used, this term is quoting the authors of cited papers.

Table 2. Other inherited syndromes assocated with scoliosis[1]

Aicardi syndrome [184]
Becker nevus syndrome [185]
Carey-Fineman-Ziter (CFZ) syndrome [186]
Catel-Manzke syndrome [187]
Cavovarus foot deformity with multiple tarsal coalitions [188]
Christian's spondylo-digital syndrome [189]
Chromosome 1q syndrome [190]
Craniofacial malformations and deglutition dysfunction [191]
Dubowitz syndrome [192]
Dsspondyloenchondromatosis [193]
Focal dermal hypoplasia (Goltz's syndrome) [194]
Gorham-Stout syndrome [195]
Ischio vertebral dysplasia [196]
Marshall-Smith syndrome [197]
Nurocutaneous malformation syndrome [198]
New syndrome with hearing impairment, distinct facial appearance, scoliosis [199]
Tsukahara syndrome [200]
VECS syndrome (vertebral and eye anomalies, cutis aplasia, short stature) [201]

[1]Syndromes reported in the literature, cited herein, in which there is evidence for one or more family members with similar symptoms, or in which one or more reports of similar symptoms in separate cases have been observed, but no information is available with regard to chromosome location or nature of associated genome changes.

Discussion

Data regarding incidence and prevalence in rare syndromes have to be regarded as preliminary because they are, by definition, from such small samples. Nevertheless, the results of this survey suggest that even in complex syndromes in which significant impairment of major body systems occurs, the development of scoliosis is not an inevitable consequence for all patients (see Table 1). Indeed, in one syndrome in which multiple skeletal deformities develop in most patients--thrombocytopenia-absent radius (TAR) syndrome--the frequency of scoliosis in one study was only 1 in 35 patients, in the range expected for the general population [39]. In syndromes in which most or all afflicted individuals do develop scoliosis, moreover, significant progression of the scoliosis is not inevitable [e.g. 59, 72, 92, 105, 125, 202].

One possible explanation for this observation is that patients with obvious symptoms receive a definitive diagnosis from infancy or early childhood. At this early stage in the disease process, patients may be prescribed ongoing interventions including physical therapy to alleviate symptoms and improve mobility and function [e.g. 125]. Peer reviewed publications exploring whether such interventions can prevent scoliosis if used before structural deformities become established have not been published to date, notwithstanding claims to the contrary [203-205].

In a study of patients with one type of osteogenesis imperfecta called Osteogenesis Imperfecta/Ehlers-Danlos Syndrome (OI/EDS), 100% (7/7) of the patients in the study group did experience progressive scoliosis [43]. Most patients with Duchenne muscular dystrophy and horizontal gaze palsy also develop progressive scoliosis [101,102,174]. Unfortunately, the use of methods like bracing and surgery are problematical for children with OI/EDS, muscular dystrophy and other complex syndromes [43,206]. The high probability that some children with spinal curvatures--however mild and flexible at diagnosis--will develop structural deformities with lifelong morbidity warrants research to develop strategies for prevention [207]. Recent success in the use of steroid streatment to forestall the onset of scoliosis in children with Duchenne muscular dystrophy illustrates the critical need for multidisciplinary approaches to such research [208-210]. These exciting results also highlight the fact that, when a clinically homogenous population with a shared genotype is identified and carefully monitored, large multi-center groups and randomized controlled design are not required for breakthrough research. Nonrandomized comparative analyses even in very small groups can yield statistically and clinically significant results [e.g. 43,208-210,211].

For the large majority of patients whose scoliosis is of unknown etiology, progress may proceed from a better understanding of the genetic mutations associated with a propensity to develop spinal deformities. In recent years the term 'idiopathic scoliosis' increasingly has been used in a manner as if to describe a specific disease or syndrome, with some authors even making reference to 'idiopathic-like' scoliosis and 'non-idiopathic' scoliosis [212,213]. It is important to bear in mind that 'idiopathic scoliosis' is not a diagnosis but a failure of diagnosis. A priori acceptance that 'no diagnosis' is adequate to judge and respond to a patient's clinical needs intrinsically compromises treatment approaches. As our understanding of human genome variability and its impact on skeletal structure and function progresses, clinical paradigms for the treatment of scoliosis and other spinal deformities can be designed to respond to the short- and long-term needs of each patient.

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Section IV

Prevention – School Screening

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How to Improve the Effectiveness of School Screening for Idiopathic Scoliosis

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Abstract. The value of school screening for idiopathic scoliosis (IS) has been questioned recently, because of its high false positive referrals and its excessive cost, although in areas where screening programs exist, fewer patients ultimately require surgery for IS. In a typical school screening setting there are numerous factors which can determine the effectiveness. The present study identifies some of these factors and provides evidence based recommendations for the improvement of school screening effectiveness. After reviewing all the research papers which originated from the Thriasio school screening program and published in peer-review journals, specific suggestions for the organization, the optimal age of screening according to the geographical latitude, the best examined position, the standardization of referrals, the follow up of younger referrals with trunk asymmetry and the reduction of the financial cost are made. We strongly suggest the introduction of these recommendations to all the existing school screening programs in order to improve their effectiveness and to reduce the negative impact they may have on families and on the health system.

Keywords. Idiopathic scoliosis, school screening, effectiveness of school screening

Introduction

School screening for IS, although it has been practiced for many years around the world, it has not escaped controversy about its value. Scoliosis screening has proven effective in many ways, and it is considered beneficial among the Orthopaedic community, as it is reported in the Consensus Paper which has been published by the Society on Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT) [1]. Furthermore, it provides the opportunity for early diagnosis and conservative treatment, which is often missed in the absence of screening [2]. In their most recently published joint information statement on scoliosis screening, the American Academy of Orthopaedic Surgeons, Scoliosis Research Society, Pediatric Orthopaedic Society of North America and American Academy of Pediatrics do not support any recommendation against scoliosis screening, given the available literature [3]. Unfortunately, a number of problems prevent it from being universally accepted. The low prevalence of IS, the high false positive referrals and the excessive cost, both direct and indirect, are raised by the negativists as reasons to abandon school screening programs.

Organization, public information, and documentation are important aspects of screening programs [4]. It is true that the lack of general standards and the resultant disparity among programs with respect to screening organization, examination procedures, referral criteria, data retrieval and management and follow up methods have limited the informational benefits of scoliosis screening programs. [2].

The initial goal of scoliosis school screening was to detect IS at an early stage when deformity is likely to go unnoticed [2]. In an effort to enhance the effectiveness of school screening programs a new goal should be to identify only those children who have curves likely to require conservative treatment as it is recommended by SOSORT [5]. Furthermore, school screening should be able to detect curves early enough to allow effective intervention treatments that will mitigate the impact of the vicious cycle of IS progression [6] and maintain curves below 30^{o} into skeletal maturity.
This would require better organization, selective screening of high-risk children, improved examination techniques, standardization of the referral process and cost reduction. The present study, by reviewing the collective experience of the Thriasio school screening program [7], provides evidence based recommendations for the improvement of school screening effectiveness.

Material-Method

After reviewing all the research papers which originated from the Thriasio school screening program, specific evidence based recommendations for the improvement of school screening effectiveness are presented. The recommendations are listed as follows:

1. Organization and preparation of a school screening program
2. Selective screening according to the geographical latitude
3. Reliable examination tests
4. Standardization of referrals
5. Follow up of younger referrals with trunk asymmetry
6. Cost reduction

Results

1. Organization and preparation of a school screening program [7]

School screening has to be set up on a district basis after obtaining permission from the local authorities. The area of screening should be easily accessible by the screening staff and the hospital which carries out the screening program should be easily accessible to all the involved individuals, either by the children and their families, or by the school staff. A team of examiners should be created, after adequate training. The examining group should have a core of 2-3 health professionals who are experienced in screening techniques and occasionally can be staffed by other health professionals on a voluntary basis. The examiners should also be familiar with data entry and maintenance of an electronic database with all the relevant information.

It is important before starting the program to organize everything in advance. After getting permission, the next step should be to educate all the interested parties (parents, pupils and school staff) and when it is necessary, they must further be informed by distribution of informative material and lectures. The cooperation of the screening staff with the parents, the pupils and the teachers is essential for the acceptance of this voluntary program and thus for a success and cost effective performance.

Before visiting a school it is important to inform the head-teacher about the program and to distribute educational material. At the same time, and prior to the visit of the examining group to the school, the parents must fill a consent form and the pupils must fill a particular form regarding their personal and demographic data. Obtaining the consent forms is mandatory in order to avoid the restrictions by various health and education privacy laws. In countries which legislate school screening, the parents or carerers should only be notified by letter as a courtesy. Both these forms should be available to the examining staff before the date of the visit so that the examination time is kept to a minimum. Furthermore, the facilities for examination should be prepared by the school stuff well in advance and the timetable of that day should be modified accordingly. It is crucial for everyone who participates to appreciate the voluntary basis of the program, in order to compensate the increased financial cost from the supplementary administrative task, which is essential in our proposed model.

2. Selective screening according to the geographical latitude

It seems that there is an ideal window of time for IS screening because those who develop IS show rib deformity by age 10 years and are no longer at risk of significant progression after menarche [2].

In a previous study we reported that IS prevalence in girls of a specific area is associated with age at menarche in that particular area and we implicated the role of environmental factors (light) and their impact on human biology (through melatonin secretion) as a possible explanation to this observation [8]. In the same study, the regression curve of both the IS prevalence and age at menarche by geographical latitude is following a parallel declining course, especially in latitudes northern than 25 degrees, which means that late age at menarche was parallel with higher prevalence of IS.

IS almost always occurs during the time of peak growth velocity, typically during the year just prior to menarche. Therefore, in order to increase the predictive value of school screening, we should screen girls who live in northern countries at an older age, i.e. one school year later and screen those who live in the south at an earlier stage. If we screen girls who live in northern geographical latitudes too early, we may miss a few IS cases, because their growth spurt occurs at a later stage. On the other hand, screening girls in southern geographical latitudes at an older age, we may increase the referrals with IS cases who are unlikely to progress, because they are post-menarche.

3. Reliable examination tests

In a study of trunk asymmetry of 2071 children and adolescents (1099 boys and 972 girls) aged 5-18 years old, the angle of trunk rotation (ATR) was measured by the use of a scoliometer, in both the standing and sitting position [9, 10]. 67.06% of the boys and 65.01% of the girls were symmetric (ATR = 0 degrees) in the standing forward bending position and 76.5% of the boys and 75.1% of the girls were symmetric in the sitting position. Mild asymmetry (ATR 1-6^{o}) was in 29.7% of boys and in 31.07% of girls in the standing forward bending position and in 21.88% of boys and in 22.69% of girls in the sitting position. Severe asymmetry (ATR $\geq 7^{o}$) was in 3.23% of boys and in 3.92% of girls in the standing forward bending position and in 1.62% of boys and in 2.21% of girls in the sitting position. Asymmetry was found to be more common in girls than in boys.

By screening children in sitting position with the use of a scoliometer, the number of referrals can be decreased dramatically because the effect of leg length inequality and pelvic obliquity on the spine is eliminated. [10]. Sitting position reveals the true trunk asymmetry which could be associated with IS and therefore it is recommended as a standard examination method in a school screening program as well as a second level test for all potential referrals. The additional time and cost required for utilization of sitting examination with the use of a scoliometer can be kept to a minimum when it is performed by experienced and well trained examiners and also results in reduction of the indirect cost, by decreasing the number of referrals.

4. Standardization of referrals

The introduction of objective deformity measurements and referral criteria provides some standardization to the referral process [11]. It is essential when we set up the screening process to try and collect information about the gender, the chronological age, the age at menarche, the pattern and the magnitude of asymmetry and the growth potential. All these are very important prognostic factors for progression of a detected curve. [12, 13, 14, 15]. Trunk asymmetry should be measured by the use of a scoliometer in three regions of the spine (thoracic, thoracolumbar and lumbar) and the laterality of the rib or loin hump should also be monitored [9]. A cut-off point of 7^{o} in the scoliometer reading should be used for referral, but other factors like the site and the laterality of the detected asymmetry, the chronological age and the age at menarche should also be considered. We do not advocate delaying screening referrals until scoliometer readings approach 10^{o}, as a measure to reduce false positives, [2] because such a practice overlooks the crucial practical element of time, which plays a major role in IS progression and predisposes to conservative treatment failure. The same factors can be used in scoliosis clinic to determine whether it is necessary to x-ray a child or not, by the more experienced Orthopaedic surgeons, as a second stage of screening. If a detected asymmetry is not at risk for progression, the child can be discharged from the clinic without having an x-ray and without the need for follow up appointments. In the model we propose [7] we standardize the referral process, by documenting all these factors, as a protocol for examination during the school screening program.

5. Follow up of younger referrals with trunk asymmetry

It has become apparent from many reports that although there is a significant correlation between clinical deformity and radiographic measurement, the standard deviation is so high that it is not possible to reliably predict the degree of spinal curvature from surface asymmetry in any given patient by any technique [11, 16, 17]. Although asymmetry in skeletally mature children is unlikely to be associated with a progressive scoliotic curve, we noticed in a previous study that in some younger referred girls from the school-screening program there is a discrepancy between the thoracic scoliometer readings and the morphology of their spine. In these girls there was a rib hump without a spinal curve and consequently, no Cobb angle reading in radiographs [18]. In the same study, 25% of patients with an ATR ≥7° had a spinal curve under 10° or had a straight spine. After statistical analysis we show that there is no significant correlation between the surface and the spinal deformity in the younger referred girls aged 8-13 years old, while in older referred girls aged 14-18 years old, this correlation was statistically significant. Therefore, all the younger individuals who are identified with a surface deformity but without a severe scoliotic curve are at risk for IS development and need to be kept under observation and not be discharged from regular follow up.

6. Cost reduction

The increased cost has been raised as a fundamental issue by school screening negativists. The financial cost can be either direct or indirect [19]; direct cost is the cost of the screening program per se, or the cost which can directly be assigned to the program relatively easily with a high degree of accuracy (examiners' salaries, wages, fringe benefits, materials, supplies, equipment, travel, consulting, printing, telephone, and photocopying) and indirect cost is the cost of false positive results, the follow up visits, the radiographs and the cost of brace treatment and/or surgery. In addition as an indirect cost can be recognized the financial and psychological impact of the screening procedure and the identification of scoliosis on the child and on his or her family.

There is no general consensus among economists as to what constitutes the indirect cost in a cost effectiveness analysis because the indirect cost cannot be measured accurately as it is related to the effectiveness of the school screening program. A more effective screening program has lower indirect cost. Therefore the economic information on screening for scoliosis which is available to decision-makers should mainly be based on studies of the direct cost of such programs. Unfortunately the unpredictable indirect cost has been adopted by the negativists to criticize the value of school screening programs.

In order to measure the direct cost of our school screening program we conducted a cost analysis study during a six year period of its performance [7]. The direct cost for the examination of each child for the above studied period was 2.04 €, which is considered low. This study provides evidence that the direct cost of a screening program can be reduced to a minimum, if it is well organized and it is performed according to the model we propose [7].

Discussion

Physicians should be more interested in quality of care for their patients than in epidemiology, numbers, statistics, or money. We always have to remember what the axiom in the cradle of western civilization, ancient Greece, was. Ancient Greeks used to say that 'metron of everything is man'; the measure, in other words, of appraising everything is only the human being, nothing else. Prevention must return as a standard health policy in civilized societies. And school screening is primarily a preventive process.

School screening programs are performed in different ways around the world. Unfortunately there is no consensus among the experts on specific criteria of screening. There are differences in screening protocols, the age and gender of the children screened, the screening staff and their level of training, the preparation and organization, the examination techniques used, the use of a scoliometer, the referral criteria, the follow up evaluation and the interpretation of data. As a consequence of the luck of standards of scoliosis screening, there is no adequate evidence based on outcome results necessary to either enhance or eliminate the school screening process.

Hawes reported that the policy not to screen because of lacking cost effectiveness is based on the obsolete assumption derived from an early study that surgery is the only proven treatment option [20] although the cited study provides poor evidence and does not justify this conclusion [21]

Today there is evidence that the incidence of surgery can significantly be reduced where conservative treatment is available on a high standard. [22, 23, 24]. School screening through detection of IS at an early stage is the only tool we have to detect mild and moderate spinal curves which can be treated conservatively in an effective way.

Furthermore, our screening vision should be strongly focused on a goal to enhance our knowledge and our treatments so that we can change the paradigm from today's "correction" goal to a stronger goal of maintaining the natural shape of the spine and "preventing" a spinal deformity from developing. In the "New World", this is actually going back to the original goal as described by Benjamin Lee in 1872 [25], *"A constantly widening field of experiences and observation only confirm me in my adherence to the conclusions thus reached (in my first essay) first, that an early recognition of the disease (scoliosis) will in a great number of cases enable us to arrest it before deformity has been produced."* Also this is going back even earlier in Europe if we will bear in mind the ancient Greek saying "*It is better to prevent than to treat*".

The present study provides evidence based recommendations for the improvement of school screening effectiveness; better organization and preparation of a school screening program; selective screening according to the geographical latitude; reliable examination tests in sitting position; standardization of referrals; follow up of younger referrals with trunk asymmetry; and reduction of cost.

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Section V

Clinical Evaluation and Classification

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Clinical Evaluation of Scoliosis During Growth: Description and Reliability

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Abstract. The clinical evaluation, even today, remains a central point in the diagnosis, prognostic definition and treatment prescription regarding scoliosis. The clinical evaluation of a scoliotic patient has been established for a long time, but it has not been standardized. The aim of the present work is to report the most common clinical measures for the assessment of scoliosis, explain the usefulness of each clinical measurement, and report the repeatability and limits in order to help the physician in making appropriate clinical choices.

Methods. The height of the hump, the angle of trunk rotation, the sagittal and frontal profiles, and the Trunk Aesthetic Clinical Evaluation (TRACE) have been fully described, and their reliability and repeatability have been assessed.

Results. The measures analyzed showed good reliability and repeatability on the intra-operator basis. The inter-operator repeatability is usually not that good.

Conclusion. The main measures of the clinical assessment of scoliotic patients have been tested, and their reliability has been evaluated. The knowledge of measurement error, as well as intra- and inter-operator reliability, are essential for the clinical evaluation and treatment of scoliosis. This is an unavoidable basis for decision making in the assessment and the treatment of scoliosis.

Keywords: scoliosis evaluation, ATR, sagittal assessment, aestethic

Introduction

The clinical evaluation, even today, remains a central point in the diagnosis, prognostic definition and treatment prescription regarding scoliosis. An early diagnosis allows a long-term programming of periodic controls for cases of progressive structural scoliosis. Therefore, the main goals of such clinical evaluation are the early detection, assessment of the progression potential, definition of an early and appropriate conservative treatment aimed at avoiding progression and the related risk on surgery, improvement in the aesthetic impact and avoidance of health risks.

The clinical evaluation of a scoliotic patient has for a long time been established, but it has not been standardized. It is basically a morphological analysis based on the surface measures taken by a physician through means of selected devices, along with his/her clinical practice and the identification of a few landmarks. Certain clinical parameters are evaluated quantitatively (e.g. Bunnell, rib hump height or trunk list), while others are evaluated semi-quantitatively by means of ordinal numbers assigned on the basis of clinical experience (e.g. curve flexibility, height differences of the shoulders, antero-superior iliac spines [ASIS] and postero-superior iliac spines [PSIS]). Thus a more reliable measurement method would be advisable.

Many devices have been designed and developed for objective quantification of the clinical examination over the past fifteen to twenty years [1, 2, 3, 4]. Some of them are able to detect morphological variations of surface landmarks with good repeatability, while others allow a deeper analysis for the clinical evaluation of morphological characteristics of the entire trunk [4].

As far as we know, the clinical evaluation has never been thoroughly validated clinically or instrumentally, except for the instrumental evaluation of rib hump or trunk inclination [1, 5, 6, 7, 8] (i.e. the most important clinical parameter).

We recently attempted to validate the most commonly used tools of everyday clinical practice, recording the measurement error, repeatability and reliability.

The objectives of the present work are to report a complete clinical scoliosis assessment, explain the usefulness of each clinical measure, and report the repeatability and limits in order to help the physician in making appropriate clinical choices.

1. History

This is the first step in any clinical evaluation. In the approach to scoliosis patients (which is usually followed up until growth is complete), the first visit is quite different from subsequent control visits. The main objectives in the first visit are to exclude the possible causes of secondary scoliosis and understand some other aspects that are useful in order to completely frame the pathological condition. Moreover, it is important to establish a first contact with the patient and his or her family, which is frequently shown to be a determinant in obtaining good treatment results.

1.1. Familiar history

It is important, in terms of the prognostic intent, to know whether another family member has developed scoliosis. Moreover, an eventual genetic or familiar disease could be fundamental to know, particularly when accompanied by a secondary scoliosis.

1.2. Physiological history

Pregnancy, maternal exposure to risk factors, delivery and psycho-physical development should be carefully evaluated. It is very frequent to find certain alterations of one of these events. For a girl, gynecological history is another relevant element: The age at menarche, which is frequently older for scoliotic patients, is also useful in determining the progression potential of scoliosis.

1.3. Remote pathological history

Minor neurological signs, febrile seizures, traumatic brain injury and vertebral pain are some of the most relevant factors that should be investigated.

1.4. Recent pathological history

It is important to collect details regarding the first detection of the pathology, as well as its evolution and concurrent factors.

1.5. Compliance with treatment

This is the most relevant anamnestic datum during clinical controls subsequent to the first visit. It isn't enough to ask, "Did you wear your brace?" or "Did you perform your physical exercises?" Instead it is fundamental to make the patient understand the importance of the treatment, even with more precise questions like, "When do you wear your brace and when do you remove it?" or "How many times each week do you perform your exercises, and how long does it take?" The answers are relevant not only in terms of their content but also for the way they are told, as well as the interaction between the patient and his/her parents, which frequently reveals complicity, dissent or difficulties.

1.6. Questionnaires

The questionnaire represents a useful instrument that allows us more easily and objectively to monitor various treatment aspects related to function, pain and psychological impact. The most commonly used are SRS-22 (which has been validated in Italian by our group and is now in use in many countries) [9, 10, 11, 12, 13, 14], the Bad Sobernheim Stress Questionnaire (BSSQbrace)[15] and the Brace Questionnaire (BrQ)[16].

2. Physical examination

For a correct physical examination the patient needs to be undressed, only with a slip on. To visit a completely naked patient could be a mistake, since he/she could take an unusual posture. T-shirts and undershirts do not allow a complete examination of the patient's body. It is sometimes necessary to avoid the patient to take a correct posture instead of his/her usual one, especially when he/she has already performed some therapeutic exercises.

2.1. Materials

Some instruments are essential for the clinical examination:

- A plumbline
- A Bunnel Scoliometer
- Some wooden tablets of progressive thickness (2, 3, 5, 10 mm)

- A scale
- A height measure
- A ruler

2.2. Record card

Every measurement should be reported on a record card in order to collect all the data and easily verify the course from one visit to another. The use of dedicated software can make this easier.

2.3. Clinical evaluation

Usually, every clinical evaluation of the scoliosis patient follows these steps:
- Observation: To derive a comprehensive impression of the patient and the aesthetic deformities;
- Eventual evaluation of differences of leg length: This is a preliminary step, since a lateral inclination of the pelvis can alter the other measurements;
- Frontal and sagittal asset evaluation;
- ATR (angle of trunk rotation) and hump height measurement;
- Evaluation of the curve rigidity;
- Deambulation, balance and neuromotor control assessment;
- Spinal resilience and muscular retraction assessment;
- Tanner signs for secondary sexual maturity assessment.

2.4. Observation

A global observation and evaluation of the patient is required in order to assess the most affected somatic areas and posture alterations. The first general evaluation begins when the patient enters the examination room observing the gait. It is possible to notice apparent rough deficits from deambulation, speech and undressing. Moreover, it is important to remember that scoliosis is considered idiopathic until the opposite is proven. Therefore, signs of possible secondary scoliosis must be sought.

The patient should be evaluated in standing position, preferably while positioned on a podoscope, with straight legs and habitual posture. From a position next to the patient it is possible to evaluate the antiversio/retroversion of the pelvis, the abdominal prominence, the anteposition or retroposition of the trunk and the anteposition of the head. From the front of the patient it is possible to evaluate eventual rib cage abnormalities such as pectus excavatum or carenatum. From the back of the patient one can evaluate the symmetry of the shoulders, scapulae thorax, waist, and finally the head.

Usually, a qualitative assessment of these findings is used. Recently we developed a clinical scale for aesthetic evaluation that showed good repeatability. Initially, the Aesthetic Index (AI) was a three-point scale for the asymmetry (0 absent, 1 slight, 2 severe) of the shoulders, scapulae and waist; the sum of those sub-scores gives the AI [17]. The AI and its sub-scores can be used in everyday clinical practice, but a change of two points for sub-scores and three for AI is required to reach clinical significance. This gives to the AI a low sensitivity. For these reasons the AI scale has been improved, ultimately becoming TRACE (see Figures 1-4).

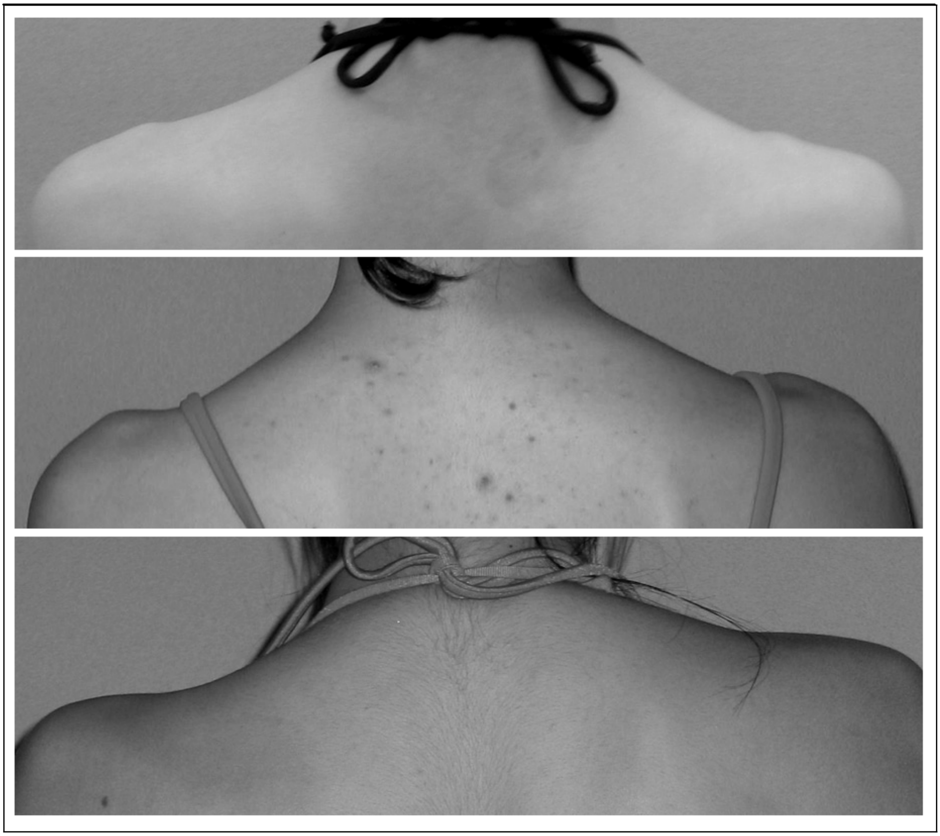

Figure 1. Shoulder asymmetry: (from the top) slight (1), modarate (2) and severe (3)

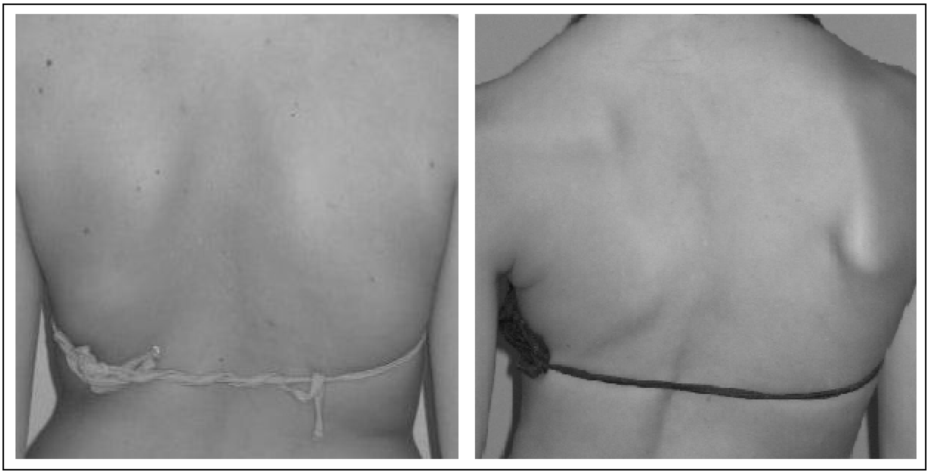

Figure 2. Hemitorax asymmetry: (from the left) slight (1) and severe (2)

Figure 3. Scapulae asymmetry: (from the left) slight (1) and severe (2)

The “Trunk Aesthetic Clinical Evaluation” (TRACE) is based on four sub-scales: shoulders (0-3), scapulae (0-2), hemithorax (0-2) and waist (0-4). Each point is fully described and gives an ordinal scale for increasing asymmetry [18]. TRACE 1 was given by the sum of the sub-score, while TRACE 2 by a percentage weighting each individual sub-score.

By calculating the level of agreement (95%), it was found that 2/11 was the minimum change between two visits to be considered significant for TRACE 1 when performed by the same operator, (or 3/11 for different operators). For single items the

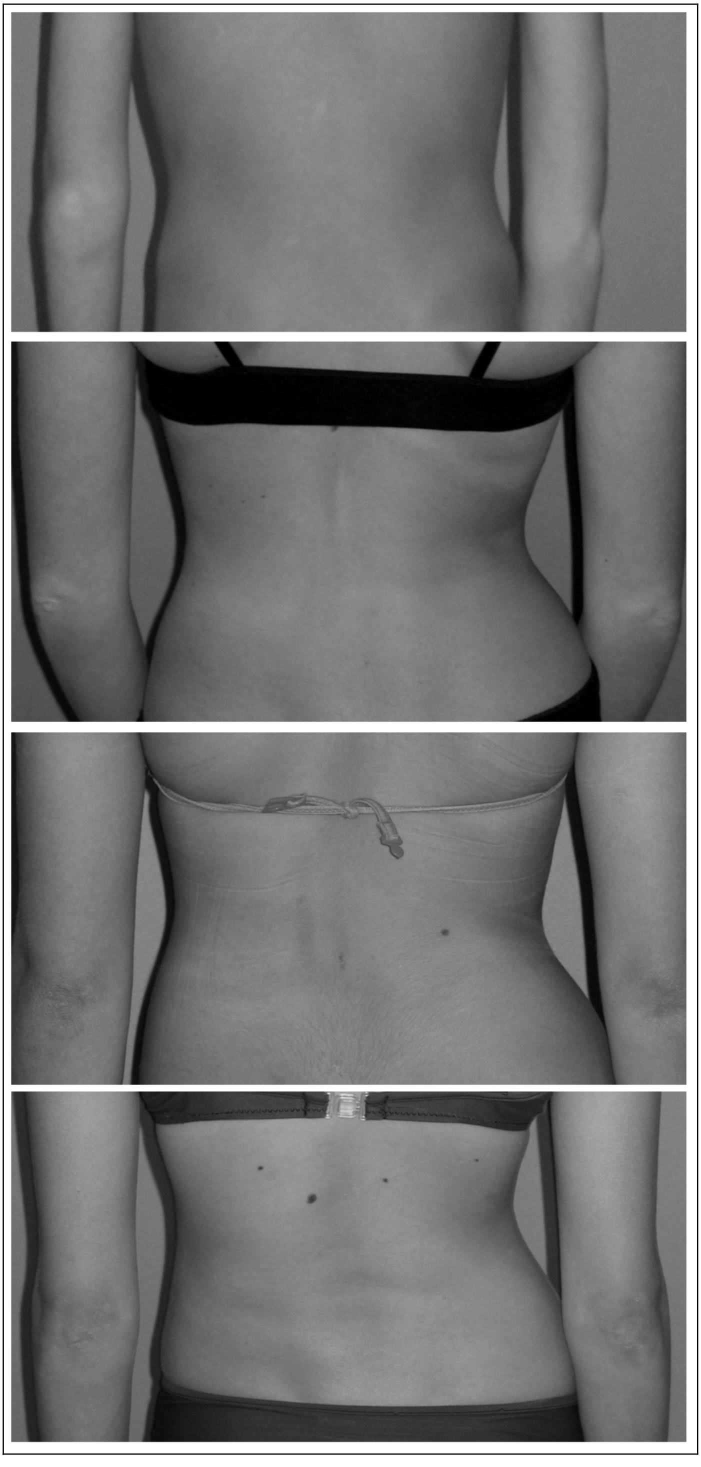

Figure 4. Waist asymmetry: (from the top) slight (1), mild (2), modarate (3) and severe (4)

shoulders, scapulae and hemithorax need a change of 1/3, 1/2 and ½, respectively, both for the same and different operator; for the waist it is 1/4 for the same operator and 2/4 for different operators.

The aesthetic aspect is important in scoliosis, since it is considered a major goal of conservative treatment by SOSORT experts [19] and one of the most relevant indications for surgery among surgeons [20, 21]. Certain questionnaires have been available for the self-assessment of aesthetic impairment, but they are not reliable tools for clinical evaluation. Since the repeatability and sensitivity of the measurement are known, it is now possible to use these instruments for everyday clinical evaluation and to monitor the aesthetic changes achieved with treatment.

2.5. Leg-length discrepancy

Numerous methods exist for leg-length evaluation, having been progressively developed and validated through various objectives. Our interest is focused on minor leg-length discrepancies (inferior to 1cm) during the growth, when it is known that limbs demonstrate different rates of growth. Most of all, it is important to remember that our interest is focused on the influence of inferior limbs on the pelvis and thus on the spine. Leg-length discrepancy is usually measured in a standing position, while the pelvis retrieval points are also evaluated and the results compared with those of a radiograph.

The measurements refer to a semi-quantitative comparison of the relative heights of the thumbs positioned on the postero-superior iliac spines, antero-superior iliac spines and iliac crests. These heights are measured in centimeters and approximated to 0.5 cm. This measurement is not extremely precise, so it is a good strategy to perform many measurements and frequently check the data recorded with this method.

2.6. Frontal-plane plumbline

The plumbline is used to assess the sagittal and frontal profiles of the spine, normally C7 and the intergluteal line (see Figure 5). The plumbline is set along the median sacral crest, and the discrepancy from the plumbline is measured at C7.

The intra-observer repeatability is of 1 cm, so 1.5 cm is the minimum to be considered significant when recorded in two different visits (see Table 1) [22].

2.7. Sagittal-plane assessment

Considering the sagittal profile, the distance from the plumbline is measured at the spinous processes of C7, T12 and L3 with respect to the most prominent points of the dorsal kyphosis (see Figure 6). The intra-observer repeatability is of 1 cm, so 1.5 cm is

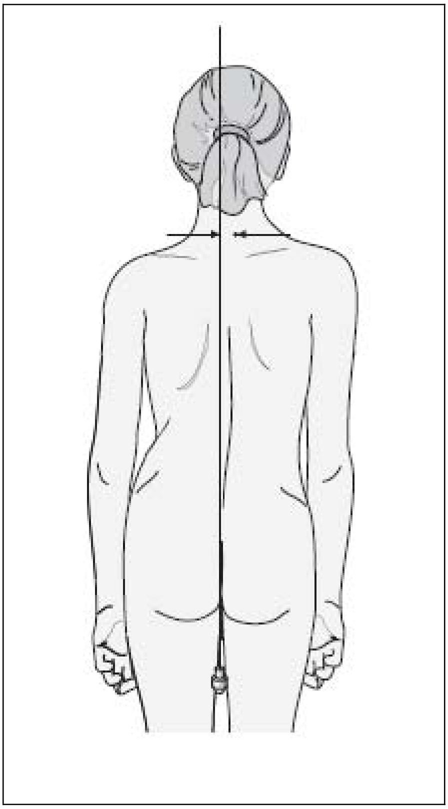

Figure 5. Plumbline assessment of frontal profile

the minimum to be considered significant when recorded in two different visits. For interobserver evaluation the repeatability is quite low at about 2.0 cm (see Table 1). It is also possible to measure forward and backward bends by comparing the data to S1 instead of the apex of the dorsal spines [23].

Plumbline measurement is reliable and sensible for intra-observer evaluation. I t is also easy to collect and has a low cost compared to other measures that require very expensive equipment. When we studied the variation of the sagittal plane with AUSCAN, an instrumental system for surface assessment, we found a similar error due to the movement of the patient. It is evident that similar results with different economic involvements make the plumbline measurements much more interesting [22, 24].

Table 1. Measument error of sagittal and scoliosis clinical evaluations

Parameter	Intra-observer	Inter-observer
Sagittal distance of C7 from the plumbline (cm.)	0.9	1.7
Sagittal distance of D12 from the plumbline (cm.)	1.3	1.9
Sagittal distance of L3 from the plumbline (cm.)	1.2	2.2
D'Osualdo Arcometer (calculated ° Cobb)	7	15
ATR (° Bunnell)	1.4	1.4
Height of the hump (mm.)	2.1	
Frontal distance of C7 from the plumbline (cm.)	1.1	

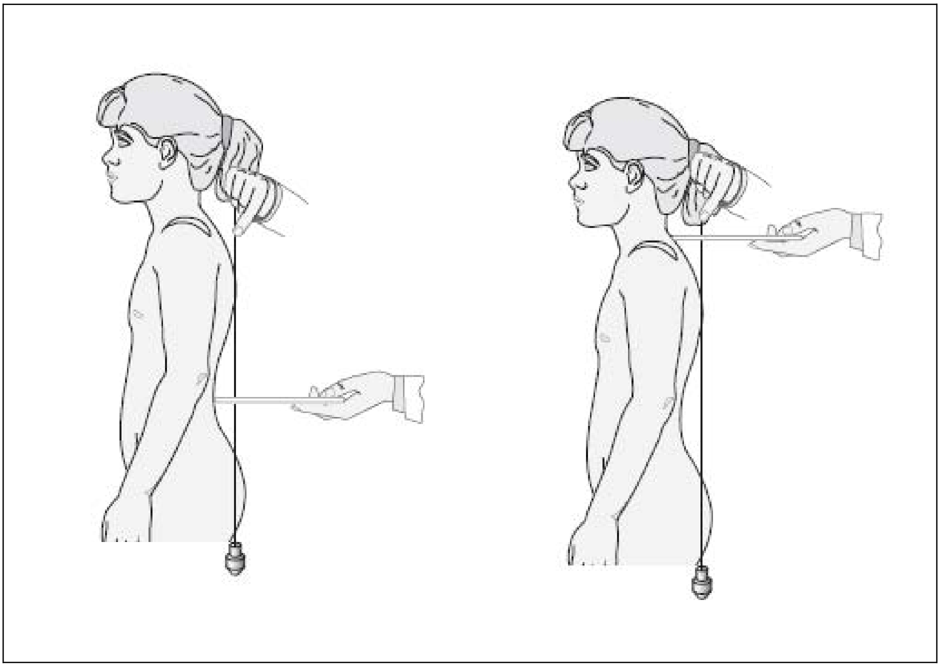

Figure 6. Plumbline sagittal profile assessment

Another cheap-and-easy instrument is the D'Osualdo Arcometer. This instrument has an intra-observer error of 7° and an inter-observer error of 14°(see Table 1) [25].

2.8. ATR and Hump height

The angle of trunk rotation (ATR) is one of the most relevant measurements in the clinical evaluation of scoliosis. This parameter is fundamental for monitoring the effects of the treatment, even without radiographic evaluation. The ATR measurement is performed using a dedicated instrument called a Scoliometer: the patient is asked to bend forward with arms dangling and palms pressed together. The Scoliometer is placed on the back and used to measure the most leaning point of each hump (see Figure 7). In this position it is also possible to measure the height of the hump (HH): It is necessary to elevate the Scoliometer on the side opposite to the hump, thus positioning it to 0° and measuring the height with a ruler. The ATR correlates to the Cobb angle. Accordingly, a minimum significant angle of trunk rotation of 5 degrees was shown by computer-analyzed data from 1,065 patients to be a good criterion for identifying curvatures of 20 degrees or more [1]. The ATR is a reliable measurement with repeatability >86%; even the HH offers 91%. A change of 2° can be considered significant for intra-observer measurement (see Table 1) [22]. According to our own experience the Scoliometer measurement of the ATR is more reliable for low-grade scoliosis, while for scoliosis of more than 25 mm of hump, the HH measurement is better.

2.9. Curve rigidity

This is an important parameter that adds information relevant to the prognosis and therapeutic choices. While bending forward, the patient is asked to side-bend on one

Figure 7. ATR measurement

side and then on the other. If the curve is not rigid or structured, it is possible to invert the hump; otherwise, if everything remains in the same way, the curve appears very rigid. This is nearly qualitative as an assessment.

2.10. Other evaluations

Tests are available as means to exclude a possible secondary scoliosis, and these tests provide certain general information. The Romberg test and the Unterberger (Fukuda) test are very useful tools for screening [26, 27, 28]. The clinical assessment of deambulation can be also used in ambiguous cases, but it should preferably be concluded with a neurological examination.

The evaluation of the extensibility of some muscular groups is also a useful parameter. The hamstrings and pectoralis major are probably the most relevant in this kind of assessment.

The evaluation of spinal rigidity is performed by asking the patient, now lying prone, to hyperextend the back, whereby the eventual restrictions in movement are brought to light.

3. Conclusion

Reliable data was available only in regard to measurements of Cobb degrees and ATR Bunnell degrees until 2002. However, with the data presented in this article and derived from our studies we now have an entire set of clinical tools with which to evaluate AIS rehabilitation. Aesthetics, psychological well-being, quality of life, and disability are the main goals of scoliosis treatment, together with the avoidance of progression. That is why we need instruments that go beyond the x-ray measurement (Cobb angle) to evaluate and monitor many other aspects that are very relevant for the patient and, ultimately, the clinician.

The knowledge of measurement error and intra/inter-operator reliability is fundamental for the clinical evaluation and treatment of scoliosis. This is fundamental for decision making in the assessment and the treatment of scoliosis.

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3-DEMO Classification of Scoliosis: a Useful Understanding of the 3rd Dimension of the Deformity

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Abstract The third-dimension of scoliosis represent a great challenge for clinicians used to think in two dimensions due to the classical radiographic representation of the deformity. This caused problems in everyday clinical approaches, and led to the development of new bidimensional classifications (King, Lenke) who tried in different ways to face these problems, mainly in a surgical perspective. Recently, some three-dimensional classifications have been proposed, all developed in laboratory by bioengineers. In this paper we present the existing classifications of scoliosis, both bi-dimensional and three-dimensional and we thoroughly discuss the 3-DEMO (3-D Easy Morphological) that has been first presented years ago, and recently thoroughly published; this classification has been developed by clinicians with the main aim of being understandable and easily applicable to everyday clinical life.

Keywords. adolescent idiopathic scoliosis, classification, three-dimensional.

1. Classifications for Adolescent Idiopathic Scoliosis

Classification schemes help clinicians to organize their thoughts about a clinical problem and to design appropriate methods of treatment. Thus, classification systems not only organize an approach to a problem and suggest a method of treatment but also may provide an estimate of the outcome of a particular treatment.

The first proposed classification for scoliosis relates to the location of the various curves according to the apex vertebra, and has been initially developed by Schulthess in 1905 [1], refined by Ponseti [2] and confirmed by the terminology committee of the Scoliosis Research Society [3]. This classification undoubtedly is bi-dimensional and based on AP radiographs. Nevertheless, it served its scope of communication among specialists, and it probably is the most widelly used classification even today, because of its simplicity based on pure morphology. According to this classification is possible to recognize: a cervical scoliosis (scoliosis having its apex at a point between C1 and the C6-C7 disc; a thoracic scoliosis (a scoliosis that has his apex at a point between the

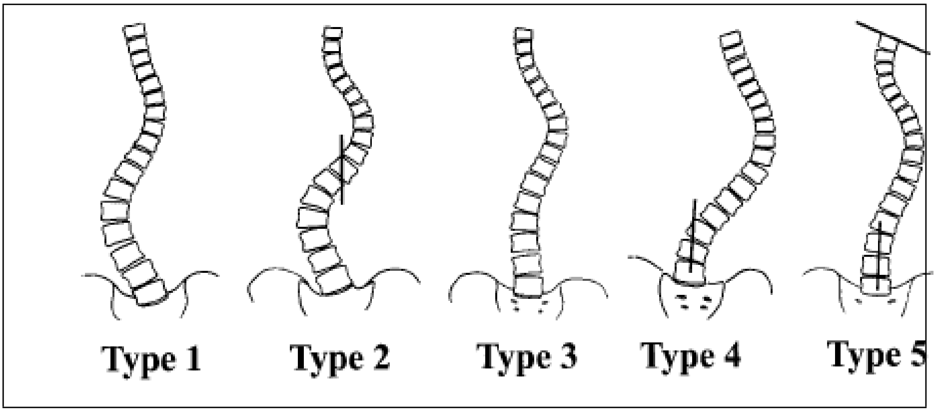
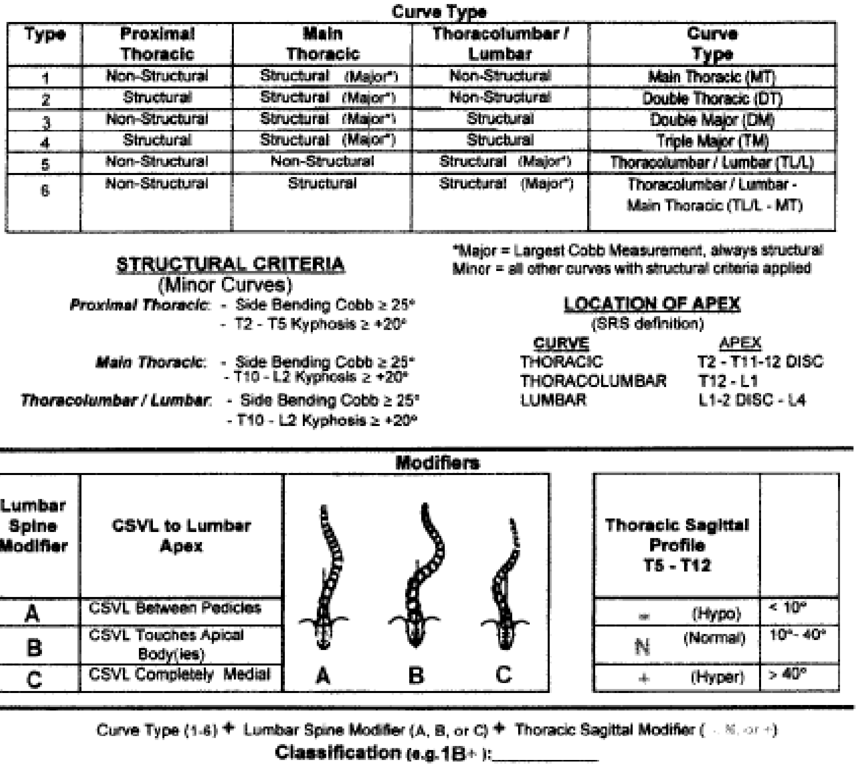


Figure 1. The five King curve types.

T2 vertebral body through the T11-T12 disc); a thoracolumbar scoliosis (a scoliosis with its apex at T12, L1 or the intervening T12-L1 disc); a lumbar scoliosis (a scoliosis that has its apex at a point between the L1-L2 disc space through the L4-L5 disc space); a lumbosacral scoliosis (a scoliosis that has its apex at L5 or below).

The two main classifications that have been developed in the past serving surgical purposes,were named after the first author of the pertinent publication, King in 1983 [4], and Lenke in 2001 [5]. The first one (see Figure 1) was revised in 1994, to facilitate the selection of the fusion areas, especially to distinguish type II curves that, in case of surgery, require a shorter fusion area than the others [4, 6]. According to this system, a type-I curve is a s-shaped curve in which the lumbar curve is larger and less flexible than the thoracic curve, a type-II curve is a s-shaped curve in which the thoracic curve is larger and less flexible than the lumbar curve, a type-III curve is a single thoracic curve in which no compensatory lumbar curve crosses the midline, a type-IV curve is a long thoracic curve in which the fourth lumbar vertebra tilts into the thoracic curve, and a type-V curve is a double thoracic curve. King et al. developed their classification system during the era of Harrington instrumentation and arthrodesis. During that time, uni-dimensional (coronal) assessment was the principal way in which curves were classified and appropriate treatment was recommended. With the advent of segmental spinal fixation, three-dimensional analysis of scoliosis became routine. The main problems of this classification were the relatively low intra- and inter-observer reliability [7, 8], the fact of totally being bi-dimensional and almost confined to thoracic curves [8,9]

Lenke's classification (see Figure 2) is far more complex, being an advancement of King's system,including lumbar and sagittal modifiers too, that represent an attempt to look at the spine three-dimensionally [6]: reliability seems to be good [10, 5, 11], but it is still relatively new and further studies are needed. The Lenke system is based on six main scoliosis types according to the level and number of curve patterns. These main types are then subdivided in two other gradings. One (A,B,or C) for the degree of a lumbar curve, is based on the deviation from the central sacral vertical line. The other is an assessment of the sagittal profile of the thoracic spine. Further developments have led to the addition of a deformity score (Lenke –Harms score) to this classification that is based on the Cobb angle, the kyphosis angle, and the balance of the spine.



Curve Type

Type	Proximal Thoracic	Main Thoracic	Thoracolumbar / Lumbar	Curve Type
1	Non-Structural	Structural (Major*)	Non-Structural	Main Thoracic (MT)
2	Structural	Structural (Major*)	Non-Structural	Double Thoracic (DT)
3	Non-Structural	Structural (Major*)	Structural	Double Major (DM)
4	Structural	Structural (Major*)	Structural	Triple Major (TM)
5	Non-Structural	Non-Structural	Structural (Major*)	Thoracolumbar / Lumbar (TL/L)
6	Non-Structural	Structural	Structural (Major*)	Thoracolumbar / Lumbar - Main Thoracic (TL/L - MT)

*Major = Largest Cobb Measurement, always structural
Minor = all other curves with structural criteria applied

STRUCTURAL CRITERIA
(Minor Curves)
Proximal Thoracic: - Side Bending Cobb ≥ 25° - T2 - T5 Kyphosis ≥ +20°
Main Thoracic: - Side Bending Cobb ≥ 25° - T10 - L2 Kyphosis ≥ +20°
Thoracolumbar / Lumbar: - Side Bending Cobb ≥ 25° - T10 - L2 Kyphosis ≥ +20°

LOCATION OF APEX
(SRS definition)

CURVE	APEX
THORACIC	T2 - T11-12 DISC
THORACOLUMBAR	T12 - L1
LUMBAR	L1-2 DISC - L4

Modifiers

Lumbar Spine Modifier	CSVL to Lumbar Apex
A	CSVL Between Pedicles
B	CSVL Touches Apical Body(ies)
C	CSVL Completely Medial

Thoracic Sagittal Profile T5 - T12	
- (Hypo)	< 10°
N (Normal)	10°- 40°
+ (Hyper)	> 40°

Curve Type (1-6) + Lumbar Spine Modifier (A, B, or C) + Thoracic Sagittal Modifier (-, N, or +)
Classification (e.g.1B+):__________

Figure 2. Summary of all the criteria necessary to determine the Lenke curve classification.

In 2003 Lenke [6] demonstrates how a selective thoracic or thoracolumbar/lumbar fusions of the major curve can be successfully performed even when the minor curve completely deviates from the midline, based on the Lenke classification system, the analysis of structural criteria between the planned fused and unfused regions of the spine, and the clinical examination of the patient. Selective fusions, when successfully performed, will optimize mobile segments of the spine in patients with adolescent idiopathic scoliosis. In the same year Puno et al. [6] published a paper in which they found that better radiologic results were achieved through the use of the Lenke classification system for the selection of fusion levels by avoiding unnecessary fusion of the nonstructural lumbar or thoracic spine as well as avoiding undercorrection of the structural secondary curves.

Moreover Richards et al. [6] conducted a study aiming to determine the reliability of King and Lenke classification systems using radiographs that had not been premeasured. The Lenke classification system was found to be less reliable than previously reported when the radiographs were premeasured. This was particularly true when all three parameters of this new classification were combined. This difference in reliability of the Lenke classification between studies can be attributed to the additional variable of determining the Cobb measurements on each of the unmarked radiographs. Although this new classification system has limitations with respect to inter-observer and intra-observer reliability, for planning operative treatment, it offers a more comprehensive radiographic evaluation of patients with adolescent idiopathic scoliosis.

Coonrad et al [6] produced a classification comprising 11 pattern types based on the Scoliosis Research Society definition of coronal pattern determination according to the location of the apical vertebra. However, the exclusion of sagittal and 3D deformity considerations still remains the limitation of this classification.

Recently Qiu G. et al. [6] proposed a new operative classification of idiopathic scoliosis known as “Peking union medical college method”. This classification of idiopathic scoliosis is a system that combines each type of scoliosis with its corresponding fusion level, and it has much higher inter-observer reliability and intra-observer reproducibility than the King system.

2. 3D Classifications for Adolescent Idiopathic Scoliosis

The third dimension has now become a real entity in the clinical study of scoliosis, but even today the evaluation of the third dimension always requires, together with the use of radiographic projections, a wealth of clinical experience and considerable powers of abstraction in order to form an idea of what might be the real 3D behavior of the pathological spine under examination. The development of new technologies has somewhat reduced the restrictions mentioned above, especially in the research sphere..

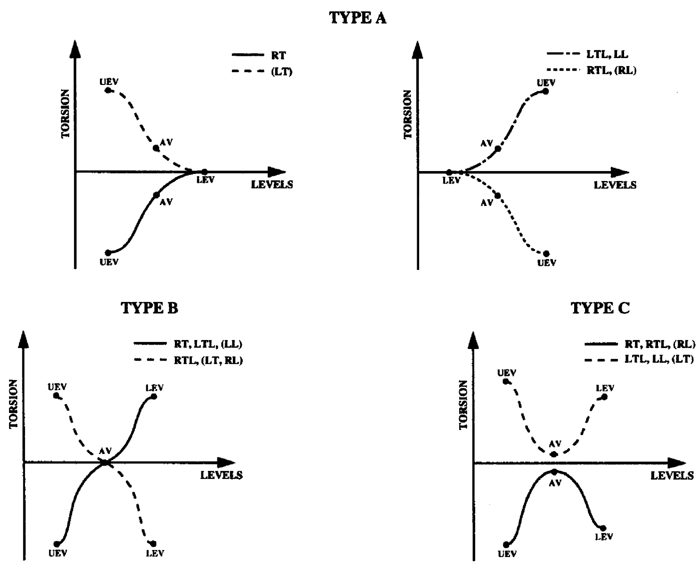


Figure 3. Three dinstinct torsion curve patterns were detected and categorized according to the apex orientation (left or right) and location (thoracic, thoracolumbar, or lumbar) of 94 idiopathic curves in 62 reconstructed scoliotic spines. Patterns of right and left curves are reversed in a mirror fashion, which allowed extrapolation of torsion patterns for the unconsidered right thoracic, left thoracic, and left lumbar curves. In Type A curves, the maximum torsion is located in the upper-end vertebrae (UEV) region, whereas in Type B and C curves, this occurs in both the UEV and lower-end vertebrae (LEV) regions. Generally speaking, minimum values of torsion occur in the apical vertebrae (AV) region. In Types A and C curves, the geometric torsion is unidirectional, whereas Type B curves are subjected to torsion in opposite directions.

However we are still far from achieving a concrete, reproducible picture and useful understanding of scoliosis as a 3D phenomenon. One of the main obstacles, due to the difficulty of visualization [12], is the inability to achieve a clinically useful representation of the deformity. A further problem, directly related to the first, is that both communication and comprehension are rendered difficult by the lack of a relevant codification of (and thus of the capacity to describe) the third dimension. Until these obstacles are removed, the use of the third dimension of scoliosis will continue to be confined to the sphere of research. Since our first presentation of this classification in 1996 [13, 14, 15, 16] and 1999 [17, 18], Poncet's group first proposed a possible 3D classification in 1998 [19] and then published it in 2001 on Spine [20], just like Duong [9] who recently proposed Fuzzy Clustering as a way to obtain it. Poncet (see Figure 3) proposed a new method of classification for describing the 3D shape of a scoliotic curve. A 3D shape analysis of scoliotic spines in terms of geometric torsion has shown that three distinct patterns of torsion are observed in single and double major scoliotic curves, that curve limits are subjected to high geometric torsion values as opposed to the apexes, that the torsion phenomenon can be unidirectional or bidirectional in both single and double major curves, and that transition zones are located at the junction of the two curves in double major curves or in the apical zone in single and double major curve. This results show the relevance of the geometric torsion parameter in the spatial distinction of scoliotic morphologies that goes beyond the frontal plane projection of the spine.

In 2001 Liu XC et al. [20] made a study to define a spinal deformity score based on three-dimensional measurements by the Quantec spinal image system (raster stereophotograph) in order to provide functional classification of spinal deformity in patients with mild idiopathic scoliosis without using radiographs. They found that the back surface image study is a method for providing a quantitative assessment of mild spinal deformity, allowing evaluation of patients by integrated three-dimensional parameters with no reference to radiographs. But both these proposals are complex to understand and to visualize, and are derived from bioengineering studies more than from clinical evaluations of 3D results.

3. 3 DEMO classification of scoliosis

The 3-DEMO classification has been first developed in the '90, and thoroughly proposed in the Journal "Scoliosis" in 2006 [21, 22, 23].

Stokes and the Scoliosis Research Society Working Group on 3D Terminology of Spinal Deformity [12] made the following assertion: "Visualization of anything three-dimensional is a great challenge". The approach that was adopted attempted to accommodate this human limitation by making extensive use of the "auxiliary" planes on to which the spine is projected. Such measurements are not truly 3D, but this approach of using "quasi-3D" measurements represents a reasonable compromise between mathematical purity, conceptual and practical limitations". On the basis of these observations, facing the problem of looking and classifying a 3D object like the pathological spine, we decided to focus on a "quasi-3D" auxiliary plane like the Top View, that is a combination of the two classical AP and LL projections that allows a different and new view. With the classic radiographic examination, the Top View is possible, but does nothing to further the understanding of spine behavior; in the literature, the Top View has already been described on the basis both of computerized

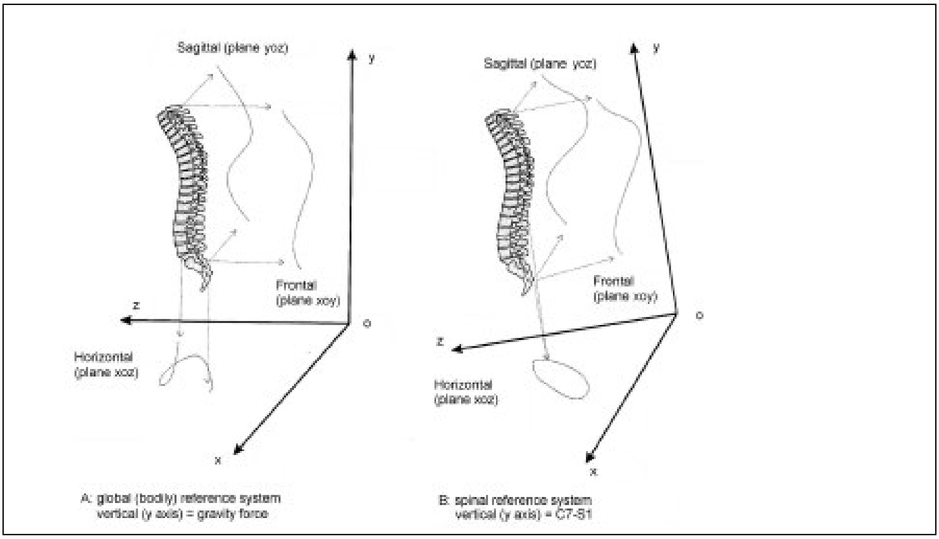


Figure 4. 3D representation of a real pathological spine (right thoracic, left lumbar scoliosis). In this figure the projections of the spine in the three spatial planes are reported: the frontal (xoy) plane is usually seen in the AP radiographs, the sagittal (yoz) is that of the classical LL x-rays, while the horizontal (yoz) plane (Top View) is not usually considered and it is the one studied here. The Top View doesn't allow to see the effect of the y axis, but joins together the sagittal and frontal plane deviations: in this respect it represents a useful auxiliary plane to have a quasi-3D projection of the spine. The Top View can be seen in a global (bodily) reference system (on the left: A) in which the vertical (y) axis is the gravity line, or in a spinal reference system (on the right: B) in which the vertical (y) axis is the line joining C7 and S1. In this last situation, that is the one that proved to be useful and it is adopted throughout this study, the entire reference system rotates with respect to the gravity line, as it can be seen on the right (B). These figures refer to the same single subject: note the differences between global (A) and spinal (B) Top Views.

reconstruction derived from conventional planar radiographic information or from stereo-radiographs, and of examinations carried out by means of a surface analysis; however, to our knowledge, nobody has so far attempted to formulate a new classification of spinal deformities on this basis.

We set out to develop a 3D codification of spinal deformities on the basis of their visualization through the Top View generated by one computerized non-invasive device. We used such a source of data because we needed a high number of 3D curves totally mathematically described to look at, already stored in a large database with the corresponding clinical and x-rays measurements, to develop and verify the possibility of defining a new classification. Nevertheless, our ultimate aim is, in order to further the understanding of third dimension complexity, to develop a 3D classification which is accessible to clinicians and which differs from the usual radiographic projections.

To develop the first classification 149 (110 females) patients affected by adolescent idiopathic scoliosis (122), hyperkyphosis (23), or both (4) have been studied. All participants underwent an optoelectronic surface examination using the AUSCAN System (AUtomatic SColiosis ANalyser) [24], which is an automatic optoelectronic device specifically developed for the postural and functional analysis of patients affected by spinal deformities. The system is designed to compute in real-time, with a sampling rate of 100 Hz, the three-dimensional co-ordinates of a series of markers previously positioned on the skin of the analyzed subject. The basic components of the system [24] are two pairs of CCD TV-cameras, a FPSR (Fast Processor for Shape

Recognition) image processor and a specially developed software package for data processing. The followed procedure includes a phase in which 27 passive skin markers (hemispheric shape, diameter 1 cm) are positioned on predetermined anatomical body landmarks: 19 on the posterior side of the patient and 8 on the anterior side. Data is acquired with the patient standing for one second: computation is then based on the mean position of the markers during the acquisition. All patients were evaluated twice, while normal sample was evaluated three times. We calculated the Top View using two different reference systems [12]:

- global: the spine is projected on to the horizontal plane, orthogonal to a reference vertical axis which corresponds to the line of gravity;
- spinal: the spine is projected on to the horizontal plane, orthogonal to a spinal vertical line that we identified in our study as the line linking the landmarks of the spinal processes of C7 and S1 (Stokes suggests D1 as a possible alternative to C7) [12].

The Top Views were obtained rotating the projection of the spine on the ground until the vertical (global) and spinal (C7-S1) axes coincide (see Figure 4).

3.1. Classification methodology

On the basis of the Top View traces of all patients in both the global and spinal reference systems, classification criteria were developed by one of the authors (SN), experienced clinician, who was blinded to the patients' clinical-radiographic data. The aim was to identify the existence of any typical morphological feature that might allow grouping and comparison of the curves. The global Top View (see Figure 4A) did not allow the curves to be grouped in a reasonable fashion on the basis of their morphology and was eliminated from any further computation. Thus, from now on, the term Top View only refers to the spinal Top View (see Figure 4B). Obtained results were then reviewed by another author (AN) not having a clinical background. This was followed by a joint evaluation. Throughout this process, particular care was taken to eliminate any information deemed redundant, especially that deducible from the classic projections in the frontal and sagittal planes. The next phase was to identify the mathematical expression of the recognized morphological features, so as to make it possible to compute all considered parameters. We present a percentage, relative to the distribution in our population of the identified classificatory options, that has been defined on the obtained normative data. Then, as documented in the second part of this study, we verified the repeatability of obtained information [21].

3.2. Graphical representation of the spinal Top View

The Cartesian reference system (see Figure 4), on to which the graphic representation of the spine of each subject is projected, is obtained rotating the global reference system to make it a spinal reference system. This is true when the vertical and spinal (C7-S1) axes are coincident, and the center of the reference system is coincident with S1.

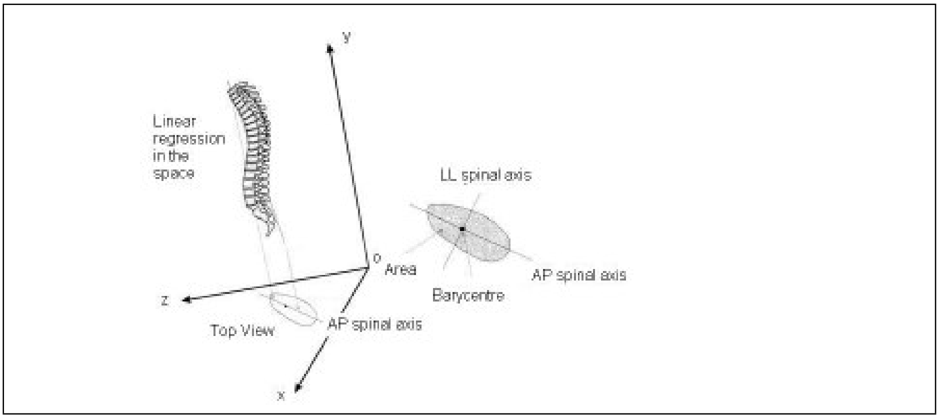


Figure 5 Graphic representation of a pathological spine according to the spinal Top View and its correspondence with the 3D real spine. Spinal Top View: projection on to the horizontal plane of the spine morphology. Barycentre: barycentre of the points reconstructing the spine projected in the horizontal plane. Antero-posterior (AP) spinal axis: projection on to the horizontal plane of the 3D linear regression of the markers on the spinal apophyses of the spine. Latero-lateral (LL) spinal axis: the axis orthogonal (90°) to the AP spinal axis passing through the barycentre. Area: the surface area limited in the horizontal plane by the Top View.

In our study we refer to a concept of spine anatomical normality, derived from the vertebral column model proposed by White and Panjabi [25]: for a normal subject , the Cartesian reference system should coincide with the laboratory one. The representation regards the top-back of the examined subject, so that the right and the front of the graph corresponds to the real right and front (see Figure 5).

The "quasi-3D" graphic representation of the spine, according to the spinal Top View, includes (see Figure 5):

- the AP (abscissa) and LL (ordinate) spinal axis defined as normal according to the White and Panjabi vertebral column model, that constitutes the Cartesian reference system; the intersection of these axes is the line joining C7-S1, that is the vertical axis of the 3D representation in a spinal reference system; the AP and LL normal spinal axes coincide with the body axes;
- the Top View, i.e. the area resulting from the projection of the spine on the horizontal plane;
- the barycentre, i.e. the barycentre (centre of gravity) of the Top View;
- the AP spinal axis, i.e. the regression line of the Top View;
- the LL spinal axis, i.e. the axis orthogonal (90°) to the AP spinal axis passing through the barycentre;
- the area, i.e. the surface area of the Top View.

3.3. Classificatory parameters of 3DEMO classification of scoliosis

We found that this new 3D classification could be extremely useful for grouping different cases of patients with spinal deformities according to their morphological characteristics. The Top View has been widely used in the past because of its capacity to integrate information usually derived from the AP and LL projections, but its

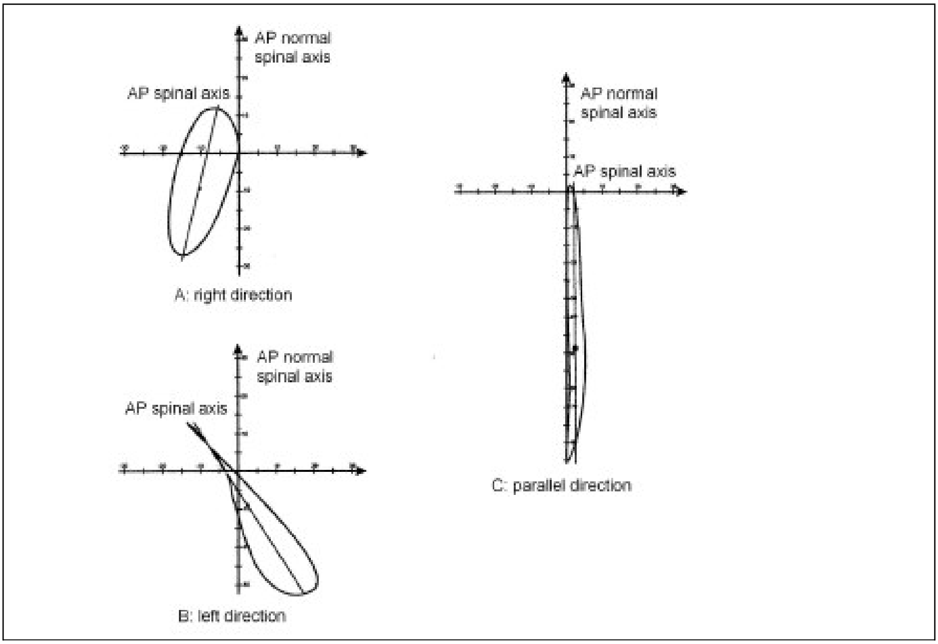


Figure 6. Examples of patients with different Directions. The Direction classificatory parameter is the angle between the AP spinal axis and the AP normal spinal axis (abscissa); it was defined as Direction because it is as if the pathological spine had changed its normal postero-anterior direction with respect to the pelvis, rotating clockwise or anticlockwise. A: right Direction; B: left Direction; C: parallel Direction. For clinical and 3 DEMO complete data of these patients see Appendix [see Additional file 1].

intelligibility has always been limited by the adopted reference system (global instead of spinal). By adopting the global reference system, the spine is projected in the horizontal plane in relation to a reference axis which corresponds to the line of gravity and not to a spinal vertical line derived from spinal landmarks. Kohashi [26]published a study in which a spinal Top View is proposed. In this case, the view was obtained from two stereoscopic radiographs, by feeding into a personal computer the data regarding the position of vertebrae centroids identified on radiographic images. The authors used the Top View in order to obtain information with prognostic value, but failed to discuss its validity as an auxiliary plane which might help to further our understanding of scoliotic deformity three-dimentionally.

We found three classificatory parameters : direction, shift and phase. Direction (see Figure 6)is defined as a rotation of the AP spinal axis with respect to the AP normal spinal axis. In conditions of anatomical normality, the Direction of the AP spinal axis should be orthogonal to the pelvis and should coincide with the AP normal spinal axis that corresponds to the AP bodi axis. However, according to our normal sample, there is a slight rotation to the right of almost 2°. This parameter is 3D in the sense that it allows the spinal curve to be defined as right or left regardless of curves localization in AP radiographs. It is a rotation which, resulting from a pathological orientation assumed by the vertebral column with respect to the pelvis, involves the whole spine. Any change of Direction in the spinal axis is obviously pathological. Such a change should generally be present in a scoliosis population, as it implies a 3D

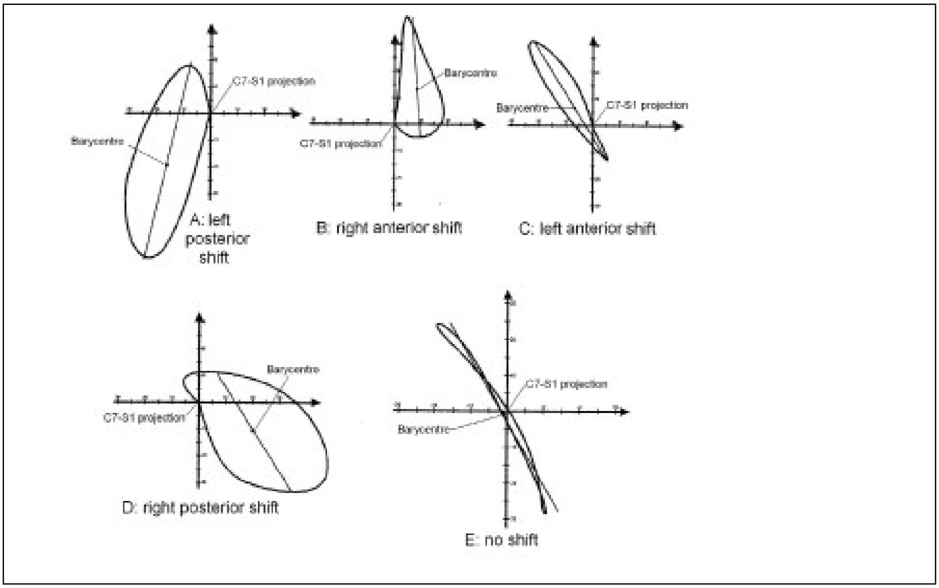


Figure 7. Examples of different Shifts. The Shift classificatory parameter is the displacement of the barycentre of the Top View with respect to the spinal normal axis; it was defined as Shift because it is as if the pathological spine had changed its position with respect to the pelvis, "shifting" away from the vertical C7-S1 axis. A: Left Posterior Shift; B: Right Anterior Shift; C: Left Anterior Shift; D: Left Posterior Shift; E: no shift.For clinical and 3 DEMO complete data of these patients see Appendix .

deformity, but not in a hyperkyphosis sample. The statistically significant difference which emerged among our groups confirms this hypothesis. The hyperkyphosis population had three-dimensionally the same behaviour as the normal one. So far it is not possible to present any definitive correspondence between such a pathological axis and elements already reported in the literature, such as the maximum curvature plane (the plane in which spine projection shows the maximum deformity) and/or the rotation between shoulders and pelvis. Although it is quite probable that a relationship does exist between this parameter and other literature data, it offers, in our view, the possibility of combining in a useful, understandable and strictly 3D spinal-related manner the information obtained using other methods.

Shift (see Figure 7) is defined as a displacement of the spinal barycentre with respect to the C7-S1 vertical line and the pelvis. In anatomically normal conditions, no lateral Shift should be present even if in our own normal sample we find a slight right shift of less than half centimetre. We also had a posterior Shift of almost 1 centimetre from the zero which coincide with S1. This parameter is 3D because it relates to a single point which integrates the information relative to spine behavior in space and to its displacement with respect to its natural basis, i.e., the pelvis and S1. A high displacement of the spinal barycentre is obviously pathological as, conceptually, it indicates an asymmetry in the positioning of the vertical central axis of spine projection. Because it implies a frontal curve, the variation along the LL spinal axis should be mainly present in a scoliosis population and far less in a hyperkyphosis sample. These statements are confirmed by our data; scoliosis population mainly shows a displacement to the left, but further studies are needed in order to elucidate these findings. The displacement along the AP spinal axis is interesting: on the basis of our

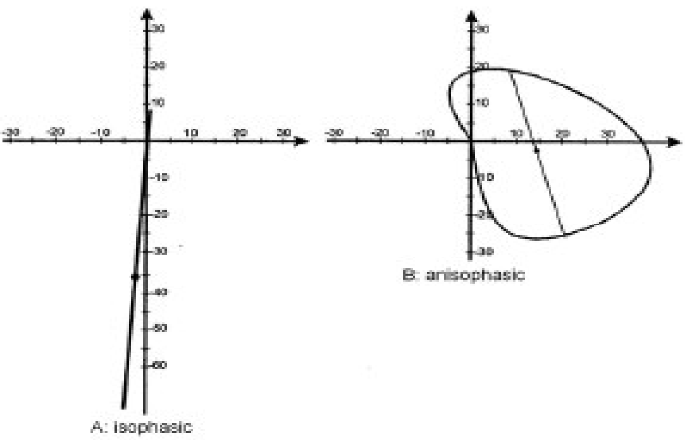


Figure 8. Examples of curves with different Phases. The classificatory parameter defined Phase is obtained dividing the spinal area for the diagonal of the minimum rectangle in which the Top View is inscribable; in practice, Phase is the Top View graphical representation of the 3D spatial evolution of the curve. A: Isophasic; B: Anisophasic. For clinical and 3 DEMO complete data of these patients see Appendix

current knowledge of the pathologies, we can hypothesize that a scoliotic deformity could show a forward localization of the barycentre, because scoliosis is known to drive the spine forward; the opposite could be true for hyperkyphosis. Only the latter was found to be true, while all pathologically sagittal oriented scoliotic spines were posteriorly Shifted (44.3%). An element which is apparently similar to the Shift, usually highlighted both during the clinical and the radiographic examination, is described in the literature in the frontal plane by the imbalance between C7 and S1. As a matter of fact, this parameter deeply differs from the Shift as, in our spinal Top View, C7 is, by definition, located on the axis of symmetry. Other everyday clinical findings, sometime discussed between specialists, but not published in indexed literature, such as the displacement of the radiological transitional point between thoracic and lumbar/thoracolumbar curve in relation with the central sacral line, or the shift of the rib cage with respect to the pelvis, or even the shift of the stable vertebra, could correlate with Shift as here defined: future studies could address these points.

Phase (see Figure 8) is defined as a description of the evolution in space that makes some curves similar to circles around the barycentre and some others similar to lines. The name derives from the relationship between the spinal curves projected in the frontal and sagittal planes that together give rise to the appearance of the Top View curve. When no curves are present in the frontal plane (anatomical normality), the Top View must be isophasic. This is not totally true, but the Phase value is very low in normals. This is a real, entirely 3D element and paradoxically the used name, which derives from our habit of viewing the spine in two dimensions (AP and LL) and which coherently describes what happens, is not so coherent with 3D reality and is less authentic than the phenomenon itself. As far as we know, in the literature there are no descriptions of this or of similar elements, and much remains to be elucidated through

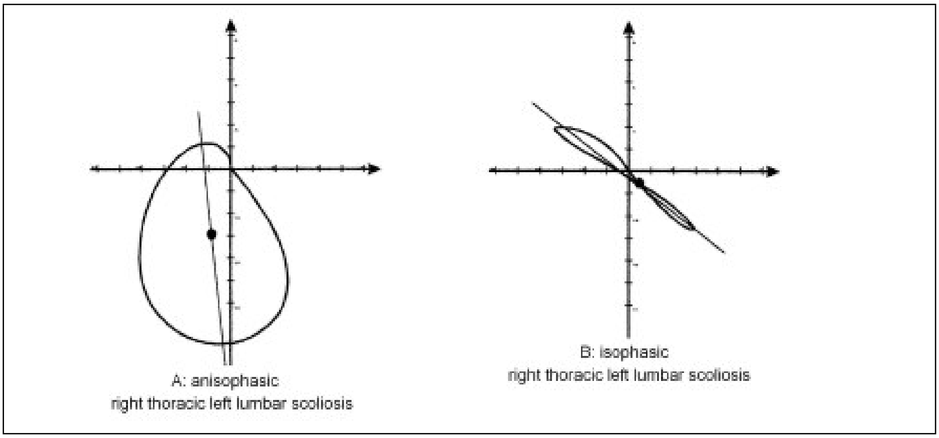


Figure 9. Graphical representation of the top view in two patients with the same Ponseti, King and Lenke classification, very similar Cobb values, completely different 3D behaviour and consequently 3-DEMO classification; for clinical and 3 DEMO complete data of these patients see Appendix .

further research. In particular, there is the question of what is the real nature of this 3D space occupation that some curves show. If a scoliotic patient does not have an alteration of Phase, he/she must not have a Parallel Direction (both elements can obviously be changed together, but without the modification of one of them there cannot be a scoliosis, because there is no curve in the frontal plane). Is it possible to hypothesize differences of pathogenesis, treatment, prognosis according to the presence of Phase?

The 3-DEMO classification could represent a basic innovation for the analysis of curve morphology, particularly in case of a 3D deformity such as scoliosis, as this analysis allows to draw a distinction between patients who, on the basis of traditional classifications, appear to be the exactly alike. Figure 9 illustrates the Top View behavior of two patients who were deemed to show the same deformity. According to traditional morphological classificatory parameters, they have the same Ponseti diagnosis, as well as King and Lenke ones; they have similar Cobb degrees in AP and LL projections (+/- 1° and 7°). They differ only slightly in regards to the position of the end and apex vertebrae. According to the quasi-3D classificatory parameters, subject A has a curve characterized by Phase, backward and slightly left shifted, not rotated: it is as if the spine had simply greatly enlarged the 3D space that it occupies; subject B has a curve characterized by Direction, isophasic like a normal spine, not shifted: it is as if the spine had somehow maintained the behavior of a normal spine, simply rotating a lot around the barycentre. On the basis of what it is possible to see, the only traditional morphological element able to explain this result is the difference between the end and apex vertebrae, which justifies a difference of Phase. This is an explanation of a 3D phenomenon (shown by our analysis) which makes use of 2D terminology.

3.4. Repeatability and correlation with clinical classification and parameters of 3DEMO classification

For a classification to be valid, it is necessary to evaluate its stability by examining the parameters variation on which this classification is based. The adoption of an optoelectronic device like the AUSCAN system guarantees a very high precision: system error is less than 1 mm; unlike typical devices used for the evaluation of a patient with spinal deformities, this non-ionizing system permits to repeat the acquisitions without risks for the subjects; it returns three-dimensional data about the spine; it allows to evaluate the dynamic aspect of the posture. This last point is particularly important, because the use of a ionizing instrumentation does not permit to evaluate the incidence of postural variability on the parameters used for Ponseti classification and for Cobb angles calculation. According to the previously proposed classification for error sources of the AUSCAN System Analysis, we focused on System error and on in vivo repeatability of the phenomenon, knowing that the latter includes the former. We designed a protocol in order to define the quantitative criteria used for the 3-DEMO classification .We demonstrate that the new 3-DEMO morphological classification has a high repeatability when evaluated with an optoelectronic system such as the AUSCAN System, whose systematic error is very low. This means that the implied physiological phenomenon is consistent and overcomes the postural variability inherent in the measured object (normal or pathological subject). If alternative methods are developed in the future, to be applied in everyday clinical usage (studies with this aim are already under way), the repeatability of each single method needs to be assessed.

The 3-DEMO classification has already been proven that is able to differentiate scoliosis patients from normals and to be repeatable [22, 21]. In the process of validation of a new classification, an unavoidable step is to verify if it describes adequately the phenomenon considered (construct validity): a way to verify this issue is the comparison with the already existing classifications (concurrent and criterion validity). The best correlation between 3-DEMO and another clinical existing classification of idiopathic scoliosis is the correlation with Ponseti-SRS. This can be easily understood when thinking that both classifications are morphological.

We have found some correlations between the 3-DEMO classificatory parameters and the classical radiographic classifications and measurements. These results support the hypothesis of a possible clinical significance for this classification, even if follow-up studies are needed to better understand these possible correlations and ultimately classification usefulness. Another study is needed to compare this classification with the existing 3D in order to understand how previously described classificatory items behave in the 3-DEMO environment.

3.5. Clinical findings of 3DEMO classification for scoliosis

The classification has been named 3-DEMO, the acronym of Three-Dimensional, Easy, Morphological classification, to summarize its characteristics. In fact, even if in this paper the Classification has been necessarily derived at first through a complex optoelectronic device, the aim was to find 3D morphological parameters easy to be understood by clinicians. This required the use of real 3D reconstructions of the spine. Through this work we propose the 3-DEMO classification of vertebral deformities from a clinical point of view. The word “Easy” refers to the final classification, because the existing 3-D classifications are not. We think that the concepts of Direction and Shift are easy, while Phase it is so graphically, but also theoretically, once understood. The technological system (AUSCAN) used to develop the classification was unavoidably a complex and not every-day clinical usage one, because we needed to have a three-dimensional representation of many curves to look at and to develop an insight (such as this one) to be translated in the next future on everyday practice. In fact, we are already working on x-rays and clinical measurements to obtain the same results without the AUSCAN System (this will be presented in a future paper). The novelty of this classification is the application of the quasi-three-dimensionality concept to spine visualization in an auxiliary plane (horizontal plane), the Top View. The chosen spinal analysis was the only one which allowed both a reduction in the inherent variability of the classic Top View (global) and the possibility of achieving an isolated view of the spine. The following steps will include the development of means to obtain (and then use) this classification in everyday clinics.

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Section VI

Inclusion Criteria

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Inclusion and Assessment Criteria for Conservative Scoliosis Treatment

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Abstract. The efficacy of brace or conservative treatment in adolescent idiopathic scoliosis is controversial due to variations in inclusion and assessment criteria. This makes the interpretation of brace studies and their comparisons difficult. The Scoliosis Research Society recently introduced new standardized inclusion and assessment criteria for future brace studies. The inclusion criteria include: age 10 years or older at initiation of bracing, Risser sign 0-2, primary curve magnitude 25 to 40 degrees, no prior treatment, and females either premenarche or less than one year post-menarche. The assessment criteria include: percentage of patients with ≤ 5 degree curve progression and percentage of patients with ≥ 6 degree curve progression at skeletal maturity, percentage of patients who had surgery or recommended before skeletal maturity, percentage of patients with curves exceeding 45 degrees at maturity, and a minimum of 2 years follow-up beyond skeletal maturity for those patients felt to have been successfully treated. All patients treated irregardless of compliance are to be included in the results (intent to treat).The use of these criteria should assist in the determination of the effectiveness of brace treatment, as well as accurate comparison between patient groups and different braces.

Keywords: Brace or orthotic treatment; adolescent idiopathic scoliosis; inclusion criteria; assessment criteria.

Introduction

The efficacy of conservative or brace treatment in adolescent idiopathic scoliosis (AIS) is one of the most controversial topics in pediatric orthopaedics. Although braces have been used for nearly 45 years, there are no definite conclusions. There have been numerous previous studies that have summarized the results of brace treatment [1-35]. Many studies have supported the effectiveness of brace treatment in preventing curve progression and the ultimate need for surgical intervention [1– 4, 7–10, 13–15,17–24,26 –30,32–36]. Others have suggested that brace treatment may not be effective [6, 11, 12, 16, 25, 31]. A major problem in the interpretation of these studies is that the inclusion criteria have varied considerably from one study to another. The age range at initiation of bracing, inclusion of both males and females, the patients maturity

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or Risser sign, the menarchal status of female patients, curve magnitude, and lack of stratification of results regarding curve pattern, curve size, and maturity have made comparisons between studies difficult.

As a greater understanding of the natural history of AIS has been gained, patients who are at increased risk for curve progression have been better identified [37-43]. Subsequently, studies over the past decade have improved, primarily through the exclusion of patients who are known to have a low risk for progression. Patients who were skeletally mature at brace initiation, those with curves so small that progression was unlikely, those who had curves so large that brace treatment would not be effective, those who have had prior treatments, and non-idiopathic (such as congenital or neuromuscular deformities) should be excluded. Unfortunately, recent studies still differ significantly among their inclusion criteria, making comparisons difficult.

There has been even less uniformity in defining appropriate assessment criteria for what represents success or failure of brace treatment. Some studies consider treatment a success only if curve progression does not exceed 5 degrees by the time patients reach skeletal maturity. For others, success has been defined as less than 10 degrees progression, if the curve is less than 45 degrees at skeletal maturity, or if surgery was not necessary irregardless of the amount of curve progression. This variation in the assessment of brace results makes it difficult to determine the efficacy of treatment and to compare the results. These differences emphasize the need to for consistent inclusion and assessment criteria for future brace studies. The controversy of brace efficacy and the lack of standardized criteria has resulted in the United States Preventive Health Task Force in 2004 recommending against screening of asymptomatic adolescents for idiopathic scoliosis [44]. One of the major reasons for this decision was the lack of an evidence-based medicine data for an effective non-operative or conservative method of treatment.

Because of these issues, the Scoliosis Research Society (SRS) Committee on Bracing and Non-operative Management in 2005 recommended and published standardized inclusion and assessment criteria for future bracing studies in AIS [45]. These criteria are to serve as guidelines and to make comparisons among future studies more valid and reliable.

SRS Inclusion and Assessment Criteria for Brace Studies

Inclusion Criteria

The SRS recommendations for optimal inclusion criteria for AIS brace studies are presented in Table 1. These include age 10 years of age or older when the brace is prescribed, Risser sign 0-2, primary curve magnitude 25 to 40 degrees, no prior treatment, and for females either pre-menarche or less than one year post-menarche. These criteria are uniform and designed to include those patients who are at the greatest risk for curve progression.

Table 1. New SRS Inclusion Criteria for Bracing Studies

10 years of age and older
Risser sign 0-2
Primary curve magnitude 25 to 40 degrees
No prior treatment
Females – premenarchal or less than one year postmenarchal

Assessment Criteria

The assessment criteria of brace effectiveness are the most controversial and variable in the orthopaedic literature. The SRS recommended criteria for assessment of brace studies for AIS are listed in Table 2. These include the percentage of patients who had 5 degrees or less curve progression and the percentage of patients who had 6 degrees or more progression at skeletal maturity, the percentage of patients who had surgery recommended or performed before skeletal maturity, the percentage of patients who progressed beyond 45 degrees indicating possible need for surgery, and a minimum 2 year follow-up beyond skeletal maturity for each patient who was considered successfully treated with a brace to determine the percentage of patients who subsequently had surgery recommended.

Skeletal maturity was defined as when less than one centimeter change in standing height had occurred on measurements made on two consecutive measurements six months apart. If standing height measurements had not been obtained, then maturity was considered to have been achieved when Risser 4 is present, and in females, when they are 2 years post-menarche.

All patients, regardless of compliance with their brace, are to be included in the analysis of the results. Therefore, these results in an "intent to treat" analysis. It is possible to include an efficacy analysis in which noncompliant patients can be excluded from the results to document the efficacy of brace treatment in those patients who were compliant.

It was also recommended that all studies should provide results stratified by curve type, curve magnitude grouping, and skeletal maturity provided there are sufficient number of patients to be statistically significant. It was further recommended that consideration be given to functional and psychological outcome parameters in future studies. This could include such analyses Child Health Questionnaire, the Self-Image Question are for Young Adolescents, and the Peds QL.

Table 2, New SRS Assessment Criteria for Brace Effectiveness

Percentage of patients with ≤ 5 degree curve progression at skeletal maturity
Percentage of patients ≥ 6 degree curve progression at skeletal maturity
Percentage of patients who had surgery or recommended before skeletal maturity
Percentage of patients with curve progression 45 degree indicating possible need for surgery
Minimum 2 years follow-up past skeletal maturity for each patient who was successfully treated

Recent Studies Using the New SRS Criteria

Two studies have recently been published which attempted to utilize the new SRS inclusion and assessment criteria [46,47]. However, both studies modified the assessment criteria, again, demonstrating the difficulty in performing standardized comparable studies.

Janicki, et al published a comparison of the thoracolumbosacral orthosis (TLSO) and Providence orthosis in the treatment of AIS [46]. The custom TLSO was worn 22 hours per day, while the Providence orthosis was worn for 8 to 10 hours a night. Only 83 of 160 potential patients met the new inclusion criteria. The reasons for exclusion included inadequate initial data, inadequate follow-up, younger age at initiation of brace treatment, previous brace treatment, advanced Risser sign (Risser 3 or 4), curve magnitude 41 degrees or greater, and a later change in diagnosis. There were 48 patients in the TLSO group and 35 patients in the Providence group. However, only a minimum of one year of follow-up was used for those patients who were felt to be successfully treated in the Providence group to increase the number of patients available for analysis. This was due to its relatively recent use. The authors reported no significant differences in age at brace initiation, magnitude of the major curve, gender, or initial Risser sign between the two groups. In the TLSO group, only 7 patients (15%) progressed 5 degrees or less, while 41 patients (85%) progressed 6 degrees or more, including 30 patients (56%) whose curve exceeded 45 degrees. Thirty-eight patients (79%) ultimately required surgery. In the Providence group, 11 patients (31%) did not progress, whereas 24 (69%) progressed 6 degrees or more, including 15 patients (45%) whose curves exceeded 45 degrees. Twenty-one patients (60%) subsequently required surgery. However, when the initial curve at initiation of bracing was 25 to 35 degrees, the results improved. Five of 34 patients (15%) in the TLSO and 10 of 24 patients (42%) in the Providence group did not progress, whereas 29 patients (85%) and 14 patients (58%), respectively, progressed 6 degrees or more, and 26 patients (76%) and 11 patients (46%), respectively, required surgery. These were statistically significant differences. The authors concluded that using the new SRS inclusion and assessment criteria that the Providence orthosis was more effective for avoiding surgery and preventing curve progression when the primary initial curve at bracing was 35 degrees or less. However, the overall success or orthotic management, in both groups, was inferior to previous studies. This raised the question of the effectiveness of orthotic management in AIS and supported the need for a larger multi-center randomized study using the new criteria.

In a companion article, Coillard, et al reported on the effectiveness of the SpineCor brace using the new standardized inclusion and assessment criteria [47]. This is a dynamic brace that provides curve-specific corrective movements. To be effective and to obtain a neuromuscular integration, the brace must maintain and amplify the corrective movement over time. The brace is worn 20 hours per day for a minimum of 18 months. Between 1993 and 2006, 493 patients were treated with the SpineCor brace. Two-hundred-forty-nine patients met the inclusion criteria. Seventy-nine patients were still actively being treated and were excluded. Overall, 170 patients could have their results assessed. They reported that 101 patients (59%) had 5 degrees or less curve progression until such time as the orthosis was discontinued, 39 patients (23%) required surgical fusion during treatment, 2 patients ultimately had curves exceeding 45 degrees at maturity, and one required surgical within two years beyond skeletal maturity. They also found that 45 of 47 patients (96%) who had 2 years or more follow-up after skeletal maturity had stable spines. They concluded that the Spine Cor brace was an effective method of treatment for AIS.

Conclusions

The success of brace treatment in idiopathic scoliosis remains controversial due to variability in the inclusion and assessment criteria. This makes comparable analyses between patient groups and braces difficult. This controversy recently has led the USPHTF to recommend against school screening because of the failure to document an effective non-operative method of treatment. The SRS has developed new inclusion and assessment guidelines, which, hopefully, will allow future bracing studies to be comparable and answer the question whether or not brace treatment is an effective method of treatment in AIS. The inclusion criteria were developed to capture that group of patients at the highest risk for curve progression and possible surgery. The assessment criteria allow a range of assessments including no progression ($\leq$ 5 degrees), mild progression ($\geq$ 6 degrees), moderate progression (curve worsens but the magnitude remains $\leq$ 45 degrees), and severe progression (curve worsens to a magnitude $\geq$ 46 degrees) with the need for surgery. The results are modified by the inclusion of non-compliant patients (intent to treat), which reflects a significant factor in brace treatment. The ultimate value of the new inclusion and assessment criteria await validation by a large multi-center study.

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Indications for Conservative Management of Scoliosis (SOSORT Guidelines)

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Abstract. This guideline has been discussed by the SOSORT guideline committee prior to the SOSORT consensus meeting in Milan, January 2005 and published in its first version on the SOSORT homepage: http://www.sosort.org/meetings.php [1]. After the meeting it again has been discussed by the members of the SOSORT guideline committee to establish the final 2005 version submitted to Scoliosis, the official Journal of the society, in December 2005. This chapter is a republication from the original paper published in "Scoliosis" BioMed journal and it is included in this book due to its high importance.

Keywords. Idiopathic scoliosis, guidelines, conservative treatment. SOSORT

Definition

Scoliosis is defined as a lateral curvature of the spine with torsion of the spine and chest as well as a disturbance of the sagittal profile [2].

Etiology

Idiopathic scoliosis is the most common of all forms of lateral deviation of the spine. By definition, it is a lateral curvature of the spine in an otherwise healthy child, for which a currently recognizable cause has not been found. Less common but better defined etiologies of the disorder include scoliosis of neuromuscular origin, congenital scoliosis, scoliosis in neurofibromatosis, and mesenchymal disorders like Marfan's syndrome [3].

Epidimiology

The prevalence of adolescent idiopathic scoliosis (AIS), when defined as a curvature greater than 10° according to Cobb, is 2–3%. The prevalence of curvatures greater than 20° is between 0.3 and 0.5%, while curvatures greater than 40° Cobb are found in less than 0.1% of the population. All etiologies of scoliosis other than AIS are encountered more rarely [4].

Classifications

The anatomical level of the deformity has received attention from clinicians as a basis for scoliosis classification. The level of the apex vertebra (i.e., thoracic, thoracolumbar, lumbar or double major) forms a simple basis for description. In 1983, King and colleagues [5] classified different curvature patterns by the extent of spinal fusion required; however, recent reports have suggested that these classifications lack reliability. Recently, a new description has been developed by Lenke and colleagues [6]. This approach calls for clinical assessment of scoliosis and kyphosis with respect to sagittal profile and curvature components. Systems designed for conservative management include the classifications by Lehnert-Schroth [7] (functional three-curve and functional four-curve scoliosis) and by Rigo [8] (brace construction and application).

Aims of conservative management

The primary aim of scoliosis management is to stop curvature progression [9]. Improvement of pulmonary function (vital capacity) and treatment of pain are also of major importance. The first of three modes of conservative scoliosis management is based on physical therapy, including Méthode Lyonaise [10], Side-Shift [11], Dobosiewicz [12], Schroth and others [7]. Although discussed from contrasting viewpoints in the international literature, there is some evidence for the effectiveness of scoliosis treatment by physical therapy alone [13].

It has to be emphasized that (1) physical therapy for scoliosis is not just general exercises but rather one of the cited methods designed to address the particular nuances of spinal deformity, and (2) application of such methods requires therapists and clinicians specifically trained and certified in those scoliosis specific conservative intervention methods.

The second mode of conservative management is scoliosis intensive rehabilitation (SIR), which appears to be effective with respect to many signs and symptoms of scoliosis and with respect to impeding curvature progression [14]. The third mode of conservative management is brace treatment, which has been found to be effective in preventing curvature progression and thus in altering the natural history of IS [15,16]. It appears that brace treatment may reduce the prevalence of surgery [17], restore the sagittal profile [18] and influence vertebral rotation [19]. There are also indications that the end-result of brace treatment can be predicted [20].

Systematic application of the modes of conservative treatment with respect to Cobb angle and maturity

Guidelines for conservative intervention are based on current information regarding the risk for significant curvature progression in a given period of time. Each case has its own natural history and must be considered on an individual basis, in the context of a thorough clinical evaluation and patient history [21]. Estimation of risk for progression is based on small (n < 1000) epidemiological surveys in which children were diagnosed with scoliosis, and radio graphed periodically to quantify changes in curvature magnitude over time [22-44]. Such surveys support the premise that, among populations of children with a diagnosis of idiopathic scoliosis, risk for progression is highly correlated with potential for growth over the period of observation. In boys, prognosis for progression is more favourable, with relatively fewer individuals having curves that progress to >40 degrees. For SOSORT guidelines, prognostic risk estimation is based on the calculation of Lonstein and Carlson [33]. This calculation is based on curvature progression observed among 727 patients (575 female, 152 male) diagnosed between 1974–1979 in state of Minnesota (United States) school screening programs, and followed until they reached skeletal maturity. (See Figure 1).

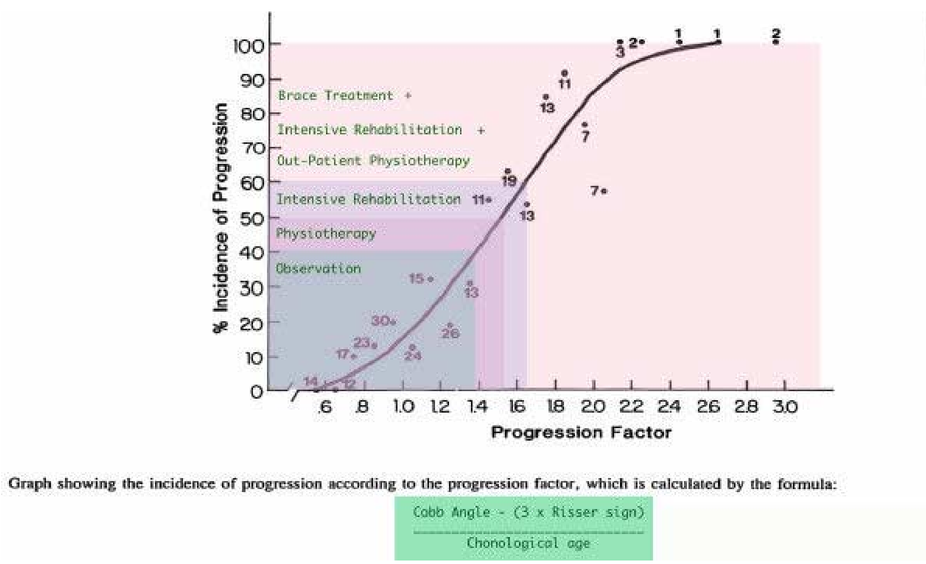

Figure 1.The estimation of the prognostic risk to be used during pubertal growth spurt (modified from Lonstein and Carlson [33]). The numbers in the figure indicate the number of cases that each data point is based on. Note the small number of cases on which the upper margins of the graph are based. Lonstein and Carlson's progression estimation formula is based on curves between 20 and 29 degrees.

Children (no signs of maturity)[21]

a. < 15° Cobb: Observation (6 – 12 month intervals).
b. Cobb angle 15–20°: Out-patient physical therapy with treatment-free intervals (6–12 weeks without physical therapy for those patients at that time have low risk for curve progression). In this context, 'Out-patient physical therapy' is defined here as exercise sessions initiated at the physical therapist's office, plus a home exercise program (two to seven sessions per week according to the physical therapy method being applied). After three months, one exercise session every two weeks may be sufficient.
c. Cobb angle 20–25°: Out-patient physiotherapy, scoliosis intensive rehabilitation program (SIR) where available. SIR, currently available at clinics in Germany and Spain, includes a 3- to 5- week intensive program (4 – 6 hour training sessions per day) for patients with poor prognosis (brace indication, adult with Cobb angle of > 40°, presence of chronic pain).
d. > 25° Cobb: Out-patient physical therapy, scoliosis intensive rehabilitation program (SIR) where available and brace wear (part-time, 12–16 hours).

Children and adolescents, Risser 0–3, first signs of maturation, less than 98% of mature height

The following section is based on progression risk rather than on Cobb angle measurement because of the changing risk profiles for deformity as the skeleton matures. For our purposes, progression risk is calculated by the formula shown in figure 1.

a. Progression risk less than 40%: Observation (3-month intervals).
b. Progression risk 40%: Out-patient physiotherapy.
c. Progression risk 50%: Out-patient physiotherapy, scoliosis intensive rehabilitation program (SIR) where available.
d. Progression risk 60%: Out-patient physiotherapy, scoliosis intensive rehabilitation program (SIR) where available + part-time brace indication (16 – 23 hours [low risk]).
e. Progression risk 80%: Out-patient physiotherapy, scoliosis intensive rehabilitation program (SIR) where available + full-time brace indication (23 hours [high risk]).

First presentation with Risser 4–5 (more than 99.5% of mature height before growth is completed)

a. > 25° Cobb: Out-patient physical therapy.
b. > 30° Cobb: Out-patient physical therapy, scoliosis intensive rehabilitation program (SIR) where available.

Adults with Cobb angles > 30°

Out-patient physical therapy, scoliosis intensive rehabilitation program (SIR), where available.

Adolescents and adults with scoliosis (of any degree) and chronic pain

Out-patient physical therapy, scoliosis intensive rehabilitation program (SIR) where available, with a special pain program (multimodal pain concept/behavioural + physical concept), brace treatment when a positive effect has been proven [45].

The prognostic estimation and corresponding indications for treatment apply to the most prevalent condition, idiopathic scoliosis. In other types of scoliosis a similar procedure can be applied. Exceptions include those cases where the prognosis is clearly worse, for example in neuromuscular scoliosis where a wheelchair is necessary (early surgery for maintaining sitting capability may be required). Other reasons for the consideration of alternative treatments include:

- Severe decompensation
- Severe sagittal deviations with structural lumbar kyphosis ('flatback')
- Lumbar, thoracolumbar and caudal component of double curvatures with a disproportionate rotation compared to the Cobb angle and with high risk for future instability at the caudal junctional zone
- Severe contractures and muscles shortening
- Reduced mobility of the spine especially in the sagittal plane
- Others to be individually considered [46]

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Section VII

Various Methods of Physiotherapy

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Specific Exercises in the Treatment of Scoliosis – Differential Indication

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Abstract. Different methods of physiotherapy are applied in scoliosis management and different opinions exist about the efficacy of conservative scoliosis treatment. Because this divergence of opinions corresponds to a great variety of standards applied, it is not surprising that also the results of conservative treatment greatly differ. Scoliosis normally does not have such dramatic effects that immediate surgery would be indicated. Moreover it is clear that functional and physiological impairments of scoliosis patients--including pain, torso deformity, psychological disturbance and pulmonary dysfunction-- require therapeutic intervention.
The triad of out-patient physiotherapy, intensive in-patient rehabilitation (SIR) and bracing has proven effective in conservative scoliosis treatment in central Europe. Indication, content and results of physiotherapy are described and discussed in this paper. The differential indication of methods of physiotherapy assigned to current "Best Practice" is documented here as well.

The positive outcome of current "Best Practice" conservative management validates a policy of offering conservative treatment as an alternative to scoliosis patients, including those for whom surgery is discussed.

Keywords. Scoliosis, conservative treatment, physiotherapy, rehabilitation

Introduction

Scoliosis is a term used to describe lateral curvature of the spine [1]. Most cases involve thoracic vertebrae, whose axial rotation fosters three-dimensional deformities of the torso [2,3,4]. A resultant loss of rib cage-spine coupling patterns leads to restrictive lung disease secondary to reduced chest wall compliance (CCW); CCW and vital capacity (VC) are inversely correlated with curvature magnitude down to a Cobb angle of ten degrees [5]. Even when resting VC is found to be normal, respiratory challenge reveals reduced exercise capacity even in children with mild curvatures [6,7]. Symptoms of thoracic scoliosis may include shortness of breath, recurrent respiratory infection, chronic pain and psychological distress [5,8,9,10,11]. In severe cases, death may result from right-sided heart failure, however it does not occur in most scoliosis patients and does not occur in those patients with detection during adolescence. The impact of mild to moderate respiratory distress occurring in thoracic scoliosis has not been examined, but recent studies have shown that in non-scoliotic adults reduced exercise capacity is a better predictor of mortality than diabetes, heart disease, and smoking [12,13,14]. Although there are many known causes of scoliosis, spinal deformity of unknown origin or 'idiopathic' scoliosis (IS), comprises 70-90% of all cases.

Once the diagnosis of IS has been made, the risk that the degree of spinal curvature will increase is of paramount clinical interest. Though it is impossible to predict with certainty whether any given spinal deformity will worsen significantly, natural histories have revealed that age, gender, and curvature magnitude are the factors most likely to influence progression in children [15]. In the immature patient, the risk of progression is related primarily to growth potential [15]. Thus, in 109 children diagnosed before the age of ten, incidence of progression was 95% [16], and among 64 children diagnosed before the age of twelve, 75% had progressive curvatures [17]. In contrast, in a study of older patients, 85% of whom were ≥12 years old, progression was only 23% [18]. In girls, the highest risk of curvature progression exists when curves are detected before the onset of menarche, which usually occurs at ≥12 years of age [19,20,21] and usually demands brace treatment. After menarche, the risk for curvature progression drops significantly. For unknown reasons, males with comparable curves have approximately one tenth the risk of progression as females.

In the USA as well as in Great Britain there has been a nearly total absence of clinical research to test the efficacy of proactive, physiotherapy-based methods to treat IS in early stages when curvatures are mild [22,23,24,25]. The rationale to justify lack of early intervention is that in natural history surveys, small curvatures of <15 degrees often remain stable and may even improve while the child is under observation [15,18]. Unfortunately, 'natural history' studies which underlie our existing knowledge base are compromised by the fact that most have included an unknown and undescribed proportion of patients who received physiotherapy including exercises and manipulation [21,26,27,28,29,30,31,32,33]. Because the impact of such treatment has been ignored, the possibility that some curvatures stabilized or improved in response to conservative therapy cannot be ruled out [34]. We believe this situation reflects a long-standing bias against exercise-based therapies in the treatment of IS in English speaking countries, especially the U.S. This bias is reflected in statements such as *"To sum up the indications for an exercise programme, you can prescribe it if you wish, as long as you understand that exercises only treat the psyches of the parents and help the muscle coordination of certain poorly muscled children, who are overweight and under-exercised"* [35].

Two original papers have been cited in support of the anti-physiotherapy position [36,37]. In 1941, a committee of The American Orthopedic Association queried physicians at sixteen clinics in the U.S. They reported that of 185 patients treated with 'exercises of all types,' the deformity was stable in 35%, increased in 61%, and improved in 4% Adequate description of patient ages, exercise regimes, supervision, or follow-up, with regard to outcome of individuals, is not provided. After screening programmes allowed early detection of IS, Stone et al designed a controlled outpatient clinical study to examine the possibility that an exercise programme can influence progression in mild curves (Cobb angle 5-20 degrees). Of 41 children prescribed a short daily home programme consisting primarily of five 'pelvic tilt' exercises, 2 curvatures increased, 31 stayed the same, and 9 decreased; these numbers were not significantly different from those in a matched control group after a follow-up period of 3 months. Unfortunately, only four of the 41 children in the test group self-reported doing the exercises 'daily or almost-daily,' as prescribed; nearly half reported doing them 'never' or only 1-3 times per week. As a result, the authors concluded that *"Based on this study, we cannot conclude that exercise has no effect on change in curvature in* *patients with minimal IS."* They proposed future studies with a longer follow-up, more intensive exercise, and daily supervision to ensure that the programme is carried out as prescribed.

Postural imbalance in response to factors like leg length discrepancy, pain, tumors, and psychological distress is known to cause scoliosis which sometimes resolves when the inducing factors are removed [38,39]. Pain-provoked scoliosis which occurs in response to bone tumors usually resolves if the tumor heals or is treated within a year, but otherwise may be progressive [40,41]. The likelihood that other postural imbalance-induced curvatures will progress to a fixed deformity if inducing factors are not removed is unknown. However, Paul Harrington established that in humans as well as in experimental animals, postural imbalance alone can induce severe scoliosis which resolves when the imbalance is removed before growth is complete [42,43]. In keeping with this conceptual framework, scoliosis treatment by postural-balancing physiotherapy has a long tradition in Europe. Spain, France, Italy and Germany employ physiotherapy in specialised centres. In Eastern Europe, especially in Russia, boarding schools offer an environment where scoliosis patients learn exercise-based treatment strategies in a therapeutic group setting [44].

In Continental Europe [45,46,47] especially in Germany, a conservative treatment approach is pursued actively from the time of diagnosis [48,49,50,51,52,53]. In adolescence, this approach includes outpatient physiotherapy beginning at 15° according to Cobb. Scoliosis intensive rehabilitation (SIR) is recommended for curvatures of 20° to 30°, with or without bracing, depending on prognosis. For adult IS, outpatient physiotherapy is offered for curvatures of 30° to 40° with moderate pain. Physiotherapists in different regions are trained, so that patients have the option of continued outpatient treatment close to their residence. For adult patients with curves over 40° in association with cardiorespiratory functional impairment and pain, SIR is recommended. In-patient treatment offers structure for a daily six-hour intensive rehabilitation treatment.

Out patient Physiotherapy (specific exercises)

Specific exercises are performed on an out-patient basis for patients with curvatures from 15 – 20 degrees. On the one hand curvatures of less than 10° are very common and in principle have a benign prognosis [15], on the other hand physiotherapy is more effective in bigger curvatures than in small ones [48,49]. In Germany, the Schroth programme [2] and exercises following the principles of Vojta [54] are commonly performed [48,49], internationally side Shift exercises [55], Dobosiewicz method [56], the Lyonaise method [46] and SEAS exercises [57] are also in use.

Scoliosis in-patient rehabilitation (SIR)

SIR employs an individualized exercise programme combining corrective behavioural patterns with physiotherapeutic methods, following principles described by Lehnert-Schroth [2] and Weiss [59,60]. The three-dimensional scoliosis treatment is based on sensomotor and kinesthetic principles and its goals are (1) to facilitate correction of the asymmetric posture, and (2) to teach the patient to maintain the corrected posture in daily activities. In Germany the Schroth clinic provides a network of certified physiotherapists to enable the continuation of specific treatment after rehabilitation on an out-patient basis.

Methods

1. The physio-logic® programme

Thoracic flatback has been assumed to be the triggering factor for thoracic Idiopathic Scoliosis [58-61]. So if coupled rotation and lateral deviation of the spine are secondary patterns of deformity in the development of Idiopathic Scoliosis (IS), it should be possible to correct or improve scoliosis by the application of sagittal forces.

Flatback seems to be a major problem in the treatment of patients with idiopathic scoliosis using braces. It has been demonstrated that flatback may be increased instead of corrected using several bracing concepts. There are also other studies to support especially the Boston brace to reduce sagittal curvatures of the spine and in a Pub Med search no study has been found to support the opposite. Boston braces, the Charleston bending brace and most of the other types of scoliosis braces up to now have no pressure points to address the sagittal profile while in the last modifications of the original Chêneau brace pressure points for the correction of thoracic hypokyphosis were introduced [62].

Physiotherapy programmes so far mainly address the lateral deformity of scoliosis [63-66], a few aim at the correction of rotation [2,45-47] and only very few address the sagittal profile [67-70] although already before 1992 Negrini stated that the sagittal deformation is also important to correct with the help of exercises [71]. In some programmes flatback is addressed to some extent, however those programmes failed to show good results [72]. All patients in the treatment programme described got worse within one year of regular treatment. To mobilize the scoliotic spine into a global kyphosis in this way does therefore not appear to be justified.

In the Schroth programme thoracic kyphosis is addressed performing a special breathing technique, however in the exercising position the flatback usually is visible. The results of the Schroth concept seem to be quite good and show that progression can be prevented in many cases [52,53,73-77].

Therefore, the Schroth programme has been developed to be the gold standard of physiotherapy for the treatment of scoliosis in many countries as well as for Scoliosis Intensive Rehabilitation (SIR)[2,50,51,78].

Meanwhile, there is evidence that correction forces applied in sagittal plane are also able to correct the scoliotic deformity in the coronal and frontal plane [79]. In an experimental study comparing the short term effect of two different braces it could be shown that sagittal correction forces lead to similar short term corrections as can be measured with the help of surface topography. This 3D correction brace is at the moment, gold standard in many European countries.

Although the Schroth method addresses also the sagittal plane in the long term [80] the results achieved in the experimental study lead us to the idea to improve excellence in scoliosis rehabilitation by the implementation of exercises to further correct the sagittal deformity in scoliosis patients give the rehabilitation a more powerful effect. We developed an exercise programme aimed at a physiologic sagittal profile to add it to the programme applied at our centre or to replace certain exercises or exercising positions. The exercises of this programme all have the same basic principle to increase and so improve lumbar lordosis at L2 level and lower thoracic kyphosis and are called physio-logic® exercises. The results obtained in an age, sex, curve pattern and Cobb-degree matched controlled study were consistent with the hypothesis that the application of physio-logic® exercises improves the short term outcome of Scoliosis Intensive Rehabilitation (SIR) [81].

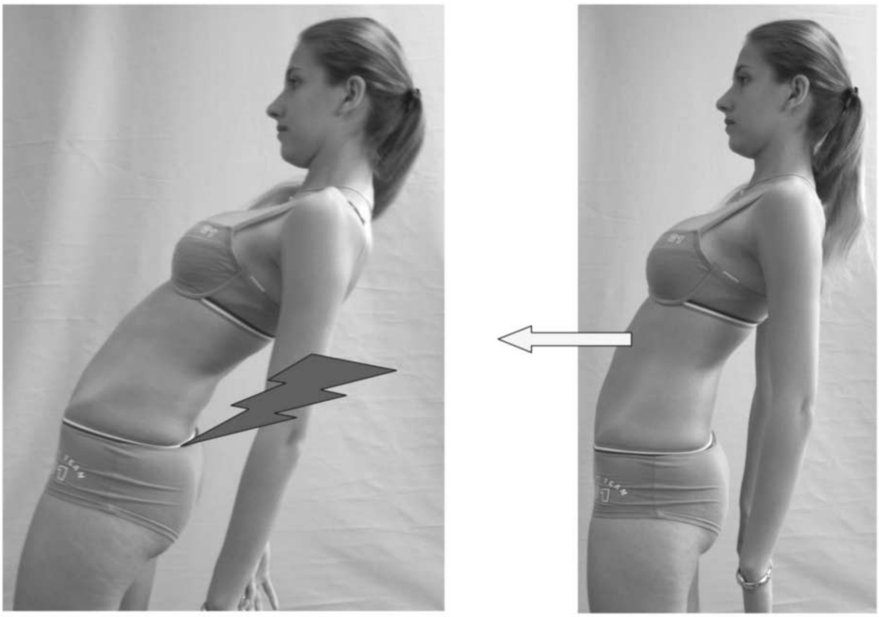

Figure 1. Simply reclining the trunk leads to an increase thoracic kyphosis but also to stress in the lumbosacral region. The last can be prevented by ventralizing the lower ribs to increase lordosis at the L2 level.

Figure 2. On the left exercising position showing the sagittal S-form we try to achieve and on the right phases of the "Catwalk" improving the sagittal profile.

Description of the physio-logic® exercise programme

Within the physio-logic® exercise programme we provide

1. Symmetric mobilizing exercises to improve lordosing mobility of the lumbar spine and kyphosing mobility of the thoracic spine.
2. Asymmetric exercises to improve postural corrections also in frontal and coronal plane and
3. the physio-logic® ADL posture

The symmetric mobilizing exercises are performed repeatedly. Those exercises can only be performed with the help of postural reflexes. Firstly lumbar lordosis is empowered actively and the pelvis is tilted forward while the upper trunk is reclined backwards to improve thoracic kyphosis respectively.

It is not the aim of the exercises to increase lumbar lordosis at the L5/S1 level for this region is responding with unspecific low back pain when stressed. Therefore, we aim to improve lordosis at the L2 level. We can enforce the exactness of the exercise by ventralizing the lower ribs (see Figure 1).

For the asymmetric postural correction in 3D we can use exercises from the Schroth programme modified in relation to the principles of the physio-logic® exercise programme.

Figure 3. "Nuba" position aiming at the physiological S-form in sagittal plane (left picture modified from: http://www.leni-riefenstahl.de).

Activities of daily living (ADL) are very important to change postural stereotype and for this reason the physio-logic® ADL posture is trained in sitting, standing and walking. Therefore, the patients are trained to perform the "Catwalk" which includes the basic principles of the physio-logic® programme addressing the sagittal plane (see

Figure 2) and the ADL (Activities of daily living) posture we call “Nuba”-position (see Figure 3). This position is derived from the normal upright standing and walking position that the Nuba (natural people from North Africa) usually perform.

There is no specific angle or possible range of thoracic kyphosis and lumbar lordosis defined to perform or maintain in the physio-logic® exercises. The muscle groups involved in the exercise action are not yet identified. This might be subject to further investigation.

Because there is evidence that the physio-logic® posture stabilizes the spine and is able at least in part, to correct scoliosis in 3D [79,81] in scoliosis management one can try to use the physio-logic® approach for curves of less than 20 degrees as the only method of treatment

2. 3D-Exercises made easy

The "3D-Exercises made easy" programme is derived from the activities of daily living (ADL). These exercises can be performed in sitting and standing position. Basically a thoracic, a lumbar and a double major exercise can be performed addressing the different curve pattern in 3D. There are also thoracolumbar curve patterns, but these can be adressed by utilising the thoracic exercise (High thoracolumbar curve with apex TH 12; see also Figure 4) or the lumbar exercise (Low thoracolumbar curve with apex L1; see also Figure 5).

The "3D-Exercises made easy" have been shown to be simple to teach [82] and can be used for the treatment of small curves (15 - 25°) together with the physio-logic® programme.

Figure 4. Three curve exercise derived from our ADL training programme: "3D-Exercises made easy". (1) pelvic hypercompensation to the right, (2) rebalancing of the shoulder girdle and retroversion to achieve a better sagittal balance, (3) rotational breathing and (4) stabilisation are the basic principles.

Figure 5. Four curve exercise derived from our ADL training programme: "3D-Exercises made easy". (1) pelvic hypercompensation to the left as there is a significant lumbar counter curve, (2) rebalancing of the shoulder girdle and retroversion to achieve a better sagittal balance, (3) rotational breathing and (4) stabilisation are the basic principles. The corrections in a functional 4-curve patient are not as obvious as in the functional 3.

3. The Schroth programme

The exercise programme according to Schroth is described at length in several publications [2,50,51,78] and in the context of in-patient rehabilitation has been subject to many scientific investigations [83]. The advantage of this programme is the specifity of postural corrections indicated for different curve patterns and the introduction of effective mechanisms to increase postural scoliosis correction in 3D [2, 50,51,78].

Basically the aim of physiotherapy is to enable the patient to attain postural corrections for him or herself, with the exclusive use of trunk muscles. To teach the patient in this objective, the various types of assistance performed by the therapist are essential at first before the patient is able to perform the exercises on his / her own. The therapist gives instructions on how to make slight corrections or adjustments to his / her posture in different parts (‘System of Blocks’ as explained later) of the trunk by means of exteroceptive stimulation or by provoking certain balance reactions. Equally important are the propioceptive stimulations, both through manual passive corrections on the deformed trunk and through changes in articular position, passive traction-compression movements or manual relaxation, activation or elongation tests of elastic structures.

The corrective movements have to be integrated into the patients “postural memory” in order to enable recognition and avoidance of scoliotic postures in daily activities.

Schroth classically considers 5 principles for correction:

1.Axial elongation
2. Deflexion
3. Derotation
4. Rotational Breathing
5. Stabilization

Active axial elongation

Active axial elongation is achieved by self-elongation. The patient has to try and elongate by the active strength of the trunk muscles.

Deflexion

All corrections in the frontal plane, in principle, aim at mirroring the deformity. The frontal deviations of a three-curve scoliosis for example are as follows: the trunk is unbalanced towards the convex thoracic side because of the lateralisation of the thorax (middle block), the pelvis (lower block) towards the concave side as is the shoulder girdle (upper block) and for weight-bearing the patient uses the leg of the convex thoracic side. These deviated blocks are shifted against each other during the correcting movements performed within the Schroth technique[2].

Derotation

For better a understanding of the corrections leading to the derotation of the column, it is recommended to refer to the 'System of Blocks' mentioned above. During the deforming process, the bases of the wedges into which the imaginary initial rectangular blocks transform [2], represent the convexities of the curves, and the apexes represent the concavities. By torsion, the bases rotate towards the dorsal side, and the apexes towards the ventral side. During correction, the apexes should be taken towards the dorsal side, and the bases towards the ventral side (see Figure 6).

Figure 6. 3D autocorrection using the Schroth principles. The pelvis is recompensated, a redressement* of the lumbar hump achieved and the sagittal profile restored in this Schroth exercise called "Hüftholz".

Schroth's rotational breathing

During the physiological respiratory movement all regions of the trunk, thorax and abdomen expand, with the purpose of increasing the volume and the air intake to the lungs. The thoracic cage and inhalation muscles on one side and the lung mass on the other, form two elastic systems acting into opposite directions, joined by the two layers of the pleura and the interpleural space. The scoliosis deformation process causes morphological changes of the trunk. Some areas of the trunk protrude or become convex, and others sink in or become concave. Breathing mechanics do not function as normal. The deformity causes an imbalance in all muscles of the trunk. This imbalance has been established in second place in the deformation process and is both a morphological imbalance and a functional imbalance. The origin and insertion of certain muscular groups move apart and therefore stretch, while the origin and insertion of other muscles move together, resulting in a shortening. And a functional imbalance also occurs: long muscles are subject to sustained passive tension showing a higher EMG activity, short muscles are not.

The result of this morphological and functional muscular imbalance, secondary to scoliosis, is the cause of modified respiratory mechanics, which in turn, influences the evolutional process of the deformity, as asymmetric muscular forces are produced which increase the deforming forces. Whether the muscular imbalance is primary or secondary, once the disorder has been established and it becomes progressive, a vicious cycle is set up in which the deformity increases the imbalance and the imbalance increases the deformity.

The passively increased tone of the overstretched muscles stops the exhalation retraction of the convex areas, causing what is called an inhalation blockage in these areas. On the other hand, in concave areas, the elastic structures adapt to a situation of retraction, with a mechanical advantage over inhalation muscles, which explains the greater exhalation retraction of these areas. During inhalation, all areas of the trunk expand to a lesser or greater degree, and during exhalation, the convex areas remain blocked in inhalation and the concave areas retract again to a situation of greater exhalation. This phenomenon results in increase of the deformity in exhalation, compared to inhalation which reduces it.

Apart from passive and active corrections and asymmetric output positions for exercises, the therapeutic effect on muscular balance is achieved by maintaining the corrections during the exhalation phase.

The patient during Schroth exercises has to tense the convexities and to guide his breath to the concavities of the trunk. The effect of this work by the patient is a propioceptive reinforcement of the sensation of detorsion reaching the vertebral column. This technique is called Schroth's rotatory breathing. Stimulation by the therapist is very important. With a slight pressure of the fingers, the therapist's hand slides over the sunken areas and moves into a corrective direction [2].

Stabilisation

Stabilisation refers to the maintenance of the correction producing a theoretically isometric tension of all trunk muscles in the exhalation phase. It is already explained in the section on respiratory mechanics, how muscular tension produced during exhalation with the maintenance of the correction has an active elongation effect on shortened muscles and an activation of the over-stretched musculature in a shorter position. In this way, the length and muscular sufficiency are recuperated. To increase isometric muscular tension, the patient can use different tools [2].

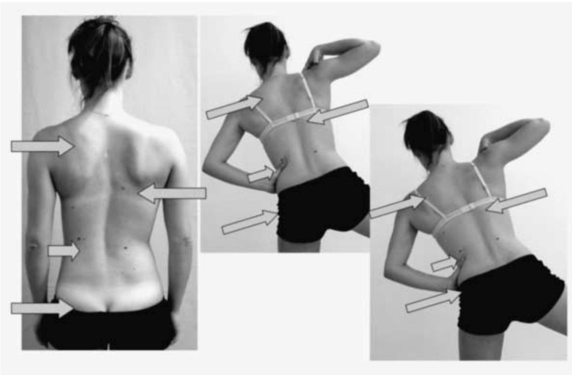

Figure 7. Exercise for a functional 3 curve pattern with neutral pelvis. On the left clinical appearance of the patient, middle picture starting position, right final correction in the exercise. The arrows indicate lateral forces as well as derotation forces directed ventrally.

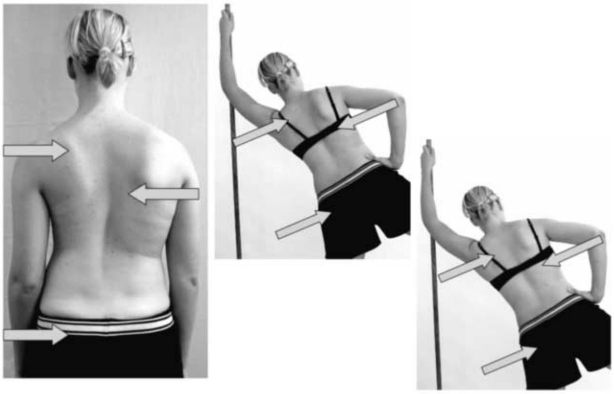

Figure 8. Exercise for a functional 3 curve pattern with decompensation. On the left clinical appearance of the patient, middle picture starting position, right final correction in the exercise. The arrows indicate lateral forces as well as derotation forces directed ventrally.

Within the Schroth exercise programme pattern-specific correction mechanisms are taught depending on the clinical findings of the patient (see Figures 7-10). Although the number of possible curve patterns seems quite high, in the Schroth system we consider four basic curve patterns, which in practice seems enough to address most of the typical findings a scoliosis can present as [2, 50,51,78]:

1. Functional 3 curve pattern with neutral pelvis (see Figure 7)
2. Functional 3 curve pattern with decompensation (see Figure 8)
3. Functional 4 curve pattern (see Fig 9), and as a special form of the 4 curve pattern
4. Lumbar / Thoracolumbar curve pattern (see Figure 10)

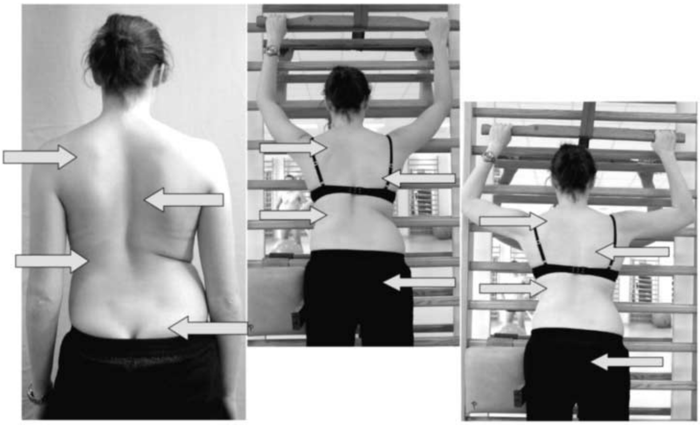

Figure 9. Exercise for a functional 4 curve pattern. On the left clinical appearance of the patient, middle picture starting position, right final correction in the exercise. The arrows indicate lateral forces as well as derotation forces directed ventrally.

Figure 10. Exercise for a lumbar / thoracolumbar curve pattern with decompensation. On the left clinical appearance of the patient, middle picture starting position, right final correction in the exercise. The arrows indicate lateral forces as well as derotation forces directed ventrally.

Due to our improved understanding of the scoliotic influence on the sagittal profile [79-82] a combination of the Schroth, "3D-Exercises made easy" and the physio-logic® principles seem desirable for curvatures exceeding 25 degrees. So for the future more emphasis should be given to sagittal corrections. As uncontrolled autoelongation may lead to flatback we have to focus on the possibilities of 3D postural corrections without elongation.

If – due to the only prospective controlled outcome study [75] available on physical rehabilitation of patients with scoliosis - we regard a combination of Schroth, "3D-Exercises made easy" and physio-logic® exercises as “Best practice” we will have to compare the treatment strategies described herein to other methodological approaches:

1. Methode Lyonaise [46]
2. Side Shift [55]
3. Dobosiewiz [56]
4. SEAS02/06 [57]

The Lyonaise Method aims at 3D postural correction and an improvement of skills the patient needs for autocorrection. The postural correction however is not comparable to that achieved by use of the Schroth technique. The sagittal correction is mainly corrected with the help of certain exercises in the brace. Without the lordosing counteraction of the lumbar pad many exercises from the Lyonaise school lead to a global kyphosis which cannot be regarded effective [72].

The Dobosiewicz Method is not well described in international literature. In Germany little is known about this method of physiotherapy. One aim of this method is the rekyphosation of thoracic flatback. During the exercises the patients are forced into a forward bending posion leading to a kyphosation of the whole spine [56]. How the relordosation of the lumbar profile is established is still an open question for this method of treatment. The only scientific investigation published so far seems questionable, when the average patient from the sample presented according to our guidelines would not be treated at all [56].

The Side Shift technique addresses the deformity in frontal plane only. Meanwhile we have gained evidence that the postural correction can be improved when lumbar lordosis as well as thoracic kyphosis is restored [79,81]. The frontal deviation can be regarded as the secondary deformity [58-61] and for this reason Side Shift exercises have to be regarded as the second choice.

The SEAS exercise programmes presented by Negrini et al. [57] are derived from the Lyonaise school.

Up to now there have been no prospective outcome studies showing the Lyonaise programme to reduce the progression risk or improve other signs and symptoms of scoliosis. Therefore, comparing two programmes without evidence in a randomized controlled study does not seem to make reasonable sense [57].

According to latest knowledge, exercise programmes should be easy to understand, simple and effective. Mobilisation techniques are necessary to change loads on the vertebra.

Results of current "Best Practice" treatment as used in SIR

Case report series have demonstrated that measurable positive changes in the signs and symptoms of IS are correlated with SIR treatment [47,49,50,52]. Among >800 patients, nearly every case revealed a small but significant improvement in chest expansion and a 14-19% improvement in VC after SIR treatment [52]. Among 794 adult patients with severe scoliosis, 55% exhibited at least one sign of right ventricular strain at admission, and by the end only 12% exhibited signs of impairment; VC improved by 250 ml in the same population [83]. Among 107 patients mean Cobb angle decreased from 43 to 39 degrees, with improvements of up to 20 degrees in individual patients after SIR [73]. Studies also have demonstrated significant improvement in pain [53,83] and psychological distress [83] in response to SIR. Results of a preliminary study were consistent with the possibility that incidence of progression among 181 patients treated with physiotherapy during the late 1980's was significantly less than the incidence that would be expected based on natural history surveys [49].

Another study to test the hypothesis that physiotherapy-based intervention can reduce incidence of progression in children with IS was performed recently [75]. A follow-up of the outcome of two prospective studies using the outcome parameter, incidence of progression ($\geq 5°$), in treated and untreated patient groups matched by age, sex, and degree of curvature at diagnosis was the content. A six-week scoliosis in-patient rehabilitation (SIR) programme offering patient-specific physiotherapy including intensive therapist-assisted exercise in diagnosis-matched groups was the method of treatment. The Incidence of progression in groups of untreated patients ranged from 1.5-fold (71.2% vs. 46.7%) to 2.9-fold (55.8% vs. 19.2%) higher than in groups of patients treated with SIR, even when SIR-treated groups included patients with more severe curvatures. Statistically, the differences were highly significant. The results of this study indicated that a supervised programme of exercise-based therapies can reduce incidence of progression in children with IS.

Discussion

Efforts to establish conservative scoliosis treatments have lingered in uncertainty for more than a millennium [1]. Reported successes in clinical studies of treatments like bracing have been controversial because of lack of standardization of protocols and data analysis and lack of reliable information about the natural history of untreated scoliosis [28]. But for judging effectiveness of exercise-based therapies, the primary problem is that no systematic, long-term clinical tests have actually been carried out [1,22,24,25].

The Schroth Clinic has used an exercise-based approach to treat spinal deformity for decades, with a continuous history of positive subjective feedback from patients who now exceed 3000 patients per year. Though the use of postural exercises for scoliosis therapy is grounded in scientific principles that relate directly to known aetiologies and symptoms of spinal deformity, its effectiveness has remained in question. During the past decade a systematic analysis has been undertaken with the long-term goal of examining scientifically the efficacy of this conservative approach to treating IS. Research to date has examined predictions of the hypothesis that physiotherapy can alleviate the signs and symptoms of IS in a multi-layered experimental approach that has included case report series, clinical studies, and population-based comparisons [83]. The results are consistent with the hypothesis that physiotherapy can significantly alleviate the primary symptoms of spinal deformity: pulmonary deficiency, pain and psycho-social issues.

The latest controlled studies cited above support the hypothesis that curvature progression can be reduced by physiotherapy alone [75] and together with effective methods of bracing lead to a reduced rate of patients for whom otherwise surgery would be necessary. Conservative management of scoliosis has to be regarded effective. There are differences in the quality of conservative management worldwide, including differences in the quality of physiotherapy and bracing.

Conclusions

The poor outcome of low quality non operative treatments should not be allowed to detract from high quality non operative management any more. “Best Practice” in physiotherapy in the treatment of scoliosis is described [78] and as long as there are no controlled prospective outcome studies available for other kinds of exercises, nor at least some examples of documented case reports [84] those exercise programmes should not be attributed with the term “evidence based” as long as there is no evidence that it actually changes natural history.

We always must keep in mind that our patients deserve to be treated to the best possible quality available, for they sacrifice their quality of life not only while being braced. They also sacrifice their quality of life to the exercises prescribed in good faith and this is why we have to apply current “Best Practice” [78].

Acknowledgement

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* Redressement = Non surgical correction of a skeletal deformity by hand or by using a brace.

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Scientific Exercises Approach to Scoliosis (SEAS): Efficacy, Efficiency and Innovation

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Abstract. SEAS is an acronym for "Scientific Exercises Approach to Scoliosis". Main characteristics of SEAS are team approach and cognitive-behavioural approach because in our view these are two indispensable elements in chronic disease rehabilitation. In this article we describe the main differences between SEAS approach and other exercise techniques as well as theoretical bases and therapeutic goals. We illustrate practical application of SEAS concept and scientific results in order to reduce the patient's progress of scoliosis so that a brace would be needed. When compared to usual care , improvement of scoliosis parameters and balance normalization in scoliosis patients.

Keywords. Idiopathic scoliosis, physical exercises, conservative treatment

1. The Scientific Exercises Approach to Scoliosis

SEAS is an acronym for "Scientific Exercises Approach to Scoliosis" [3, 4]. As we are used to see in software products, after the acronym there is a dot followed by a number, to indicate the protocol version and the year in which substantial changes were introduced. We now use version ".06". Although SEAS originated long ago (about 30 years)[8, 9, 10], it has been continuously updated so to meet contemporary needs. An exercise-based approach remains updated only if it isn't based on a rigid original idea but can update itself by following acquisitions proposed by the scientific world.

Among the more well-known exercise treatments are the ones of Mézières, Sohier and Klapp [11, 12] that have remained almost unchanged over time, while others, more dynamic, like the Global Postural Rehabilitation according to Souchard, or Schroth [13, 14, 15, 16], have changed over time with the stimulus of new proposals claimed by the original authors and their followers (however, it must be said that today only Schroth [15, 16, 13, 14] and Dobosiewicz [17, 18, 19], together with SEAS[3, 4], have results published in indexed literature).

Hhowever, these innovations are directly suggested by the present leader's intuition, and that some exercises remained basically unchanged since the beginning, contrary to SEAS, which regulates its changes according to evidence coming from new developments proposed by scientific research. For example, in the beginning, Active Self-Correction movement (which is currently proposed as a methodological basis within SEAS [1]) was a simple auto-elongation that was considered to be the best correction solution due to the scientific knowledge in the 1970s (in a consistent way with Harrington's fusion and Milwaukee brace techniques) [20]. Today, however, everything has radically changed because of the knowledge considering three-dimensional deformity,[21] and auto-elongation has been almost completely abandoned, having been replaced by Active Self-Correction on the three spatial planes, according to what is reported below.[22] So, by definition SEAS can radically improve in accordance with new developments, regardless of the original ideas of the person who first devised it.

The team concept is an important prerequisite of SEAS. We believe that we can obtain the best results only if every single element of a heterogeneous team contributes by giving the best of his/her specific competencies, and if effective communication instruments are warranted. The ideal team is an extended group that in its "therapeutic" segment includes the physician, the physiotherapist, trainer and orthotist along with the patient and his/her family.

1.1. From a biomechanical perspective, what are exercises for? Neurophysiology developments indicate the role of Active Self-Correction

To fully understand the biomechanical role of exercises in scoliosis treatment (which, as we will see later, have other equally important roles),[11, 12, 20, 23, 24] and to understand why SEAS has certain unique characteristics relative to other exercise treatments, an in-depth consideration is necessary. Every biomechanical treatment for scoliosis tries to contrast the "vicious cycle" [25] described by Stokes, favouring a less pathological growth of affected vertebrae. In that sense, Active Self-Correction is seen by all experts as the crucial moment of treatment, as was confirmed by the SOSORT Consensus Conference.[24] However, the point is: how can exercises influence this "vicious cycle"? Consider the following:

- Correction obtained with exercises lasts only for the duration of exercise execution;
- Even in more "aggressive" exercise methodologies, in which for certain periods patients are required to do an inpatient exercise treatment lasting up to eight hours per day, [26, 27]it would not be possible to hold the real correction for more than two or three hours, taking into consideration pauses and exercise intervals.
- No one would ever think of proposing a corrective brace for such a short time.

Given all the above, it is obvious that exercises can work from the biomechanical point of view but only through a permanent change in posture. So, the real question is: how can I work better to modify my patient's posture? Which is the best learning method by which to obtain a new posture? Over the years, we have seen a definite evolution from a purely mechanistic model--in which motor learning was considered as related only to obsessive repetition--to a more complex functional model in which repetition plays a role, but its execution in confounding situations facilitates the creation of the correct cortical engrams [5, 6, 7]. Moreover, another question must be asked here: does obtaining the maximum possible correction work better for learning a new posture (passive auto-correction), or is it better to accept a smaller correction but

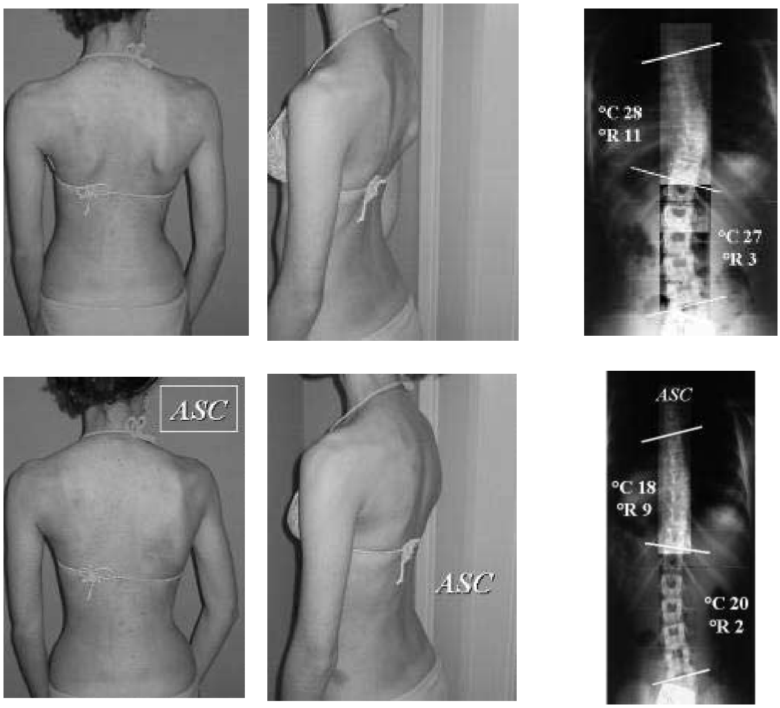

Figure. 1. From a neurophysiological perspective,[5, 6, 7] active movement is much better than passive one to learn neuro-motor behaviours, like posture. Active Self-Correction instead of passive autocorrection, goes towards this direction, with a conceptual passage from "correction" (passive corrective exercises) to "neuromotor rehabilitation" (active exercises to learn behaviours). First line: normal posture. Second line: Active Self-Correction (ASC). Observe normalization of flanks, increase of thoracic kyphosis and better lumbar lordosis, radiographic results (C: Cobb; R: Raimondi rotation

actively obtained without external aids, i.e. limb attitudes, supports or muscles that are not peculiar to the spine (Active Self-Correction)? According to the same literature,[5, 6, 7] and from a neurophysiological perspective, active movement is much better than the passive one to learn neuro-motor behaviours such as posture (obviously once accepted that posture is not only a matter of anatomy but also of neuro-motorial behaviour). Moreover, this Active Self-Correction (see Figure 1) can be replicated in a thousand different exercises with "distracting" situations, thereby "strengthening" the neuromotor behaviour. The SEAS answer specifically addresses this direction, with a conceptual passage having a precise neurophysiological basis that brings the patient from "correction" (passive corrective exercises) to "neuromotor rehabilitation" (active exercises to learn behaviours).

Therefore, even if during the SOSORT Consensus Conference [24] the importance of auto-correction has been underlined, we must notice that almost every school of exercise, with the exception of SEAS,[22] is based on a passive auto-correction approach. From our point of view, auto-correction to become Active Self-Correction should be done by the patient exclusively through the spinal deep paravertebral musculature, without external help, thus pursuing the precise control of movement without using muscular contractions strategies that drive the spine into a passive

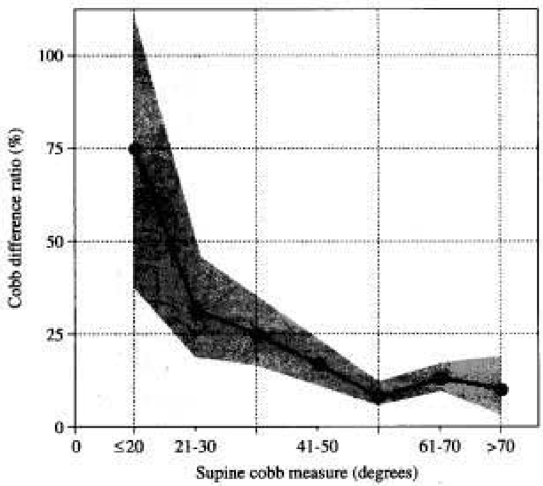

Figure. 2. The postural component has been measured,[2] and corresponds to almost 10°, whose importance is obviously higher in scolioses < 20 °Cobb, that are the ones most targeted by exercises for preventive purposes.

alignment (for example, contraction of concavity psoas muscles in order to reduce lateral flexion component in a lumbar scoliosis).

2. SEAS therapeutic goals

Exercises do not have a strictly biomechanical role[11, 12, 20, 23, 24]. Before we explain the essential principles on which SEAS is based, it is necessary to underline two other preliminary remarks: From a scientific point of view, we are still far from defining the cause of idiopathic scoliosis. Regarding idiopathic scoliosis, we are certain of only a few elements regarding the functional impairments it causes or those with which it is associated. The research has chiefly served to clarify a series of dysfunctions that the scoliotic patient experiences and that exercise treatment based on the SEAS approach tries to reduce. The treatment schedule points to the identification of a series of therapeutic goals that vary depending on the phase of treatment and that must be pursued each time with the most effective weapons available. The main dysfunctions experienced by a scoliotic patient can be schematically described as follows.

2.1. Posture and stability impairments

Increasing spinal stability is a primary therapeutic goal of the SEAS approach. The importance of this rehabilitation aspect is derived from a series of fundamental studies. Duval-Beaupère [28] showed that scoliotic curve magnitude is not only the result of a structural deformation but that there is also a postural component signifying a difficulty of the stabilizing system in the spine to counterbalance the alignment loss. This component, which is always present, is particularly important in the scoliosis < 20°

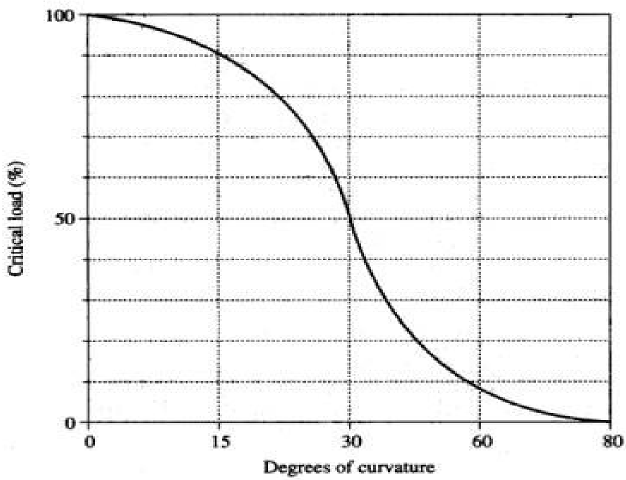

Figure. 3. Load threshold beyond which the spine begins to get deformed (critical load) diminishes as curve increases.[1]

Cobb [2] that are most targeted by exercises for preventive purposes. From these observations, as well as Bunch and Patwardhan's[1] studies--which showed how the load threshold beyond which the spine begins to get deformed (critical load) diminishes as curvature increases--emerge the importance of improving spinal stabilisation in order to reduce postural collapse and the consequent spinal structural deformation potentials. The importance of improving spinal stability derives not only from scientific experiments but also from clinical evidence: a scoliotic spine can be seen as a structure whose constituent elements, being subject to stimuli causing a loss of balance, are no longer able to maintain their physiological alignment and primitive stability. The natural history of a progressive scoliosis could therefore be a postural collapse on several planes, which afterwards becomes a bone deformity in accordance with the "vicious cycle" theory ideated by Stokes[25] (see Figure 2). Even during the SOSORT Consensus Conference, which took place in Milan in 2005,[24] in regard to defining the most important therapeutic goals for scoliosis conservative treatment, the pursuit of vertebral stabilisation was indicated as the second priority. The difficulty probably lies in the practical way that such result can be obtained. The therapeutic strategy proposed by the SEAS approach is based on improving reactions to force of gravity and on enhancing the function of those muscles that have a major stabilizing vocation [29, 2] (see Figure 3).

2.2. Neuromotor impairments

High experts in scoliosis research, like Dubousset [30] Nachemson,[31] and Stagnara [32] and Herman (see Figure 4) [33] have intuitively postulated the correlation between postural deficits and spinal balance/stability. More recently, several authors have also identified, among the aetiological cofactors for scoliosis, balance dysfunctions. This is because a correlation between idiopathic scoliosis and postural control proved to be evident, even if the relationship between deficit magnitude and the progressive potential of curvature has not yet been clarified. On the basis of these observations and

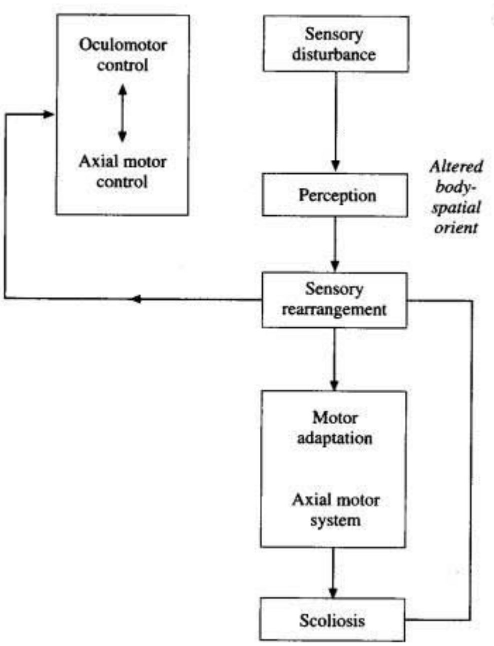

Figure 4. Herman's theory, awarded with the Harrington Lecture by SRS that considers scoliosis as compensation to neuromotorial dysfunctions.

the research results, we can say that the development of **balance reactions** is a fundamental therapeutic goal to which the treatment schemes proposed by SEAS devote particular attention.

2.3. Sagittal plan impairments

Several researches, among which those of Perdriolle[21] and Graf [34] in particular indicate that the evolution of scoliotic curvature is characterised by a reduction of the curves on the sagittal plane (flat or hollow back), a biomechanical condition that, according to White and Panjabi,[35] also facilitates axial rotation. In the exercises proposed by the SEAS approach, the search and preservation of a physiological sagittal orientation in the scoliotic spine is also a main therapeutic goal.

2.4. Other impairments

Finally, we cannot neglect the impairments that scoliosis causes at an organic (aerobic) level, with a reduction of both vital capacity and oxygen conduction ability (VO_2max), [36, 37]the latter of which, among other things, proves to be disproportionate to vital capacity reduction but related to deficient physical conditioning. Furthermore, the psychological aspect is a crucial one: it is partly due to the age at which the pathology appears but also to the often iatrogenic influence on the psyche as determined by treatments and healthcare operators. All these aspects are taken into consideration within the SEAS approach.

A B

Figure. 5. Active Self-Correction on the frontal plane. A - The therapist puts his/her fingers on the spinous processes correspondent to thoracic curve apex, while the patient lets the vertebrae shift towards concavity. B – The therapist puts his/her fingers on the spinous processes correspondent to lumbar curve apex, while the patient lets the vertebrae shift towards concavity side. The counter-support of the therapist's hand on the hemitorax and hemipelvis opposed to curve convexity avoids imbalances.

3. Practical application of SEAS concept

Scientific research showed that scoliosis causes functional impairments at a neuromotor, biomechanical, organic and psychological level[38, 39, 12] Based on the knowledge of these impairments, we derive therapeutic goals to be pursued through exercises in order to prevent and reduce them in the treatment of both low-degree scoliosis and progressive forms in association with bracing. Furthermore, exercises allow us to slow down and in some cases stop progression in low-degree scoliosis, [40, 4] while in braced ones this kind of therapy is useful to increase the orthosis corrective action and avoid its side effects.

3.1. Exercises in low-degree scoliosis treatment

Goals at the neuromotor and biomechanical levels are directed towards postural control and spinal stability, while the goals at the bodily and psychological levels are directed towards aerobic functioning and development of a positive body image.

3.2. Postural control and spinal stability

Nachemson[31] claimed that good spinal stability could neutralize postural deficits and thereby stop the progression of an initial scoliosis. The therapeutic modalities to obtain postural control and spinal stability are postural rehabilitation, muscular endurance strengthening in a correct posture, development of balance reactions and neuromotor integration. [41] Let’s take into consideration these modalities.

A B

Figure 6. Active Self-Correction on the sagittal plane A -By leaning against the upright, the patient then does a pelvis antiversion (to recreate lumbar lordosis) and a thoracic kyphotization (to recreate thoracic kyphosis). B- The patient does the same exercise without the help of the upright, at first looking at him/herself in the mirror.

3.3. Postural rehabilitation

It includes becoming aware of body posture, becoming aware of defects of posture and Active Self-Correction on the three spatial planes. Becoming aware of body posture and defects of posture is obtained through visual (mirror) and tactile (contacts in the various postures) biofeedback and rehabilitator guidance.

3.4. Active Self-Correction

Active Self-Correction on the three spatial planes is the most important individualized therapeutic moment directed towards one's own deformity. It includes several phases, as follows:

- The first phase includes becoming aware of curve apex translation towards concavity on the frontal plane, and is done in several postures (see Figure 5). For example, in the case of a double-curve scoliosis, first we teach how to execute thoracic curve translation and then lumbar curve one; subsequently, we associate the two movements, beginning with lumbar translation.
- The phase immediately following includes becoming aware of correction on the sagittal plane. The studies of Perdriolle,[21] Graf,[34] White and Panjabi[35] highlighted that idiopathic scoliosis, in the case of progression, reduces physiological curvatures on the sagittal plane, favoring vertebral rotation. Exercises must ensure thoracic kyphosis and lumbar lordosis. At the lumbar level, we ask the patient to do pelvis anteversion and a kyphotisation movement at the thoracic level (see Figure 6).
- Finally, we associate active Self-Correction movements on the frontal and sagittal planes. According to Dickson's studies,[42] an action done on two

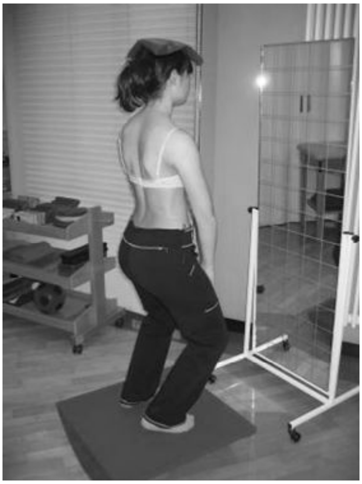

Figure 7. Muscular endurance strengthening in the correct posture.

spinal planes (frontal translation and kyphotisation and/or lumbar increase of lordosis) causes an involvement of the third plane (cross-sectional derotation).

Following the end of the initial learning phase, Active Self-Correction is performed by the patient in an independent manner and applied in every standing exercise.

3.5. Muscular endurance strengthening in the correct posture

Muscle endurance strengthening aims at developing paravertebral, abdominal, lower limbs and scapulo-humeral girdle muscles through isometric contractions. It uses loads that are one-third to two-thirds of maximal load in Active Self-Correction. We ask the patient to execute an Active Self-Correction movement and to hold it for the entire duration of isometric contraction of the chosen muscles (see Figure 7). Panjabi and Abumi's studies showed that the spine needs good muscular support in order to guarantee greater stability in a scoliotic spine. We ask the patient to execute an active Self-Correction movement and to hold it for the entire isometric contraction of the chosen muscles duration (see Figure 7).

3.6. Development of balance reactions

This is aimed at improving axial, static and dynamic balance of the trunk. Proposed exercises are always done in Active Self-Correction, even on unstable planes, developed with growing difficulties (see Figure 8). Stagnara[43] claims that the development of balance reactions must be one of the main goals of rehabilitation because scientific research has shown the presence of some impairments in cortical centers that control balance in scoliotic patients.

Figure 8. Development of balance reactions Proposed exercises are always done in Active Self-Correction, even on unstable planes, developed with growing difficulties

3.7. Neuromotor integration

This aims at integrating in everyday behaviors a more correct and better-balanced spinal posture, progressively developing the ability to react with correct functional

Figure 9. Preparation to bracing. Exercises aimed at increasing range of motion of the spine on all planes, in order to allow the brace to exert the maximum possible correction

attitudes (Active Self-Correction) to the different requirements of social life. We propose exercises that associate Active Self-Correction with global movements, e.g., walking with a simple gait and oculo-manual education exercises, even on unstable planes. In this conclusive phase of treatment, we give ergonomic information so as to avoid spinal damage in adulthood.

3.8. Aerobic functioning and development of a positive body image

These goals are reached through modalities that aren't specific to the therapeutic field: we are discussing, in particular, motor and sport activities that stimulate aerobic functioning (vital and oxygen uptake and consume capacity) and help develop a positive body image. When the patient does not wear a brace, we advise against competitive sports that require an increased range of motion of the spine, particularly in maximum thoracic extension and/or lumbar flexion. According to Stagnara,[23] for a scoliotic patient every motor activity done at a recreational level is beneficial. Such activities, for their limited duration and intensity over time, cannot determine structural changes but offer huge benefits at the bodily and psychological levels.

3.9. Exercises in brace treatment

The main goals of exercises in brace treatment are: elimination or reduction of side effects caused by immobility (muscular hypotrophy), or the brace itself (reduction of sagittal curves, mainly kyphosis, and breathing impairment) and accentuation of brace corrective pushes. [44, 45, 23] Such goals are pursued through specific therapeutic modalities, subdivided into treatment phases:

3.9.1. Preparation for bracing

We request the execution of exercises aimed at increasing the range of motion of the spine on all planes, so as to allow the brace to exert the maximum possible correction (see Figure 9). We also continue proposing mobilisation exercises in the first phase of brace wearing, when it is worn for at least 21 hours per day.

3.9.2. Brace wearing period

We initially propose exercises of "wriggling out of supports" by using the upper and lower limbs so as to facilitate adaptation to brace usage for the recommended number of hours. We propose strengthening exercises, requiring lumbar lordosis and thoracic kyphosis preservation , while frontal and cross-sectional plans correction is guaranteed by brace pushes. During brace treatment, it is of fundamental importance to pursue continuatively these other two goals: aerobic functioning and development of a positive body image. For that reason, we recommend intensifying participation in motor and sport activities, both agonistic and/or recreational, even with a brace that must be worn full time (see Figure 10).During brace treatment, we recommend to intensify participation in motor and sport, both agonistic and/or recreational activities, even while wearing a brace, like in the two cases presented. The presence of the brace should never force any limitation upon the young patient's personal and social life.

3.10. Cognitive-behavioural approach and counselling: compliance and acceptability through humanisation

Chronic pathology tends to cause a change in behaviour and relationships with the outer world[46]. Scoliosis can fall within the group of chronic pathologies because of the long time period required for its therapy, and due to the fact that treatment outcome will not be a complete patient recovery but the best possible control of the deviation[9]. The correct management of this disease is not always easy, because it usually appears in a frail period of life, i.e., the stage of pubertal growth spurt. When treatment includes a brace as well, the young patient's reaction is rarely good. [47, 48] The brace causes a sudden shock and modifies the adolescent's human relationships during a period of dramatic physical change, when he/she is grappling with the acceptation of his/her rapidly changing body, this being the period involving the development of his/her personality and in which the young person is concentrated on weaving the first complex plot of relationships with the other sex. For the parents, it is also a difficult situation. Their natural ambition is to seek the utmost happiness for their children, but they are forced to struggle with the difficult problem of whether to ask the person they love most to make a big sacrifice that is necessary for the child's health, or to try and find a different path with a doubtful efficacy that could be dangerous and create even bigger problems.

In the treatment of chronic pain, the importance of formulating the treatment on the basis of a far less mechanistic nature than before is shared internationally [49]. Chronic back pain is described as a bio-psycho-social problem, i.e., a disorder that has a biologic origin, causes psychological implications of non-acceptance, growing fear and distrust towards problem resolution, until it finally results in depressive behaviours that eventually have repercussions even on relationship dynamics with the outer world. Thanks to this new awareness, we consider every facet of a condition that is much more complex than what we used to think. [50] This has suggested the use of integrated treatment techniques that draw on the experience of other medical disciplines as well. It is the case of cognitive-behavioural approach that originated from experiences developed in psychology field halfway through the past century. [51, 52] The transposition of a cognitive-behavioural approach to scoliosis treatment is aimed at

Figure 10. Aerobic functioning and development of a positive body image

simplifying treatment acceptance, reassurance, looking for a solution to practical problems and stimulating faith towards the outcome. [53]

The essential condition for an effective development of treatment is the definition of the clear and effective two-way communication necessary to win the trust of the patient[54] and family alike. This allows us to:

- Carefully listen to doubts and explanation requests;
- Let the patient/family feel that we understand his/her/their distress;
- Solve practical problems that might arise.

For the practical application of these principles, treatment protocols used at ISICO include a family counselling meeting to be held at the end of each session. This meeting sees the participation of the patient, his/her family, the ISICO rehabilitator who has taught the new exercise plan and, if present, the therapist who in practice follows the patient each time he/she does exercises. It is a moment of utmost importance to reach the described objectives, to regularly consolidate the "therapeutic contract" agreed upon with the patient and his/her family, and to cement the "extended" therapeutic team. It is an indispensable element for an optimal attainment of the final outcome

4. Scientific results of SEAS

4.1. SEAS treatment reduces the need for bracing

The main objective of exercise treatment is to avoid that patient's progress of scoliosis so that a brace would be needed. To verify the efficacy in this respect of the SEAS protocol, we compared in a prospective and controlled cohort study[3] the results obtained in 69 patients at risk of brace treatment; they were divided into two groups and were followed up for a period of one year. Among patients treated with our protocol (SEAS group), bracing was prescribed in one out of twenty cases (6%), while in those treated with standard exercises (CONT group) bracing was prescribed in one out of four cases (25%). This result is statistically significant, and it is relevant because it demonstrates how correctly designed exercises can guarantee scoliosis stability in most cases, thus avoiding more invasive treatments. The follow-up examination after two years of treatment in 38 patients confirmed the differences already highlighted at one year (10% SEAS vs. 27% other group), even if with a reduction of the gap between the two treatments. Further studies with longer follow-up periods and larger study populations will offer more definite results, but already today we know that with correct exercises we can reduce the number of prescribed braces or at least delay their prescription. Because the end of brace treatment always coincides with the end of bone growth, this delay at the start of therapy is another significant result from the patient's point of view.

4.2. SEAS treatment improves scoliosis parameters

In the study already mentioned[3], we also documented exercises results with traditional measures. In terms of Cobb degrees, the percentage of patients who showed a radiographic improvement was 24% in the SEAS group vs. 11% in the CONT group, while the number of worsened cases was superimposable even if slightly lower in the

SEAS group (12% vs. 14%). Upon a clinical evaluation of the largest curve hump using Bunnell's scoliometer, in the SEAS group we noticed a stability/improvement in 73% of cases vs. 58% in the CONT groups.

4.3. SEAS treatment normalizes balance and coordination in scoliosis patients

According to the SEAS protocol, exercises aim at improving some specific impairments of the scoliotic patient so as to normalize them and reduce the risk of progression of scoliosis. Among these, we have equilibrium and coordination. In a controlled cross-sectional cohort study,[55] we evaluated 190 subjects divided into two groups (forty Adolescent Idiopathic Scoliosis patients and 150 controls), and those patients were divided in two sub-groups (twenty treated for one year with SEAS and twenty not treated). All participants were evaluated through Unterberger (Fukuda), Romberg (sensitised and not sensitised) and lower-limb oscillation tests. Patients treated with the SEAS protocol showed results that were superimposable to the ones of control subjects, and on a statistical basis both groups were definitely better than untreated scoliosis patients.

4.4. Active Self-Correction according to SEAS principles reduces the radiographic curve

Auto-correction has been considered by SOSORT experts as a key aim of exercises for idiopathic scoliosis: the Active Self-Correction (ASC) is a kind of auto-correction actively performed by the patient, without any external aid, that forms the base of SEAS. ASC is a selective (i.e. only on the vertebrae involved) lateral de-flexion, sagittal correction (usually increase of kyphosis and preservation of lordosis) and horizontal de-rotation: this movement is very difficult and require some months to be learned. 27 consecutive patients under treatment that required x-ray examination for their clinical follow-up have been included in the study[22]. All patients performed x-ray exam both standard and in ASC; moreover, they all were photographed frontally and laterally to have an evaluation of the quality of ASC. The statistically significant percentage of reduction of scoliosis was 11.0±12.3%, with a reduction of rotation of 13.2±63.4%. This study proves that it is possible to reduce actively the curvature with a selective action, without any external aid, and that expert physiotherapists can teach ASC.

4.5. SEAS treatment improve results in case of bracing

To confirm whether the SEAS protocol, mobilizing and preparatory to the brace, had this ability, we compared, with a controlled prospective cohort study[4] of the beginning of brace therapy, the results obtained at the first radiographic follow-up at four months in 110 patients, divided into two groups. Data showed a higher efficacy of SEAS treatment, compared to standard exercises (CONT group) in regard to cosmetic appearance (Aesthetic Index) and Cobb degrees of the largest curve and hump.

4.5.1. SEAS kyphotisation exercise is the most useful to help bracing push work

We performed a study [45] in seventeen consecutive adolescents to quantify and compare different exercises (kyphotisation, rotation and "escape from the pad" in different positions – sitting, supine and on all fours) performed in braced condition so as to increase their corrective forces. We verified that in static and dynamic conditions the position adopted does not alter the total pressure exerted by the brace. Kyphotisation and rotation exercises guarantee a significant increase of pressure (+ 58.9% and 29.8% respectively), while the "escape from the pad" exercise, despite its name, does not produce any significant variation of pressure. We concluded that exercises in braced condition allow the application of adjunctive forces on soft tissues and, through those tissues, presumably on the spine. Different exercises can be chosen in order to obtain different actions; physical exercises and sporting activities are useful in mechanical terms, although other important actions are not to be neglected.

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Scoliosis Intensive Out-patient Rehabilitation Based on Schroth Method

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Abstract. Conservative management of idiopathic scoliosis (IS) and other spinal deformities is a real alternative to surgical treatment. Most of adolescent with IS can be managed conservatively with high safety. Many infantile and juvenile cases show also a good immediate response to conservative care, which can be considered a sign of good prognosis. Only patients showing a continue deterioration even treated conservatively with efficient techniques should be considered candidates to surgical correction and stabilization. Rehabilitation (including specific exercises) and bracing are usually involved in conservative care of IS. In this paper we describe our personal approach in conservative scoliosis care regarding rehabilitation. Bracing has been described in a different paper also published in the present book. Specific exercises can change the signs and symptoms in scoliosis patients. Specialists in physiotherapy for spinal deformities teach the patient how to perform a routine of 'curve pattern' specific exercises with the purpose to facilitate the correction of the asymmetric posture and to teach the patient to maintain the corrected posture in daily activities. Principles of correction are based on those developed by the German physiotherapist K. Schroth.

Keywords. Scoliosis, physiotherapy, specific exercises, Schroth

Introduction

Although supported by 'old disciplines' like rehabilitation and bracing, conservative management of idiopathic scoliosis and other spinal deformities has gained more and more interest during the last years due to a better definition of the treatment protocols, the development of more specific techniques and the increase of scientific papers reporting outcomes.

The foundation of the SOSORT reflexes this interest. In the SOSORT, three main groups have proposed different rehabilitation protocols all well described in the present book. Since 1968 we have been using similar protocols and techniques than the German school represented currently by the Asklepios Katharina Schroth Rehabilitation Center (AKSK). Weiss has fully described protocols and techniques in his book 'Best practice' in Conservative Management [1]. The objective of this paper is to present our particular approach and to describe the principles of specific exercises which are based on the original Schroth method. The principles used by the so called Barcelona school can be considered as a logic evolution based on the current knowledge of the three-dimensional nature of IS and its pathomechanism of progression. Our evolution has been running parallel to the evolution in the AKSK. However we have received also some influences from the French School (nowadays not well represented in the SOSORT for several reasons). Personal contributions of two of the authors of this paper NP and MR have been essential for such a development.

Barcelona's scoliosis rehabilitation school.

Our approach on conservative management of Idiopathic Scoliosis (IS) is based on:

1. Accurate diagnose and clinical evaluation of the patient.
2. Medical advice according to doctor's knowledge which combines 'evidence based medicine' with clinical acquired experience.
3. Decision making process is further based on the previous medical advise, individual particularities, realistic expectations and patient's consent.
4. Oral information regarding *'not indication for any specific treatment'* is the minimum intervention we offer.

Diagnose is not the issue of the current paper. Notwithstanding, it is remarkable that our treatment principles and program are suitable for spinal deformities in the sagittal plane like the Scheuermann's disease as well as for IS and other spinal deformities 'idiopathic like'. Thus, it can be used also in congenital deformities and those secondary to Marfan syndrome, neurofibromatosis, etc. It is not appropriated to treat neuromuscular scoliosis. Treatment indications are based on the general guidelines of the SOSORT [2], although exceptions due to individual particularities are not uncommon. The SOSORT guidelines are mainly based on the risk for progression. Over-treatment or treatment at the wrong time as well as under-treatment should be avoided. Patient evaluation includes:

1. *Anthropometric measurements;*
2. *Clinical photos;*
3. *Measurement of the Angle of Trunk Inclination or Rotation (ATI);*
4. *Regional angles in the sagittal plane (inclinometer);*
5. *Surface topographic measurements;*
6. *Non-invasive measurements of the scoliosis angles;*
7. *Radiological measurements and*
8. *Breathing function*

Anthropometric measurements

We are currently measuring standing height, sitting height, wingspan, diameter of the thorax at mammary level and weight.

Clinical photos

It is very useful information to diagnose the functional type according to K. Schroth [3] which is related to the curve pattern. Follow-up is also possible by comparing photos in time. Negrini et al. have developed a scale to assess the deformity from the cosmetic point of view from regular photos [4]. Photos are from the back, from the front, from both sides as well as in forward bending. We used in the past photos from dorso-lateral to obtain a dorsal-oblique view but we stopped because these photos did not offer an additional information for follow-up to that already offered by the classical views.

Measurement of the Angle of Trunk Inclination or Rotation (ATI)

We use the classical Bunnell's scoliometer to measure the ATI at three different levels called: upper thoracic, main thoracic and lumbar/thoracolumbar. It is also possible to represent the surface rotation in a graphic by measuring the ATI at 10 equidistant levels according to the Nottingham's approach. Burwell et al [5] found that standing forward bending position had the best reproducibility. However, in a non published study, we found that sitting FB position was reliable enough and correlated better with the surface rotation measured with a surface topography system. Surface rotation (root mean square) can be calculated from the 10 ATIs values and compared in time for follow-up.

Regional angles in the sagittal plane

The thoracic region is normally kyphotic and its angle (regional kyphotic angle) can be measured by using a Saunders® digital inclinometer. Also the angle of lordosis in the lumbar region can be measured with this device. The SpineScan® is another device to measure the kyphosis in the thoracic region. We have found the Saunders to be comparable with the classical Myrin® inclinometer [6]. The Myrin® inclinometer was shown to be accurate and reliable enough [7]. In any case, lecture is easier with the Saunders® compared with Myrin's inclinometer.

Surface topography measurements

We have been using the Formetric® system since 1994 [8,9,10]. The system is able to reconstruct the spinal midline and reports about its shape in the frontal plane as well as in the sagittal plane. A graphic showing surface rotation is also provided. The Formetric® produces an impressive amount of values like trunk length and imbalance, pelvis tilt and torsion, lateral deviation surface rotation, kyphotic and lordotic apexes and angles, inflectional point, etc. Two graphics showing segmental inclination and segmental convex/concave surface profile can be found in the Formetric® report.

Formetric® system measures the back asymmetry and reports about the virtual geometry of the spine. This information can be used for follow-up independently of the real spinal shape which can be observed just in the radiograph.

Non-invasive measurement of the scoliosis angles

The Cobb angle of the scoliotic curve can be measured by using a non-invasive method from the surface with a recently presented system called Orthelius ®. The Cobb angle measured with the Orthelius is comparable to the Cobb angle measured on the radiograph [11].

Radiological measurements

We recommend the measurement of the Cobb angle of the main curve/s as well as the minor and compensatory curve/s. The End Vertebra Angle (EVA) is also useful to determine if the scoliotic curve is symmetric (e.g. EVA A ≅ EVA B) or asymmetric (EVA A ≠ EVA B). It is important to measure the angle of axial rotation (Perdriolle and/or Raimondi). Spinal imbalance according to the Central Sacral Line (CSL) can be determined at T1 (or C7) and at the transitional point between the thoracic and the lumbar/thoracolumbar curve. The Risser sign can be also established using a standard AP or PA radiograph. The regional thoracic (T3-T12) and lumbar (L1-L5) angles can be measured in the latero-lateral projection. Thoracic region is normally kyphotic and lumbar region lordotic. The anatomical transitional region should act as geometrical transitional region (the sub-region T10-T12 should be kyphotic and the sub-region T12-L2 should be lordotic). The restricted sagittal Cobb angle is more accurate than the regional in order to define a thoracic or a lumbar flat back [12]. The scoliotic End Vertebrae are taken as End Vertebrae also for the restricted sagittal angle (see Figure 1).

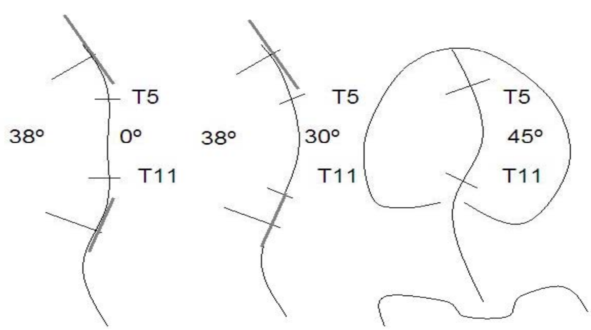


Figure 1. An example where the regional thoracic angle (38º) is the same in two different cases presenting the same Cobb angle in the frontal plane (45º). However, the restricted thoracic angle is different, 0º in the first case and 30º in the second case. The restricted thoracic angle (between T5 and T11 which are at the same time the End Vertebrae of the scoliotic curve) represents better the geometrical flat back in the first case, not present in the second case.

Breathing function

Although incomplete, a basal spirometry with a simple spirometer is useful for follow-up, especially in patients under brace treatment. A full description of the necessary tests to assess breathing function in scoliotic patients is not the objective of the present paper.

The etiology and pathogenesis (cause/s and first event/s) of Adolescent Idiopathic Scoliosis (AIS) is still not known. Prevention would be possible only according to some hypotheses and theories. Consequently, the theoretical basis for specific exercises and bracing is more closely related to the current knowledge on the pathomechanism of progressive AIS and its three-dimensional (3D) nature rather than its etiology. Some factors for progression have been well established and new ideas for the 3D correction of scoliosis have been developed. These factors and ideas will be explored in more detail in the present paper.

Three-dimensional nature of AIS

Scoliotic deformity can be described as a *'series of vertebral segments placed in extension or lordosis, which deflect and axially rotate towards the same side'* (Dubousset 1992). Rather than a succession of lateral deviations '*idiopathic scoliosis represents the combination of torsional regions joined by junctional zones'* [13]. However, the intention of the specific exercises is to change the geometry of the spine. The shape of a scoliotic column is better defined from a geometric perspective rather than anatomic. Aubin described (1998) scoliosis as a '*complex process of trunk deformation including morphological changes and a global transformation of the shape of the column, which moves from its original position in the sagittal plane, to a complex torsional geometry in the three dimensions of space'* [14]. The Scoliosis Research Society (SRS) recognize two meanings to this term torsion [12]: The first is mechanical torsion, which refers to the torsional deformity of the column considered as a plastic structure. Mechanical torsion affects the disc (intervertebral torsion) as well as the vertebra (intravertebral torsion) [15]. The second meaning is geometrical torsion. Geometrical torsion is defined as the 'tortuosity' of the spine considered as a line in space. The column changes its physiological shape in the frontal, transverse and sagittal planes, adopting extremely diverse anatomoradiological patterns. Torsional forces produce both mechanical and geometrical torsion. Geometrical torsion is related to translation of the apical vertebra. Several authors have described the evolution of a right thoracic scoliosis as a torsional phenomenon that translates the apical vertebra first ventro-lateral and further latero-dorsal, away from the upper end vertebra (UEV) [16, 17]. Consequently, the scoliotic spine initially becomes more or less lordotic, from any given configuration, and further develops as a paradoxical kyphoscoliosis. Obviously, nowadays few scoliosis cases progress to reach this last condition. It must be differentiated between geometrical lordosis and structural lordosis (see Figure 2). Morphologically, IS is a fixed lordotic deformity of the spine, however the degree of this anatomical lordosis is variable. On the other hand, the scoliotic spine can adopt highly variable saggittal profiles from a geometrical lordosis to a paradoxical kyphosis.

Generally speaking, scoliosis correction may be achieved through distortion corrective forces, with the intention of better aligning the column in the frontal plane and normalizing the sagittal configuration of the spine [13].

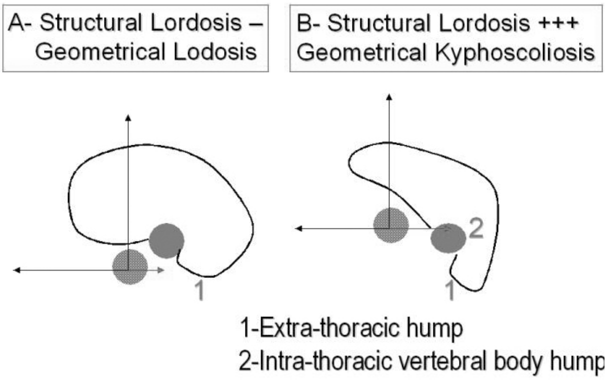


Figure 2. A) represents a case with a thoracic scoliosis geometrically lordotic. According to Dubousset and Dangerfield, B) represents a case with a severe morphological lordosis and lateral deviation. However, due to hypertorsion, the lateral curve progresses to dorsal in an oblique plane (Paradoxical Kyphoscoliosis).

The pathomechanism of progression

This section is described in another chapter of this book (The Chêneau concept of bracing – biomechanical aspects by Rigo M and Weiss HR) but here fully repeated to an easier and better understanding of the current chapter. R.G. Burwell in Pediatric Rehabilitation published the most recent and complete revision on this topic [18]. Burwell, in agreement with the biphasic concept, concluded that *"there is a view that there are two types of pathogenetic factors for idiopathic scoliosis: initiating (or inducing) factors and those that cause curve progression*". He deeply explores the description of these factors: *"progressive AIS that mainly affects girls is generally attributed to relative anterior spinal overgrowth from a mechanical mechanism (torsion) during the adolescent growth spurt."* There are some biological, morphological, neuromuscular and biomechanical susceptibilities but four main factors have been well established as progression factors: Asymmetrical loading of the spine, vertebral growth modulation, spine slenderness and growth potential.

The four factors are related to the "vicious cycle concept" described by Stokes [19] or "the growth-induced torsion concept" modified by Burwell from Stokes. Stokes showed that an imposed vertebral deformity could be corrected by reversing the load used to create it. *'This implies that the principles of the Hueter Volkmann law are applicable to the correction of an existing vertebra deformity providing there is sufficient residual growth'.* They also showed that '*when the external loading is removed, growth rates return to normal, demonstrating that growth was not permanently affected by previously applied external loading'*. The results of their study have implications in the design, use, and effectiveness of bracing (also physiotherapy) as a treatment method for scoliosis. They suggest that '*if sufficient force is applied to the vertebra the progression of a scoliosis could be arrested, or even reversed'*. Whether or not the progression of a established scoliotic deformity is secondary to asymmetric loading, correction of the deformity using the principles of Hueter-Volkmann law is possible as long as there is sufficient residual growth. Other studies [20,21] have demonstrated the feasibility of the modeling approach achieving at the same time a complete representation of the scoliotic spine.The important question is if any rehabilitation treatment can teach a patient to constantly produce and maintain the desired forces to correct scoliosis and to reverse by correction the causal loading. Inciting the first factor, in human scoliosis, asymmetrical loading can result from:

- *The effect of gravity*
- *Muscle action*
- *Lordosant reactive forces*
- *Human gait*
- *Growth induced torsion*

The effect of gravity.

Gravity promotes progression in any curvature exceeding a critical point. Axial forces produced by gravity become asymmetric in a scoliotic spine. In the presence of a structural lordo-scoliosis, asymmetric loading produces a lateral force vector which increases translation with coupled vertebral rotation. The 'vicious cycle' model explains how lateral deviation increases vertebral and disc deformity. Haderspeck and Shultz [22] (1981) studied the muscle and body weight actions in scoliosis progression, and their conclusions were reviewed by the same Shultz in a paper [23] published in the proceedings of the International Symposium on 3D Scoliotic Deformities joined with the VIIth International Symposium on Spinal Deformity and Surface Topography (Montreal 1992). Schultz summarized that *'application of superior body segment weights were capable of causing substantial increases in Cobb measures. Body weight application effects were influenced by initial spine morphology. The Cobb measure changes produced were to some extend dependent on whether and how the trunk was restored to its upright position after the given force application'*. Thus, it seems that the consequences of the need for the trunk structures to support the weight of the body segments superior to them would be obviously different when comparing passive scoliotic posture and active 3D corrected posture, at least theoretically.

Muscle action.

Nevertheless it has been studied at large, whether or not a muscle disease is a primary factor in the etiopathogenesis of IS is still controversial. However, it seems clear that IS produces a secondary muscle imbalance which is one of the most important factors in the progression of the deformity [24]. Recent studies have shown that in the natural history of IS spinal growth velocity and electromiographic ratio at the lower end vertebra are prominent risk factors of curve progression [25,26]. The asymmetric muscle activity has been clearly associated with increased axial rotation, lateral deviation and decreased kyphosis.

Lordosant reactive forces.

This is related to the bi-planar theory of Dickson et al. [27] In the presence of a lateral deviation and/or axial rotation, combined with an asymmetrical shortening of the dorsal elastic structures, any flexion effort is converted into a lordotic force. Due to reflex mechanisms, flexion movements of the spine provoke tension on the dorsal elastic structures that produce a reactive asymmetrical concentric force increasing lordosis, axial rotation and lateral deviation as well.

Human gait and torsion.

According to the Nottingham thoracospinal concept torsional forces are produced during gait [28]. When examining gait dynamics, axial pelvis-lower spinal rotation is counteracted by axial upper spinal counter-rotation. Burwell called it the 'dinner plate tent-pole' concept where the pelvis is likened to a dinner plate and the spine to a flagpole or tent-pole. The gap between the upper spine and the lower spine represents the transitional point above which axial rotation is in the direction opposite to that below. In the thoracic spine rotation is maximal about T7 and minimal at the lower three levels.

Growth induced torsion.

Progression in AIS has been related with a relative anterior spinal overgrowth [29] which causes a growing induced torsion. According to the Burwell's model lordoscoliosis formed by growing torsion (intrinsic torsion) is what causes eccentric loading, eccentric growing and vertebral and disc deformity. Theoretically, corrective dynamic-eccentric forces could be just produced from inside (breathing mechanics). This is closely related with the three-dimensional nature of the deformity. According to the above described factors, the principles of conservative treatment should be based on: Prevention of asymmetric compressive forces related to passive posture, reduction of the secondary muscle imbalance, prevention of the lordosant reactive forces (passive posture, repeated forward bending movements), prevention of asymmetric torsional forces from gait, production of dynamic detorsional forces involving breathing mechanics.

'The vicious cycle' must be converted into a 'virtuous cycle'. Correction of the spine in 3D is a premise.

The rehabilitation program

The Scoliosis Intensive Rehabilitation (SIR®) program original from the 'Asklepios Katharina Schroth Spinal Deformities Rehabilitation Center' has been fully described by HR Weiss in his book "Best Practice" in Conservative Management [1] as well as in another chapter of this same book. SIR employs an individualized exercises program combining corrective behavioural patterns with physiotherapeutic methods, following principles described by Christa Lehnert-Schroth [3]. The three-dimensional scoliosis treatment is based on sensomotor and kinesthetic principles and its goals are (1) to facilitate correction of the asymmetric posture, and (2) to teach the patient to maintain the corrected posture in daily activities. We have adapted the original program to our private institute where ambulatory but not in-patient physical therapy is offered. Two main protocols are used in our institute (1) Outpatient Rehabilitation –OpR- and (2) Outpatient Intensive Rehabilitation -OpIR. In both programs patients are admitted in groups, with the first days devoted to instruction in basic anatomy, spinal deformity and principles of correction according to curve pattern. Each patient will learn about his/her scoliosis curve pattern and its principles of correction according to the Schroth method. Education and motivation help patients cope with feelings about the diagnosis of their deformity as well as the impact of treatment (our institute is not able to offer psychological counseling on-site but we refers the patients to an external psychologist, as needed). After 3-4 introductory sessions all the patients start an individualized training working usually in groups of 6-8 patients per physiotherapist (variable). After a fixed number of sessions (usually 30 two-hours sessions), the primary goal is for a patient to be able to assume her personal corrected postural stereotype, independent of the therapist and without mirror control, and maintain this position in her daily activities. The patient is then recommended to practice 30 minutes daily (3-4 exercises) in order to maintain the improved postural balance. Depending on risk for progression and other factors, the patient repeats a supervised session with a Schroth's physiotherapist once a week, every two weeks, a month and so. More intensive courses are repeated eventually. The main difference between OpR and OpIR is the proposed schedule. In OpR patients attend the clinic eight days during the two first weeks and later they decrease gradually the number of sessions per week (3 sessions per week, 2 sessions per week and 1 session per week until finish the 30 sessions. It takes 3-4 months as a whole). The patient is asked to do a short routine of exercises at home approximately in the middle of the treatment course. In OpIR, patients attend the clinic 5 days per week during four week and they receive two group sessions of treatment every day (the duration of each session is 1.5 hours)

Principles of correction according to K. Schroth

Katharina Schroth developed the three-dimensional treatment of scoliosis during the second decade of the XX century in her first institute in Meissen (Germany). She opened a second clinic in Sobernheim (nowadays Bad Sobernheim) where Christa Lehnert-Schroth made further steps forward. Elena Salvá introduced the Schroth method in Barcelona (Spain) in 1968 after a learning period in Germany.

K. Schroth suffered from scoliosis herself. One of her first concerns was to correct the postural component of the main curve with no deterioration of any of the compensatory curves. At that time, most of the available methods were based just on mechanical aspects and she developed mechanisms to change postural behavioral on a neurophysiologic basis. The correction was supported by the 'rotational breathing'. This was created as a special breathing technique to produce intrinsic forces capable to shape the trunk. Thus, at the beginning the method was also called 'Orthopaedic Breathing'. Three-dimensional correction was possible using the trunk deformity as a monitor of the spinal deformity. K. Schroth noted that consequently to the spinal translation, axial rotation and collapse, different anatomical structures of the trunk also translated, axially rotated and collapsed one against the other, coupled to the spine. By direct observation K. Schroth drew a clear picture of the scoliotic deformity. Her first full description corresponded to a classical single thoracic scoliosis, right convex, combined with compensatory minor lumbar and high thoracic curves. She later called this pattern 'three-curve scoliosis pattern'. It was the first 'functional type' described by K. Schroth: "*Scoliosis was associated with trunk deformity. The main thoracic curve affected the rib cage with the exception of the upper and the lower ribs. The upper ribs were influenced by the upper compensatory curve. The neck and head were both coupled to the upper curve. Also, the shoulder girdle posture was modified by the upper curve but the caudal third of the scapula was affected instead, by the main thoracic curve. The two last couple of ribs were more affected by the lower lumbar* *compensatory curve. The pelvis was coupled to the lumbar minor curve".* Thus, in this particular pattern, K. Schroth divided the trunk in three imaginary sections called from caudal to cranial: a) Lumbo-pelvic section; b) Main thoracic section; c) Neck and shoulder section – including the upper thoracic region. (see Figure 3)

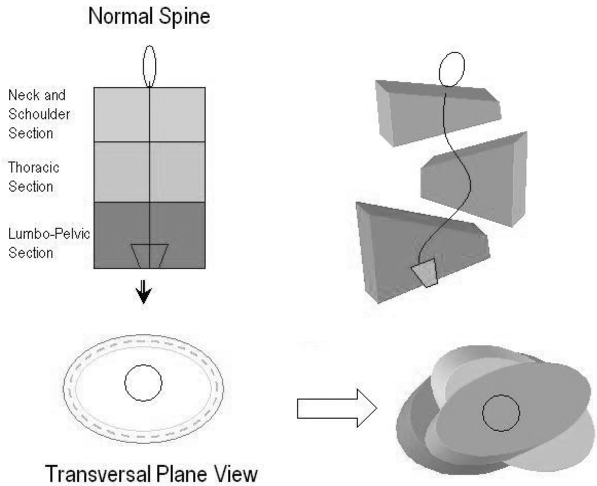


Figure 3. Schema of blocks by K Schroth. In a three-curve scoliosis pattern, the trunk is divided in three deformed sections which are translated, rotated and collapsed in the concavities, one against the other. In a normal spine, the sections are represented as rectangles well aligned in the frontal plane. The top view shows the lumbo-pelvic section rotated to the left and the most translated to the left. The thoracic section is rotated and translated to the right and the neck and shoulder section is rotated to the left and translated to the left according to the main thoracic section. The trunk is imbalanced to the right.

Scoliosis is defined as a torsion affecting both the spine and trunk. The three imaginary sections are rotated and translated one against the other as well as axially collapsed in the concave areas. In right convex thoracic scoliosis, the 'lumbo-pelvic section' rotates and translates to the left according the 'polygon of sustentation'. There is collapse in the right lumbar concavity. More cranially, the 'main thoracic section' rotates and translated to the right, collapsing on the left. Still more cranially, the 'neck and shoulder section', rotates and translates to the left, collapsing on the right, like the 'lumbo-pelvic' section. K Schroth described the three sections as rectangles well aligned one over the other, in a normal spine. During the initiation and progression process of the scoliosis, the rectangles become trapezoids which translate laterally and rotate one against the other. In order to re-establish the postural balance of the affected sections, K. Schroth described the principles of correction for a typical 'three curves scoliosis' as:

Axial-elongation
Deflection
Derotation
Facilitation
Stabilisation

We have made further development describing modified principles that can be called 'derivated Schroth's principles according to the school of Barcelona':

1. *Detorsion by axial Self-elongation*
2. *Curve pattern specific deflection*
3. *Derotation: Asymmetrical Sagittal Straightening (ASS) + Breathing Mechanics*
4. *Sagittal Normalisation*
5. *Stabilisation*
6. *Facilitation*

Detorsion by Axial Self-elongation.

Detorsion is here understood as ‘correction of the torsional deformity’ and it can be achieved partially by axial self-elongation. The patient has to growth upward as far as possible by using exclusively her own muscles. A stable pelvis is required in order to avoid trunk flexion or extension. Self-elongation is necessary to de-collapse the concave areas of the trunk and produces a certain degree of detorsion. Thus, the greater the severity of the scoliosis, the more essential it is to apply this first principle properly. Even not so essential, in mild scoliosis it is necessary to activate all the trunk muscles. In other words, auto-elongation, via proprioception, prepares the muscles of the trunk for postural correction. To accomplish stabilisation, fixation of the pelvis is required. The pelvis is a part of the lumbo-pelvic section and has to be corrected in all the three planes of space. K. Schroth used five pelvis corrections in order to form a proper basis for the further trunk correction in 3D but this is only possible in the ‘three-curve scoliosis pattern’. The pelvis section is stabilised in a right position and posture according to the treated curve pattern. During self-elongation the patient try to keep his/her sagittal profile as normal as possible.

Curve pattern specific Deflection.

Deflection means correction of the scoliosis curvatures in the frontal plane (lateral deviation of the spine). A certain amount of deflection can be obtained by just combining the correction of the pelvis-trunk postural imbalance in the frontal plane with self-elongation. However, if we want to produce some real change in the curvature, we should totally correct the postural component reaching the structural one. In the ‘three-curve scolisis pattern’ it is necessary to overcorrect the two caudal sections, lumbo-pelvic and thoracic by translating one against the other: lumbo-pelvic section left to right and thoracic section right to left. It is different in other curve patterns.

Thus, postural hyper-correction in the frontal plane results in an additional deflection effect, at least for the lumbo-pelvic and the thoracic sections. The upper section, neck and shoulder, however, will tend to be worsened. Thus, it is necessary to introduce some additional corrections in the frontal plane to compensate. To compensate the upper section K. Schroth suggested a further correction with the right shoulder pulling the spine in a medial to lateral direction (Shoulder traction). The tendency of the patient when practicing the shoulder traction on the right is to lose the correction in the thoracic section. To avoid it the patient needs to maintain the contraction of the lateral muscles of the right thorax. Before such a contraction the rib cage and the thoracic spine should be derotated, otherwise any correction just from lateral to medial will tend to increase the rib cage torsion. The whole corrective movement was describe by K.Schroth as a straightening of the rib hump in a ‘dorsal to ventral direction’ followed by the shoulder traction ‘medial to lateral’, against the contraction ‘lateral to medial’ of the thoracic lateral muscles. She called the whole exercise ‘shoulder counter-traction’ on the convex thoracic side. (see Figure 4)

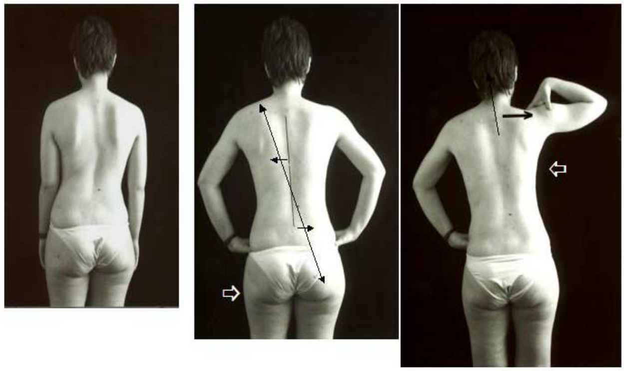


Figure 4. Three-curve scoliosis pattern: The lumbo-pelvic section and the main thoracic section translate one against the other during the corrective movement over-correcting in the frontal plane. The upper section has to be re-compensated –'shoulder-counter-traction- SCT'(e.g. during the exercise 'hand on shoulder' to facilitate the SCT)

Thus, correction in the frontal plane is achieved by active translation of the different sections of the trunk. The direction of the translation at each section is variable depending on the curve pattern. The original classification used earlier by Lehnert-Schroth [3] divided the scoliosis in two main functional patterns: three-curve scoliosis pattern and four-curve scoliosis pattern. This classification has been amplified further by the authors in order to introduce more complete criteria to define the active correction. The classification has been used also for brace design. The curve patterns are classified in five basic types called as follow:

1. *Three-curve pattern*
2. *Four-curve pattern*
3. *Non-three Non-four without lumbar curve pattern*
4. *Non-three Non-four with lumbar curve pattern*
5. *Lumbar/thoracolumbar single pattern*

The three-curve scoliosis pattern (see Figure 5) is related to a single long thoracic curve with a lumbar counter-curve (A1) or a shorter single thoracic curve combined with a functional (A2) or a minor structural curve (A3). The main radiological criteria are defined by an imbalance of the transitional point* to the convex thoracic side according to the central sacral line (CSL). The first thoracic vertebra (T1) is also imbalanced to the convex thoracic side although this criteria is not so consistent (e.g. in a structural upper thoracic curve -D- can be imbalanced T1 to the concave thoracic side). When looking at the patient from the back, it can be recognized the trunk imbalance to the convex side with the pelvis translated to the concave side in the frontal plane (see Figure 6). A dorsal rib hump is the major clinical trait. The four-

* Transitional point: it is located in the middle of a disc in between the lower end vertebra (LEV) of the thoracic curve and the upper end vertebra (UEV) of the lumbar or thoracolumbar curve. It can be also in the middle of a vertebra which act as LEN of the thoracic and UEV of the lumbar curve.

curve scoliosis pattern (see Figure 5) fits with a double major radiological pattern, thoracic/lumbar (B1) or thoracic/thoracolumbar (see B in figure 8). The main radiological criterion is defined by the imbalance of the transitional point to the concave thoracic side according to CSL. A second highly consistent criterion is a positive counter-tilting between L4 and L5, sometimes between L4 and L3. Finally, T1 is also imbalanced to the concave thoracic side. The trunk is imbalanced to the concave thoracic side with the pelvis translated to the convex thoracic side (see Figure 6). There is a thoracic dorsal hump and a lumbar or thoracolumbar prominence.

Non-three Non-four scoliosis pattern is divided in two according to the presence (C2) or not (C1) of a lumbar curve (see Figure 5). In both cases, the transitional point and T1 are more or less on the CSL. Clinically the rib cage can be translated as well as the lumbar region but the trunk is quite balanced and the pelvis is not translated to any side. An upper thoracic structural curve is possible in any of the types but more common in three curve. Triple structural scoliosis pattern is formed by the combination of a four curve with upper thoracic structural curve. Single lumbar and thoracolumbar curves are like four regarding the lumbar and pelvic sections (see Figure 7).

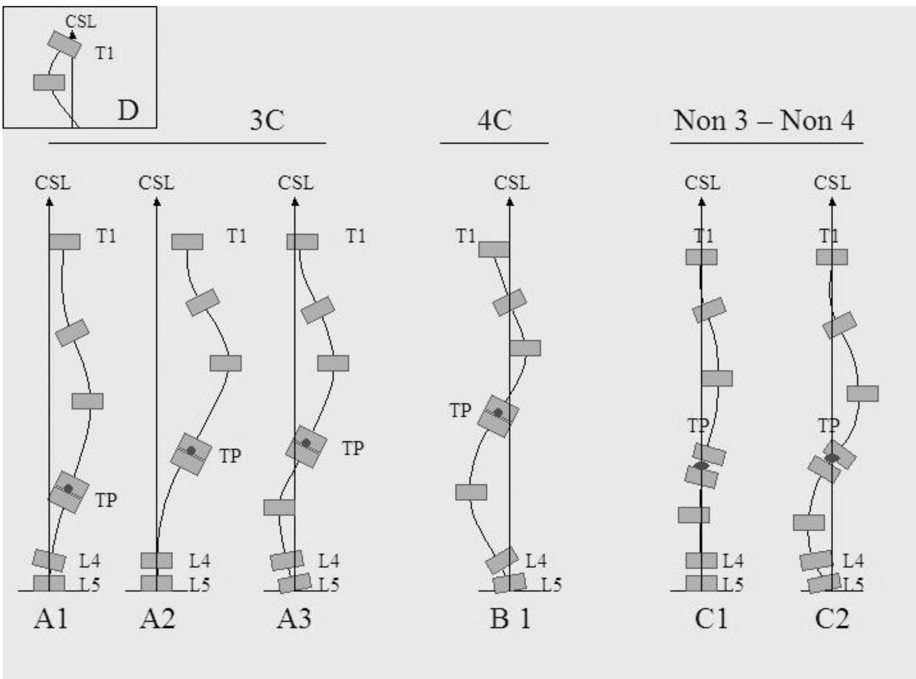
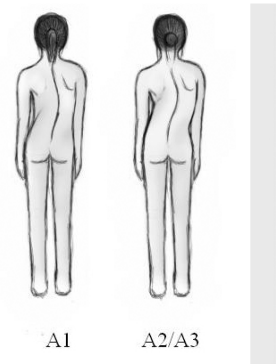


Figure 5. Radiological criteria for three curve (A1,2,3), four curve (B1) and non-3 non-4 curve, without lumbar curve (C1) and with lumbar curve (C2). CSL= Central Sacral Line. TP= Transitional point. Four curve scoliosis pattern is the only with positive counter-tilting L5-4 to the concave thoracic side.



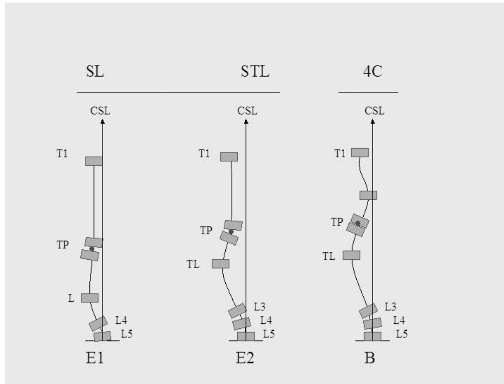


Figure 6. Clinical aspect in 3-curve (A) and 4 (B)

Figure 7. E1 Single lumbar (SL) and E2 thoracolumbar (STL).Double Thoracic/Thoracolumbar is like four (B).

The principles of correction in the frontal plane have been defined for each type. Translation in the frontal plane is always made in combination with the first principle of correction 'self-elongation'. Thus, it is not just a side-shift. The correction in 'three-curve scoliosis pattern' has been fully described above. In addition to the clinical and radiological criteria, the 'Four-curve scoliosis pattern' has been also represented by using the 'schema of blocks' according to K Schroth (see Figure 8).

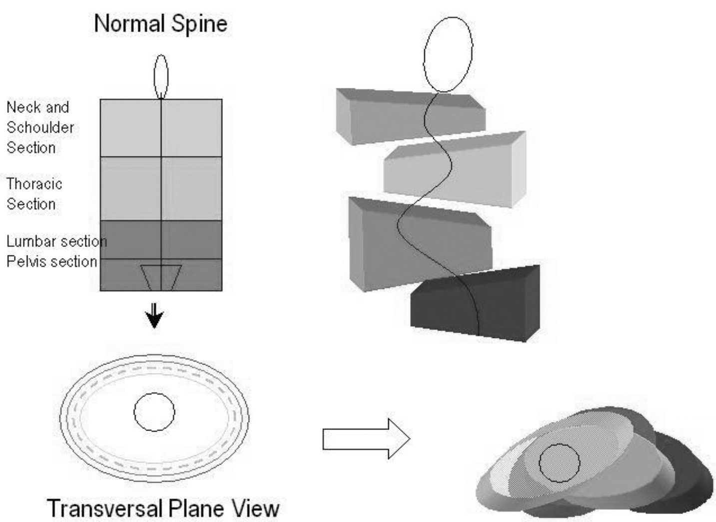


Figure 8. The 'four-curve scoliosis pattern' represented by Ch. Lehnert-Schroth. In this pattern, the lumbar/thoracolumbar curve is uncoupled to the pelvis region and the lumbar and pelvis sections are represented by two sub-divide blocks rather than one unique lumbo-pelvic block (Three-curve patter). The trunk imbalance is towards the concave thoracic side and the pelvis is prominent to the convex thoracic side. Each block translates, rotates and collapses in the concavities one against the other.

Thus, its correction in the frontal plane can be better understood: in the classic right thoracic/left lumbar scoliosis, the pelvis section and the lumbar section, here uncoupled, must be corrected by active translation, pelvis right to left and lumbar region left to right, bringing all the trunk to the CSL. However, the main thoracic section tends now to decompensate to the right and must be corrected with a traction exercise from the left shoulder area. The upper part, at the same time, has to be corrected by using the exercise shoulder-counter-traction in the right side. (see Figure 9)

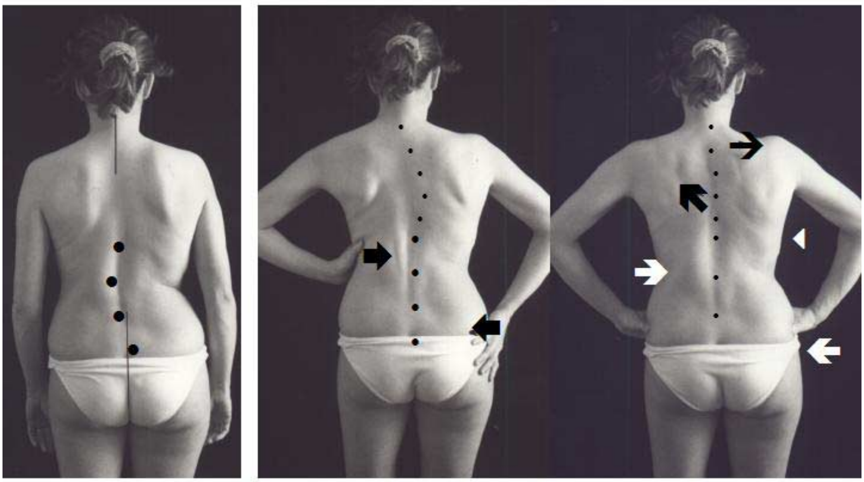


Figure 9. 'Four-curve scoliosis pattern': correction in the frontal plane. See explanation in the text.

Description of the correction in the frontal plane for the rest of the patterns overpasses the objective of this paper.

Self-elongation produces a certain degree of detorsion. Deflection, which is made always in coordination with self-elongation, increases the correction effect in the frontal plane. It is also necessary to increase the derotation effect by adding active forces to create 'pair of forces' at any transversal plane. To achieve this correction effect we have developed the concept of 'Asymmetrical Sagittal Straightening'.

Derotation

For a better understanding of the correction leading to the derotation of the column, it is recommended to refer to the system of blocks. During the deforming process, the bases of the wedges into which the imaginary initial rectangular blocks transform by deformity, represent the convexities of the curves, and the vertices represent the concavities. By torsion, the bases rotate towards the dorsal side, and the vertices towards the ventral side. In the correction, the vertices should be taken towards the dorsal side, and the bases towards the ventral side. However, rather than a simple derotation of every affected section, in practice, derotation is better increased throughout the concept so called 'Asymmetrical Sagittal Straightening' (ASS). ASS is based on a clinical observation: torsion makes both hemi-bodies to present a converse sagittal profile (e.g. in a right convex thoracic scoliosis, the right hemi-body is lordotic in the lumbo-pelvic region, kyphotic in the main thoracic region and lordotic in the upper thoracic and shoulder region. Conversely, the left hemi-body is flat-to-kyphotic in the lumbo-pelvic region, flat-to-lordotic in the main thoracic region and finally flat-to-kyphotic in the upper thoracic and shoulder region). Thus, during ASS, always in combination with self-elongation, the hemi-body in the convex thoracic side is straightened towards dorsal at the lumbo-pelvic level, ventral at the main thoracic level and dorsal again at the upper thoracic-shoulder level; conversely, the concave thoracic side goes ventral at the lumbo-pelvic level, dorsal at the main thoracic level and dorsal again at the upper thoracic-shoulder level. ASS provides a minimum of three 'pair of forces' in the transversal plane to increase axial derotation. Derotation is also increased from inside throughout breathing expansion. Breathing expansion of the collapsed areas 'in the corrective way' can be achieved just once these areas have been decollapsed and actively corrected. This principle was originally described by K Schroth and it is called 'Schroth's rotatory breathing'.

Figure 10. a) Mobilization exercises with the help of the therapist.
b) stabilization/strengthening exercise.

Facilitation

The neurophysiological bases of facilitation can not be described in this paper. Interesting to note is that propioceptive and exteroceptive stimuli combined with visual input (the patient can check her correction by using a mirror) facilitates the active correction.

Stabilization

Stabilization is achieved by isometric tension during the exhalation breathing phase. In this way, the length and muscular sufficiency are restored. The patient is asked to maintain the best possible correction during exhalation, producing muscular tension which is called isometric just from a theoretical point of view. In practice, the shortened muscles will contract an-isometric eccentrically and the elongated muscle will do it an-isometric concentrically. To generate greater isometric muscular tension, the patient can use different tools.

a b

Figure 11. A special Schroth's exercise called 'Muscle Cylinder' in a three-curve scoliosis pattern a) and in a four-curve scoliosis pattern b).

Most of the above described principles of correction can be introduced in different exercises performed from different starting positions. Generally speaking, the exercises can be divided according to its purpose: mobilization or stabilization-strengthening (see Figures 10-11).

Discussion

The benefits of the scoliosis intensive rehabilitation as performed in the AKSK have been reported in several papers which can be found in the references of the correspondent paper published in this same book by Weiss et al. In the present paper we have described our particular approach rather than deeply discuss the key points of the scoliosis rehabilitation.

We have found that the combination of specific exercises with bracing reduces the incidence of surgery in adolescent idiopathic scoliosis [30]. The exclusive employment of specific exercises was effective in reducing the incidence of progression in mild scoliosis [31]. An intensive course of out-patient rehabilitation according to the above described program is effective in correcting the spinal midline in three-dimensions, improving at the same time the harmonic profile of the spine [32]. Although other authors have shown the efficiency of the Schroth exercises [33], it must be noted that outcomes does not come automatically just by using a particular name of a technique. One of the limitations of the Schroth method is its complexity. Physiotherapists need a relatively long learning period before they are able to teach patients.

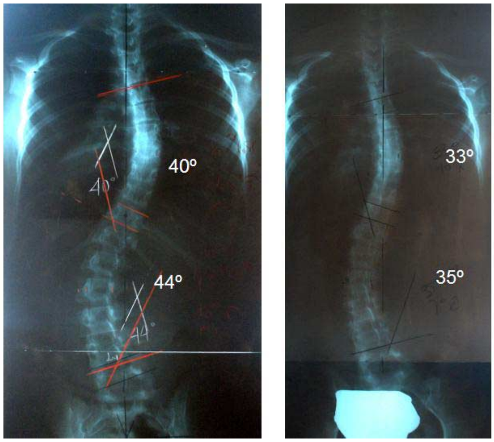


Figure 12. A 16 years old girl (Risser 4) showing a double major curve right thoracic (40º) and left lumbar (44º) in June 2006. A new Xray from March 2007, 8 months after an intensive course of rehabilitation with Schroth's exercises, the curves measured 33º and 35º respectively. The girl had been practicing exercises 30' everyday since she finished the treatment course.

Conclusions

In this paper it has been described the particular approach for scoliosis rehabilitation of the so called Barcelona school. Specific exercises according to Schroth become an essential part of this rehabilitation program. The whole program including rehabilitation and bracing is effective in reducing the signs and symptoms in IS. Scoliosis rehabilitation and bracing is a real alternative to surgery.

Acknowledgement

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The Conservative Scoliosis Treatment
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Dobosiewicz Method Physiotherapy for Idiopathic Scoliosis

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Abstract. The method developed since 1979, comprises active 3-dimensional auto-correction, concerning the primary curve mobilization towards the correction of the curvature, with special emphasis on the kyphotization of the thoracic spine, carried on in closed kinematic chains, and developed on a symmetrically positioned pelvis and shoulder girdle, followed by active stabilization of the corrected position, and endured as postural habit. The positions for exercising and the movements involved are described in details. Small, moderate and important curves can be managed with DoboMed, however the effectiveness of the therapy depends on the curve flexibility and patient's compliance. DoboMed has been used as a single therapy or together with bracing, as well as preparation for scoliosis surgery. The published results demonstrated that the DoboMed has a positive influence on inhibition of the curve progression in idiopathic scoliosis, the improvement of respiratory functions, assessed by the spirometric values, and the general exercise efficiency evaluated using ergospirometry.

Keywords. Dobosiewicz method, idiopathic scoliosis, physiotherapy, active kyphotization

1. History

The idea of the method was developed in 1979. Initially it was realized tentatively on an out-patient group. It was continually modified. The method has been used by Dobosiewicz since 1982 as the main strategy of therapy of out-patients with scoliosis. Next, it has been used in the Department of Rehabilitation as stationary scoliosis intensive rehabilitation (in-patients). Patients were admitted to the department for a 3-4 weeks period and have been undergoing an intensive rehabilitation. Next, they have been continuing specific exercises at home and have been controlled in an out-patients' clinic. In case of necessity, the patients were re-admitted to the Department of Rehabilitation for another 2-3 weeks period.

Since the beginning, the method has been used as a single therapy or combined with bracing (Cheneau brace) [1].

2. Definition

Dobosiewicz Method (DoboMed) is the method of conservative treatment of the deformity of the trunk and of the impairment of respiratory functions that are caused by idiopathic scoliosis in children and in adolescents. The method consists of:

(1) the preparatory phase, which is comprised of physiotherapy and physicotherapy,

(2) the basic technique of active 3-dimensional auto-correction, concerning the primary curve mobilization towards the correction of the curvature, with special emphasis on the kyphotization of the thoracic spine, carried on in closed kinematic chains and developed on a symmetrically positioned pelvis and shoulder girdle,

(3) followed by active stabilization of the corrected position and endured as postural habit.

This biodynamic method of 3-dimentional auto-correction of idiopathic scoliosis is based on the pathomechanism of idiopathic scoliosis [1].

3. Mechanism of correction

In this paper the mechanism of correction is discussed on the basis of an example of the thoracic idiopathic scoliosis.

3.1. Pathologic displacement of the thoracic vertebrae in the 3-D space during the development of idiopathic scoliosis

A complex spatial displacement combining (1) anterior displacement resulting in loss of the physiological kyphosis, (2) axial rotation towards convexity and (3) lateral inflexion in the frontal plane is imagined. Whether sagittal plane displacement originates and transverse plane displacement follows or vice versa [2,3], it is not considered in the DoboMed.

3.2. Correction of scoliotic spinal curvature

The method aims to reverse the displacement by introducing the movement of the thoracic vertebrae towards their normal position in the middle sagittal plane together with their normal kyphotic orientation. The desired movement of the thoracic vertebrae consists of:

- kyphotisation – backward displacement,
- axial derotation obtained partly by active movement of the thorax versus stable pelvis and shoulder girdle and partly by active asymmetrical breathing,
- frontal plane correction is obtained automatically, while the sagittal and axial planes are being corrected, no lateral inflexion of the spine is required.

3.3. Degree of curvature

Small, moderate and important curves can be treated with DoboMed, however the effectiveness of the therapy depends on the curve flexibility and patient's compliance (frequency and correctness of exercises).

3.4. Symmetry of pelvis and shoulder girdle

DoboMed uses exclusively symmetric positioning of the pelvis and the shoulder girdle. This position is considered (1) to facilitate active correction in between two symmetric and stable zones, as well as (2) to support consolidation of the correct postural habit beyond the therapeutic session.

3.5. Closed kinematic chain

The exercises are designed in closed kinematic chains in order to enhance their effectiveness. This is obtained by the fixation of the pelvis and the shoulder girdle with the upper and lower limbs.

4. Techniques

In case of the thoracic scoliosis exercise, positions presented on the pictures are applied (see Figures 1.-3.). At the beginning of the session, after warming up, exercises in low positions are performed (see Figures 1.,2.,3.A). These positions free the back muscles from the influence of gravitation. Probably because of that, the largest correction of scoliosis was observed in low positions. Between exercises in low positions a very difficult intermittent exercise – a break (see Figure 3.A) was performed. The break consists of active maximum kyphotization of the thoracic spine and lordotization of the lumbar spine with simultaneous 3D correction of the spine deformation.

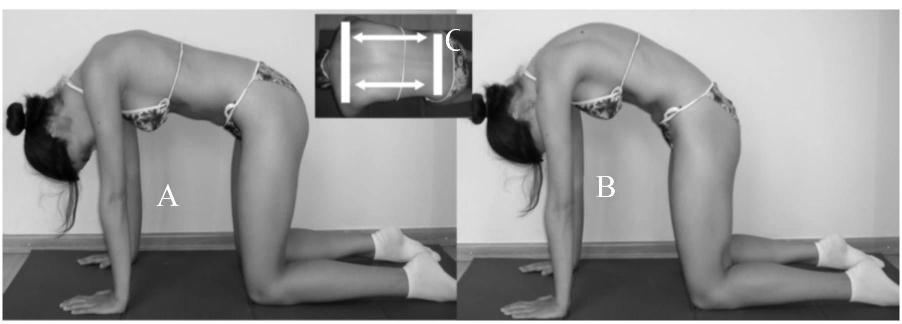

Figure 1. Exercises position N° 1. (side view) A - the position before the exercise. B- the position during the exercise (with active maximum kyphotization of the thoracic spine).

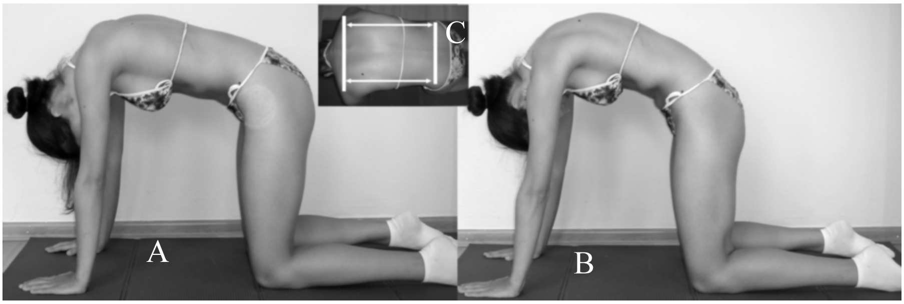

Figure 2. Exercises position N° 2. A - (side view) the position before the exercise. B - (side view) the position during the exercise (with active maximum kyphotization of the thoracic spine). C - (top view) strict symmetric fixation of the pelvis and the shoulder girdle.

Next, active 3-dimensional auto-correction exercises are performed in high positions (the spine is placed vertically) and gravitation affects fully the back muscles (see Figures 3.B-D).

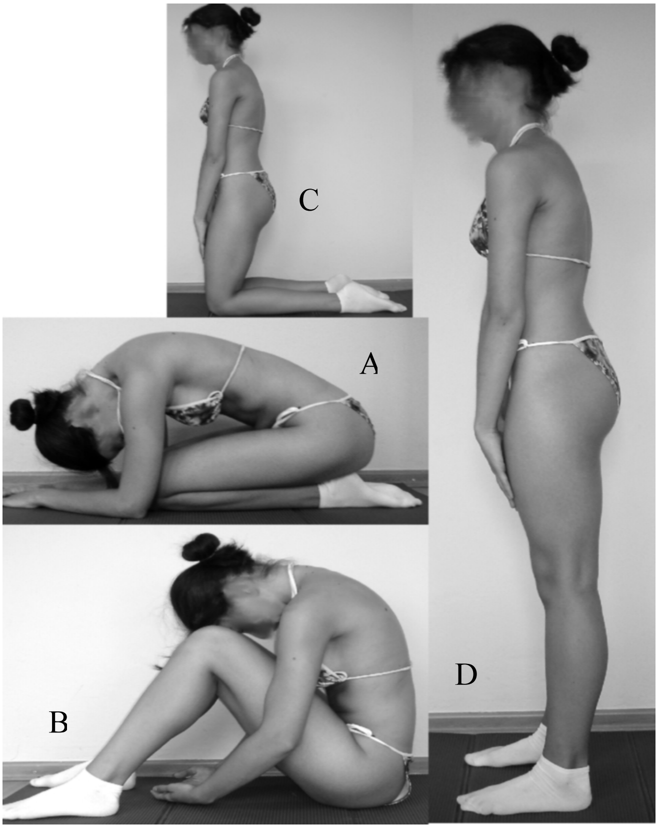

Figure 3. Exercises positions (side view). A - position "break", B - position N° 3., C - position N° 4., D - position N° 5.

All exercise positions require strict symmetric arrangement by fixation of the pelvis and the shoulder girdle with the upper and lower limbs during all phases of the respiratory cycle (see Figures 2.C and 4).

The course of action focuses on the vicinity of the apical vertebra. On the concave side of the curvature a strong local pressure is applied, and on the convex side a subtle facilitation is applied. The correction and facilitation are phase-locked with the particular phases of the respiratory cycle. In details, during inspiration a strong local pressure is applied on the concave side (see Figure 4.B, 5.B-D), and during expiration a subtle facilitation is applied on the convex side (see Figure 5.F-G). During expiration, achieved correction or hypercorrection is being stabilized by an isometric contraction (see Figure 5.H-I).

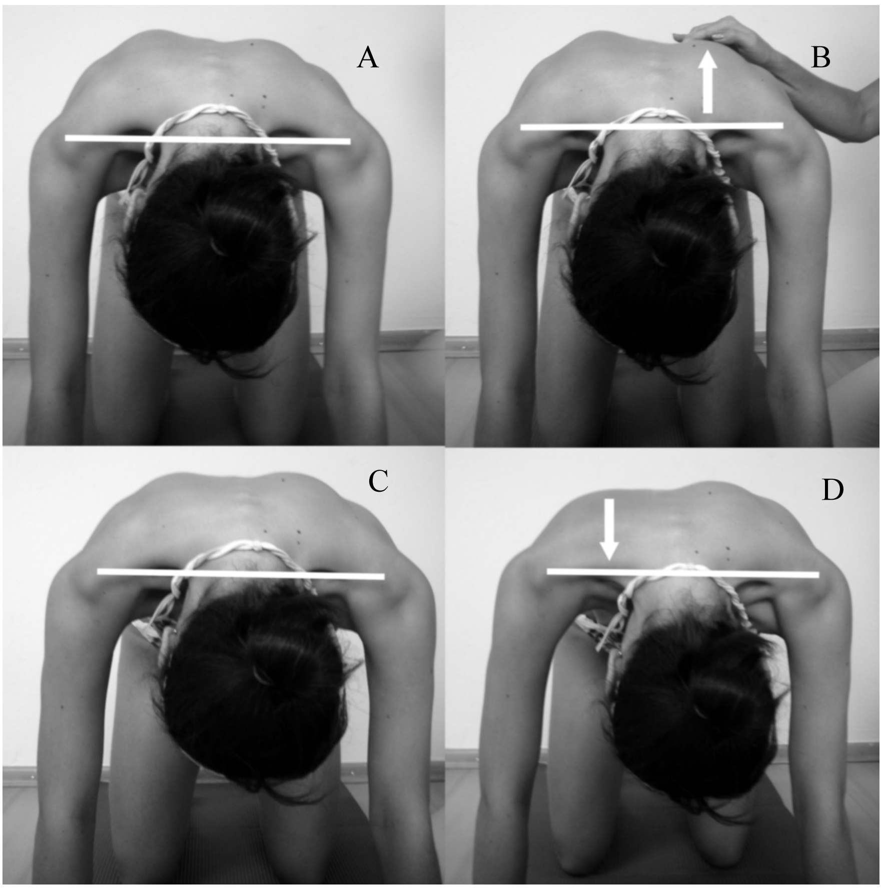

Figure 4. Exercises position N° 1. (front view). A - start of the exercise, B - during inspiration with facilitation, C - end of inspiration, D - final phase with hipercorrection. White line - strict symmetric fixation of the shoulder girdle during all phases of the exercise.

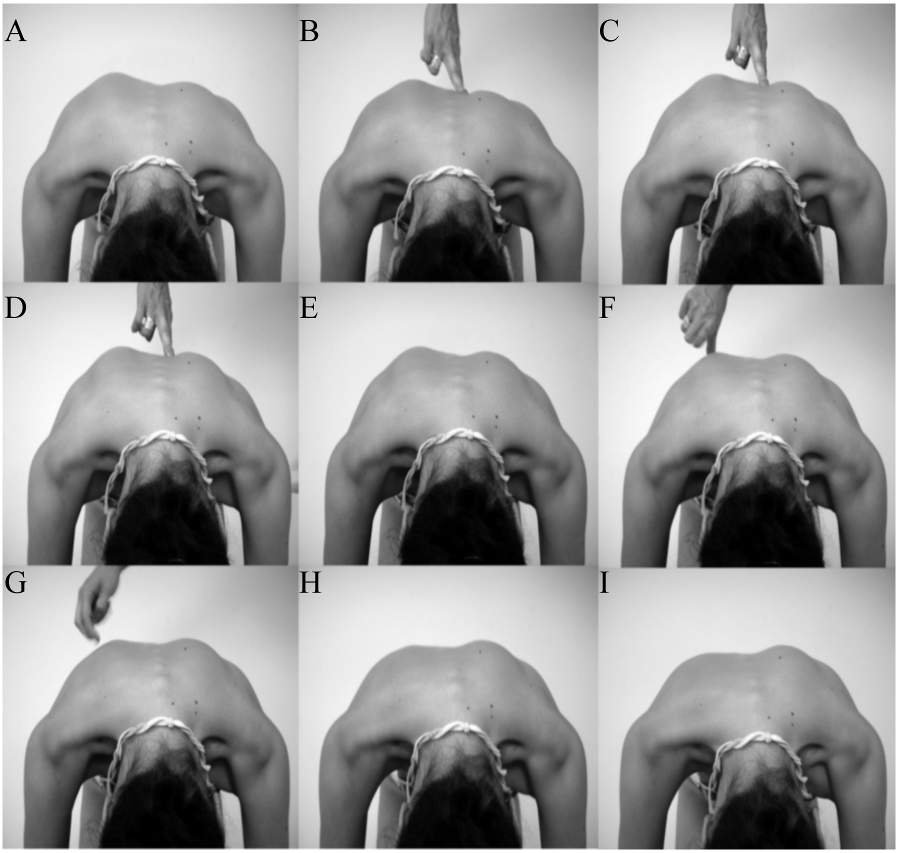

Figure 5. (front view) A - start position, B-D - during inspiration with facilitation (a strong local pressure on the concave side), E - end of inspiration (partial correction), F-G - during expiration with facilitation (a subtle facilitation on the convex side), H-I - end of expiration (hipercorrection by isometric contraction).

Exercise positions for thoracic scoliosis.

- Position 1. The patient is kneeling, the distances between the knees and the shoulders are the same, the knee-joints are bent at the right angles, the thoracic spine is maximally kyphotic, the chin is bent to the chest, the upper limbs are straight and propped on the floor, the hands lay parallelly, the shoulder-joints are bent at the right angles, the feet, the knees and the hands are at the same line (see Figure 1.).
- Position 2. One difference comparing to the first position – the shoulder-joints are bent at the angle of 70-75 degrees (see Figure 2.).
- Position – Break. The patient sits in a "japan bow" position – on the heels, the thoracic spine is maximally kyphotic and the lumbar spine is maximally lordotic, the chin is bent to the chest, the shoulder-joints are bent at the right angles, the patient is propped on the floor on his elbows, the elbow-joints are bent at the right angles, the forearms lie parallelly, the palms are arranged in supine position (see Figure 3.A).

- Position 3. The patient sits on the floor, the knees are bent at the angle of 90 degrees, the thoracic spine is maximally kyphotic, the chin is bent to the chest, the hands lie on the floor in supine position, the fingers touch themselves (see Figure 3.B).
- Position 4. The patient is in a kneeling position, distance between the knees and the shoulders is the same, the upper limbs hang along the trunk, the palms adhere to the front side of the thigh, the head is straight (see Figure 3.C).
- Position 5. The patient is in a standing position (see Figure 3.D).

It is important that:

1. While fixating in each of the positions, the patient should correctly position the pelvis in 3 dimensions.
2. The method requires detailed training and then can be applied in a patient's home under periodic control of a physician and a physiotherapist. The greatest effectiveness is achieved by systematic daily exercises.
3. The method can be applied in tandem with a Cheneau brace (exercises without brace – 1-1.5 hour per day and in-brace exercises), as well as a surgical pretreatment.

5. Indications

The basic aim of this method is to stop a progression or to achieve the correction of scoliosis.

The second aim (contemporary) is the improvement of the functions of the respiratory system.

Small, moderate and important curves (idiopathic scoliosis) can be treated with DoboMed, however the effectiveness of the therapy depends on the curve flexibility and patient's compliance (frequency and correctness of exercises).

Active cooperation is the basic requirement of using DoboMed, therefore DoboMed is not recommended in small children.

6. Results of therapy

DoboMed has a positive influence on inhibition of the curve progression in idiopathic scoliosis. The radiological results were assessed on the basis of retrospective [3-7] and prospective [8] studies. They demonstrated prevalent stabilisation of scoliotic curves in children with progressive idiopathic scoliosis treated with the DoboMed. The best effects of the treatment were observed in single curve scoliosis. The reduction of the Cobb angle and /or rotation angle of the apical vertebra depended on the correctness of exercising and their regularity. As DoboMed may be considered as a difficult method, therefore frequent checking of the correctness of practising is required. The best effectiveness was achieved by daily, systematic exercises, actively supervised by the parents, who were previously educated (during the initial in-patient rehabilitation period).

The evaluation of the radiological results was performed in the cohort of premenarchial girls, who presented a radiologically confirmed progressive idiopathic scoliosis. The progression was defined as 6 degrees or more in the six months interval. The mean initial Cobb angle was 27.7° (range 15.0÷45.0). The stabilization of the curve angle was succesfully achieved; the mean progression of the Cobb angle was of 0.6° (range minus 14.0 ÷ plus 15.0°) in the observation of 50.9 months (range 37.0÷91.0 months) [9]. Further evaluation of the DoboMed revealed the increasing values for the treatment of the thoracic kyphosis in scoliotic patients, initially presenting the flat back [10]. The improvement of respiratory functions, assessed by the spirometric values (vital capacity, forced expiratory volume in one second), was noted [11]. The general exercise efficiency evaluated using ergospirometry was observed to increase significantly during the therapy with the DoboMed [12].

7. Conclusions

The principal distinctive features of the DoboMed are listed below:

1- symmetrical positions for exercising
2- asymmetrical active movements
3- thoracic spine kyphotization
4- transverse plane derotation
5- apical area involvement
6- concave ribs mobilization
7- exteroceptive facilitation
8- respiration-directed movements of the thorax and spine
9- three-dimensional displacement of vertebrae
10- active autocorrection

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Function of the Respiratory System in Patients with Idiopathic Scoliosis: Reasons for Impairment and Methods of Evaluation

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Abstract. The paper presents the review of pathological changes which develop within the respiratory system in patients with structural progressive idiopathic scoliosis. The impairment of the function of the respiratory system is one of the principal impact of idiopathic scoliosis on the general health and function, as well as on the quality of life. Although the fatal outcomes of respiratory failure are usually prevented by a successful conservative treatment or by the spinal surgery, the reduction of the volume of the thorax, the restriction of the thorax, as well as decreased efficacy of the respiratory muscles are still a major issue (problem) for many patients with structural scoliosis that may lead to respiratory insufficiency or failure. The papers presents main functional tests to assess the respiratory impairment and the basic rules for interpretation of the results of the examination.

Introduction

Idiopathic (IS) scoliosis is the abnormality of the spine with direct effects on the shape and mechanics of the thoracic cage. The deformity of the thoracic spine in scoliosis is responsible for the respiratory dysfunction. The relationship between deformities and altered pulmonary function has been known since the time of Hippocrates [1]. A reduction in vital capacity (VC) in severe scoliosis was first reported by Schneevegt in 1854 [2].Numerous studies have shown that the level of respiratory dysfunction was dependent on the thoracic curvature value and the degree of the thoracic cage deformation. Figure 1 presents an anatomical base for respiratory failure in thoracic idiopathic scoliosis, illustrated by CT scans of the thorax, made at the level of the Th8 vertebra.

A significant decrease of the lung volume is described in scoliosis >60 degrees of Cobb angle, whereas curves over 90 degrees produce significant changes in the pulmonary function. Above 100 degrees of Cobb angle the exertion dyspnoea may be observed. The alveolar hypoventilation and the chronic respiratory failure are probably to occur above 120 degrees of Cobb angle. Abnormal results of the pulmonary function tests are seen in thoracic or thoracolumbar scoliosis; lumbar curves generally do not affect lung function. [1, 3].Few studies, which have focused on scoliosis, have measured only spirometric values and have not analyzed the homogeneous group of scoliosis.The deformation of the spine and the chest has the influence on the function of the respiratory system in idiopathic scoliosis and is ascribed to the secondary dysfunction of respiratory muscles. Maximum respiratory pressures as an index of respiratory muscle strength have been found to be reduced in IS [2, 4, 5].The principal respiratory muscles are composed of four groups: the diaphragm is the main respiratory muscle; the intercostals muscles (the second group) consist of two bands of muscles that are placed between the ribs; the muscles of the abdominal wall represent the third group. The additional, auxiliary respiratory muscles, which are used only in the sultriness condition, form the fourth group.The structure and function of respiratory muscles do not change *per se* in idiopathic scoliosis. The limitation of the respiratory muscles function is caused by the biomechanical changes of the thorax.The knowledge about the deformed thorax morfology in connection with the scoliotic spine are necessary to understand the process of the respiratory problems and dysfunctions in scoliosis.The reduction of the lung volume is determined by the angle of scoliosis, the number of involved vertebrae and the level of the deformity in the sagittal and horizontal planes [6], (see Figure 1).

The linear relationship between the Cobb angle and the reduction of the lung volumes has been reported by many authors (first observation was made by Johnson et.al. and Shannon et al.) [8, 9]. Muirhead and Conner [10] observed the marked relationship between the degree of curvature and reduction of the percentage vital capacity values, stronger in infantile idiopathic scoliosis comparing to adolescent IS. It depends on the onset of idiopathic scoliosis and stage of the pulmonary alveoli development. More expressed decrease of pulmonary function is observed if the onset of IS occurs before the end of the pulmonary alveoli growth.

Pathophysiology

There exist a complex mechanism that is responsible for the respiratory impairment in patients with idiopathic scoliosis. Generally, it should be listed that (1) the rib cage is reduced in volume, (2) the thoracic wall presents decreased excursion, and (3) the respiratory muscles lose their efficacy by deformation of their architectural arrangement and pattern of activation.

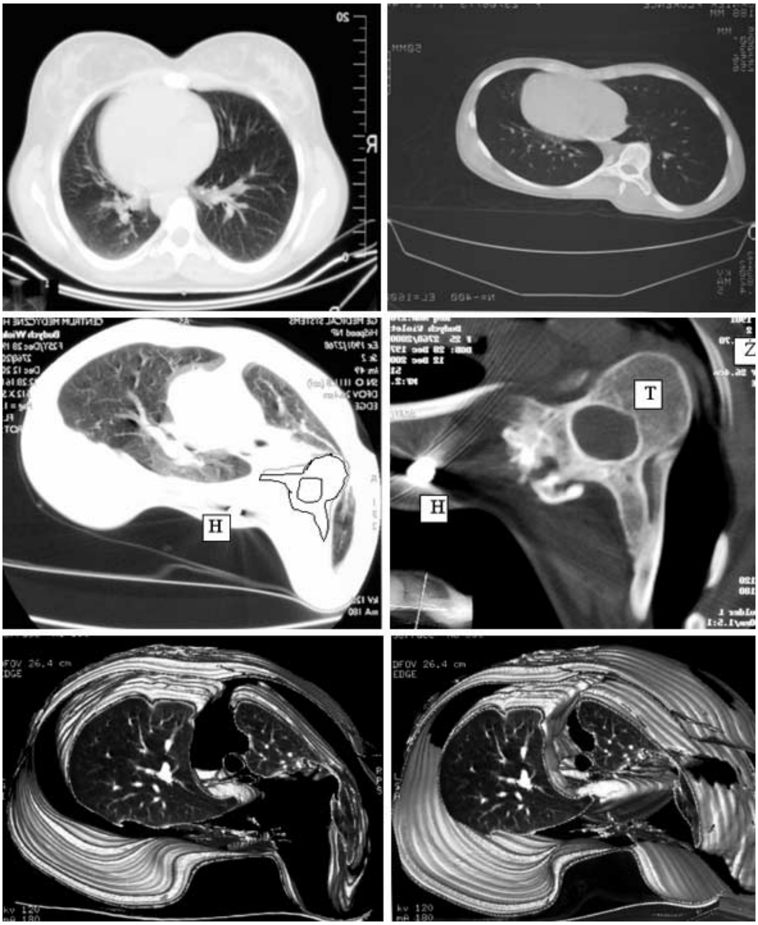

Figure 1. Anatomical reasons for respiratory failure in thoracic idiopathic scoliosis, illustrated using CT scans of the thorax, made at the level of the Th8 vertebra. All images are presented as seen from above (top view)..
In a normal subject (*top left*) the sagittal to the coronal chest diameter ratio reveals the value of about 0.66, while in a girl with moderate thoracic scoliosis of 45° of Cobb angle (*top right*) the ratio is decreased below 0.5 and the mechanics of the thorax becomes impaired due to changed spatial orientation of the axis of left and right costo-vertebral joints, which limits rib movement.
Middle left: CT scan of a 27-year-old woman operated at the age of 15 years with a Harrington distraction rod, which did not effectively prevent the development of severe lordoscoliosis. The spine is situated inside the right hemi-thorax, occupying the room for the right lung. Image magnification (*middle right*) shows direct contact of the antero-lateral aspect of the vertebral body with the internal surface of the rib. Dubousset proposed the term of "internal hump" to describe the respiratory restriction caused by the lordotic thoracic spine entering the rib cage [7].
Bottom left: pulmonary tissue over pressed by the vertebral bodies; the bony elements are subtracted. *Bottom right*: when the image is tilted, the defect in continuity of the pulmonary tissue, which disappears under the pressure of the vertebral column, becomes evident. The vital capacity of this patient is of 27% of the predicted volume.

(1) Reduction of the volume of the thorax is caused directly by the deformity itself considered in the three dimensional aspect. Sommerville [11] used the term "rotational lordosis" to design pathological loss of thoracic kyphosis, which is a constant morphological defect of idiopathic scoliosis. Roaf [12] demonstrated that

the anterior column of the spine, composed of the vertebral bodies and intervertebral discs, is longer than the posterior column, and this signifies lordotic configuration of the spine. For Winter et al. [13], in severe scoliosis a true thoracic lordosis develops; it is directly responsible for the reduced chest volume. Dubousset [7] analyzed how the thoracic scoliosis influenced the reduced thoracic physiological kyphosis. According to this concept the thoracic spine "enters" into the thorax and progressively proceeds deeper into it (see Figure 1). The displacement of the thoracic spine is anterior, lateral and with rotation. The sagittal chest diameter decreases and the ratio of sagittal/coronal chest diameters also decreases [14]. Dubousset proposed an original term of "the internal hump" to emphasize the harmful influence of the deformed spine onto the lung volume [15]. Kearon et al. [16] did not find direct dependence of the restricted vital capacity on a single parameter describing shape or size of the spinal curvature (Cobb angle, kyphosis angle, axial rotation angle of apical vertebra, apex location, curve length). The authors concluded on the additive influence of these parameters on the pulmonary impairment, however the highest negative correlation of vital capacity with the Cobb angle and with the decreased kyphosis angle was noted. The frontal curvature reduces the height of the rib cage, while the lordosis diminishes the antero-posterior rib cage diameter. The curve location was reported to influence the vital capacity, because the higher thoracic curvatures involve more functionally important ribs [16]. For Wee et al. [17] and Hofner et al. [18] the thoracic lordoscoliosis may directly cause atelectasis. Direct compression of the bronchus by the crocked spine, with subsequent atelectasis of one lobe was reported by Wee et al. [17]. The possible mechanism could be the sputum retention provoked by the compression of the bronchus with superimposed infection, which leads to the development of atelectasis.

(2) Restriction of the thorax is the pathology consisting of decreased capability of the chest to expand during inhalation [19]. Normally, the chest wall expands while the person inhales, resulting in the increased volume of the thorax and subsequently in the increased volume of the lungs. Full contact brace, which impedes thorax movements, resembles a restriction model of the thorax. Occupational situations, such as wearing a bulletproof vest, may be considered. However, in patients suffering from idiopathic scoliosis, there is a restriction without any external device impeding thorax movements. There is no external restraint but there is an intrinsic restraint in the thorax wall, due to soft tissue shortening and contractures (the superficial and deep fascia, the intercostals muscles, ligaments, the capsules of the costo-vertebral and costo-transverse joints, the diaphragm) as well as to the bony deformity of the ribs, including the increase of the rib angle at the convexity and decrease of the rib angle at the concavity. The mobility of the chest is reduced especially in the concavities, for example for a right thoracic scoliosis the area of reduced chest mobility concerns the concave left para-vertebral hemi-thorax behind, and the right concave hemi-thorax on the front. The reasons for reduced thorax mobility are anatomical: loss of physiological thoracic kyphosis together with spatial reorientation of the costo-transverse joints. The concave costo-transverse joint becomes more frontally oriented while the convex costo-tranverse joint becomes more sagittally oriented, comparing to the physiological position [14], creating obstacle for the corresponding ribs movement, which is simultaneously executed by the left and right rib.

The above described abnormalities in the spatial rib cage arrangement are also responsible for the (3) decreased efficacy of the respiratory muscles. Cooper et al. [20] suggested that low lung capacity in adolescents with mild to moderate idiopathic scoliosis is partly caused by defective mechanical coupling between the inspiratory muscles and the ribs cage. Smyth et al. [21] demonstrated that even in mild scoliosis, asymptomatic and without impairment of resting pulmonary function, abnormal patterns of ventilation occur during exercise or in response to chemical stimuli. Radioaerosol ventilation scintigraphy was used by Giordano et al. to assess the pulmonary ventilation and diaphragmatic movement in 24 patients with scoliosis of various Cobb angle from 35 to 130 degrees [22]. The authors found more impairment in the concave side lung for both more uneven distribution of ventilation and less diaphragmatic movement. There are not sufficient data to explain how the diaphragmatic excursion is impaired in idiopathic scoliosis. Diaphragmatic excursion is certainly markedly impaired in obesity, as well as in supine position.

Assessment of lung function in IS

As pulmonary impairment is the most serious implication of the scoliosis, which – when uncontrolled and not relevantly treated may lead to cardiorespiratory failure, lung function testing is essential in the care of patients with scoliosis. Consequently, understanding pulmonary function tests in group of patients with IS is important.

Spirometry. As the primary dysfunction of the respiratory system in scoliosis is of the restrictive character, spirometry is the first method of choice to identify any changes in the course of the disease. Spirometric examination normally should include two procedures: the measurement of vital capacity (VC) and its subdivisions, and the measurements of the flow-volume curves. There are many types of spirometers available on the market, including very simple ones, but according to the recommendations diagnostic spirometry should be performed in a lung function laboratory. Currently, updated versions of joint American Thoracic Society/European Respiratory Society recommendations define all the steps of those measurements. Spirometry can be performed even by young children aged 5 years of less, but in preschool children it is rather difficult and regulated by recommendations addressed to this age group [23]. For older children, adolescents and adults, preparation, procedure and quality assessment are defined by the statement published in 2005 [24]. In patients with idiopathic scoliosis, with the progress of the disease a decrease in vital capacity (or forced vital capacity) is observed – as stated above. When condition of the patients worsen, they may also develop signs of peripheral obstruction (a concave shape of the expiratory part of the flow-volume loop). This peripheral obstruction, which might be the result of the chronic inflammation of the lower airways caused by poor clearance of secretions, is often reversible with bronchodilators [25].

As the reduction of vital capacity is not sufficient to quantify the restrictive defect in the respiratory system, the next step is to measure the lung volumes (i.e. total lung capacity, TLC, functional residual capacity, FRC and residual volume, RV) using body plethysmography [26]. The plethysmograph is a rigid box enclosing the patient, and it is possible to measure total amount of air in thoracic cage. The decrease of the total lung capacity below the lower level of the normal value indicates restrictive defect of the respiratory system. TLC, FRC and RV can also be assessed using gas dilution methods, which use helium in the respirable mixture – however both techniques give similar results, and plethysmography is much more popular in lung function laboratories.

Last but not least, diffusing capacity for carbon monoxide should be determined – as with the loss of alveolar space the gas exchange is affected. This procedure is done in specialized lung function laboratories – and is also subject of standardization statement [27].

Lung function in scoliosis might be also determined by other factors – among them the most important are maximal respiratory pressures. The maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) might be measured during simple procedure using a portable meter [28]. The measurement of MIP is performed from the level of residual volume, while MEP is measured at the level of total lung capacity by registering maximal pressure sustained for at least 1 second during inspiring/expiring against closed tube. In patients with scoliosis MIPs and MEPs are decreased.

Table 1. Summary of lung function impairment in scoliosis.

Symbol	**Description**	
VC	Vital capacity – maximal volume change during deep inspiration/expiration. Determined by spirometry	Decreased
FVC	Forced vital capacity – determined during forced expiration.	Decreased
FEV1	Forced expiratory volume in one second – volume of air exhaled during the first second of forced expiration. Determined by spirometry	Decreased (due to decreased (F)VC)
MEFs	Maximal expiratory flows – registered during forced expiration at respective levels of the forced vital capacity	Slightly decreased
TLC	Total lung capacity – the whole amount of air in the lungs at the level of maximal inspiration - determined by plethysmography or gas dilution method	Decreased
FRC	Functional residual capacity – the amount of air in the lungs at the level of end expiration. Determined as above.	Decreased
RV	Residual volume – the volume of air remaining at the lungs at the level of maximal expiration	Decreased
Dl,co	Diffusing capacity – measured with the use of carbon monoxide	Decreased
Kco	Dl,co per liter of alveolar volume	Normal
MIP	Maximal inspiratory pressure	Decreased
MEP	Maximal expiratory pressure	Decreased

An important issue concerning the assessment of severity of lung function analysis must be noted. Normative values derived from population studies depend on standing height. In patients with scoliosis, it may be necessary to replace standing height with arm span. Such way of comparing results to the reference values implies that the results that are close to the lower limit of normal should be interpreted very carefully.

A study of Kearon et al. [29] analyzed pulmonary function in adolescent idiopathic scoliosis in 66 patients. They have shown that, in general, idiopathic scoliosis patients had mild non-obstructive changes in spirometry (reduced VC, slightly reduced maximal expiratory flows). Total lung capacity, functional residual capacity an residual volume were decreased to a similar extent, and the diffusing capacity for carbon monoxide was decreased due to the loss of alveolar volume. Changes in VC were closely related to the decrease of TLC.

Vital capacity expressed as a percentage of predicted significantly correlated to the Cobb's angle, curve length (expressed as the number of vertebrae and curve position). They conclude that, "*position of the curve one vertebrae above in the thoracic spine, involvement of more than one vertebrae in the curve, a 15 degrees increase in the angle of scoliosis, and an 8 degree loss kyphosis were each associated with a roughly equal reduction in VC of approximately 3% of predicted VC*".

The individual progression of the deterioration of lung function in patients with idiopathic scoliosis might be determined only by direct measurements.

The parameter of the height and the corrected height in pulmonary function tests

The height of the body is a very important data in the analysis of pulmonary function. In pulmonary function testing observations in an individual patient are recorded and compared to predicted norms, expressed as predicted percentages. The normal values in pulmonology are based on age, sex and height. In scoliosis the spine is deformed and the height of the trunk is smaller comparing to the normal spine. The undeformed height in scoliotic patient may be defined by using mathematical equations (which are used very rarely in the clinical practice), and by using the value of the arm span instead of "the normal height" (this method is used very often). The most practical method of estimating the "true" height was described by Hepper et al. [30]. This method was modified for using in scoliotic patients by Johnson and Westgate [8] and Linderholm and Lindgren [31]. They applied to calculations of the "true" height the ratio of the correction. Johnson and Westgate [8] were using one standardized ratio (1.03±0.02) for both sexes. To give the "true" height the arm span should be divided by 1.03. Linderholm and Lindgren [31] used different ratio for males (1.029) and females (1.012).

Johnson and Westgate, Linderholm and Lindgren observed greater arm span value than height value. In both cases authors had to use the correction factor, because of using in their study small groups and not only children and adolescent. In group of older people a tendency to compress the spine was observed. In healthy children group (124 boys and 128 girls aged 8 years and 120 boys and 140 girls aged 12 years studied annually on six and seven accessions respectively by Hibbert et al.) the arm span was so close to the height that adjustment is not necessary, and this did not change with age in the young population. Hibbert et al. reported that the correction factor of (Johnson and Westgate) height would be underestimated by 3%, and with that of (Linderholm and Lindgren) height would be underestimated by 2.9% in boys and 1.2% in girls. In conclusion by Hibbert et al. the height can be directly estimated by measuring the arm span, particularly in the young patients [8, 31, 32].

The arm span is measured as the distance between the tips of the right and left middle fingers, while the arms are stretched horizontally with the back to the ruler and the patient is standing with his feet together [1, 32].

Conclusion

Reduced thoracic volume, thorax restriction and inefficient respiratory muscles contribute to the final respiratory impairment in patients with idiopathic scoliosis. Spirometry still remains as the first method to assess the respiratory function, and all steps of the measurement are defined and recognized by international societies. Other methods, including respiratory pressure measurements and body pletysmography are expected to gain on importance. Proper use of the functional respiratory test will allow a reliable assessment of the influence of the deformity, as well as the impact of treatment on the natural course of the respiratory impairment in patients with structural progressive idiopathic scoliosis.

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Side-Shift Exercise and Hitch Exercise

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Abstract. We use side-shift exercise and hitch exercise for the treatment of idiopathic scoliosis. Outcomes of side-shift exercise used for the curves after skeletal maturity or used in combination with part-time brace wearing treatment are better than the natural history. Side-shift exercise and hitch exercise are useful treatment option for idiopathic scoliosis.

Keywords. Idiopathic scoliosis, exercise, side-shift, hitch

Introduction

Since 1986, we adopted side-shift exercise and hitch exercise for the treatment of idiopathic scoliosis. Our indications of physical therapy are:

1. Curves too small for brace treatment (e.g., Cobb angle < 25º)
2. Curves after skeletal maturity that include curves after weaning of the brace (e.g., Risser sign IV or V, post menarche > 2 years)
3. Combined with part-time brace wearing treatment (e.g., Cobb angle > 25º, Risser sign 0 to IV)

We describe methods and outcomes of the treatment.

1. Methods of the Treatment

1.1. Side-Shift Exercise

Side-shift exercise was originally described by Mehta [1]. The exercise consisted of the lateral trunk shift to the concavity of the curve. Lateral tilt at the inferior end vertebra is reduced or reversed, and the curve is corrected in the side-shift position (See Figure 1). Patients are instructed to shift their trunk repetitively to the concavity of the curve and hold the side-shift position for 10 seconds while they are standing and to maintain the side-shifted position while they are sitting.

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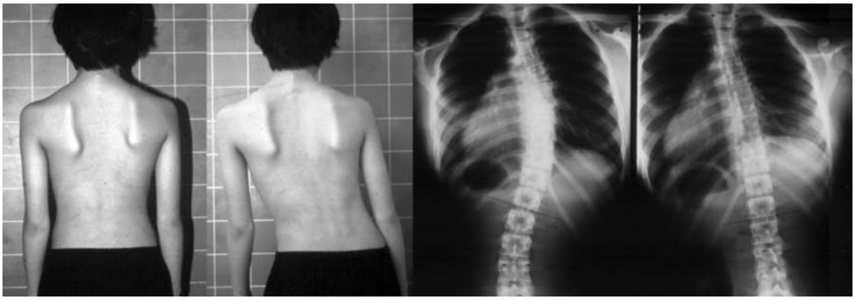
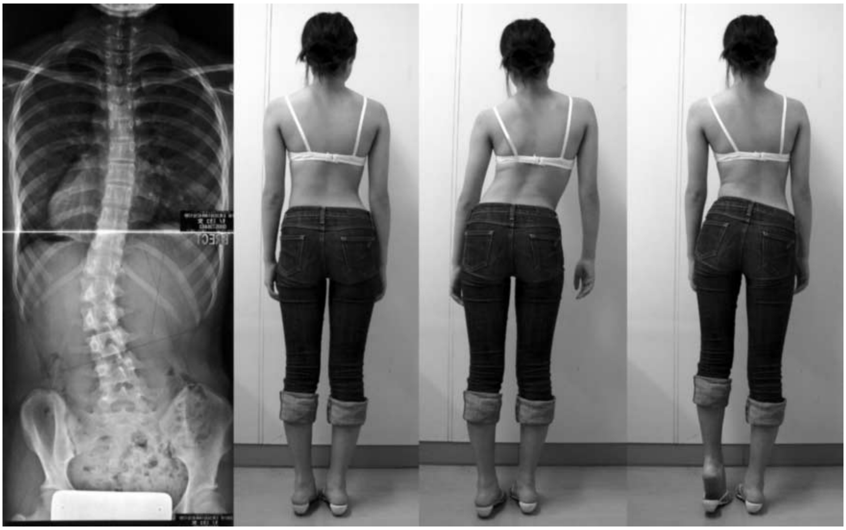


Figure 1. A patient standing in the neutral and side-shift position. Note that lateral tilt at the inferior end vertebra is reversed and the curve is corrected in the side-shift position.

If C7 plumb line lies to the convexity of the curve at the level of the sacrum, large shift is indicated, and if C7 plumb line lies to the concavity of the curve at the level of the sacrum, small shift is indicated. For a double major curve, the larger curve is the subject of the treatment.

1.2. Hitch Exercise

For lumbar curve or thoracolumbar curve, another option is hitch exercise. Patients are instructed to lift their heel on the convex side of their curve while keeping their hip and knee straight, and to hold the hitched position for 10 seconds (See Figure 2). In the hitch position, pelvis on the convex side is lifted, lateral tilt at the inferior end vertebra is reduced or reversed, and the curve is corrected.



(a) (b) (c) (d)

Figure 2. For a lumbar or thoracolumbar curve (a, b), either side-shift exercise (c) or hitch exercise (d) is indicated.

Figure 3. For double curve, hitch-shift exercise is indicated. Patients are instructed to lift their heel on the convex side of the lower curve as the hitch exercise, immobilize their lower curve by the hand, and shift their trunk to the concavity of the upper curve.

1.3. Hitch-Shift Exercise

Hitch-shift exercise is an option for a double major curve. Patients are instructed to lift their heel on the convex side of the lower curve as the hitch exercise, immobilize their lower curve by the hand, and shift their trunk to the concavity of the upper curve (See Figure 3).

2. Outcomes of the Treatment

2.1. Literature Review

In 1985, Mehta [1] reported the results of side-shift exercise of 35 patients (33 girls and 2 boys) whose average age was 14.1 years and average Cobb angle was 23.8º at the beginning of the treatment. After a mean treatment period of 1.9 years, their average Cobb angle changed to 24.8º. Of 42 curves in 35 patients, nine curves (21.4%) improved of 5º or more and change of 21 curves (50%) were less than 4º.

In 1999, den Boer et al. [2] compared the results of side-shift exercise with historical control group treated with a brace. They concluded that there was no difference between the efficacy of the brace treatment and the side-shift therapy.

2.2. Our Results

2.2.1. Curves after Skeletal Maturity

Results of a total of 69 patients with idiopathic scoliosis who were treated only by side-shift after their skeletal maturity were analyzed [3]. The average age at the beginning of the treatment was 16.3 years and the average follow-up period was 4.2 years. The average Cobb angle was 31.5º at the beginning of side-shift and 30.3º at the follow-up. Most of the long-term follow-up studies reported that idiopathic scoliosis progressed even after skeletal maturity. For thoracic and thoracolumbar curves from 30º to 50º, Weinstein SL and Ponseti IV [4] reported 0.25º per year progression with 40.5 years follow-up, and Ascani E et al. [5] reported 0.36º per year progression with 33.5 years follow-up. However, in our results, 33 curves of 30º to 50º showed 0.1º per year decrease during the follow-up period of 4.2 years.

2.2.2. Combined with the Part-Time Brace Treatment

Results of a total of 39 female patients with adolescent idiopathic scoliosis, whose Cobb angle was larger than 25 º degrees and whose Risser sign was 0-3 at the start of the treatment, were analyzed [6]. The patients followed-up for more than one year and at least until Risser sign of IV, or deteriorated in this period and discontinued the brace treatment were included in an analysis. At the commencement start of the treatment, patients' mean age was 12.8 years and mean Cobb angle was 37.1º. The average Cobb angle changed to 45.4º after the averaged follow-up period of 2.8 years. Of 39 patients, 28 (72%) were classified as unchanged because the change of their Cobb angle was within 10º, and 11 (28%) as progressed because their Cobb angle increased of 10º or more. Comparing these results with natural history of the identical sized curve reported by Bunnell [7], follow-up period was longer in our study, while prevalence of progression more than 10 degrees was lower.

Conclusion

Side-shift exercise and hitch exercise are useful treatment option for idiopathic scoliosis.

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"FITS" Concept Functional Individual Therapy of Scoliosis

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Abstract. Functional Individual Therapy of Scoliosis - FITS concept may be used as a separate system of scoliosis correction, a supportive therapy to bracing, children preparation to surgery and also shoulder and pelvic girdle correction after surgical interventions.

Taking into account the dysfunctions accompanying scoliosis, the authors of the concept propose an individually adjusted programme of exercises depending on a curvature angle and a result of clinical examination of a patient. On this basis both general and specific goals are set.

FITS concept consists of two stages:

- Elimination of myofascial restrictions which limit a three-plane corrective movement, by using different techniques of muscle energization.
- building new corrective posture patterns in functional positions;

By sensory motor balance training and exercising the lower trunk stabilization we can start teaching corrective breathing (with the scoliosis convexities) and adjust corrective movement patterns (in open and close chains). A selection of corrective movement patterns will depend on a type of scoliosis, a direction of spine rotation and a place of building functional compensation.

Every corrective pattern includes three components: flexion/extension (the saggital plane correction), elevation/depression (the frontal plane correction) and external/internal rotation (the transverse plane correction). In the processs of therapy the corrective movement patterns are being changed depending on curvature angle behaving and clinical picture of a patient.

Keywords. Idiopathic scoliosis, three-plane correction, sensory motor balance training , corrective breathing, functional compensation, corrective movement patterns

According to the authors, the most important factor in conservative management of idiopathic scoliosis is an individualization of the therapy. After careful examination of the patient, the exercise program can be established for each child. The therapy aims not only to apply a passive correction of the deformity but attempts to accomplish the correction in an automatic fashion. Mechanical obstacles to curve correction need to be removed, for example muscle contractures and articular dysfunctions. The child should learn to manage to maintain a corrected posture.

The postural reeducation is an active process of attaining and maintaining proper posture. It requires a child to establish and consolidate the postural habit. Proper education is necessary to establish such a habit therefore maintaining good posture automatically is not possible even taking under consideration great power and endurance of postural muscles. Scoliotic children frequently have impaired body awareness. They perceive scoliotic posture as a natural one. They feel any attempt to attain the correct posture as something unnatural and artificial. This phenomenon is due to a long time of the presence of scoliosis. During that time the improper pattern of posture has been established because the entire system of postural control has been functioning under abnormal conditions [1]. Muscular balance continuously adapts the posture to forces of gravity. Improper posture results in the displacement of the center of gravity which initiates kinetic reactions requiring muscular response. Change in mechanical response of a joint results in the change of neuro-reflexive activity of related muscles, secondary to aberration of afferent impulsation from joint mechanoreceptors. Long term improper stimulation from joint mechanoreceptors may cause change in plasticity of the nervous system, which controls normal movement and lead to foundation of improper movement patterns that may perpetuate scoliosis [2].

According to the authors, the FITS concept fulfills the following criteria of non-invasive treatment of scoliosis.

FITS stands for Functional Individual Scoliosis Therapy and can be used as:

- a separate system of scoliosis correction;
- a supportive therapy to bracing;
- a preparation of children for surgery by increasing the elasticity of soft tissues and the joint mobility;

Dysfunctions associated to scoliosis

1. Insufficient awareness of his/her own posture which makes children less involved in the treatment process.
2. Myofascial limitations which make three-plane corrective movements of scoliosis corrections difficult.
3. Incorrect feet loading.
4. Disturbed stabilization of lower trunk.
5. Increased myofascial tension between the thoracolumbar scoliosis apex and the iliac crest which limits the spine shift of the scoliosis correction.
6. Limited mobility of 3-4 ribs on the side of the scoliosis concavity, disturbed mechanism of thorax movements during breathing (breathing with convexities).
7. Incorrect posture patterns caused by the long-lasting scoliogenic stimulation.

Main goals of FITS concept

1. To make a child aware of existing deformation of the spine and the trunk and to provide a direction for scoliosis correction.
2. To release myofascial structures which limit a three-plane corrective movement.
3. To teach correct foot loading in order to improve the pelvic position and produce symmetrical loading of the lower limbs.
4. To strengthen the force of pelvic floor muscles and short rotator muscles of the spine in order to improve the lower trunk stabilization.

5. To teach the correct shift of the spine in the frontal plane in order to correct the main curve, while stabilizing (or maintaining in correction) the secondary curve.
6. To facilitate the ability to perform the correct three-plane corrective breathing in physiological positions.
7. To make the child aware of the correct patterns and any trunk deformations connected with the curve of the scoliosis (asymmetry of head position, asymmetry of the lines of shoulders, shoulder-blades, waist triangles and pelvis and hip joints).

Therapy according to FITS:

1. The authors of the concept attach a great role to the child awareness of the type of curvature, the trunk deformations connected with existing scoliosis and the possible scoliosis correction depending on the position of shoulder and pelvic girdle. We analyze the x-ray with the child, show the three-dimensional position of scoliosis on the spine model and show the direction of correction. On the first visit the child can see his or her figure with the use of camera and TV set. In our opinion, the child's awareness of his or her deformation, explaining the way of treatment, making the child a partner not a subject of therapy significantly increases the motivation to exercise and improves the effects of therapy

Figure 1. Making the child aware of his trunk deformation connected with the spine curvature.

2. During the our long-standing work with scoliosis, we has observed distinct myofascial limitations in the area of many muscle chains. The limitations are especially seen while trying to make passive corrective movement either sitting or standing. By making corrective movement, the therapist can feel which myofascial structures should be targeted by to the therapy first. Prior to and effect each therapy session specific corrective movement tests are done to document any changes and to direct future treatments. At the beginning of the therapy the

corrective movement can be done only in one plane – shift, rotation or flexion/extention. In later therapy stages one should account the three-plane movement.

Figure 2. Checking scoliosis correction abilities in functional positions.

In children with scoliosis one observes the deformation of sagittal plane caused by segmental stiff and shallow or even lordosed thoracic kyphosis [3]. The sagittal plane of the spine is stabilized mainly by two muscle lines: at the back of the trunk – SBL (superficial back line) and in the front of the spine – DFL (deep front line) [4]. These are mainly muscles which fill the space between spinous and transverse processes of the vertebra and the space between transverse processes, vertebral bodies in the front of the trunk. The authors of the concept have observed a greater tension in the back muscle line especially in the plantar fascia, the short head of the biceps muscle of the thigh, the sacrotuberal ligament, thoraco-lumbar fascia and the back extensors. Similar dysfunctions are observed

Figure 3. Myofascial relaxation along SBL – ischiocrural group.

Figure 4. Myofascial relaxation along back extensor in order to increased the forward bend.

in some elements of other muscle lines. For the relaxation of this myofascial structures we use the muscle energytechniques: positional release, myofascial release, trigger points [5, 6, 7, 8, 9].

3. The authors pay attention to the correct foot position considering three support points, correct arch of the foot (flat foot, hollow foot), valgus, varus deformity (the position of forefoot towards rearfoot). In the therapy we use the training of "the short foot"according to Janda in different initial positions starting with sitting to standing, reducing support surface and making the exercises more difficult by changing support surface from stable to unstable. We use the biofeedback equipment. The therapist shows the child his/her incorrect foot position by indicating the line of the Achilles tendon to the calcaneal tuber. Sensory motor balance training is essential in creating the child's corrected posture[2].

Figure 5. Teaching foot loading with the use of feedback.

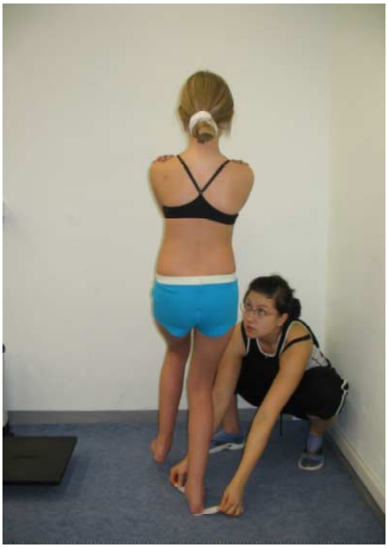

Figure 6. Teaching correct foot loading maintaining scoliosis correction without visual control.

In obtaining a corrective movement one should pay attention not only to the sagittal plane but also to the transverse one.

The spiral muscle line (SL) plays a significant role in holding the good posture [4]. Often observed dysfunctions deal with the front part of the line – between the anterior superior iliac spine and the external surface of lower ribs on the opposite side. For instance, in single curve left scoliosis, the therapy concerns right external oblique muscle and left internal oblique muscle of abdomen.

Figure 7. Shortenings in the area of right spiral line associated to single curve thoracolumbar scoliosis.

Figure 8. Myofascial relaxation with the stabilization of anterior iliac spine.

4. We observe distorted stabilization of lower trunk in the children with scoliosis, especially during everyday activity. In clinical examination we observe an increased lumbar lordosis while in the sagittal plane x-ray a smaller lordosis in upper lumbar part and an increased one in the lumbosacral junction. The exercises of lower trunk stabilization are the basis for teaching corrective patterns in the area of upper trunk and shoulder girdle [10, 11, 12]. Without this stabilization the children create a compensation in the lumbar part during exercises using the upper limbs patterns and scoliosis correction in a thoracic segment, which results in incorrect loading of the pelvis and the lower limbs.

Figure 9. Teaching a lower trunk stabilization on the unstable ground with additional loading and maintaining three-plane scoliosis correction.

5. In obtaining a corrective movement children have especially great difficulties with doing a lateral shift (a frontal plane correction).

Figure 10. Measurement of range of thoracolumbar spine shift.

Figure 11. Shift range after one session of FITS therapy.

The limitations are connected with a greater tension of myofascial tract between the iliac crest and the scoliosis apex. These usually are: the lower fibers of quadrate lumborum, the internal and external oblique muscles of abdomen, the thoracolumbar fascia and the back extensor between spinous and transverse processes of lumbar spine, gluteus medius muscle and of hip – on the side of thoracolumbar scoliosis convexity. The exercise of shift in the functional positions (sitting and standing) is advisable. In the case of double major scoliosis one should be aware that the shift of the lower curve of the scoliosis should be done without increasing the upper curve. In the future therapy we shall aspire to do the shift in lower thoracolumbar segment maintaining upper arch also in correction.

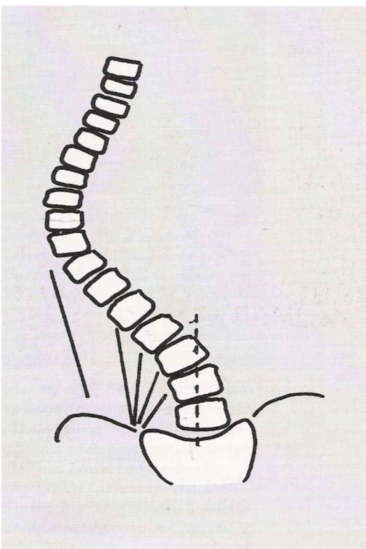

Figure 12. Myofascial structures limitating shift of the spine to correction.

Figure 13. Teaching shift in functional position.

If we still observe joint dysfunctions after the therapy of soft tissues, we shall use joint mobilization techniques [13, 14] . In the thoracic scoliosis we are usually used techniques that enlarge thoracic kyphosis, costotransversal joints mobilization and techniques derotating scoliosis. In the lumbar scoliosis we use joint mobilizations depending on the dysfunction: increased/decreased lordosis. Also techniques of sacroiliac joints mobilization are used.

Figure 14. Joint mobilizations to increased thoracic kyphosis.

Figure 15. Costotransversal mobilizations to improve breathing function.

6. Teaching correct breathing should be done after the relaxation of myofascial system and after restoring the best possible joint mobility in the area of thoracic spine and thorax.

   The goal of our therapy is directing breathing movements towards the concavities [15]. We teach the child to breath in towards the scoliosis concavities with deeper phase of breathing out on the side of convexity. This way we stimulate both the dorsal side of concavity and abdominal side of convexity. Teaching these exercises is started in the lying position (the easiest for the child) trying to reach the functional position (sitting, standing).

   We can gain the correction of these functions by derotative breathing exercises (breath in with making scoliosis concavity convex, breath out – maintaining the activity of muscles on the side of concavity with mobilizing convexity to

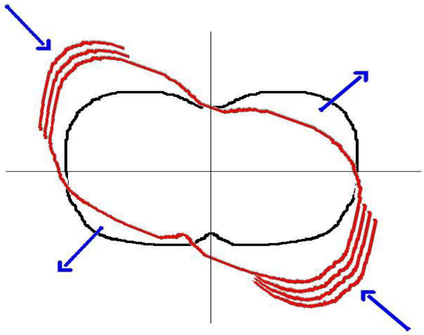

Figure 16. Pattern of correct movements of the thorax for thoracic scoliosis.

Figure 17. Correct stimulation of breathing movements of the thorax in the functional position

derotate). We can increase the effectiveness of the mentioned exercises by adding elongation of scoliosis concavity by upper and lower limbs patterns (besides derotation we have three-plane scoliosis correction). In every case the attention should be paid to correct position in the sagittal plane. The exercises are essential elements of costal hump corrections especially when they are done in functional positions and especially while sitting and standing (most often used positions during a day).

7. Teaching patterns correcting scoliosis and all deformations connected with is (asymmetry of head position, asymmetry of the lines of shoulders, shoulder-blades, waist and pelvic asymmetry) is done with the use of exercises in open and close chains [16].

To perform thoracic scoliosis corrections we use the shoulder girdle and upper limbs, for thoracolumbar and lumbar scoliosis – pelvic girdle and lower limbs. Each limb pattern consists of three elements:

- in frontal plane – elevation/depression (raising/lowering)
- in sagittal plane – flexion/extension of the shoulder joint
- in transverse plane – external/internal rotation of shoulder joint [17].

The choice of these elements depends on Cobb's angle size and direction of the trunk rotation, position of the spine in the sagittal plane and the location of the compensation (secondary curve) [18].

Figure 18. Patterns correcting scoliosis (with the shoulder line asymmetry)

Figure 19. Derotative breathing exercises in patterns correcting scoliosis with elongation.

In the therapy of scoliosis the correction of primary structural curve in three planes is the most desired. However, in many cases it can be impossible due to the significant curvature or it's resistance to correction. In these cases we believe creating or extending compensating curves above and below the primary curve is beneficial. This compensation should be created only in soft tissues (functional one) not allow to become structural, not seen in the x-ray, because the correction of two or three curves of structural curvatures is significantly harder and less effective than of one structural curve. By creating functional compensation we can improve the body shape and have a good clinical effect. Based on a thorough analysis of the curvature and the child's body shape and x-ray one should decide on which level the compensation is the most advisable [19].

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Section VIII

Braces

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The Conservative Scoliosis Treatment
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Brace Treatment for Adolescent Idiopathic Scoliosis

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Abstract. Adolescent idiopathic scoliosis (AIS) presents as an abnormal curvature of spine with vertebral rotation. It may impact the patient for their entire life. Approximately 0.25% of adolescents will require treatment. Brace treatment is the most commonly used non-surgical treatment for AIS. Its goal is stop the progression and maintain the curve at an acceptable level through the high risk growth phase of adolescence. However, its effectiveness is controversial and the actual biomechanical action of the brace is not fully understood. Recently, the Scoliosis Research society (SRS) created a standard criterion for AIS brace studies. However, to evaluate the effectiveness of the brace treatment, the spine flexibility, in brace correction and patient's compliance should also be included in a study. Although bracing has been used for more than 50 years, there are still many unknowns. How much wear time per day is needed for an optimum treatment outcome? How much brace tightness is optimal? What is the best weaning protocol? What is the best method to determine the curve flexibility? How much in-brace correction is needed to obtain good results? Without accurate and precise methods to objectively measure or answer the above questions, it is misleading to state whether or not brace treatment is effective. Therefore, a lot of research is still required before one can answer the effectiveness of the brace treatment.

Keywords. Scoliosis, Brace Treatment

1. Introduction

Adolescent Idiopathic Scoliosis (AIS) is a three-dimensional deformity of the spine associated with vertebral rotation within the curve and with unknown cause. This lateral curvature affects the rib cage and presents as deformities of the trunk. It is usually detected between about age ten and skeletal maturity, with females comprising approximately 70% of cases. Approximately 2-3% of adolescents have scoliosis and 10% of these may require treatment. Cosmesis is one of the primary reasons to motivate adolescents with AIS to seek treatment [1,2]. Parental concern about their child's future pain and disability are also factors pushing them to seek medical advice [3]. Compared to non-scoliotic controls, most patients with untreated AIS do not lose function. However, AIS patients have an increase in pain prevalence. Symptoms that commonly occur in association with scoliosis include pain [4] and psychological stress [5]. If scoliosis is left untreated and a large curve develops, it can injure both the lungs and heart causing significant health problems. Treatment modality depends on the severity, skeletal maturity, curve location and received risk of progression. The Cobb method is the gold standard [6] to measure the severity of the scoliosis. The Risser sign estimates the skeletal maturity. The primary goal of treating scoliosis is to stop the progression. Cobb angle between 10 to 15 degrees usually require no active treatment. Patients with curvatures above 15 and below 25 degrees and have significant growth left will be monitored regularly. Patients with curvature between 25 to 40 degrees and have growth left usually will receive non-operative treatment. Surgery is the final method to stop the curve progression.

2. Brace treatment

Non-operative treatment includes electrical stimulation, exercises, chiropractic manipulation, scoliosis intensive rehabilitation and brace treatment. Among these, bracing is the most accepted as changing the natural history and commonly used non-surgical method for the treatment of AIS.

2.1. Brace Candidates

Scoliosis curves may progress unpredictably and treatment is usually based on serial observations and on an individual basis. Guidelines for bracing usually depend on the risk of curvature progression and the severity (Cobb angle) in a given period of time. Lonstein [7] established an estimate of the risk of progression based on the following formula:

Risk of progression (in percent) = (Cobb angle – 3 x Risser sign)/chronological age

Table 1 shows Lonstein's estimated risk of progression in AIS. Brace treatment is usually recommended if the progression risk is greater than 40% and the Cobb angle is between 25° to 40°. Prescribed braces are either a CTLSO (Cervico-Thoraco-Lumbo-Sacral Orthosis) or a TLSO (Thoraco-Lumbo-Sacral Orthosis), depending on the curve type and the location of the curve apex.

Table 1. Risk of progression in AIS

Degree of curve Cobb angle	Age 10-12	Age 13-15	Age over 16
<20°	25%	10%	0%
20°-30°	60%	40%	10%
30°-60°	90%	70%	30%
>60°	100%	90%	70%

2.2. How a brace works

Brace treatment does not 'cure' scoliosis, but its purpose is to stop the progression and maintain the curve at an acceptable level through the high risk growth phase. Some authors believe that the Hueter-Volkmann principle contributes to the development of adolescent idiopathic scoliosis [8-10]. This theory suggests that asymmetric loadings or compression force applied to the growth plates on the concave side of the curve inhibits the normal growth of the vertebral bodies leading to wedging of the vertebral bodies. In theory, bracing a scoliotic curve should unload the growth plates on the concave side of the vertebral bodies near the apex of the curve [10]. Bracing should be more effective if applied prior to the vertebrae becoming wedge. However, the evidence of the brace action based on the Hueter-Volkmann principle is still limited.

Two other concepts of brace actions have been discussed in the literature; one is the brace provides mechanical support to the body (passive component) and the other is the patient pulls her body away from pressure sites (active component) imposed by the brace (active component) [11].

2.2.1. Mechanical Forces Principle

There are many contradictory brace designs and concepts applied by orthotists to support the spine. A questionnaire with scoliotic cases was sent to 17 surgeons who attended the SOSORT 2005 meeting. The results of that study [12] showed that no single biomechanical concept is accepted to correct scoliosis; each participant presented their concepts based on their experiences. The most commonly accepted principle was the ‘three point concept’. Researchers generally believed that correcting the scoliotic curve in the frontal plane was the most importance followed by the derotation of the major curve. For example, in the case of a right thoracic curve, the three point forces will be applied to the left lumbar, the right thoracic and the left upper thoracic. To better understand the mechanical principles, forces generated by braces and the strap tension have been measured [13-15]. A correlation was found between the strap tension and the forces generated by Boston braces [15]. Wong et al. [16] and Jiang et al. [17] also found a correlation between the strap tension and Cobb angle correction. Aubin et al. [18] reported that the tension was correlated to the postural position of the patient.

In addition to force measurements, simulation software based on finite element model had been developed to investigate the biomechanical action of a brace. Andriacchi et al [19] simulated the action of the Milwaukee brace for 5 types of scoliotic curves and concluded that the Milwaukee brace was efficient in reducing the curve in the frontal plane. Aubin et al. [20] compared the effect of purely transverse forces and of posterior forces applied to rib hump. The results showed that the transverse forces reduced frontal curves but worsened rib hump and axial rotation. The posterior forces had the opposite effect. Patwardhan et al. [21] modeled the scoliotic spine as a buckling column. They found that the brace improved the spine stability and reported that the forces should be applied at and below the apex of curve.

The truly three dimensional forces induced by the brace to treat scoliosis are still not well known in how they act upon the rib cage and spine. More research is required to understand the mechanical principles of brace treatment.

2.2.2. Active Muscle Principle

The active component of the brace treatment is similar to the intensive training concept; patients pull away from the pressure site area. Three groups [22-25] found posture training to be beneficial in managing mild scoliosis, but required someone to provide on-going coaching to maintain the desired posture. El-Sayyad et al. [26] showed that exercise alone helped to decrease mild curvatures of the spine. The Australian Physiotherapy Association and the European Biofeedback group also believe that exercise can correct postural scoliosis. Dworkin *et al.* [27] suggested that behavioral principles and therapeutic theory helped scoliotic children improve their cosmetic appearances. Dworkin et al. used the Micro-Straight device to correct spinal deformities. The Micro-Straight detects the length of the trunk and compares it to a pre-set value. If the length of the trunk is different from the preset value and lasts longer than 20 seconds, a beep tone will alert the patient to correct the posture. Wong *et al.* [28] used this device recently to conduct a clinical study. The results presented by Dworkin et al. and Wong et al showed that this approach successfully improved the patients' postures. However, the Micro-Straight can only measure the deformity in one-dimension, and the audio tone feedback was disruptive and drew unwanted attention to the wearer. These studies suggest that children with poor posture should be able to transfer the learned corrected posture to a long-term improvement of trunk deformity. The mechanism for this may be that continuous muscle training results in a re-education of the poor posture into a more balanced posture. However, the length of training required and amount of followed-up coaching to achieve a long term balanced posture is still unknown.

Although no conclusive statement has been made, it is reasonable to assume that the passive component work together with the active action of the brace. If a patient wears the brace properly, pressure from pad areas should push on the rib cage and be transferred to the spine. Patient response to these pressures should be by moving the body away which create the active muscle actions. Therefore, the effectiveness of brace treatment should depend on the quality (tightness) of brace usage in addition to the quantity (compliance).

2.3. Effectiveness of brace treatment

Although bracing for scoliosis has been used for more than fifty years, its effectiveness is still debatable [29-32]. Some researchers believe that brace treatment does not alter the natural history but others believe that braces can help stop some curves from progression. The controversial results are mainly due to non-consistent inclusion criteria and different definition of brace effectiveness. Some studies included both male and female patients for data analysis. Some studies only included the compliant patients. Most studies used the amount of curve progression (Cobb angle) to determine the effectiveness of brace treatment. Some used 5 degrees or less curve progression to count as success; some used if a curve progressed 6 degrees or more to count as failure; and some used patients who required surgery at the end to count as failure. Without a consistent definition, it is difficult to evaluate the effectiveness of the brace treatment.

Recently, standardization of criteria for AIS brace studies has been set out by the Scoliosis Research Society Committee on Bracing and Non-operative Management [33]. Recommended inclusion criteria for future AIS brace studies consist of: age 10 years or older when brace is prescribed, Risser 0-2, primary curve angles 25°-40°, no prior treatment, and, if female, either pre-menarchal or less than 1 year post-menarchal. Assessment of brace effectiveness should include: (1) the percentage of patients who have $\leq 5°$ curve progression and the percentage of patients who have $> 6°$ progression at maturity, (2) the percentage of patients with curves exceeding 45° at maturity and the percentage who have had surgery recommended/undertaken, and (3) 2-year follow-up beyond maturity to determine the percentage of patients who subsequently undergo surgery. All patients, regardless of compliance, should be included. Every study should provide results stratified by curve type and size grouping.

Genders, the skeletal age, curve type and the initial curve magnitudes affect the risk of progression and responsiveness to bracing. The compliance, in-brace correction and the curve flexibility contribute to the outcome of the brace treatment. The effectiveness of the brace treatment is difficult to predict without knowing the compliance, in-brace correction and curve flexibility,

2.4. Brace wear time and tightness

With improvement of electronics technology, recent studies have investigated brace wear compliance by using temperature or humidity sensors and force switches [34-39]. However, these studies did not measure how tightly the brace was worn. It may be misleading to conclude about the effectiveness of bracing without recording both the quantity and the quality of brace usage. Some work has been done to measure the loads while patients wore their brace. Cochran and Waugh [40] used standard mechanical sensors and Chase et al [13] used pneumatic sensors to measure the lateral pad forces. These two studies measured forces in a single pad area where the major corrective forces are applied to the body. Jiang et al. [17] used an Oxford pressure monitor and tension sensor to investigate the magnitude, location and direction of the pressure generated by the brace as well as the forces imposed by the straps. They found that there was considerable variation (axillary pad pressure 3-12 KPa) in how braces were worn. Cote et al. [41] used thin polymeric Force Sensing Resistor sensors to measure the entire pressure distribution inside the Boston brace. This study reported that the Boston brace did not generate a uniform distribution of pressure. Wong et al [16] developed a tension transducer to measure the tension of the brace strap. They found that the standing Cobb angle (severity of the scoliosis) is correlated with the pressure applied by the pad and the strap tension measured in a laboratory. More recently, Perie et al [42] analyzed the Boston brace biomechanics, through pressure measurements and finite element simulations and reported that mechanisms other than the main pressure pad area also produced correction and contributed to the force equilibrium within the brace. However, all of the above studies were done in a laboratory environment because the recording equipment was not portable. The brace may act quite differently during daily activities and thus it is problematic to infer brace characteristics from a clinic setting. The observed pressures may not be true indicators of the pressure exerted by braces over a treatment period lasting several months or years. To study the brace usage in terms of wear time (quantity) and wear tightness (quality), a low-powered portable load monitoring system was developed [43-45]. This system records how much time (quantity) a brace was used and how tightly (quality) it was worn. The system had been validated and used in a clinical study [43, 44]. The compliance research agreed with other studies [45]. From the study, it was suggested that simply wearing a brace may not be sufficient to affect an improvement in spinal curvature or even to prevent curve progression. The quality of the brace usage was as important as the quantity of the brace usage to prevent the curve progression during brace treatment. It was important that patients wore their braces to the prescribed length of time each day as well as to at the appropriate tightness to get the best outcome. Recently, an active brace system [46] was developed which could maintain the major interface pad pressure at the prescribed level during daily activities. A preliminary study [47] demonstrated that patients using this system had the forces applied by their brace within the target range more often and maintained their Cobb angle at the initial value. A larger clinical trial or multi-center clinical studies should be conducted before further conclusion can be made.

Brace Treatment Effects

The purpose of brace treatment is to stop curve progression during the high-risk growth period of early adolescence, minimizing the permanent deformities and to reduce the need for surgeries. Brace treatment results in successful outcomes in only a subset of patients. Is this because of the variable underlying causes of scoliosis, timing of brace usage, curve responsiveness, brace design, how the brace is worn (quality), how often the brace is worn (quantity) or more likely a complex combination of these and other factors. Typical brace candidates are young girls at a stage where they pay close attention to their appearance. It is a big commitment for a patient to wear a brace because it is restrictive, uncomfortable and draws unwanted attention. Significant initial in-brace correction and good compliance are positive indicators to have successful treatment outcomes [48]. Borders mentioned that patients' belief on treatment outcome is one of the important factors [49] in predicting compliance.

In addition to monitoring the curve, quality of life which includes physical function, social activities, pain, self image and mental health should be considered in evaluating brace treatment. Many patients are distressed when told they are to wear a brace. In general, physical function and social activities usually are lower for braced patients [50]. There is no significant difference on pain between the braced group and non-scoliotic group. The self image is decreased during the treatment period; however, it usually returns to normal after the completion of brace treatment [51]. The mental health shows no difference among surgical, brace and control groups at a minimum of 20 years follow-up in a study [52]. Family and peer support and encouragement are important during the brace treatment period.

Discussion

Even though bracing has been used for many years, there are still many unknowns. Brace treatment effectiveness is limited and needs to be improved. The amount of time a brace is to be worn is generally based on intuition. The most commonly recommended wear time is 23 hours per day; this number is not based on any objective data. In recent years, the Scoliosis Research Society has raised doubt as to whether part-time brace wearing is effective and if so, how many hours per day is enough? During the weaning period, patients are told to wear their brace only at night while brace forces are significantly lower. What is the optimal weaning protocol? How to define the optimal brace wear tightness? The in-brace correction depends on curve flexibility which correlates to treatment outcomes, but how much correction is needed to provide the optimal results? What is the best way to determine the flexibility of the spine? Although bending radiographs can provide certain flexibility information, exposing growing children to additional radiation is undesirable.

Orthotists are craftsmen as well as artisans, who play a significant role in the brace treatment and its ultimate outcome. The skill and experience of the orthotist affects the design of the brace as well as the brace wear tightness. How tight the brace should be worn to receive the optimal correction? Too much force will cause discomfort and likely reduces compliance, but too little force will not have any effect and waste patients time and money. More research is required before the actual function and the effectiveness of bracing can be answered.

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Biomechanical and Clinical Perspectives on Nighttime Bracing for Adolescent Idiopathic Scoliosis

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Abstract. The present review article aims at providing an update on the basic science and clinical information underlying the use of nocturnal braces for adolescent idiopathic scoliosis. The use of nocturnal braces has been dictated by the encouraging results recorded by some studies on part-time bracing, combined with increasing concerns on poor patient compliance noted with the use of full-time bracing. The cardinal feature of nighttime braces lays in their ability to hypercorrect the scoliotic curvature, thereby eliminating the asymmetric water accumulation that occurs in the apical and adjacent intervertebral discs, thus restoring a close-to-normal force application through the Hueter-Volkmann principle and preventing curve progression. The two nighttime braces mostly used hypercorrect the spine through different mechanisms, one acting by bending the spine and the other by the application of opposing forces. Based on the clinical results available, nighttime braces constitute an attractive option for single-major lumbar/thoracolumbar curves not exceeding 35° in magnitude. Multi-center, randomized studies using strict criteria set forth by the Scoliosis Research Society and the Study group On Scoliosis Orthopaedic and Rehabilitation Treatment are needed to better define the role of nocturnal bracing in the conservative treatment of adolescent idiopathic scoliosis.

Keywords. Adolescent idiopathic scoliosis, conservative treatment, nighttime braces, nocturnal braces

1. Introduction

With regard to treatment of adolescent idiopathic scoliosis (AIS), the only potentially effective alternative to operative correction and fusion is orthotic management alone[1], or coupled with exercises[2-4]. The cervicothoracolumbosacral orthosis (CTLSO) was the first to be used in a full-time mode to treat scoliosis conservatively, albeit with modest success[5].

Problems with patient compliance and poor self-image[6] and the questionable results of the Milwaukee brace prompted the need for the development of underarm braces (thoracic-lumbar-sacral orthoses, TLSO) in curves with an apex at T8 or below. The prototype TLSO, the Boston brace, developed by Hall and Miller in the mid

1970s[7,8], remains a popular choice today. Although results have been encouraging[7, 9], the need to decrease the psychological burden of the young patients still remained. Thus, further refinements in the conservative management of AIS entailed the reduction in the amount of time the brace is worn on a daily basis. Part-time bracing has been reported to have contradictory results in the literature[7, 10, 11].

The newest strategies today employ the concept of part-time orthotic use during nighttime. Conceivably, this type of treatment is likely to have the least negative psychosocial impact on patients. The purpose of this article is to provide an overview of the theory and clinical results of nighttime bracing used for treatment of AIS.

2. Indications for Use

Current indications for use of a nighttime brace in AIS appear to include patients aged >10 years old with single-major curves ranging between 25-35° with an apex below T8. Double curves should be considered an advanced indication, especially with the Charleston brace. Skeletally immature patients (Risser 0-2) are the best candidates for nocturnal bracing, as they have more time for treatment and their endplates are more amenable to repair.

3. The Rationale behind Nighttime Bracing

It is generally agreed upon that the critical question in the decision-making process for treatment of AIS is: where is the child in his or her growth spurt[12]? The answer to this question, together with additional information derived from clinical and radiographic examination, will determine the type of treatment required, if at all.

One must remember that natural history data refer to 'estimates' and 'likelihoods' derived from findings in large population samples. They do not tell us what will happen to an individual child. Therefore, each patient should be carefully managed on a strict case-by-case basis, in the context of a multidimensional approach, taking into consideration every piece of clinical, radiographic and social information available and defining the goals of treatment very clearly right at the outset.

In defining those goals, the physician plays a key role. Apart from correcting or delaying the progression of the deformity, other aspects of treatment, including, but not being limited to, balance, aesthetics, psychological well-being and disability, have been gradually incorporated to the list of outcome measures.

As one would expect, these goals are not prioritized similarly amongst treating physicians. Recently, the consensus paper of the Scientific Society On Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT) on the reasons scoliosis is treated for cited aesthetics, quality of life and psychological well-being as the first three primary outcome criteria in the conservative treatment of AIS; the same factor is only minimally taken into account in the literature (about 3%). Interestingly, back pain, Cobb angle and Perdriolle angle ranked 5th, 12th and 15th respectively in that study[13].

This finding corroborates other reports[14, 15] concerned with the psychosocial well-being during orthotic treatment and highlights the current trend of physicians treating scoliosis toward an holistic therapeutic approach[16], in which technical factors, such as the Cobb angle, are only a secondary outcome. It is also in accordance with an important element of brace treatment, namely poor patient compliance, which has been frequently cited in the literature as a factor leading to inferior results[17-20] .

Adolescence is a sensitive phase in the development of a young person. Patients diagnosed with AIS must commit to a lengthy, confining and uncomfortable course of treatment. In light of this, the use of nighttime bracing seems, at least in theory, justified.

4. Function of Nighttime Braces

4.1. Biomechanics

The rationale for conservative management of scoliosis during skeletal growth assumes a biomechanical mode of deformity progression, based on the Hueter-Volkmann principle[21], whereby extra axial compression decelerates growth and reduced axial compression accelerates it[22]. In treating scoliosis conservatively, bracing does nothing more than exploiting this principle, by applying appropriately directed forces through the skin, soft tissues and ribs to the vertebral growth plates.

The biomechanical function of nocturnal braces is discussed below. Four different perspectives are presented which, although seemingly different, are at the same time complementary to each other, as will be demonstrated.

4.1.1. The Vicious Circle Model

This theory, first described by Roaf[23] in 1960, claims that, asymmetric loading of the spinal axis is the primary force for the development and progression of pathologic spinal curves, with increasing deformity causing more asymmetric loading, which in turn will worsen deformity. Roaf attributed the asymmetric damage on the vertebral endplates to the application of this unequal load upon them. On the premises of this theory, Roaf described the action of hyperextension jackets for patients with Scheuermann's kyphosis. In an earlier report of his[24], Roaf cited gravity and muscle imbalance as the primary deforming forces in scoliosis; thus, prolonged recumbency, by eliminating gravity and, to some extent, muscle action, would, in theory, cease the vicious circle of scoliosis – despite its obvious disadvantages precluding its use[23].

This model was most recently revisited by Hawes and O'Brien[25] who, in their literature review, describe experimental and clinical evidence supporting the contention that a functional scoliotic curve may evolve to a fixed structural curve, if the spine is not relieved of the offending agents[25-27]. Differences in progression amongst individuals are due to differential muscle activation strategies, rather than other inherent differences[28]. Interestingly, the authors present evidence for the reverse: because vertebral growth is not permanently affected by applied loading, a structural curve may correct, if postural asymmetry is corrected, provided adequate growth potential exists[25, 27, 29, 30].

Macroscopically, the model is confirmed by the presence of wedged intervertebral discs and vertebrae in scoliosis [22, 25, 31, 32]. Vertebral wedging has consistently been found to reach its maximum at the apex of thoracic curves[25, 33, 34]. At the cellular level, increased apoptotic cell death has been found[35], secondarily leading to inhibition of matrix turnover in involved discs[36]. Again, cell apoptosis has been observed to be highest in the apical discs, irrespective of the aetiology of scoliosis[37].

Hawes and O'Brien predict that "the activation of programmed cell death in response to mechanical loading comprises the molecular mechanism by which a reversible spinal curvature is converted into an irreversible spinal deformity"[25].

In summary, according to the vicious cycle model, whatever the cause of the original deformity, a sustained imbalance of forces acting along the spine will eventually lead to structural disc and vertebral changes that clinically manifest as scoliosis. However, if the asymmetric biomechanical environment is reversed, these changes are reversible, provided significant growth potential remains[25].

4.1.2. The Recumbent Position

The scoliotic deformity is hereby described as consisting of two components, namely the elastic and the plastic components of the deformity. The former is the one that is readily correctable by merely changing body position or lying down, while the latter is what is targeted with any form of treatment[38].

The influence of gravity on scoliosis is long known[23, 39] and a diurnal variation in the magnitude of Cobb angle has been described[40, 41]. Elimination of gravity and muscle tone minimisation during recumbency have been already referred to in Roaf's work[23, 24]. The novel element introduced by this theory is the fact that, during recumbency, self-induced corrective forces are exerted through the rib cage upon the spine.

This is accomplished by the patient's own weight, which is transferred through the ribs, in the form of pressure to the costovertebral joints, changing the spinal curvature accordingly. Of course, the magnitude and direction of the force vector and its final influence on the curve are highly dependent on the patient's position in bed. In essence, there is an alteration of the direction of gravity relative to the body axis (along the body axis in the erect position, perpendicular to it in recumbency); stated otherwise, in the recumbent position gravity acts to the patient's benefit[38].

During sleep, not only is there this beneficial effect of gravity, but muscle tone is minimised as well. Therefore, it appears as if this is the optimal time for the application of an additional corrective force, which will fully restore the elastic element and possibly continue to correcting part of the plastic deformity. Nachemson and Elfstrom[42] have demonstrated the tremendous increase in the magnitude of side forces applied by a brace in the recumbent position. Additional data have been provided by Mulcahy et al[43], showing that side forces almost double in magnitude, especially in larger (>40°) curves. Although longitudinal distraction forces are also exerted by braces, side forces constitute their key aspect of action[42].

In summary, this hypothesis points to the utility of using a brace in the recumbent position as a result of the following sequence:

1. The vector of gravity is used to the patient's benefit, creating corrective forces through the ribs to the spine.
2. Muscle tone is minimal. This, combined with point 1, renders elastic deformity almost fully self-correctable.
3. The plastic component of scoliosis is now amenable to side corrective forces from braces; these forces, in any case, are significantly increased in the recumbent position.

4.1.3. The Role of the Intervertebral Discs

The theory of the intervertebral disc (IVD) being the primary offending agent in scoliosis is proposed by one of the authors (TBG). It has been reported that in mild scoliotic curves, when the deformity is initiating, the IVD is found wedged, but the vertebral body is not. The spine is deformed first at the level of the IVD, due to the increased plasticity of the IVD, in the way of either torsion or wedging as an expression of other initiating factors that may result in idiopathic scoliosis (IS) [44]. The IVD contains the aggrecans of glycosaminoglycans (GAGs) which imbibe water through the so called Gibbs-Donnan mechanism. The highest concentration of aggrecans is in the nucleus pulposus (NP) where they are entrapped in a type II collagen network[45].

There is an increased collagen content in the NP of AIS IVD, which is maximal at the apex of the curvature. Furthermore, in the scoliotic spine the NP in the IVD is displaced towards the convex side of the wedged interspaces[46]. Differences also exist in the collagen distribution between the concave and convex sides of the scoliotic annulus fibrosus in AIS, with depleted levels in the former compared to the latter[47].

Composing all the above findings, it has been suggested[44] that the imbibed water, mainly in the apical IVD but also in the adjacent discs above and below it, must be in a greater amount in the convex side that in the concave. This asymmetrical pattern of the water distribution in the scoliotic IVD, in association with the diurnal variation in the water content of lumbar IVD[48], imposes asymmetrical, convex-wise, concentrated cyclical loads to the IVD and the adjacent immature vertebrae of the child during the 24 hours period. The convex side of the wedged IVD sustains greater amount of expansion than the concave side, leading to the sequelae of asymmetrical growth of adjacent vertebrae (Hueter-Volkmann law).

The strong correlation between lumbar **L**ower **I**nter**V**ertebral **D**isc **W**edging (LIVDW) and thoracic Cobb Angle (CA)[44] implicates the important role of the lumbar spine and particularly that of the lumbar LIVDW to the progression of the scoliotic curve, as the lumbar IVDs are significantly higher. The correlations found[44] imply that the apical intervertebral disc wedging through the proposed mechanism seems to be an important contributory factor in the progression of IS curves, emphasizing the role of the apical intervertebral disc in IS pathogenesis.

The nighttime brace corrects or overcorrects the mild or moderate scoliotic curve, acting also on the apical and adjacent wedged IVDs, thereby reducing the previously described asymmetrically imbibed water (greater amount in the convex side rather that in the concave). Hence, the diurnal variation in the water content of IVD occurs under more normal conditions. Under the action of the nighttime brace, the convex side sustains no greater amount of expansion than the concave side, (ceasing the asymmetrical application of Hueter-Volkmann law), reversing the deleterious hypothesis of progression of IS curves; consequently, the growth of the apical and adjacent immature vertebrae turns more normal, within a close-to-normal biomechanical environment.

A pertinent observation on changes in body height and scoliosis angle under the influence of gravity was also reported by Zetterberg et al [40, 49], namely a decrease in the scoliosis angle occurring during the day in younger and more skeletally immature individuals.

4.1.4. The Effect of Moment Arms

An explanation on the efficacy of nighttime braces based on the action of moment arms has also been proposed: in a full-time brace worn in the upright position, a vector is created to displace the curve toward the patient's midline; at the same time, an opposing vector maintains the patient upright, with the head over the pelvis. The limiting factors in the placement of the vectors are the axilla proximally and the iliac crest distally. When applying a three-point vector for curve correction, the vector moments must remain constant for the patient to remain balanced, meaning that the magnitude of the vectors increases as the distance (moment arm) between the vectors decreases. This often involves a significant amount of pressure to be applied to correct a curve by 50%[50].

Nighttime brace design eliminates two factors associated with vector placement in full-time braces: (a) the iliac crest being the most distal level for vector placement, and (b) the need to maintain the head in line with the pelvis, as in the upright position. In this way, it is possible to increase the distance between vectors, thus decreasing the applied force. Ultimately, a nocturnal brace is able to obtain much greater in-brace curve corrections[50].

4.1.5. Summation of Biomechanical Theories

In an effort to best explain the action of nighttime braces, four theories/models have been presented. These may be best regarded in conjunction with each other, rather than in isolation. Hence, a nighttime brace disrupts the crucial state of asymmetric loading of the spine (vicious circle model), mainly by taking advantage of the unique transformation of gravity direction relative to the body during recumbency (recumbent position theory); in this condition, the shape of the apical and adjacent intervertebral discs is restored and symmetrical growth stimuli are now transmitted to the endplates (role of intervertebral discs). Increased moment arms used by those braces facilitate this scenario (effect of moment arms).

4.2. Biology

In addition to their biomechanical mode of action, nocturnal braces have been demonstrated to take advantage of the daily peak of growth hormone, which occurs between midnight and 2a.m. as part of the normal circadian rhythm of adolescents [51]. It is theorized that corrective action taken during that time stands the best chance of having the desired effect.

This might also be related to the neuroendocrine or 'melatonin-deficiency' hypothesis[52], as a possible cause for AIS. Bagnall et al [53] have suggested that activity of melatonin may be mediated through growth hormone. Decreased melatonin levels have been correlated with scoliosis in both chickens and humans [54-56], although other studies have failed to confirm this [53, 57-61]. Two recent studies by Moreau et al[62] and Azeddine et al[63] strongly suggest that the problem with melatonin may be qualitative, rather than quantitative, and may lie in the melatonin cell receptors of osteoblasts. Based on these conflicting data, the additive role of melatonin and nighttime bracing (in cases with normal melatonin levels) or the compensatory role of nighttime bracing (in cases with decreased melatonin levels) is currently only conjectural.

5. Types of Nighttime Braces

At present, two braces are mostly used at nighttime. These are the Charleston Bending Brace (Sea Fab, Inc., Orlando, FL, USA), introduced in 1979 by C. Ralph Hooper, Jr., CPO and Frederick E. Reed, Jr., MD and the Providence Nighttime Scoliosis System (Spinal Technology, Inc., West Yarmouth, MA, USA), developed by Barry McCoy, MEd., CPO.

The two nighttime braces available have distinctly different mechanical modes of action. The Charleston brace works by bending the spine, whereas the Providence brace works by the application of opposing forces which push the curve apices to the midline.

The Charleston brace (see Figure 1), is based on the side-bending theory for correction of deformities of the spine, first introduced by Guérin[64, 65] and popularized by Risser, who developed the turnbuckle cast initially and the localizer cast later[65, 66]. Braces of this kind are based on the premise that scoliosis is caused by muscle imbalance, accentuated by asymmetric forces predicted by the Hueter-Volkmann principle; the deformity is accompanied by soft-tissue stretching on the convex side and contracture on the concave side[65]. The Charleston brace is a rigid custom-made orthosis aiming at stretching the contracted concave side at nighttime, when muscle tone is minimal.

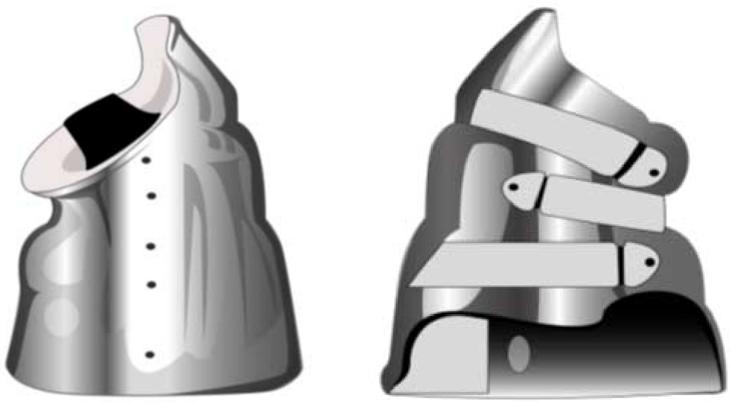

Figure 1 The Charleston Bending Brace [schematic representation]

The computer-fitted Providence Scoliosis System, originally developed to demonstrate spinal flexibility in the supine position for purposes of pre-operative planning, was further marketed as a true scoliosis orthosis when it was observed that significant correction of scoliotic curves could be achieved using an acrylic frame to apply direct corrective forces to the patient. It is fabricated of polypropylene plastic from measurements or a plaster impression, but carbon fibre-reinforced braces are also available. Over the last years, cast molds are scanned into a CAD/CAM computer so that fabrication is done with measurements alone in all cases of AIS (see Figure 2). Patients with other types of scoliosis are still casted[67].

In the Providence brace, the amount of corrective force required is monitored with the use of pressure-sensitive film. When the patient outgrows the brace, this becomes tight circumferentially but the pressure drops at the apex of the curve. During the recommended three-month check-up visits to the orthotist, pressure readings serve to evaluate the ongoing effectiveness of the brace as the patient grows [67].

6. Design and Manufacturing of Nighttime Braces

The Charleston brace is custom-made from a negative impression taken by an orthotist and fabricated of thermoplastic material[68]. The exclusive manufacturing and quality control responsibility has been assigned to SEA FAB, INC.

The Providence brace features a double curve design which provides an overlapping three-point pressure system approach. In addition to the use of a three-point pressure system, this involves the use of void areas that are located opposite the pressure application points. Voids, as opposed to holes, are necessary to maintain the shell in continuity, if pressure application is to remain constant at all times. However,

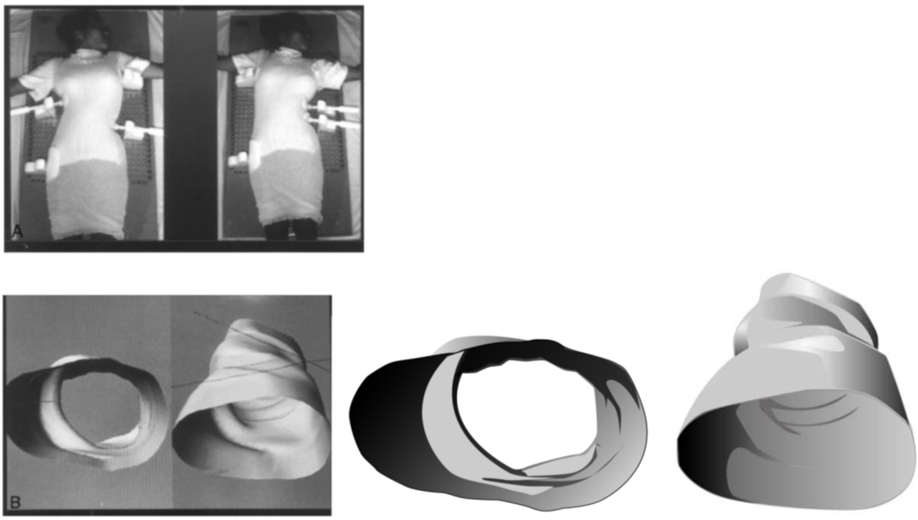

Fig.ure 2 A. Measuring frame for the Providence brace, B. Mold made on CAD/CAM milled bank [reproduced with permission from D'Amato CR, Griggs S, McCoy B. Nighttime bracing with the Providence brace in adolescent girls with idiopathic scoliosis. Spine 2001;26(18):2006-12].

the advent of carbon fibre-reinforced braces, has allowed cutting out the void areas; this has made the brace much more patient-friendly[67].

The three-point system helps control double curves (in those cases the two 3-point systems overlap) and theoretically allows for treatment of curves with apices as high as T6 without the use of a neck extension (though a neck extension may be used for treating higher apices)[67].

Derotation is effected differently, depending on the location of the curve. In the lumbar spine, segmental derotation is accomplished by the lumbar pad itself, placed at the appropriate angle between the iliac crest and the 12th rib. In the thoracic spine, the ribs are used, acting as long lever arms, to derotate the vertebrae. Derotation in the thoracic section of the brace is accomplished on the CAD/CAM model. The thoracic section is separated from the lumbar section. Then the thoracic portion is rotated a specific amount and rejoined to the lumbar section of the model. Obtaining rotational control by rotating the thoracic portion of the orthosis is something that can not be done with full-time or daytime braces; it is only possible in the supine or prone position[67].

7. Results

7.1. Providence Brace

Few studies on the results of the Providence brace have been reported (see Table 1). In a prospective study, D'Amato et al were the first to report on the results of a series of 102 female adolescents with Risser sign between 0-2[69]. The authors found their results (26% progression) comparable to those of the SRS non-randomized controlled multi-center prospective study[70]. In the subgroup of patients with Risser 0-1, 23% progressed; this was noted to be clearly superior to the natural history data published by Lonstein and Carlson (68% progression rate)[71].

Table 1 Summary of studies on Providence brace

Authors	Year	Design	Follow-Up (yrs)$^{\#}$	No. Patients	No. Curves	Initial in-brace correction rates	**Progression Rates**
D'Amato et al	2001	prospective	2.6	102	148	96%	**26%**
Yrjönen et al	2006	comparative*	1.8	72 (36+36)†		50%; 92%†	**22%; 27%†**
Janicki et al	2007	comparative**	not recorded	83 (48+35)†		not recorded	**85%; 69%†**

\# after cessation of brace wear

* prospective for the Providence group and retrospective for the Boston

** retrospective

† TLSO and Providence groups respectively

Two recent studies have compared the results of the Providence brace with a TLSO orthosis. Yryönen et al[72] studied 36 patients treated with the Providence brace and compared them to a matched group treated with the full-time Boston brace. Progression rates were 27% for the Providence group and 22% for the Boston group. The authors concluded the Providence brace may be recommended in lumbar and thoracolumbar curves of <35°.

Janicki et al[1] published the first study to be conducted using the new SRS Committee on Bracing and Nonoperative Management inclusion and assessment criteria[73]. Although the overall rates of successful treatment were 21% and 40% for the TLSO and Providence groups respectively, the authors were able to demonstrate a statistically significant superiority of the Providence brace in the curves of lesser magnitude (25°-35°) only.

7.2. Charleston Brace

Results on the Charleston brace are summarized in Table 2. In 1990 Price et al[51] published their early report using the Charleston brace and later reported their long-term follow-up results[74]. Despite the very good overall results, the first report raised concerns on the fate of double curves, as approximately 46% (11 of 24) of them showed deterioration of their second component. In the long-term study of the same patients, 20 (13%) compensatory or secondary curves progressed >5° and four patients required surgery because of an increase in their compensatory curves alone.

Table 2 Summary of studies on Charleston brace

Authors	Year	Design	Follow-Up (mos)#	No. Patients	No. Curves	Initial in-brace correction rates	**Progression Rates**
Price et al	1990	prospective, multicentre	not recorded	139	191	73%	**17%**
Price et al	1997	prospective, multicentre	14	98	149	87%	**34%**
Katz et al	1997	comparative*	0	319 (153+166)†	457 (217+240)†	41%; 83%†	**34%; 57%†**
Howard et al	1998	comparative*	20; 16†	140 (45+95)†	198 (63+135)†	40%; 84%†	**29%; 52%†**
Trivedi &Thomson	2001	retrospective	41	42	42	104%	**40%**
Gepstein et al	2002	comparative*	24	122 (37+85) †	122 (37+85)†	mean not recorded	**19%; 20%†**

after cessation of brace wear

* retrospective

† TLSO and Charleston groups respectively

Federico and Renshaw[75] conducted a retrospective review of 32 patients, 11 of which had successful treatment, while two were listed as failures. Nineteen patients had not completed treatment at the time of paper submission (not listed in table 2).

Katz et al[68] compared the efficacy of the Charleston to that of the Boston brace. The Boston brace achieved statistically superior results, both in curves 25-35° (progression rates 29% vs. 47%), as well as in larger (36-45°) curves (progression rates 43% vs. 83%). The Boston brace was more successful in double major and single thoracic curves. These findings were strikingly similar to the ones by Howard et al[76], who also compared the efficacy of TLSO vs. Charleston braces in concurrently treated groups.

Climent and Sanchez[14] have conducted the only study so far on the impact of different types of braces on self-perceived patient health status, using the QLPSD instrument[77]. Of 102 patients included in the study, 75 were diagnosed with idiopathic scoliosis. Charleston brace-treated patients achieved the best scores (42.8, denoting least impact on quality of life), although results were not statistically significant from those of TLSO-treated patients (45.6). Of note, back flexibility subscores were significantly superior in the Charleston group (5.6 vs. 8.9).

Treatment of single-curve AIS with the Charleston brace has been reported by Trivedi and Thomson[78] and Gepstein et al[79]. Progression rates were 40% and 20% respectively (no significant difference to the 19% achieved with the TLSO[79]). The former study only included curves between 25-40º in magnitude, whereas there were 32 curves less than 25º in the latter, possibly accounting for the different results.

8. Discussion

Two important issues merit investigation, when evaluating a brace. Firstly, the brace has to be checked as to its potential to alter the natural history of scoliosis. Secondly, it has to be compared against its counterparts, with regard to the clinical results. The efficacy of a brace is also a function of factors including initial in-brace correction, Risser sign and location of major curve apex. The highest success rates of part-time (16 hours daily) bracing ever reported in the literature have reached 89%[80].

Rowe et al[81] have conducted the only meta-analysis study available on the efficacy of non-operative treatment modalities for idiopathic scoliosis. The authors found bracing to be significantly more successful than electrical stimulation or observation. The Milwaukee brace was the most and the Charleston brace the least successful type of brace, with TLSO braces demonstrating intermediate success. Moreover, 23 hours of daily use of bracing was proven the most successful bracing regimen; no statistical difference was found between the 16- and 8-hour daily bracing duration. However, only two studies[51, 75] on the Charleston brace were included in this analysis, both being preliminary, as many patients in each of them were still undergoing treatment at the time of their publication. For this, as well as for other reasons, this meta-analysis has been criticised as being methodologically flawed[82]. However, other studies[70, 83, 84] have indisputably demonstrated that bracing does have a positive effect on the natural history of scoliosis.

Both the Providence and Charleston orthoses are described as ‘hypercorrective’ (see Figure 3). Indeed, this was confirmed in the study by d’ Amato et al[69]: average initial in-brace correction for thoracolumbar and lumbar curves was 111% and 103%, respectively. Flexible, low (below T8) curves and those associated with higher Risser sign were likely to fare better. Similarly, the study by Yrjönen et al[20] demonstrated a far superior in-brace correction, compared to the Boston group. For the Charleston brace, Trivedi and Thomson[78] recorded a mean correction of 104%. Given the fact that maximum correction while in the brace is a desirable factor in conservative treatment of scoliosis[7], this feature may be a strong indication to their potential to halt progression.

Vasiliadis et al[85] studied the influence of a modified Boston brace on patient quality of life (QoL), using a newly developed, validated disease-specific questionnaire[86]. They found physical functioning and vitality to be the factors most affected. Initial in-brace correction has been shown to have another interesting effect, relating to QoL. Climent and Sanchez[14], in their multiple linear regression analysis model, found a significant correlation between initial correction and QoL for all patients. The authors attribute this finding to the patients’ satisfaction with no curve progression. Therefore, the superiority of nocturnal braces on patients’ psychosocial functioning may not result as the consequence of nighttime use only and merits further study.

Another advantage of nighttime bracing is the opportunity patients have for a concurrent comprehensive exercise treatment programme during daytime. The role of exercises in the treatment of AIS was until recently not clear-cut[87]. However, increasing evidence now exists[2], pointing to several potential benefits (better pulmonary function, improved proprioception, reduced pain, positive psychological

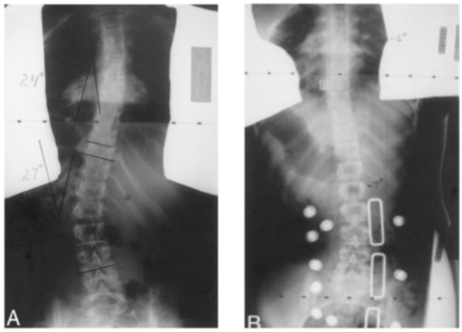

Figure. 3 Case demonstrating in-brace overcorrection of both curves in a double-curve pattern [reproduced with permission from D'Amato CR, Griggs S, McCoy B. Nighttime bracing with the Providence brace in adolescent girls with idiopathic scoliosis. Spine 2001;26(18):2006-12].

impact and less chance of curve progression) from specific physical therapy and intensive rehabilitation[88]. None of the studies on the two nocturnal braces[1, 51, 68, 69, 72, 74-76, 78, 79] have combined bracing therapy with a structured physical exercise programme.

The conclusion that is uniformly drawn from all clinical studies on the Providence brace so far is that it may benefit patients with curves up to 35°. Natural history data from Lonstein and Carlson[71] in patients with Risser 0-1 and curves of 20 to 29° reveal a 68% risk of curve progression. The same curves in patients with Risser 2-4 dropped the risk of progression to 23%. In the Iowa series[89], 68% of 133 curves progressed. We agree with Janicki et al[1] in that to be considered an effective management method, an orthosis must prevent progression in at least 70% of patients.

Based on this figure, two out of three studies[20, 69] on the Providence brace did show results better than the natural history studies. Janicki et al[1] attributed their poor results in a multitude of reasons, including the new SRS criteria, according to which even noncompliant patients are to be included. However, the study by D'Amato et al[69], although it was conducted before the establishment of these criteria, included noncompliant patients as well, albeit with good results.

A technical difficulty in the use of the Charleston brace is the management of compensatory or secondary curves. This is reflected in their significantly lower initial in-brace correction (33%) and the fact that these had the poorest response to treatment in the series of Price et al[74]. Katz et al[68] showed that the Boston and Charleston braces were equally effective in all curve patterns, except for double major and single thoracic curves. There is certainly a concern that there may be a difficulty in 'unbending' two opposite curves[74] or that the forces unbending a curve can worsen the opposite one[69]. In any case, treating a double curve is considered an advanced application of the Charleston brace[90].

Both nocturnal braces appear less effective in larger (>35°) curves. A possible explanation of this observation has been offered by Katz et al[68], based on review of previous biomechanical studies[41, 91, 92]. The authors suggest that patients with larger curves have reduced load-carrying capacity. Despite the fact that the load generated by the upper torso is eliminated in the recumbent position, i.e. when nocturnal braces are used, it may be that larger curves need additional support, with a daytime brace, when the patient is standing.

Comparison of the efficacy of braces across the literature is difficult, due to the disparity of the study groups (patients of mixed aetiologies often included), the variable definition of lack of curve progression among authors (<5° or 10°) and the absence of results according to significant factors, e.g. curve magnitude or maturity. Part-time bracing has been shown to have results equal to full-time bracing, but this may reflect poor compliance of full-time protocols inasmuch as it represents success of part-time bracing[74]. In the authors' view, patients should be included and evaluated in nighttime brace studies according to the criteria seen in Tables 3 and 4.

Table 3 Inclusion criteria proposed by authors for future nighttime brace studies

Criterion	*Definition*
Diagnosis	AIS
Age	>10 when diagnosis is made
Gender	both
Risser sign	0-3 (4 if curve >35°)
Curve magnitude	>30°
Curve location	lumbar / thoracolumbar
Previous treatment	no
Compliance	any
Menarchal status	pre- or up to 1 year post-menarchal

Table 4 Assessment criteria proposed by authors for future nighttime brace studies

Criterion	*Definition*
Curve progression	<5° (no progression) or >6° (progression)
Failure endpoint	>45° or recommendation for surgery
Patient subgroups	pattern magnitude rotation Risser sign flexibility menarchal status previous treatment compliance cessation brace use vs. latest follow-up
Follow-up	latest after cessation of brace use
Quality of life	BrQ score

These recommendations are unique in taking into account the SOSORT guidelines[88] for conservative treatment of AIS (e.g. progression risk is used instead of absolute magnitude values for curves <30°) and the modern trend toward a more functional patient evaluation[16, 86] (hence the inclusion of BrQ), combined with the authors' feeling that a detailed stratification in subgroups is essential for results to be comparable.

Nocturnal braces fulfill the two most important factors for successful treatment, namely primary correction and compliance [93, 94], and have shown encouraging results in the literature. Present data render them an attractive alternative for adolescents with single lumbar or thoracolumbar curves. Multi-center, randomized studies using the new SRS inclusion and assessment criteria or the SOSORT guidelines[88] are needed to better define the role of nocturnal bracing in the conservative treatment of AIS.

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The Chêneau Concept of Bracing – Actual Standards

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Abstract. In-brace correction and compliance are the main predictors of a successful outcome of brace treatment in the management of patients with Idiopathic scoliosis. The latest CAD / CAM or module based bracing concepts, related to a proper classification have lead to a better in-brace correction and have made the braces easier to wear for the patient. Nevertheless, the latest developments on the market do not allow successful treatment in every case.

The latest biomechanical models of brace correction therefore may lead to a differential indication for certain concepts described in this paper. Thoracic curves with Cobb angles < 50° may be treated with the best possible success with the latest Chêneau derivates enabling a real 3D-correction including also the sagittal correction of the spine. The application of those braces demands a proper classification of curve patterns.

Thoracic curves with Cobb angles > 50° demand to increase the force vector from dorsal with the ventral counteraction of subclavicular pads both sides, although this may be at the cost of sagittal correction.

The percentage of in-brace correction is a good indicator for brace action, however in the individual case this is not always the most important factor.

Keywords. Scoliosis, Chêneau brace, CAD / CAM, Rigo-Chêneau brace, Chêneau light, Rahmouni Style brace

Introduction

The effectiveness of brace treatment in the management of patients with Idiopathic Scoliosis cannot be denied anymore. Curve corrections are possible [1], vast clinical improvements have been described [1,2] and the prevalence of surgery in patients treated conservatively is significantly less [3,4,5] than in patients without any treatment [6]. However, the studies on bracing differ a lot (Curve pattern, age, maturation and Cobb angle), which makes them hardly comparable [7].

Additionally, if one believes in the self reports of different technicians, they seem to be able to achieve similar results with a variable number of approaches. Their success seems to depend on what is deemed to be the most important outcome factor. One approach maybe effective with respect to in-brace correction whereas a competitor maybe more effective when clinical appearance and function are regarded as the most important factors of a successful outcome. Each technician has a different aim, but all braces have at least something common: All principles of treatment have their failures!

No brace, not even those with the highest standard in construction, will be able to halt progression in every case or produce final corrections in every patient treated.

To reduce the number of failures a differential indication of different braces should be established. This will increase the patient safety with respect to outcome, which this paper aims to contribute towards.

Treatment indications

The classical indication for a brace in the treatment of scoliosis previously was a curve of 20 – 40° in a growing child. An indication based on this proposition, however lacks accuracy. For instance a 14-year old girl with Risser 3 and 20° Cobb surely will still grow to some extent, however according to Lonstein and Carlson [8] she has a risk for progression of less than 10 % which allows observation only - without any treatment at all. The lack of accuracy has been felt to be constantly unsatisfactory and this is why the international community of conservative specialists has developed new guidelines allowing to estimate, the indication for conservative scoliosis treatment more precisely [9].

The fact that operated patients with Idiopathic Scoliosis did not experience less back pain or less degeneration, that pulmonary function and general health were not improved in patients treated surgically when compared to patients treated conservatively [10] and that the long-term risk of operation has to be regarded much higher than usually proposed by the surgeons [10], has lead to a widening of indications for the use of bracing.

Figure 1. Correction from 56 to 53 degrees in a Milwaukee brace and to 27 degrees in a Rigo-System Chêneau brace using 3D correction. After 6 months of treatment the curve had improved significantly (36 degrees as shown on the right) [31].

Because until now there is no proof that surgery can change health related signs and symptoms of scoliosis and that the long-term outcomes of surgery are better than the long-term limitations of scoliosis itself [11], we should be allowed to brace also patients with curvatures of > 50° when surgery is not taken into account by the patient.

Basic biomechanics

Idiopathic scoliosis, like most other forms of scoliosis as well is regarded as a three dimensional deformity of the trunk and the spine [12]. Lateral deviation of the spine in frontal plane is accompanied by a torsion of certain parts of the spine producing the rib hump or lumbar hump and at least in Idiopathic Scoliosis by a deterioration of the sagittal profile, in the case of a thoracic curve pattern with loss of thoracic kyphosis as well as in the case of a lumbar curve pattern with loss of lumbar lordosis [13].
Therefore, when trying to correct a spinal curvature with the help of braces, all three dimensions have to be addressed [14] in order to allow a correction in frontal, horizontal and sagittal plane (see Figure 1.). Frontal and horizontal curve corrections are the aim of most of bracing systems, however the sagittal plane corrections and especially the preservation of lumbar lordosis are focused on no earlier than 2004 [15,16].

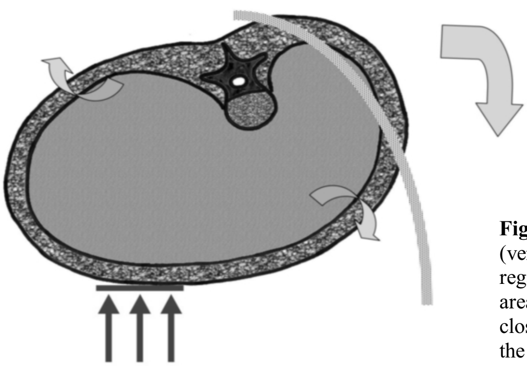

Figure 2. The ventral Chêneau point 4 (ventral ribhump as seen on the left) has to be regarded to be the most important redression area for thoracic curve correction, which, by closing the brace, acts as a hypomochlion for the redression of the ribhump. Free areas are necessary to enable the corrective movement [31].

Correction of thoracic curves

The reduction of a thoracic correction manoeuvre to simple frontal 3-point correction (Lumbar pad – Thoracic pad – Axilla pad) with redression of the rib hump from the dorsal aspect (pushing into the flatback) will not be enough. As we now know the flatback has to be addressed. The most important redression area to be addressed for thoracic correction has to be regarded to be the ventral Chêneau point 4, which by closing the brace acts as a hypomochlion for the redression of the ribhump (see Figure 2.). The preconditions for an optimum functioning of the thoracic redression system are:

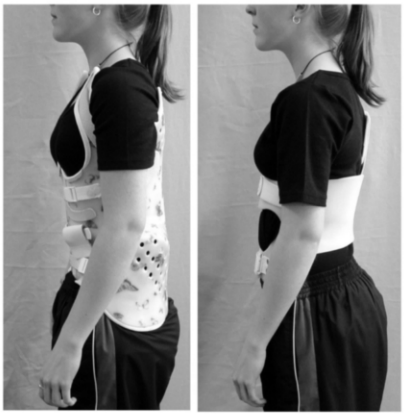

Figure 3. Sagittal realignment on the right in a modern Chêneau brace, while in the older concepts the sagittal profile may be inversed (see left side) [31].

- *Free space ventral on the ribhump side, laterally from the ventral axilla line to the parasternal vertical line ventral on the concave side.*
- *Free space laterally on the concave side between the ventral redression area (Point 4 Chêneau) and the axilla redression area (Point 3 Chêneau).*
- *An optimal positioned axilla pad, positioned high.*
- *A relatively "soft" and redressible curve and a rib hump with a smoother angle.*

Correction of lumbar curves

In lumbar curves one 3-point system in frontal plane (lateral pelvic pad – lumbar pad – thoracic pad) is necessary for frontal correction. Additionally a sagittal 3 point system for the correction of lumbar lordosis has to be implemented consisting of the lower ventral abdominal pressure point (Point 37 Chêneau), the lumbar pad from the rear and the ventral redression area (Point 4 Chêneau) (see Figure 3).

Because the pelvis is hooked to the spine like a pendulum to a chain, a pure side shifting of the pelvis alone will never be possible. In the development of a lumbar curve with hip prominence on one side a pelvic tilting appears and in the correction of a lumbar curve besides the side shift of the pelvis, a lateral tilt to the opposite side also occurs which has to be considered to some extent when adjusting a brace. The preconditions for optimal functioning of the lumbar redression system are:

- Iliac crest superiorly positioned to the pelvic pressure area is adjusted caudally to the iliac crest on the side of the lumbar pressure zone (see Figure 4.).
- The pelvic pressure zone caudally has a more medial tilt than cranially (see Figure 4.) or the trochanteric area is included for a better lever arm.
- Free space is left ventrally to the lumbar hump including space for the lower ribs in front.
- Implementation of a ventral redression area (Point 4 Chêneau).

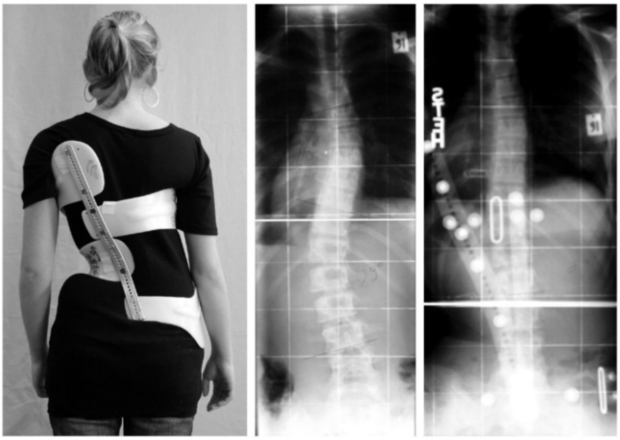

Figure 4. Iliac crest superiorly positioned to the pelvic pressure area is adjusted caudally to the iliac crest on the side of the lumbar pressure zone on the left and the pelvic pressure zone caudally has a more medial tilt than cranially leading to a good in-brace correction as can be seen on the right pictures [31].

The thoracolumbar correction principles may be a little different in a way that curves with apical vertebra L1 are more treated like lumbar and curves with apical vertebra Th 12 more like thoracic with the ventral redression area (Point 4 Chêneau) on the opposite side. However this may depend on many different factors and this is why we will not go into thoracolumbar correction principles more deeply in this section. This will be done in the certification courses for orthopedic technicians.

Different Chêneau derivates

The cast based custom Chêneau braces differ a lot with respect to quality and function. Those braces usually show the signature of the technician, who most of the time is specialized in certain curve patterns while in others the quality of the brace in terms of in-brace correction is the most significant factor.

CAD / CAM designed braces can achieve a constant high quality in case the user has access to an expert-based brace library (Rigo System Chêneau [RSC] brace). Basic mistakes may be avoided from the very start when the expert is on-line deciding what kind of brace the individual patient gets. Three systems, which are regarded as high quality systems, are on the market:

- Régnier Orthopédie SAS Germany. Hauptstr. 38 - D-77652 Offenburg, Sanitätshaus Vogel GmbH
- Rigo-System-Chêneau® [RSC] brace, Ortholutions, Rosenheim, www.ortholutions.de, a system where the brace type is decided on by the author of the classification himself, depending on curve pattern, age, sex and maturity.
- The LA Brace®, www.thelabrace.com/index.html, which is not a real Chêneau brace but very similar.

A new way for brace construction is the use of the ScoliOlogiC® off-the-shelf system which enables the adjustment of a brace from a number of pattern specific shells, available in three different sizes each (www.koob-scolitech.com). However not all curve patterns can be treated with the help of this system because only shells are available for right thoracic and left lumbar curvatures. This system at the moment does not provide shells for the treatment of thoracolumbar curves. The Rigo key pattern system is used to adjust those braces specifically and a homepage based system for quality management is also implemented. As this brace is able to correct with much less of material it is called the Chêneau light® brace (see Figure 5.).

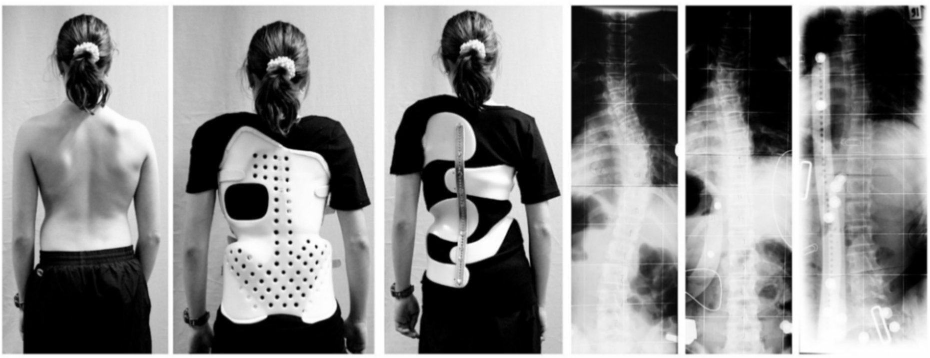

Figure 5. Similar correction in an "old fashioned" high correcting Chêneau modification and in the Chêneau light® [22].

All of the braces have to be adjusted to the patients individual body first and will usually have to be finely adjusted, though improved and may still continue to need slight adjustments. The in-brace corrections of the Chêneau brace [17,18,19,20] have been improved by use of the latest classifications and technology [21,22].

All Chêneau braces named above aim at a real 3D correction of the deformity including the sagittal profile as well and for the RSC brace® we have already gained evidence that a restoration of thoracic kyphosis, in case of thoracic flatback, is possible [23].

The results of the treatment with the Boston brace [24,25,26] have not been better than the results achieved with the Chêneau brace [17,21,22] and as for other brace modifications used in central Europe no scientific studies are available with evidence for good in-brace corrections or patient outcomes, the Chêneau brace and its' derivates can be regarded as the gold standard of bracing at the present. Additionally to that, the Boston brace and all braces still using abdominal pressure lead to an increase of a thoracic flatback [25,26] and it is this fact which has to be avoided when knowing that a loss of lumbar lordosis, the consequence of a thoracic flatback, correlates well with reports of low back pain in adulthood [27].

Bracing of thoracic curves > 50° Cobb

According to our experience the Chêneau derivates described above are very effective in curvatures of less than 50°, when the ventral and lateral voids are implemented. Beyond 50° the described correction system for thoracic curves looses its' effectiveness and the more the curve is stiff, the sharper the angle of the rib hump is. The stiff rib hump resists the de-rotation manoeuvre and finds a place in the dorsal void and may additionally get compressed via lateral forces. This is why the deformity can be increased instead of improved (see Figure 6. left). In these cases, the corrective force should gain a more sagittal orientation from dorsal to ventral. Therefore, the ventral pressure area (Point 4 Chêneau) will not be strong enough to counteract this problem. As a consequence subclavicular pads have to be added correcting the rib hump in sagittal plane even if this is at the cost of the sagittal profile (see Figure 6. right). Furthermore, caudally this anti-kyphotic corrective movement has to be counteracted by a reduction of lordosis.

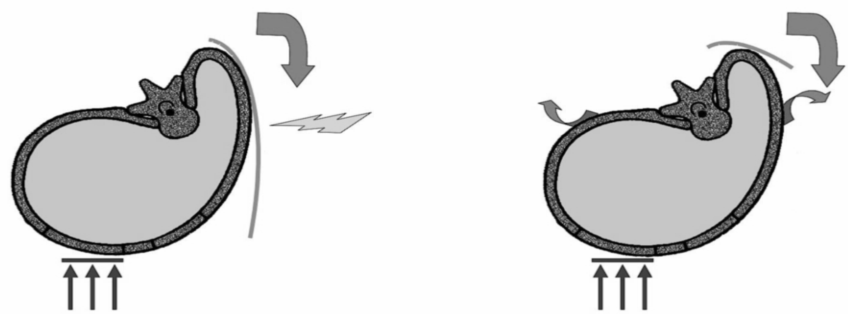

Figure 6. On the left compression forces are generated when the curve is too stiff to follow the de-rotation manoeuvre. Therefore sagittal antikyphotic correction principles can be applied here (right) [31].

This brace type is derived from the initial Chêneau braces and has been elaborated on by Rahmouni [28]. There are indeed partly exceptional in-brace corrections achieved with this brace, however a large number of patients will not be able to comply due to severe pain whilst wearing the brace. The correction effects in this brace are achieved by opening the facet joints and therefore will stress the ligaments more than the bony tissue during correction. Maybe this is reason why the prevalence of pain in this brace is much higher than in the Chêneau derivates aiming at a physiological sagittal profile.

This so called Rahmouni brace is in use for decades, however outcome studies are not yet published. But the in-brace corrections are comparable to other high correction braces in use today.

It would be interesting to know as to whether or not the patient treated with this brace suffer – as to be expected – more pain in adulthood than patients treated with other kinds of braces.

Nevertheless, patients with stiff thoracic curves and more than 50° Cobb angles should be treated according to this concept, at least to give them a chance to reduce their rib hump and improve clinical appearance. The Rahmouni Style brace meanwhile also is available via CAD / CAM (see Figure 7.) and we do hope we will be able to reduce pains in this brace in the future while improving pad action and reduce in-brace compression.

Figure 7. Good in-brace correction achieved in a stiff thoracic curve exceeding 50° Cobb using a CAD/CAM constructed Rahmouni style brace.

In-brace corrections

In certain limits the in-brace correction (% of initial Cobb angle) determines the outcome of brace treatment [18]. But what use is a brace with the highest possible correction effect when the outcome is a stiff flatback with loss of function and more back pain in adulthood? Another question arises when looking at "insufficient" in-brace corrections: Is it worthwhile wearing a brace with little in-brace correction? How can the in-brace correction (% age of initial Cobb angle) in bigger curves be seen?
In principle the in-brace correction is crucial to the outcome. According to Landauer [29] if, in a growing child, a correction of 40% can be reached, the outcome will be a final curve correction of at average 7°. This is why we should aim at an in-brace correction of more than 40% in order to make sure that for the patient it is worthwhile wearing the brace. However, not all curvatures can be corrected to the same extent. The in-brace correction is dependent on curve pattern age, sex, Cobb angle and stiffness of the curve.

We have experienced a curve of 38° being overcorrected to – 14°, while there was a curve in the same sample of patients correcting from 40° to only 38° even though the brace, according to our guidelines, has been constructed well [22]. In stiff curves the in-brace correction can also be improved by the time when the brace is constructed well (see Figure 8.). Therefore, a good brace will also help to stop progression when the in-brace correction achieved is not > 40%.

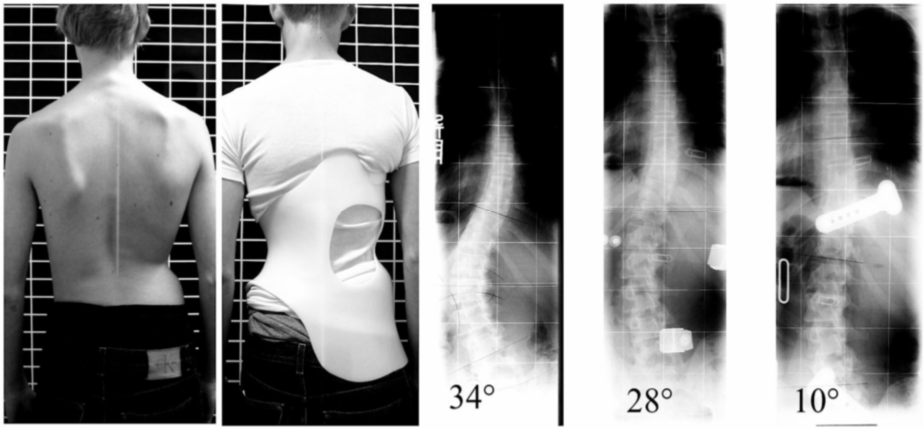

Figure 8. At first insufficient in-brace correction from 34 to 28 degrees, after another 6 weeks and re-adjustments of the correction effect have improved drastically (10°).

We will rarely be able to correct a curve bigger than 60% to more than 40 – 50%. Nevertheless, in curves bigger than 60°, stable curve corrections after brace weaning, have been described [30]. In the case cited, we had to brace a 13 year old patient with initially 64° thoracic curvature who refused surgery. The in-brace correction was nearly 20°. The end result, nearly 2 years after weaning, was 41° thoracic (see Figure 9.).

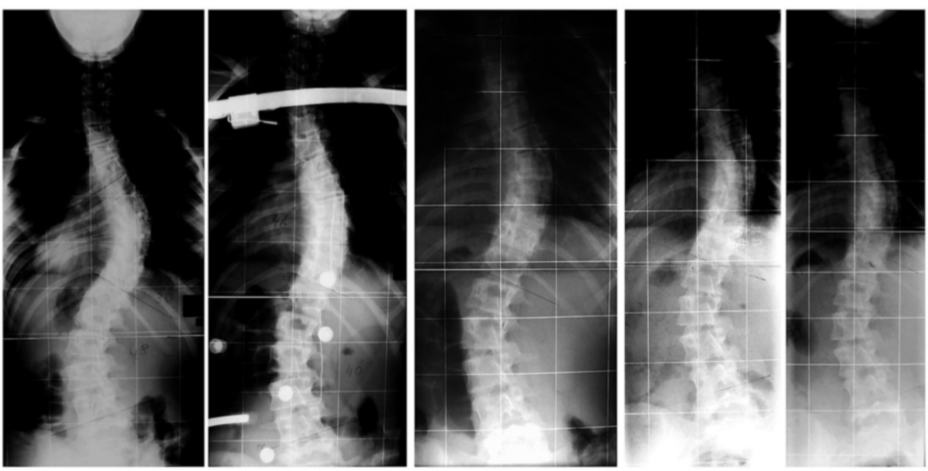

Figure 9. On the left 13 year old girl with 64 degrees and on the right two years after weaning at the end of treatment (in-patient rehabilitation and two braces) at the age of 19 41 degrees. This example shows that conservative management may have a benign effect even in curvatures exceeding 60 degrees [30,31].

Histories like this let us assume that not the %age of correction, but an absolute angle of correction achieved, is the determinant for prognosis and the end result. As to our experience, independently from the initial Cobb angle, a correction of at least 15°

will be enough to change the individual prognosis. For a change of paradigm, however it is too early and we will have to wait for more research.

Discussion

When we rely on the most accepted theory that a change in load leads to a change of spinal growth [12] and when we are aware of the fact that scoliosis (I.S) leads to a 3D deformity of the spine and trunk, we are allowed to conclude that the best possible treatment will be a true 3D correction of the spine and trunk. This means that besides frontal curve correction and de-rotation in thoracic curves, the thoracic kyphosis has to be restored and in the case of lumbar curves lumbar lordosis has to be preserved. Correction of lumbar lordosis gains even more importance considering that loss of lumbar lordosis and lumbar kyphosis is correlated to low back pain in adulthood [27]. A true 3D correction is supported also by the fact that clinical signs of scoliosis can be improved while spinal function is preserved. Stiff flatbacks should not regularly be the outcome of today's bracing but this should actually be clinically improved spines with restored function (see Figure 10.).

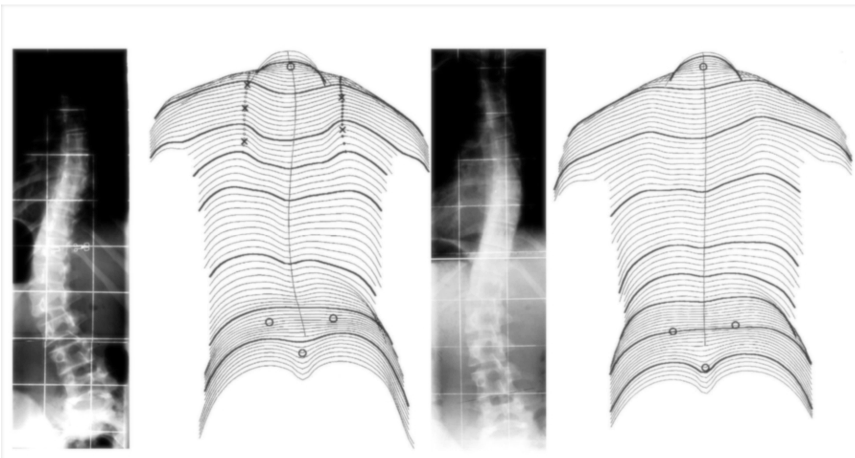

Figure 10. Reduced Cobb angle and improved clinical result in a relatively mature girl 15 years at the start and 17 at the end of treatment [31].

In stiff thoracic curves beyond 50° however, the corrective pressure has to be directed more to the dorsal than to lateral areas, which on the one-hand unfortunately leads to an increase of flatback but on the other leads to good in-brace corrections and rib hump reductions. In these cases – when a patient wants to avoid surgery – primarily decreasing the rib hump and stopping the progression of the curve have to be regarded as most important, whereas the sagittal profile seems of secondary importance [31].

Looking at cases with initial angles of more than 60°, shown to be correctable 2 years after weaning with in-brace correction effects of far less than 40%, it seems that not the in-brace correction in % of the initial Cobb angle, but rather the absolute angle of correction (> 15°) should be considered in order to change the prognosis in the individual case. A 20° correction will allow a corrected end result also in curves exceeding 50°.

Conclusions

The latest biomechanical models on scoliosis curve correction lead to a differential indication for different approaches. Thoracic curvatures of less than 50° and all lumbar curves can be treated with the actual derivates with highest treatment security, improving the sagittal profile, which may lead to a better clinical outcome, better function and less pain. The precondition therefore, is the exact classification of curve patterns [32].

In stiff thoracic curves beyond 50° however, the corrective pressure has to be directed more to dorsal than to lateral areas, which on the one-hand unfortunately leads to an increase of flatback, but on the other leads to good in-brace corrections and rib hump re-addressing as well.

The in-brace correction in % of the initial Cobb angle is an important variable to predict the outcome in certain limits however, it seems that in curvatures exceeding 50°, an absolute correction of 15° can be regarded as sufficient and one can expect corrected end results once the absolute correction reaches 20° in a compliant patient who is still growing [31].

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The Chêneau Concept of Bracing – Biomechanical Aspects

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Abstract. Current concept of bracing must take in consideration both the three-dimensional (3D) nature of Adolescent Idiopathic Scoliosis (AIS) and its pathomechanism of progression. A modern brace should be able to correct in 3D in order to break the so called 'vicious cycle' model. Generally speaking, it is necessary to create detorsional forces to derotate in the transversal plane, to correct the lateral deviation in the frontal plane and to normalize the sagittal profile of the spine. Breathing mechanics can be used to fight against the thoracic structural flat back.
The original Chêneau brace was introduced at the end of the 70's and its principles were based more in anatomical observations rather than in biomechanics. A further evolution , enunciating new principles, has allowed a higher standard, improving in brace corrections and trunk modelling. This biomechanical principles have been developed under the name of Rigo-Chêneau-Syatem® (RSC) and used later in latest brace models like the Chêneau light® with reduced material, and similar in brace corrections. Experience is also important to improve the end results. The blueprints to built the brace according to the anatomorradiological pattern are very helpful.

Keywords. Scoliosis, Chêneau brace, Rigo-Chêneau brace, Chêneau light

Introduction

In a previous paper, 'The Chêneau concept of bracing – Actual standards', indications for treatment, basic biomechanics, different Chêneau derivates and in-brace correction have been discussed. The etiology and pathogenesis (cause/s and first event/s) of Adolescent Idiopathic Scoliosis (AIS) is still not known. Prevention would be possible only according to some hypotheses and theories. Consequently, the theoretical basis for bracing is more closely related to the current knowledge on the pathomechanism of progressive AIS and its three-dimensional (3D) nature rather than its etiology. Some factors for progression have been well established and new ideas for the 3D correction of scoliosis have been developed. These factors and ideas will be explored in more detail in the present paper.

The 3-D nature of scoliosis seems to be very important to not only correct the scoliotic spine. The 3-D Chêneau braces applied today enable the patient to achieve even more: a true 3-D correction of the trunk and though, a better clinical appearance and because of that, in the very end, a better quality of life [1,2].

Three-dimensional nature of AIS

Jean Dubousset wrote in 1992 [3]: *"The tri-dimensional nature of scoliosis was identified the 19th century. John Shaw recognized it in 1824 and clearly demonstrated that the apex of the deformity is lordotic, with the anterior column longer than the posterior column. In 1865, Adams also described the presence of lordosis in the thoracic apical region. With the arrival of radiology in 1895, the anatomical observations made by Shaw and Adams were quickly forgotten. The projections of the skeleton produced by X-rays were so attractive for doctors, surgeons, etc. that their thoughts were concentrated only on what was projected, the anteroposterior view and rarely the sagittal view. As a result of this unidimensional approach, errors occurred in the use of instrumentation systems of the spine, creating the lumbar flat back syndrome, for example. This occurred throughout the world, in spite of the efforts made by Roaf and Somerville in their persistent descriptionof the 3D nature of the scoliotic deformity. Dickson has recently underlined these finding of his British colleagues. In France, Rene Perdriolle was a pioneer in promoting the reality of the tri-dimensional nature of the deformity"* Within this unidimensional or bidimensional maximum context and for those who at least considered rotation, during the second half of the XX century a series of orthoses were developed and are still used as standard scoliosis treatment in some countries. This includes such orthoses as the Milwaukee brace, the Boston brace system, the 'Stagnara-Lyonnaise' brace, the Willmington brace, the Charleston Bending Brace and others. These brace concepts were later related to the thoracic and lumbar flat back syndrome (see Figure 1) [3,4,5,6,7,8,9].

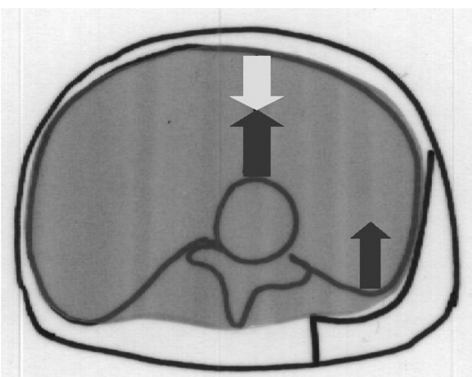


Figure 1. Thoracic flat back and Boston® system

Scoliotic deformity can be described as a series of vertebral segments placed in extension or lordosis, which deflect and axially rotate towards the same side (Dubousset 1992). Rather than a succession of lateral deviations idiopathic scoliosis represents the combination of torsional regions joined by junctional zones. The

Scoliosis Research Society (SRS) recognize two meanings to this term torsion [10]: The first is mechanical torsion, which refers to the torsional deformity of the column considered as a plastic structure. Mechanical torsion affects the disc (intervertebral torsion) as well as the vertebra (intravertebral torsion) [11]. The second meaning is geometrical torsion. Geometrical torsion is defined as the 'tortuosity' of the spine considered as a line in space. The column changes its physiological shape in the frontal, transverse and sagittal planes, adopting extremely diverse anatomoradiological patterns. Torsional forces produce both mechanical and geometrical torsion. Geometrical torsion is related to translation of the apical vertebra. Several authors have described the evolution of a right thoracic scoliosis as a torsional phenomenon that translates the apical vertebra first ventro-lateral and further latero-dorsal, away from the upper end vertebra (UEV) [12,13]. Consequently, the scoliotic spine initially becomes more or less lordotic, from any given configuration, and further develops as a paradoxical kyphoscoliosis. Obviously, nowadays few scoliosis cases progress to reach this last condition. It must be differentiated between geometrical lordosis and structural lordosis (see Figure 2). Morphologically, IS is a fixed lordotic deformity of the spine, however the degree of this anatomical lordosis is variable. On the other hand, the scoliotic spine can adopt highly variable saggittal profiles from a geometrical lordosis to a paradoxical kyphosis.

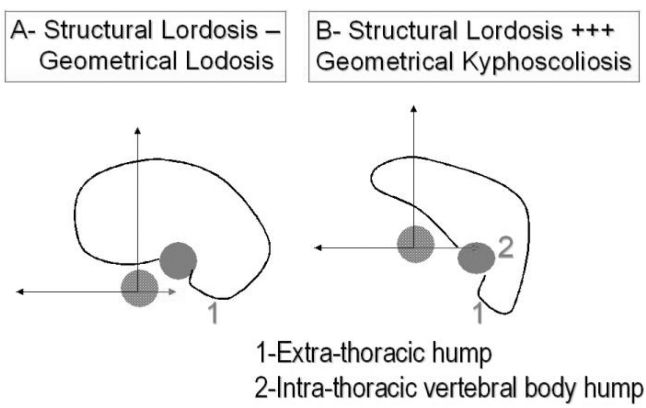


Figure 2. A represents a case with a thoracic scoliosis geometrically lordotic. According to Dubousset and Dangerfield, B represents a case with a severe morphological lordosis and lateral deviation. However, due to hypertorsion, the lateral curve progresses to dorsal in an oblique plane (Paradoxical Kyphoscoliosis).

Generally speaking, scoliosis correction may be achieved through distortion corrective forces, with the intention of better aligning the column in the frontal plane and normalizing the sagittal configuration of the spine [3]. Yet, most braces are not capable of producing these forces. The Chêneau brace comes close to producing these corrective forces. The mechanism proposed by Aubin [14] for the Boston brace appears to act in this way as well, but in practice there are many difficulties it does not overcome. The first major challenge is how to convert static forces into dynamic forces. There is no clear understanding about torsional forces, how they act or which spinal deformity patterns they produce.

The pathomechanism of progression

R.G. Burwell in Pediatric Rehabilitation published the most recent and complete revision on this topic [15]. Burwell, in agreement with the biphasic concept, concluded that *"there is a view that there are two types of pathogenetic factors for idiopathic scoliosis: initiating (or inducing) factors and those that cause curve progression*". He deeply explores the description of these factors: *"progressive AIS that mainly affects girls is generally attributed to relative anterior spinal overgrowth from a mechanical mechanism (torsion) during the adolescent growth spurt."* There are some biological, morphological, neuromuscular and biomechanical susceptibilities but four main factors have been well established as progression factors: Asymmetrical loading of the spine, vertebral growth modulation, spine slenderness and growth potential.

The four factors are related to the "vicious cycle concept" described by Stokes [16] or "the growth-induced torsion concept" modified by Burwell from Stokes. Stokes showed that an imposed vertebral deformity could be corrected by reversing the load used to create it. *'This implies that the principles of the Hueter Volkmann law are applicable to the correction of an existing vertebra deformity providing there is sufficient residual growth'.* They also showed that '*when the external loading is removed, growth rates return to normal, demonstrating that growth was not permanently affected by previously applied external loading'*. The results of their study have implications in the design, use, and effectiveness of bracing (also physiotherapy) as a treatment method for scoliosis. They suggest that '*if sufficient force is applied to the vertebra the progression of a scoliosis could be arrested, or even reversed'*. Whether or not the progression of a established scoliotic deformity is secondary to asymmetric loading, correction of the deformity using the principles of Hueter-Volkmann law is possible as long as there is sufficient residual growth. Other studies [17,18] have demonstrated the feasibility of the modeling approach achieving at the same time a complete representation of the scoliotic spine.The important question is which brace design is able to produce the desired forces to correct scoliosis and to reverse by correction the causal loading. Inciting the first factor, in human scoliosis, asymmetrical loading can result from:

- The effect of gravity
- Muscle action
- Lordosant reactive forces
- Human gait
- Growth induced torsion

The effect of gravity.

Gravity promotes progression in any curvature exceeding a critical point. Axial forces produced by gravity become asymmetric in a scoliotic spine. In the presence of a structural lordo-scoliosis, asymmetric loading produces a lateral force vector which increases translation with coupled vertebral rotation. The 'vicious cycle' model explains how lateral deviation increases vertebral and disc deformity. Haderspeck and Shultz [19] (1981) studied the muscle and body weight actions in scoliosis progression, and their conclusions were reviewed by the same Shultz in a paper [20] published in the proceedings of the International Symposium on 3D Scoliotic Deformities joined with the VIIth International Symposium on Spinal Deformity and Surface Topography (Montreal 1992). Schultz summarized that *'application of superior body segment weights were capable of causing substantial increases in Cobb measures. Body weight application effects were influenced by initial spine morphology. The Cobb measure changes produced were to some extend dependent on whether and how the trunk was restored to its upright position after the given force application'*. Thus, it seems that the consequences of the need for the trunk structures to support the weight of the body segments superior to them would be obviously different when comparing passive scoliotic posture and active 3D corrected posture, at least theoretically.

Muscle action.

Nevertheless it has been studied at large, whether or not a muscle disease is a primary factor in the etiopathogenesis of IS is still controversial. However, it seems clear that IS produces a secondary muscle imbalance which is one of the most important factors in the progression of the deformity [21]. Recent studies have shown that in the natural history of IS spinal growth velocity and electromiographic ratio at the lower end vertebra are prominent risk factors of curve progression [22,23]. The asymmetric muscle activity has been clearly associated with increased axial rotation, lateral deviation and decreased kyphosis.

Lordosant reactive forces.

This is related to the bi-planar theory of Dickson et al. [24] In the presence of a lateral deviation and/or axial rotation, combined with an asymmetrical shortening of the dorsal elastic structures, any flexion effort is converted into a lordotic force. Due to reflex mechanisms, flexion movements of the spine provoke tension on the dorsal elastic structures that produce a reactive asymmetrical concentric force increasing lordosis, axial rotation and lateral deviation as well.

Human gait and torsion.

According to the Nottingham thoracospinal concept torsional forces are produced during gait [25]. When examining gait dynamics, axial pelvis-lower spinal rotation is counteracted by axial upper spinal counter-rotation. Burwell called it the 'dinner plate tent-pole' concept where the pelvis is likened to a dinner plate and the spine to a flagpole or tent-pole. The gap between the upper spine and the lower spine represents the transitional point above which axial rotation is in the direction opposite to that below. In the thoracic spine rotation is maximal about T7 and minimal at the lower three levels.

Growth induced torsion.

Progression in AIS has been related with a relative anterior spinal overgrowth [26] which causes a growing induced torsion. According to the Burwell's model lordoscoliosis formed by growing torsion (intrinsic torsion) is what causes eccentric loading, eccentric growing and vertebral and disc deformity. Theoretically, corrective dynamic-eccentric forces could be just produced from inside (breathing mechanics). This is closely related with the three-dimensional nature of the deformity. According to the above described factors, the principles of conservative treatment should be based on: Prevention of asymmetric compressive forces related to passive posture, reduction of the secondary muscle imbalance, prevention of the lordosant reactive forces (passive posture, repeated forward bending movements), prevention of asymmetric torsional forces from gait, production of dynamic detorsional forces involving breathing mechanics.

'The vicious cycle' must be converted into a 'virtuous cycle'. Correction of the spine in 3D is a premise.

The Chêneau renewed principles

The Chêneau brace is basically defined as a thermoplastic brace molded on a hyper corrected positive plaster model. The corrective pads are not added into a symmetric plastic cylinder, as in the Boston brace technique, but designed directly into the positive model. Shape, depth and orientation of the pads are specifically built to act on the convex areas of the deformed trunk. The brace design appears radical, but that comes from the large expansion spaces rather than from the pads. The expansion spaces make hypercorrection possible by allowing the patient to move, to breathe and to grow towards the open spaces. Chêneau outlined the rules to correct the positive model in several books and papers [27,28]. However, Chêneau has enunciated his principles in terms of anatomical observations rather than biomechanical principles. The first author [MR], with essential contributions from the second one [HRW], has developed a correction model based on biomechanical descriptions (Rigo-System-Chêneau or RSC principles). The RSC® technique will provide the necessary passive forces by means of highly selective pads which produce several 'pair of forces' to derotate in the transversal plane, combined with three-point-pressure systems correcting in the frontal and sagittal plane as well. The correction of the morphological thoracic lordosis is achieved by coupling to derotation from the ventral pad pushing the ventral rib hump. Combination of such passive forces with expansion rooms facilitates breathing mechanics. Corrective forces produced by breathing mechanics can be considered as dynamic forces. Such a forces is hypothesized provide the only effective mechanism able to reverse the growth induced torsion. The brace presents a physiologic sagittal profile and adequate saggittal alignment. In the frontal plane, the pad areas form several three point systems depending on the curve pattern.

Detorsion can be produced by combining forces in the three planes of space: Derotation, deflection and saggittal normalization.

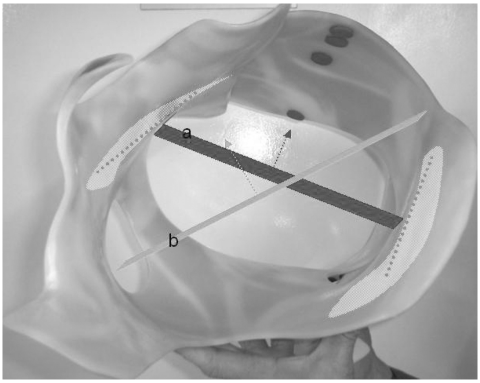


Figure 3. Regional derotation: The brace derotates the thoracic section (b) against the lumbar section (a), with a counter-rotation pad at the upper thoracic region.

Derotation

'Regional derotation' means derotation between two adjacent sections of the trunk and the spine. The thoracic region is derotated against the lumbar region and at the same time against the upper thoracic region. The particular design of the brace offers a highly effective 'regional derotation' effect (see Figure 3). Both main sections of the brace, thoracic and lumbar, have a 'bean' shaped profile contrary to each other in the transversal plane. For a right convex thoracic scoliosis the frontal plane of the thoracic section is rotated to the left compared with a frontal plane of reference. In opposition, the coronal plane of the lumbar section is rotated to the right. The 'bean' shaped profile -anatomical- in the transversal plane is essential for the migration of the soft tissues. Any dorsal pad has a corresponding ventral expansion room and any ventral pad has its corresponding dorsal room. It is necessary an optimum derotation mechanism at the apical level for a 'local derotation' (see Figure 4).

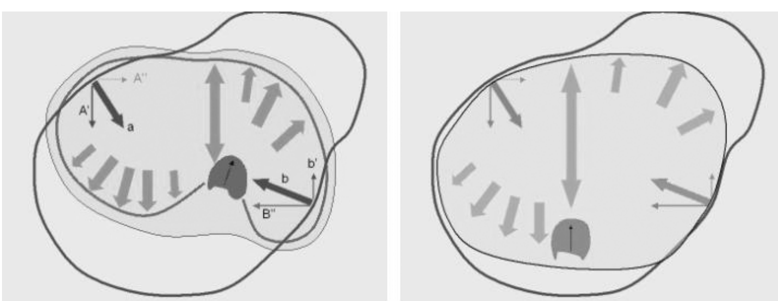


Figure 4. Biomechanics of the RSC at thoracic level. Two main vectors are formed (a,b).The physiological saggittal profile of the brace allow (a) to be the major force and (b) the minor. Both forces form a pair A'-b' for derotation. Due to the specific orientation of the pads (a pushes more saggittal than b) the spine moves backwards, coupled to the concave ribs, when the thorax expands.

The maximum 'local derotation' effect should be achieved at the apical level of any curve and it is produced by a pair of forces acting at the same level offered by the pressure or pad areas of the brace. For a classical thoracic curve the maximum local derotation effect should be produced at the apical level by two pads acting on the dorsal rib hump and another, the main pad, on the ventral aspect of the concave ribs. The dorsal and the ventral rib humps are out of phase -different level- due to the collapse of the rib cage in the concavity. Thus, looking at this anatomical fact, theoretically both pads should be at different levels. However, from a biomechanical view, any pair of forces aiming to derotate in the transverse plane around the axial axis, should be at the same horizontal level. For this reason it is necessary to move the ventral rib hump cranially to approximate the horizontal level of the apical vertebra. To achieve this ideal mechanical situation the scoliotic deformity must be inverted in the frontal plane – 'the mirror effect' (see Figure 5).

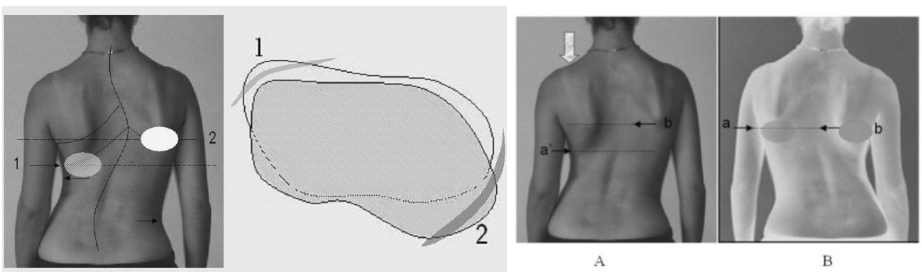


Figure 5. Ventral and dorsal rib humps are out of phase. Pads 1 and 2 should push forming a pair for derotation at the same transversal plane. To allow this, the concave collapse has to be corrected with forces in the frontal plane forming a three point system which produces a mirror effect.

Deflection

Correction in the frontal plane is achieved by translation of the different sections of the trunk (including pelvis) as well as a classical three point system in the coronal plane. The design of the brace regarding the correction in the frontal plane is variable depending on the curve pattern. There are several classifications defining curve pattern in the frontal plane but no classification is good enough for brace treatment. Chêneau simplified this problem describing two patterns and two different brace design. The types were called three and four curve pattern. This classification was used earlier by Lehnert-Schroth [29]. This classification has been amplified further by the authors in order to introduce a more complete criteria to define the brace action. The curve patterns are classified in five basic types called as follow:

1. *Three-curve pattern*
2. *Four-curve pattern*
3. *Non-three Non-four without lumbar curve pattern*
4. *Non-three Non-four with lumbar curve pattern*
5. *Lumbar/thoracolumbar single pattern*

The three-curve scoliosis pattern (see Figure 6) is related to a single long thoracic curve with a lumbar counter-curve (A1) or a shorter single thoracic curve combined with a functional (A2) or a minor structural curve (A3). The main radiological criteria are defined by an imbalance of the transitional point* to the convex thoracic side according to the central sacral line (CSL). The first thoracic vertebra (T1) is also imbalanced to the convex thoracic side although this criteria is not so consistent (e.g. in a structural upper thoracic curve -D- can be imbalanced T1 to the concave thoracic side). When looking at the patient from the back, it can be recognized the trunk imbalance to the convex side with the pelvis translated to the concave side in the frontal plane (see Figure 7). A dorsal rib hump is the major clinical trait. The four-curve scoliosis pattern (see Figure 6) fits with a double major radiological pattern, thoracic/lumbar (B1) or thoracic/thoracolumbar (see B in figure 8).

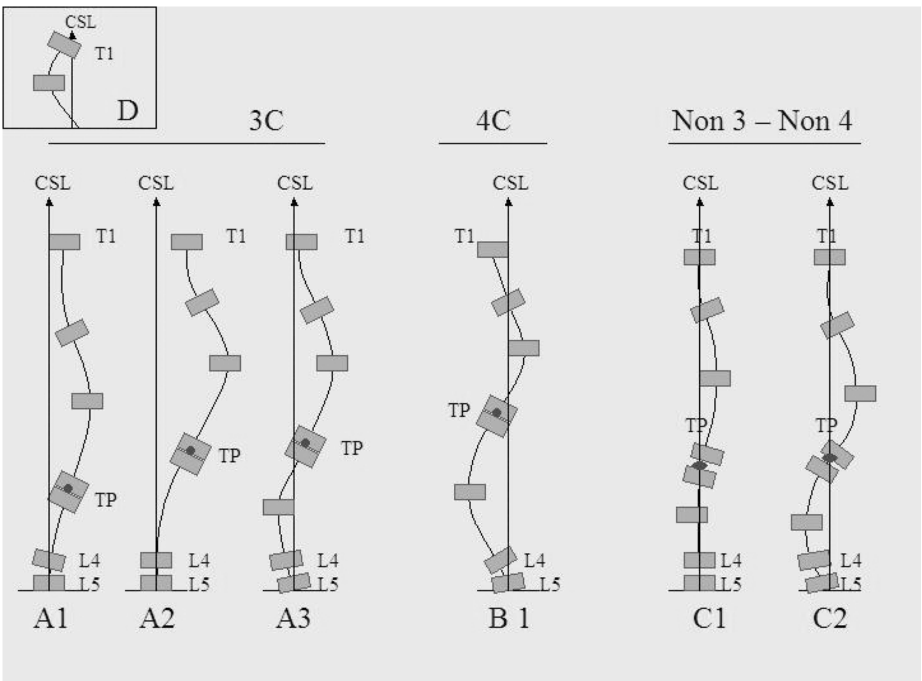


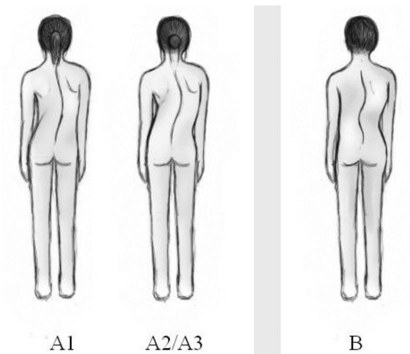
Figure 6. Radiological criteria for three curve (A1,2,3), four curve (B1) and non-3 non-4 curve, without lumbar curve (C1) and with lumbar curve (C2). CSL= Central Sacral Line. TP= Transitional point. Four curve scoliosis pattern is the only with positive counter-tilting L5-4 to the concave thoracic side.

The main radiological criteria is defined by the imbalance of the transitional point to the concave thoracic side according to CSL. A second highly consistent criteria is a positive counter-tilting between L4 and L5, sometimes between L4 and L3. Finally, T1

* Transitional point: it is located in the middle of a disc in between the lower end vertebra (LEV) of the thoracic curve and the upper end vertebra (UEV) of the lumbar or thoracolumbar curve. It can be also in the middle of a vertebra which act as LEN of the thoracic and UEV of the lumbar curve.

is also imbalanced to the concave thoracic side. The trunk is imbalanced to the concave thoracic side with the pelvis translated to the convex thoracic side (see Figure 7). There is a thoracic dorsal hump and a lumbar or thoracolumbar prominence. Non-three Non-four scoliosis pattern is divided in two according to the presence (C2) or not (C1) of a lumbar curve (see Figure 6). In both cases, the transitional point and T1 are more or less on the CSL. Clinically the rib cage can be translated as well as the lumbar region but the trunk is quite balanced and the pelvis is not translated to any side. An upper thoracic structural curve is possible in any of the types but more common in three curve. Triple structural scoliosis pattern is formed by the combination of a four curve with upper thoracic structural curve.

Single lumbar and thoracolumbar curves are like four regarding the lumbar and pelvic sections (see Figure 8).



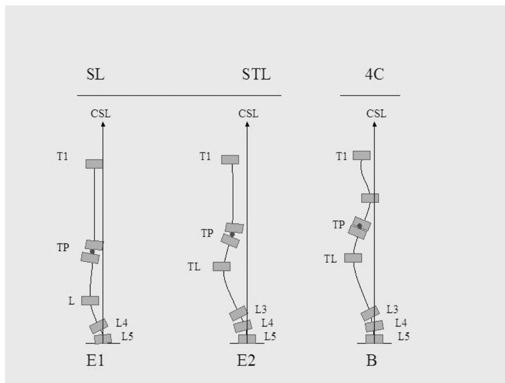


Figure 7. Clinical aspect in 3-curve (A) and 4 (B)

Figure 8. E1 Single lumbar (SL) and E2 thoracolumbar (STL).Double Thoracic/Thoracolumbar is like four (B).

The principles of correction in the frontal plane have been defined for each type. Translation in the frontal plane is produced by the pad areas pushing the convexities. The pad is oriented in a way that can produce simultaneous derotation and translation. Three points pushing one against the other at different trunk levels is defined as a three-point-pressure system. In three curve pattern is necessary to apply a single ‘three-point-pressure system’. In a case of a right thoracic scoliosis, pelvis and lumbar convexity are pushed left to right, thoracic convexity right to left and upper thoracic convexity left to right. There will be a room in the opposite side. It is usually necessary a right trochanter counter-pad to maintain balance in the frontal plane (see Figure 9).

The RSC® three-curve scoliosis brace is eventually built with no plastic covering the pelvis in the convex thoracic side in order to better translate the pelvis in the frontal plane (see Figure 10). This model is called ‘open pelvis’ and the radiological criteria for this type is defined by L4 tilted to the convex thoracic side and/or right rotation -for a right convex thoracic scoliosis- reaching L2 or even L3. The RSC principles can be

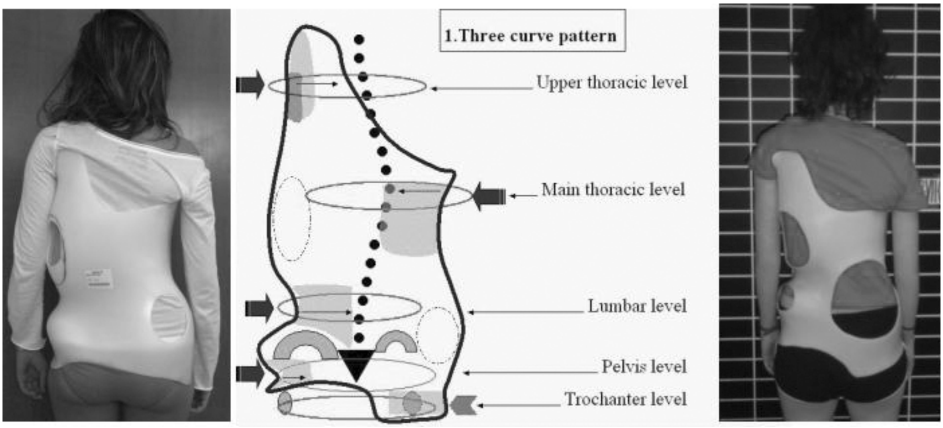


Figure 9. Blueprint to build an RSC® three-curve scoliosis brace with a trochanter counter-pad in the convex thoracic side.

applied to built the so called 'Chêneau light ®', originally designed by the second author (HRW) in order to reduce material and weight. The Chêneau light® has been used for any three curve scoliosis pattern. This brace has shown a similar correction than the RSC® with reduced psychological stress [30]. Thus, theoretically compliance would be better.

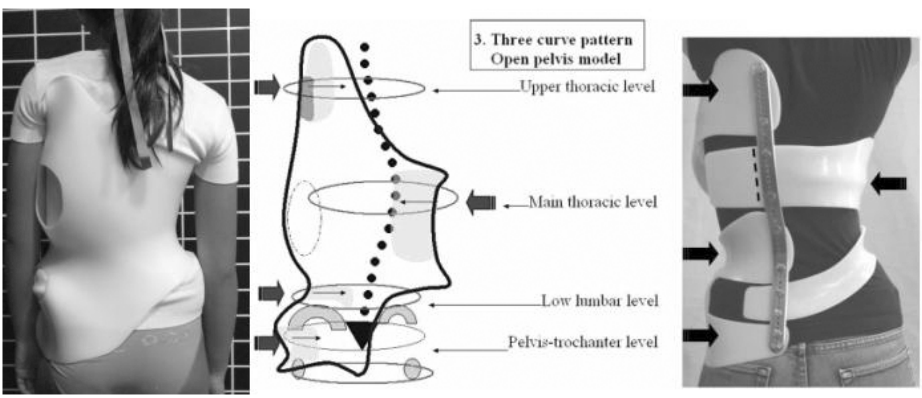


Figure 10. Blueprint to built a RSC® three-curve scoliosis brace ('open pelvis'). The picture shows on the left an original RSC and on the right a Chêneau light®.

In four-curve scoliosis pattern it is necessary to apply two 'three-point-pressure systems' (see Figure 11).

For a right thoracic/left lumbar, there is a lateral pad pushing the pelvis right to left, lumbar convexity left to right and thoracic convexity right to left (this is the first 'three-point-pressure system' correcting the lumbar curve). A pad pushing the upper

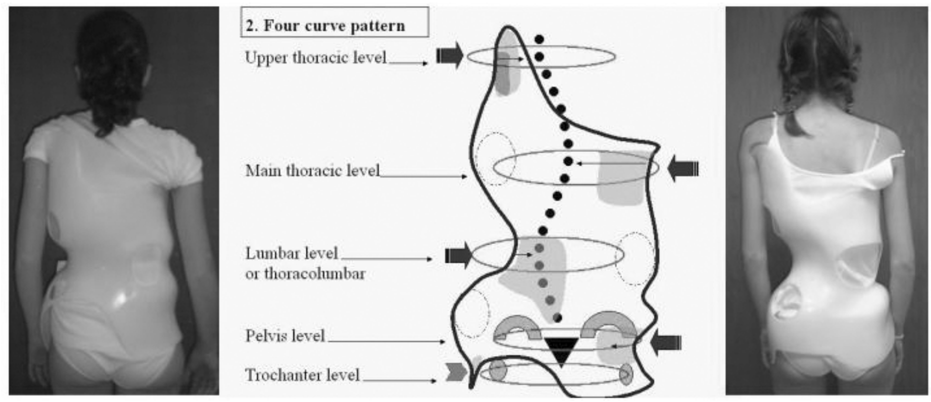


Figure 11. Blueprint to build a RSC® four-curve scoliosis brace. The size of the lumbar pad (in the cranial-caudal direction) depends on where the apex is located and how long the curve is. As higher and longer the curve is as wider is the pad.

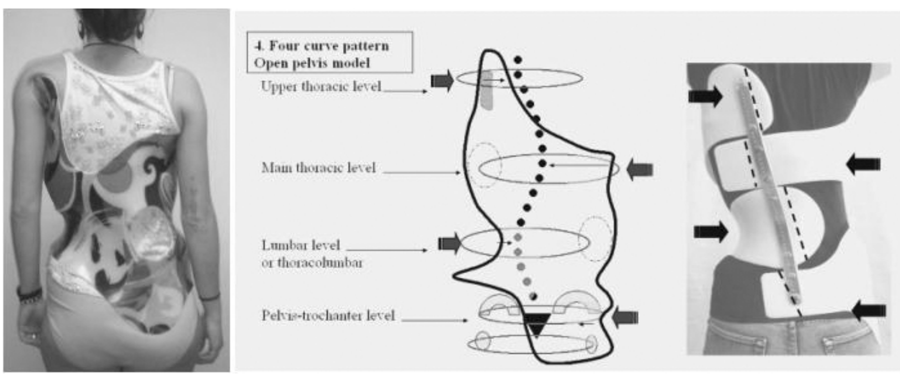


Figure 12. Blueprint to build an 'open pelvis' RSC® model. On the right its equivalent Chêneau light® where the material can be still reduced (cut-lines).

thoracic region left to right forms a second 'three-point-pressure system' to correct the thoracic curve together with the thoracic and the lumbar pad. In the original Chêneau and RSC® technique it is usually necessary a left trochanter counter-pad, but not in the Chêneau light® (see Figure 12).

The RSC® can be built both with and without the counter-trochanter-pad ('open pelvis' model). Criteria for 'open pelvis' model have not been defined so the decision whether or not to use it is based on doctor's preference.

Non-three Non-four brace does not push the pelvis to any side. When there is a lumbar curve it is important a counter-push in the low pelvis -trochanter level- at the convex thoracic side in order to rotate the pelvis in the clock-wise direction (for right thoracic convexity). It is not necessary in non-3 non-4 without lumbar curve (see Figure 13). Non-3 Non-4 with lumbar curve has its equivalent Chêneau light model (see Figure 14).

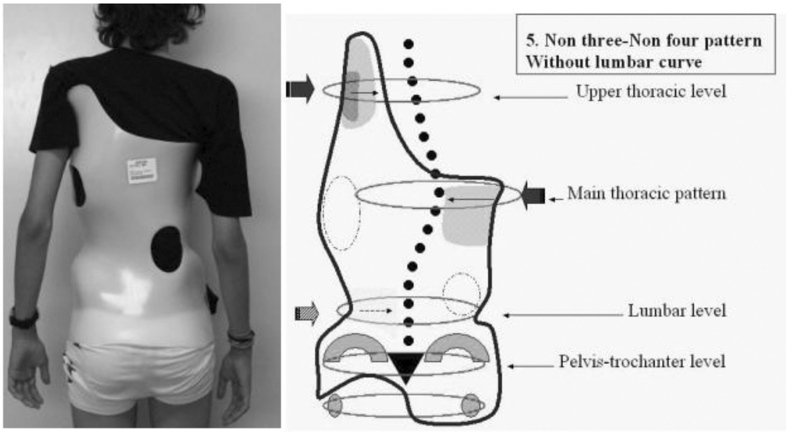


Figure 13. Blueprint to built a non-3 non-4 RSC® brace without lumbar curve.

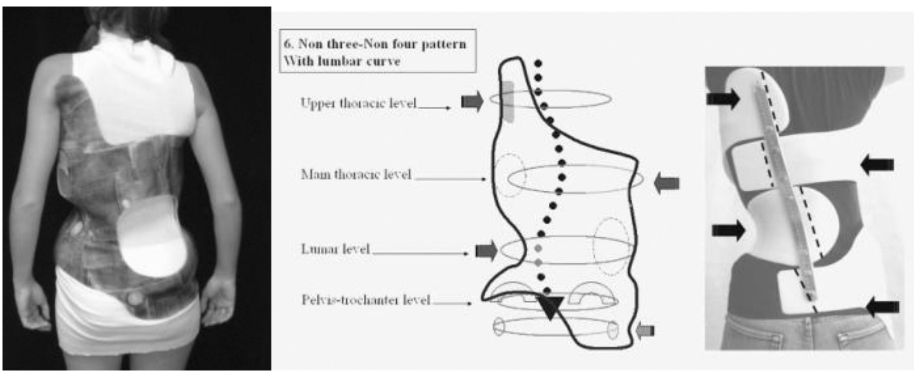


Figure 14. Blueprint to build a non-3 non-4 RSC® brace (left) . The Chêneau light® is on the right.

A highly specific model for thoracic double major pattern has been also defined (see Figure 15).

Lumbar and thoracolumbar curves can be treated with short braces (see Figure 16). The short brace works with a single three point system. The pad is in fact a counter-pad pushed down the supposed thoracic apex. It exists also a short Chêneau light® model.

Sagittal normalization:

The brace has a physiological profile in the saggittal plane and every trunk section (upper thoracic, main thoracic, lumbar and pelvis) must be aligned in a way that allow such a profile. However, even necessary a physiological profile is not enough to fight effectively against the flat back syndrome, especially at the thoracic region. The mechanism to correct the thoracic morphological lordosis is based on breathing mechanics (see Figure 17). The anterior thoracic pad (pushing on the ventro-lateral rib hump) together with the increased saggittal expansion make the spine to move backwards coupled to the concave ribs (see Figure 4).

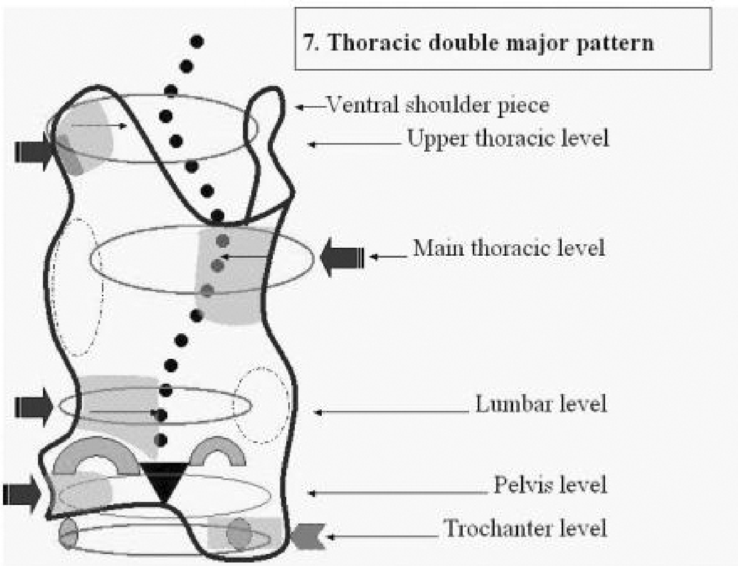


Figure 15. Blueprint to build a Thoracic Double Major RSC® brace. In this case with the lower part three like.

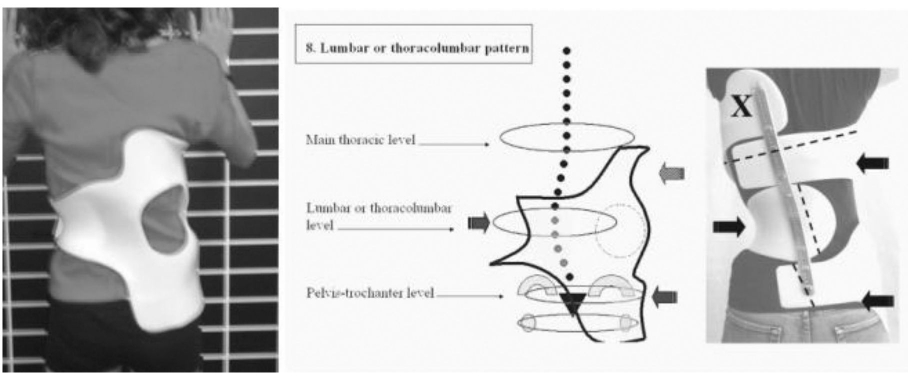


Figure 16. Blueprint to build a short brace. On the right a Chênau light® model.

Discussion

The in-brace correction determines the success of bracing [18,31]. Many brace concepts have shown good to very good in-brace corrections, however with a deleterious effect on the saggittal profile. Thus, modern built of braces should be based on the premise that a 3-D correction is desirable. The most analyzed technique is the Boston system. It has been sufficiently demonstrated that the Boston system does not correct in 3D, as it is related to the production of lumbar and thoracic flat back. Some efforts have been made by the promoters of the Boston system to change this paradigm, from the creation of a model with a more physiological profile to the addition of a pad

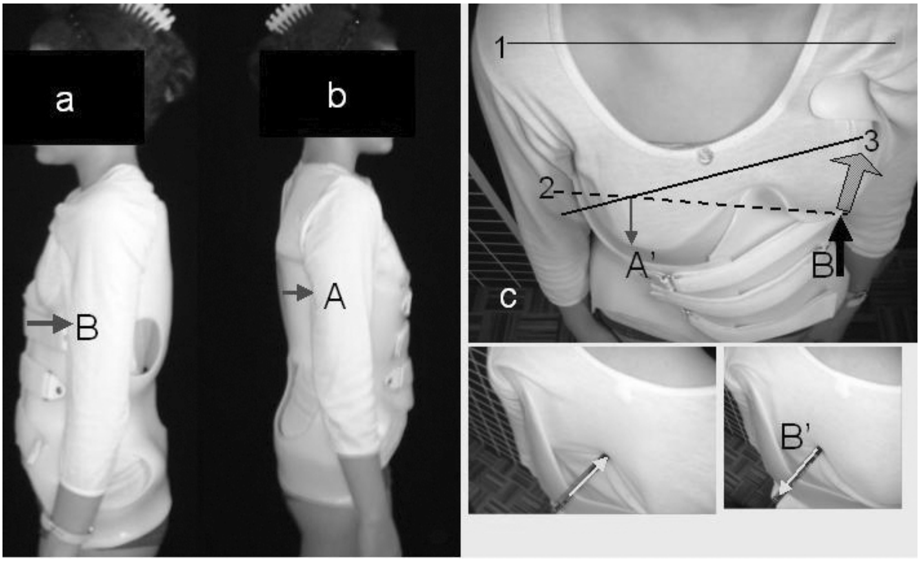


Figure 17. Physiological sagittal profile. A pair of forces B and A for derotation. The spine moves backwards B' coupled to the concave ribs during inhalation. Inhalation also expand the anterior flat region in the convex thoracic side A'. The rib cage and spine are derotated and translated from 2 to 3 away from the upper thoracic region 1.

pushing from ventral to dorsal on the concave thoracic side (on the ventral rib hump) [32], following the Canadian's approach [14]. Chêneau [33] started around 1979 the construction of braces following 3-D principles, similar in practice to those suggested later by the Canadian group. However, no studies have clearly shown that a brace built following Chêneau principles corrects a scoliosis in 3-D, with the exception of perhaps a study presented by Kotwicki [34]. On the other hand what is a Chêneau brace?. In a recent study conducted by the brace consensus group of the International Society on Scoliosis Orthopedic and Rehabilitation Treatment (SOSORT) the Chêneau brace was the preferable to treat a particular case [35]. However, there was substantial variability of answers on the function of the biomechanical correctional forces required of which indicated there were differing treatment methodologies.

Consequently, the use of a particular name for a custom made brace, like the Chêneau, is no guaranty that there is a consistent standard in design and treatment. The RSC is based on the original Chêneau principles but the enunciation and description of such a principles are both closely related to biomechanical terminology rather than to the initial anatomical explanations. The experience gained during almost two decades by the authors of the current paper together with the technical evolution have to be considered essential points in improving the in brace correction no matter the methodology, 'custom made' [36] or CAD/CAM assisted RSC [37]. Clinical experience and technical evolution brought also the so called Chêneau-light® [38]. Three-dimensional correction of the back shape and the virtual reconstruction of the spinal midline have been possible with the RSC technique [39], which strongly suggest that the brace corrects the scoliotic spine in 3-D, however, further biomechanical studies are necessary to conclusively demostrate it.

Conclusions

The RSC principles have been developed to improve the standards in brace construction. A brace designed according to these biomechanical principles, based on the 3-D nature of IS and its pathomechanism of progression, can produce an immediate correction effect of the trunk deformity and the scoliotic spine in three-dimensions.

Acknowledgement

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Passive and Active Mechanisms of Correction of Thoracic Idiopathic Scoliosis with a Rigid Brace

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Abstract. Contemporary bracing developed numerous novel technical solutions to most of main aspects of the correction of structural progressive idiopathic scoliosis. This paper presents a short review on principal biomechanical rules for the three dimensional scoliosis correction. Apart from the tissue transfer, which is a known passive mechanism of rigid bracing, the other passive mechanisms are described, containing the “cherry stone” distraction effect, the thoracic derotation and the bending. A demanding technical construction of the orthosis enables active mechanisms to develop: the corrective factor of the vertebral growth, hypercorrection-oriented trunk movements and respiration, as well as the anti-gravitational mechanism, by which postural reflexes maintain the curve correction, proximally and distally out of the limits of the brace. We believe that systematic investigations unfolded in the area of neurophysiological aspects of postural control of the spinal balance will continuously improve the fascinating capabilities of the active scoliosis autocorrrection assisted by the brace.

Key words. Idiopathic scoliosis, thoracic scoliosis, correction with brace, mechanism of brace action.

Pathology of thoracic scoliosis

We describe the passive and active mechanisms of corrective bracing on the example of single structural right thoracic idiopathic scoliosis, with non structural lumbar component. Such curve repartition, involving one structural and two compensatory curvatures, may be called a three-curve scoliosis, after Christa Lehnert-Schroth (see Figure 1). Thoracic scoliosis usually presents the apical region at Th8, Th9 or Th10 vertebrae. The physiological thoracic kyphosis is often reduced in this area, while pathological compensatory hyperkyphosis develops in the adjacent proximal thoracic spine, and often in the upper lumbar segments. The trunk imbalance is usually to the convex side, so the left hemipelvis protrudes laterally and produces asymmetry of the waists. The rotational deformity, which may be moderate in the upright position, becomes evident in the forward bending. Scoliometer is a useful tool for monitoring trunk rotation throughout the period of bracing. Shoulder imbalance and pelvis rotation appear as secondary body asymmetries. Radiography reveals the upper most tilted vertebra (upper limit

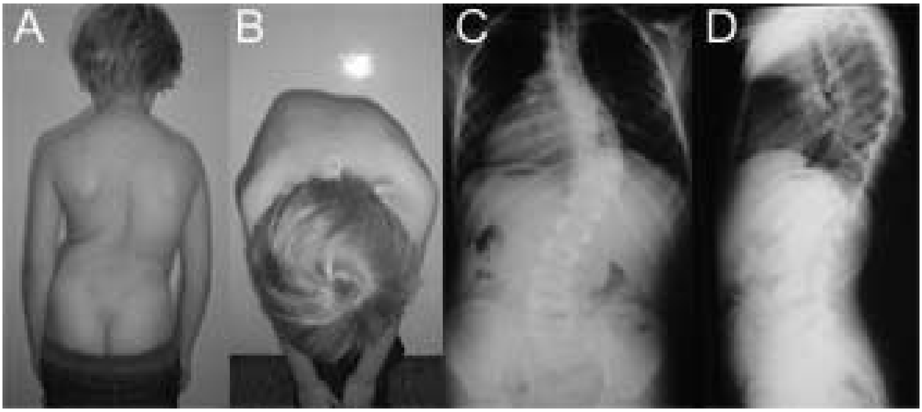

Figure 1. Ten-year-old prepubertal girl presenting single right thoracic idiopathic scoliosis: A) standing back view, B) Adams' forward bending view, C) radiological frontal view, D) radiological lateral view.

vertebra) usually at the Th4 - Th5 level, the lower limit vertebra at the Th12 or L1 level. Radiological vertebral axial rotation gradually increases from the limit vertebrae to the apical vertebra. The apical vertebrae are most deviated from the body axis, most rotated and cuneiform but not tilted. Lateral radiograph reveals segmental decrease of physiological thoracic kyphosis.

Deformity of the thorax

The key deformity in structural thoracic scoliosis considers the complex relation of the thoracic spine and the rib cage. In consequence the volume of the thorax decreased, the shape of the ribs becomes asymmetrical and the mobility of the chest wall decreases. The restriction of the thorax depends on (1) the soft tissues, revealing shortening and contractures, involving the superficial and deep thoracic fascia, the intercostals muscles, the ligaments and capsules of the costal joints as well as the muscle of the diaphragm, pleura and the pulmonary tissues, and (2) the osseous thorax deformity. In severe scoliosis the rib angles become flattened at the concavity and sharp at the convexity; the phenomenon markedly limiting capabilities of corrective bracing. In early stages, accessible for brace correction, these deformations are less expressed and concern a decreased posterior rib angle at the convexity and an increased posterior rib angle at the concavity. Moreover the posterior part of the rib, including the head, the neck and the angle of the rib, is oriented more sagittal at the convex side and more coronal at the concave side, comparing to the physiological orientation. Thus, the thorax seen axially presents an elliptic shape (see Figure 2). The direction of the long axis of the ellipse is from the right posterior to the left anterior area, this is expressed on the trunk surface as the right posterior rib prominence (rib hump) and the left anterior rib prominence. The short axis of the ellipse is oriented from the left posterior to the right anterior direction, and corresponds to two surface concavities: left posterior para-apical and

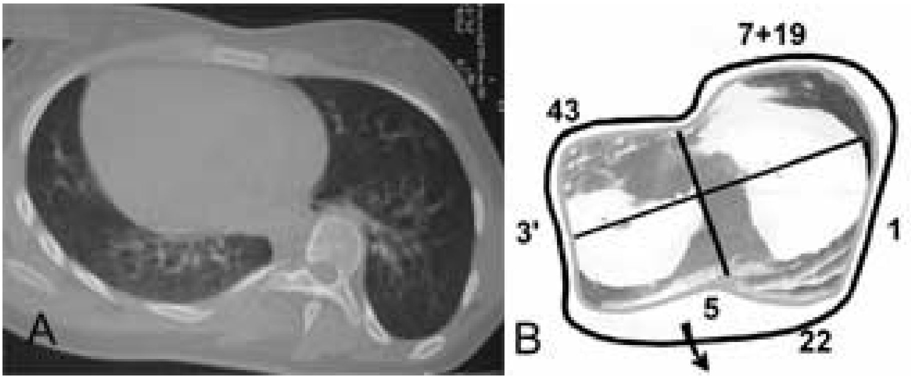

Figure 2. Transverse plane deformity of the spine and the thorax (top view): A) computer tomography at the apical level, showing the ellipsoid shape of the thorax; B) schematic representation of the idea of the action of the brace: (1) derotation by the force of the pads – the initial direction of 25° results from the displacement of the axis of the thorax which were respectively horizontal and vertical before bracing, in addition the 20° of the pressure pad 1, the resultant force direction is 45° to press on the patient's back; (2) reduction of the greater oblique diameter of the thorax by a clamp of the pads 1 and 43; (3) expansion of the smaller diameter towards the zones 5 and 7 - 19, being the expansion of the hollow back.

right anterior located around the right breast, giving an impression of a smaller breast. The thorax has amazing mechanical properties. When pressed from the back to the front or reversibly, or when pressed from the sides, it appears stiff. However when pressed obliquely, as in figure 2 in between zone 1 and zone 43, it reveals supple, at all ages. Scoliosis profits from this property and rushes into both sides to form an ellipse. The brace makers also take advantage of it and press the thorax in clamp, in order to restore its normal shape. The timing of the thorax growth contains a phase of rapid growth spurt, occurring shortly after the rapid growth of the spine [1]. Thus, during the period of the most effective correction of the spine, the thorax is intensively growing up and reveals important plasticity. Therefore, the remodeling of the thorax may occur together with or independently to the curve correction.

Biomechanical considerations

The brace enables the tissue transfer by pushing on convex parts of the trunk. At the apical level of thoracic scoliosis the corrective force acts over the right convex posterior rib prominence, and simultaneously on the left anterior rib prominence. The corresponding parts of the brace are formed in the shape to push perpendicularly to the body surface. The pressure is local, directed precisely against the apex of the external convexity, providing the maximum of the pressure force to the maximal prominence. The concept derived from the Milwaukee bracing, pushing along the two para-apical ribs, is not used. The thorax is considered as an entity, possessing visco-elastic proprieties. The correction being more active than passive in this system, the pressure as high as at the thoracic apex has an effect on the whole slice of this apex. Convex side, directly pressed, migrates centripetally.

The other side, concave, migrates centrifugally, as a result of a natural tissue dodging, associated with a voluntary inflating of this concave area, enhanced by the exercises guided by a physiotherapist. The ribs being all together united by the ligaments, which are not extensible, have their orientation normalized by the straightening of the thoracic curve. That explains the paradox fact that at the apex, the convex side ribs become less vertical although pressed, and the concave side

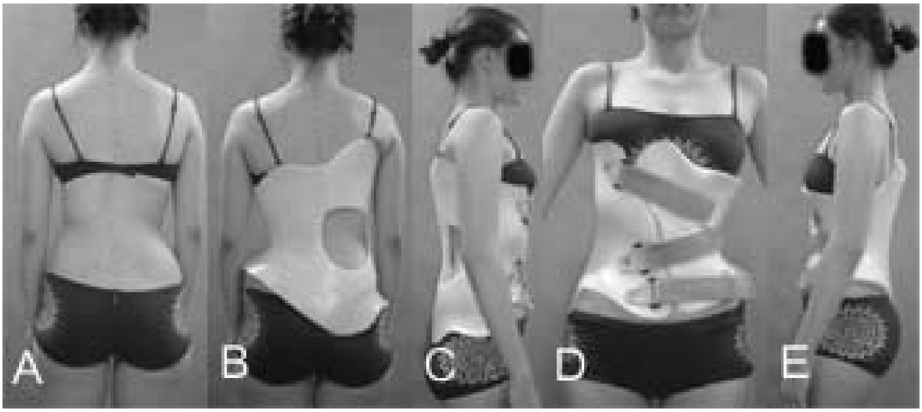

Figure 3. Restoring of the balance is obligatory, hypercorrection desirable. Here demonstrated for a double curvature with predominant left thoracolumbar component, producing left trunk imbalance (A), hypercorrected with a brace (B). Figures B through D present the anti-gravitational effect. Elimination of the left pelvic part does not result in loss of the balance of the trunk, and the elimination of the left axillar part does not result in the shoulders imbalance, due to the anti-gravitational effect.

ribs become less horizontal although free for expansion, as demonstrated by Chêneau [2] and confirmed on X-rays made in-brace. In opposition to a simple three-point orthosis, in the contemporary bracing the combination of multiple three-point systems is designed and constructed, in order to allow the three-dimensional scoliosis correction.

The trunk balance is reestablished by left or right translation of the pelvis against the thorax, using the three-point system of forces acting in the coronal plane. Restoring the balance should be considered as an imperative; any failure is unacceptable. Frontal plane hypercorrection, meaning creation of the trunk imbalance to the opposite side, may be desired in particular patterns of scoliosis (see Figure 3).

An indispensable condition for the tissue transfer mechanism to act, the important free spaces are managed in the strictly defined areas. This enables the expansion of the concavities without loosing any corrective effect. In front of the right anterior and the left posterior trunk concavities (Figure 4) the brace presents huge free spaces. At these two areas the brace does not come into the contact with the skin, neither in normal position nor on the deepest inhalation. In our opinion, the preparation of these two free spaces in the brace should be considered to be one of the most typical features of contemporary brace design. This is also one of the reasons, why the term of "total contact" orthosis is not appropriate for contemporary bracing. Detailing the description to the thoracic level, the arguments supporting such a construction aim in obtaining the derotation effect of the brace:

1) passive displacement of the thorax towards decreased rotation,

2) passive squeezing of the convex parts of the thorax, resulting in simultaneous expansion of the concave parts - shortening of the long axis of an elastic ellipse results in lengthening of the short axis,
3) controlling the active movements of the trunk towards curve correction,
4) guidance for thorax growth,

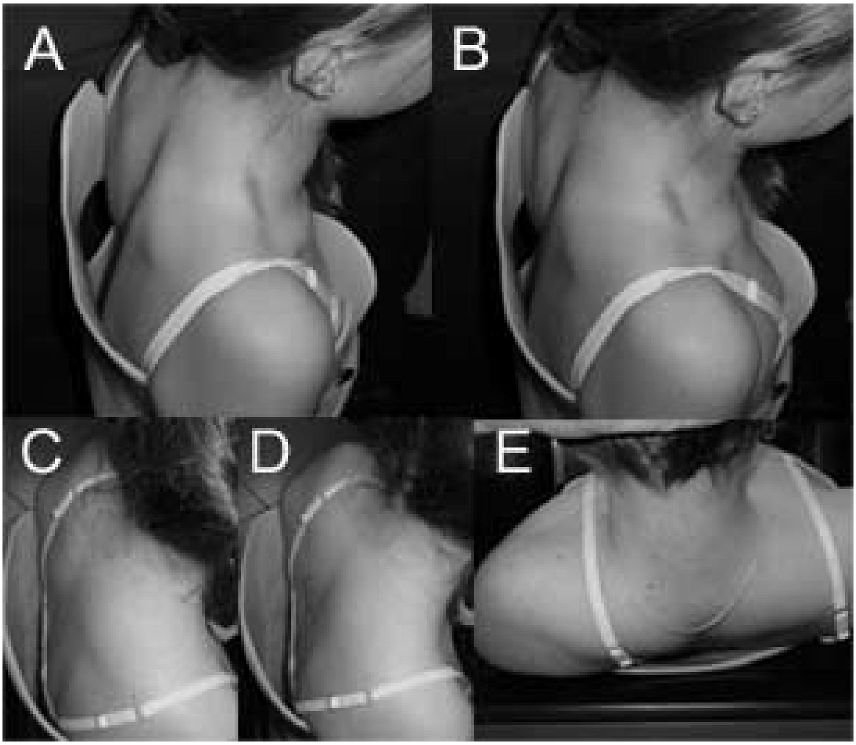

Figure 4. Concave thorax expansion enhanced by the brace. The right posterior and the left anterior convexities are blocked with 1 - 43 pads. A) relaxed upright position reveals free spaces prepared within the brace at the concave areas, B) deep breathing results in expansion of the left posterior and the right anterior concavity, C) another girl in brace presented on maximal inhalation, D) on exhalation position the posterior room seems to be unnecessarily large, E) disappearance of the large posterior room in the supine position demonstrates the possibility to increase thoracic kyphosis in brace.

5) deep breathing not limited by the brace contributes to the curve correction,
6) guidance for asymmetrical respiratory exercises in brace,

These corrective phenomena are complex and contain both passive and active mechanisms. It is also worth to mention that in the supine position in nighttime bracing the posterior free spaces enables the thoracic spine to arrange in more kyphotic orientation.

During brace manufacturing, the modeling of the positive of the brace should strictly follow the precisely described system of mutually dependent zones of pressure and expansion [3]. The plaster manufacturing is now challenged by computer assisted fabrication [4]. Chêneau has actively contributed to the development of a software aiming in this purpose [5]; the main software of computer-aided brace manufacturing derives from this search.

Preserving or restoring the physiological sagittal curvatures of the spine is one of the principal goals of brace treatment. At the lumbar level the lumbar lordosis is promoted by posterior selective pushing. At the thoracic level no direct pressure can be applied. The preparation of huge free spaces is essential, together with a special design of anterior thorax wall pads. Exercises are extremely helpful in kyphotizing the thoracic spine, under the condition that an appropriate space for kyphosis is managed within the brace.

"Cherry stone effect" is a name used to describe the action of the brace comprising trunk distraction. Similar to the Milwaukee system, the pelvic piece serves as the base to apply the distractive forces, however the proximal area of counter action is not occipito-mandibular but infra-thoracic. Particular design of the pieces supporting costal arches together with a tulip form of the thoracic piece and a large superior opening of the brace, results in important passive elongation of the body, resembling that of a cherry stone pressed in between fingers. This mechanism is supported by the bending which involves the proximal thoracic spine. The bending is a natural way of straightening the spinal curvature, often performed with the examiner's hands in order to assess curve flexibility. The bending by the brace is provided by the zones around the left axillary region; special design protects from the compression on the neurovascular structures. The biomechanical importance of the bending relies not only on the passive straightening of the upper thoracic hemicurve, but includes also the participation in the elongation mechanism of the "cherry stone" and gives a strong stimulation to the anti-gravitational effect. To provide the bending mechanism, a large portion of plaster of Paris is cut out from the positive at the level of the left underarm region during brace manufacturing, making impression of an intolerable obliquity of this part. However, the brace put on the patient automatically returns to the vertical position, decreasing the underarm pressure and increasing the translation force not only locally, but simultaneously providing a distant action of translation at the level of the pelvis.

Anti-gravitational effect represents an active mechanism of bracing, which is responsible for transmission of the corrective action of the orthosis outside its limits. This paradox mechanism acts due to the postural control system, which, once pushed away from the axis of balance, provides reaction of the locomotor system to reestablish the balance (Figure 3). Anti-gravitational effect is particularly helpful, when the superior limit of the curve is too high, or the inferior limit is too low, to be directly controlled by the brace, for example for correction of the curves with the apex above Th8. Another interesting application is possibility of reducing the pelvic part of the brace. Thus, the traditional understanding of the pelvic piece, reposing on the iliac bones, was redefined. There is no need to cover the pelvis with a brace, if the anti-gravitational mechanism is correctly applied.

Other active mechanisms are asymmetric respiration guided by the brace (mentioned above) and asymmetric growth of the trunk. The latter, being a known risk factor for scoliosis progression in the absence of appropriate management, becomes an important corrective factor in case of unloading the vertebrae with orthosis, because it is the optimal mechanism to fix the new form of the spine, due to vertebral remodeling [6]. Stokes et al. [7] provided a theoretical rationale for the clinically observed phenomena, involving biomechanical interruption of the vicious circle of scoliosis progression. We strongly believe, that continuous (20 hours per day) spinal concave unloading during the rapid growth spurt phase, provides the best conditions for durable scoliosis correction. Technical demands to achieve this purpose comprise: (1) sufficient straightening of the curvature to obtain concave vertebral plates unloading and (2) providing enough room within the brace for the growth and development of bones and soft tissues. The common fault is to promote the former and postpone the latter or vice-versa; the first situation results in crushing the trunk, the second results in its escape from the pads and in the loss of correction.

Conclusions

Continuous improvement of the quality of rigid bracing, due to better understanding of the 3D nature of the deformity, of biomechanics of scoliosis correction and of neurophysiologic aspects of posture control, is observed. We shortly reviewed the following basic mechanisms:

Passive mechanisms of orthosis:

1) convex to concave tissue transfer, achieved by multiple three-point system acting in 3D, with the aim of curve hypercorrection,
2) elongation and unloading by the “cherry stone” effect,
3) derotation of the thorax,
4) bending.

Active mechanisms of orthosis:

1) vertebral growth acting as a corrective factor,
2) asymmetrically guided respiratory movements of the thorax,
3) repositioning of the spatial arrangement of the trunk muscles to provide their physiological action,
4) anti-gravitational effect.

The principal attributes of contemporary corrective orthosis for idiopathic scoliosis in children and adolescents should take advantage of these specific passive and active mechanisms, allowing curve correction to occur together with (1) the preservation of the function of the vertebral column as a harmoniously curved and flexible framework of the human body, as well as (2) the preservation of the respiratory function of the thorax.

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Lyon Brace

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Abstract. For the last 60 years, the impressive progress of the scoliosis surgery has hidden the development of the conservative orthopedic treatment. The stabilization of the scoliosis, which implies the safeguarding of a spine as mobile as possible, remains a valid objective. The Lyon Brace management combines 3 techniques

A reduction of the scoliosis using a plaster cast fixed on an EDF (Elongation Derotation Flexion) Cotrel's frame. It carries through a flow of the musculoligamentar structure of the concavity.

A contention by Lyon Brace. Orthesis without any cervical superstructure is adjustable, symmetric, see through and active. The elongation between the two scapular and pelvic girdle leads to a disc decompression which makes easier the 3D correction of the curves. The individual moulding (custom made) is actually electronic using a "full 3D imaging" system by Orten. To every 14 types of Lenke's classification matches a specific blue print.

A specific physiotherapy combining the consciousness of the deformity, suppling up of the retracted elements of the concavity, compensatory suppling up of the girdles, improvement of the vital capacity based on exhalation, reharmonisation of the static, static strengthening in order to facilitate the ability to be still in a corrected position, kyphotisation proprioceptive exercises to stimulate the maturation of the postural system. We advise the scoliotics to practice sport during the treatment period.

The long term follow up confirms a global effectiveness indication of 0,89 with the rib hump declining by half. When we treat scoliotics with Cobb angle less than 45°,surgical treatment can be prevented in 98% of the patients.
In France 60% of the families agree with this stringent treatment which becomes easier thanks to its ambulatory realization and the excellent formation of the partners, the physiotherapists and the orthesist.

Keywords. Scoliosis, Lyon brace, results, management, orthotics, plaster cast, physiotherapy[1]

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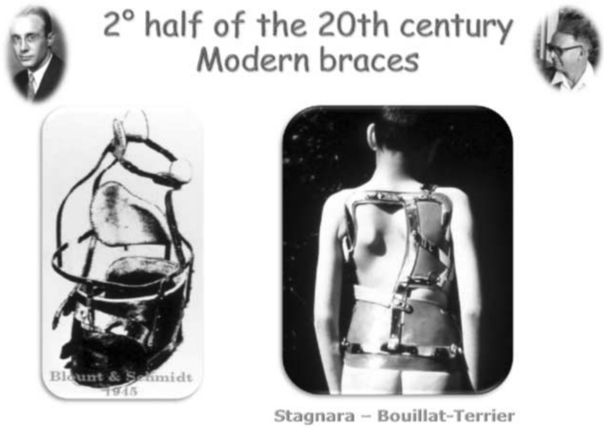
[2] – CHR de Mulhouse : 20 rue Laennec - 68070 Mulhouse (FR)
[3] – Medicasud : Via della Resistenza 82 - 70124 Bari (I)
[4] – Studio Lusenti : Stradone Farnese 25 - 29100 Piacenza (I)
[5] – Centre Lionese : Via Ricasoli 55 – 90139 Palermo (I)

Introduction



The Lyon Brace was created by Pierre Stagnara in 1947. [8][10]
It is an adjustable rigid brace, without any collar. (see Figure 1)

Figure 1. Milwaukee and original Lyon brace

The brace is :

- **A**djustable on seven centimeters of growth, it's efficient. We do not need to change the brace every six months.
- **A**ctive: Because of rigidity of the plexidur structure, the child is stimulated. The active axial auto correction decreases the pressures.
- **D**isc decompression: It is the consequence of the "Adjustable". The effect of extension between the two pelvic and scapular girdles decreases the pressure on the intervertebral disc and allows a better effectiveness of the pushes.
- **S**ymmetrical: In addition to the esthetic aspect, the brace is much easier to build.
- **St**able: The stability of both shoulder and pelvic girdles facilitates the intermediate corrections.
- **T**ransparent: Usually, it is not necessary to use the "pads", we can thus control directly on the skin the pushes, stops, drives and reliefs.

The Lyon brace management consists of:

- a time of reduction by one or two braces realised in an EDF frame (Elongation, Derotation, Flexion) by Cotrel. [1]
- a contention thanks to the Lyon Brace
- a specific rehabilitation complementary to the pursue of a sport activity almost normal

1. The Plaster Cast:

Figure 1a. Plaster cast in Cotrel's frame

The plastered brace is nowadays applied in ambulatory (day hospital). It provides many advantages.

The plaster cast:

- gets the skin ready to improve the tolerance to the orthesis,
- allows a maximal reduction when the child is more flexible,
- enables us to predict the success of the conservative orthopedic treatment when the reducibility is more than 50%,
- generates a flow of the musculo-ligamentar structures of the scoliotic concavity,
- cannot be taken off the child, that avoids all the conflict with the parents. The brace experience will therefore be more positive.

The technique was described by Marc Ollier. [6] It is carried out in an Cotrel's frame of reduction allowing the Elongation, Derotation and Flexion (EDF). [1] This frame comprises in longitudinal axis, a system of pelvic traction independent for each hemi pelvis and a system of cervical traction with dynamometer. Laterally one has on the right and on the left, 3 adjustable bars of inflexion and derotation, 2 low bars, 2 medial bars in the plane of the child and 2 high bars. On each bar, mobile cursors facilitate the fixing of the soft tapes.

The child is prepared with the physical therapist by supplings.

- The thorax of the child is covered with 2 jerseys; the first jersey of 20 cm is wider to cover the edges, the 2nd jersey of 15 cm encloses the child well and makes it possible to avoid the creases.
- The practitioner slips at the pelvic level between the 2 jerseys 2 beveled square felts of 15 cm side to protect the iliac crest.
- The child is placed in the frame lengthened in a lying position on a strong removable ticking band.
- A transverse metal bar is placed at the lower end of the sacrum, and another under the head of the child.
- Pelvic traction then is installed and one sets up the cervical traction. Axial traction is controlled by a dynamometer. This traction will always be weak, approximately 12 Kilograms (twice the weight of the head). An excessive traction makes lateral bending difficult, derotation and especially kyphotisation; it concerns only severe angulation exceeding 40°of Cobb angle.

Installation of the ticking tapes:

If we take the example of a right thoracic and left lumbar double-major scoliosis, the technique with 4 tapes is used.

- The first tape from 20 to 25 cm wide is placed under the thoracic rib hump, its horizontal lower segment leaves on the left concave side, it is rolled up upwards i.e. from the spine towards the anterior part of the thorax, it is reflected in an oblique way on the higher bar of the frame on the left concave side.

- The second tape, about 20 cm wide is placed on the level of the lumbar rib hump in reverse order, i.e. that the lower horizontal segment leaves of the right concave side and is rolled up upwards, carefully marking the iliac crest and the fold of the waist protected by the pelvic felt. It reflected at the level of the abdomen in an oblique way on the higher bar of concave right side of the frame. It can be also reflected vertically if one seeks a lordosis effect.
- The third tape, about 15 cm wide is placed on the axillary right level; it produces a counter-push and rebalances the spine. It is symmetrical with the lumbar tape.
- The fourth tape, about 5 cm wide is placed on the level of the pelvis which is essential each time a coronal pelvic tilt exists. It is a tape of purely horizontal shift which surrounds the right hemi-pelvis. The practitioner makes a node on the level of the left trochanter to facilitate the rolling out of the tapes and one fixes it on the left medial horizontal bar.

One puts in partial tension the ticking tapes to balance the child, and then we place 2 beveled longitudinal felts of 5 cm thickness, 25 cm broad and 60 cm length under the ticking tapes. The felts must largely overflow on the axillary level.

Then one carries out the setting in final tension while being progressive, by alternating inflexion-derotation and axial traction without exceeding 12 kilos, and while making sure the spine is kept balanced in the axial plane.

When the spine is well balanced, the plaster tapes are unrolled in a derotation way i.e. like the ticking tapes. One uses initially 2 circular tapes of 20 cm broad to cover completely the ticking tapes. Then, 4 plaster splints of 30 cm broad are placed on the front, back and laterally. We cut out the circular tapes carefully all around the ticking tapes. 3 circular tapes of 20 cm stabilize the cast definitively. Making the plaster cast, the practitioner carefully models the counter anterior rib hump on the left and tries to improve kyphosis on the level of the rib hump by raising the shoulder girdle. This is why we prefer a ticking tape reflecting itself on the high bar on the axillary level. The practitioner can also raise a little the bar of cervical traction to carry out an effect of hammock.

The plaster cast dries in the frame during approximately 10 minutes, then the child stands up and the first cuts are carried out in upright position.

The physician delineates trim lines according to the X-rays.

- On the level of the pelvis, one largely releases the inguinal fold to allow a 90° flexion of the thighs.
- On the level of the shoulder girdle, cutting is asymmetrical to release the right arm of the child and to allow more functional independence, but especially to facilitate the rehorizontalisation of the upper limit vertebra.
- On the level of thoracic and lumbar concavities, one cuts out a window intended to facilitate maintenances of skin and to allow a possible felting of the rib humps.
- At the abdominal level, a triangular window with xiphoidean peak facilitates maintenances of skin and makes it possible to check the stomach in the event of gastric dilatation.

- At the thoracic level, one releases the chest by reinforcing the stabilization of the chondro-costal band and the sterno-clavicular support.

The Lyon Brace

1.1. Description type

The Lyon brace for a thoracic scoliosis or double major scoliosis.

Figure 2. Lyon Brace - Frontal view

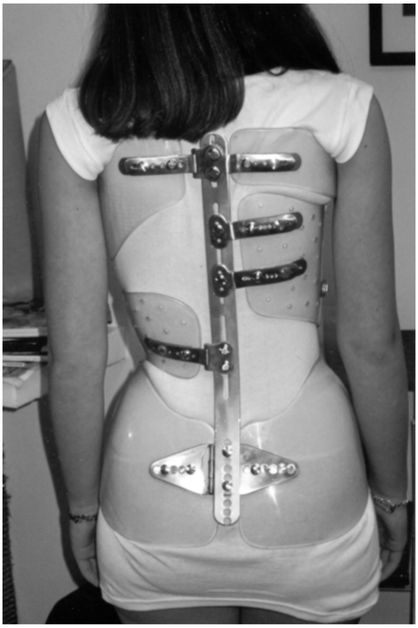


Figure 3. Lyon Brace - Back view

It is made from top to bottom :
- a pelvic basis insuring the optimal stability of the orthesis,
- a lumbar shell T12-L4 either independant, or extending at the abdominal-chondro-costal level,
- a thoracic shell at the level of the scoliotic convexity,
- an opposite thoracic shell used as a counter push,
- we can eventually use little crutch to balance on the side of the scoliotic convexity. The shells are fixed on the posterior and the anterior masts. They have some hem made for the adjustement and this enables an adaptation of 7 cm during the growth.

The plexidur shells realise according to the application :
- a stop,
- a drive,
- a push.

For esthetical and mechanical reason, we avoid as much as we can the pads under the shells.

We realise a lumbo-sacral lordosis in order to favor the thoracic kyphotisation.

1.2. Force couples

Rotational deformity is an important component of scoliosis. In addition to the emphasis given to the lateral curve correction, the Lyon Brace emphasize correction of rotational deformity. We believe that the application of rotational forces is potentially much more effective when "force couples" are used. Thus, for every rotational force applied another force opposite the desired center of rotation, in the same rotational direction, is applied to enhance the rotational force. Thus an anteriorly directed derotating force in the lumbar spine is counter balanced by (coupled with) a posteriorly directed force in the anterior abdomen. (see Figure 4)

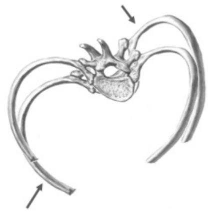


Figure 4. Derotating force couples

Figure 5. Medial gibbosity pad

At the thoracic level, it's possible to add a pad on the medial side of the rib hump. (see Figure 5)

1.3. The Variants

1.3.1. Lyon Brace for a lumbar scoliosis.

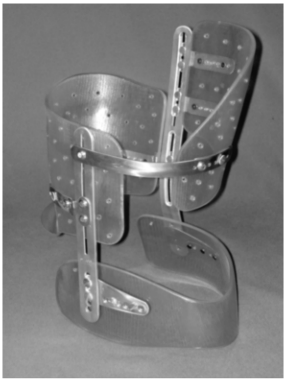


Figure 6. Lyon brace for a lumbar curve

It was created by Michel & Allègre. [5]
It is made of three components:

- An ilio-lumbar push (T11-L4) on the convexity, the illiac support is horizontal and enables an extension effect
- A tochanterian semicircle at the concavity level.
- A thoracic push (T6-T12) on the concavity side.

(see Figure 6)

1.3.2. Lyon Brace for a thoraco lumbar curve

It is only made of one large thoraco lumbar push T6-L2 at the level of the convexity. No lumbar shell.

1.3.3. Soft Lyon Brace

The material used is polyethylen for a neuro-muscular scoliosis.

1.3.4. Elastic Lyon Brace

The thoracic plastic shells are replaced by elastic strap. They are used in case of major obesity.

2. Physiotherapy

2.1. The principles

- No complex material. All the exercices have to be repeated at home.
- No sportive counter indication. The sport practiced by the child must be continued by adapting if necessary the sportive gesture (avoid the deep quick inspiration, and the flexion of the trunk forward) and by completing if necessary the sportive activity thanks to physiotherapy.
- The exercices are symmetric in the frontal plane.
- No chapel and miracle exercice. Choosing the best technical way for every child, at every age, and every therapeutic sequence.
- No revolution, but an evolution in the exercices which are repeated few minutes a day at home.
- We treat a child and not a scoliosis or an X-ray. The look of the child is fundamental. [9]

2.2. Objectives, means, obstacles

Table 1. Physiotherapy during the Lyon Brace treatment

OBJECTIVES	MEANS	DANGER-CARE
Modification of the spoiled body image of the scoliotic	When we first see the patient, back and vertical height difference pictures are shown to the child He has to be conscious of the deformity thanks to the mirror or a video tape	The cortical representation of the back is weak and damaged by the fast growth, but let's be careful not to devalorate and depreciate the image of the body
Suppling up of the retracted elements of the concavity	Stretching posture (Mézières, RPG)	The rigidifying scoliosis curve may be a natural element of stability. An excess of the suppling up can lead to a progressive revival of the scoliosis.
	Dynamical mobilization	In some double curves case, the mobilisation is the same on the right and on the left, in fact the bendings show us that 80% of the movement happen in the correction sense and 20% in the worsening sense.

	Manual modeling of the vertical height difference	Be careful not to favour the flat back. The support has to happen on the internal side of the rib hump. A cushion is put under the left chondro costal canopy and the transversal movement leads to exhalation.
Suppling up of the griddles	Segmentar and analytical correction of the deficit of the extension of the hip measured by Biot at 43%, since the youngest time of the patient	The girdles have to compensate
Improvement of the vital capacity	Highering of the VEMS Blow a balloon every night	The deep inspiration favours the rotation (Geyer) thus slow inspiration and quick exhalation.
Saving of the spine Diminution of the mechanical constraint on the axis	Development of the compensation at the girdle level and the limbs on a trunk which is still close to vertical	
Reharmonisation of the static	Repositioning of the head on the gravity line in the frontal and sagittal plane. Exercice to carry big charges. We look for the global balance, the sand pack must stay on the head, the harmony and the movement coordination. The walk must be synchronised with breathing. For lumbar scoliosis and thoraco-lumbar: learning of the shift.	A pelvis unbalance or of the scapular girdle can compensate a scoliosis, we have to respect them. All types « C » of Lenke, the opening of the illio-lumbar angle goes in the direction of the accentuation of the lumbar curve. In the sagittal plane, we have to avoid favouring the lordosing vertebral rear.
Strengthening of the muscle in order to make the behavior in a corrected position easier	Reinforcing of the fibers of the deep paravertebral muscle structure and muscles stabilizing the girdle such as the psoas, the abdominals and the pectorals by powerful slow static contraction supported in a corrected position.	« The brain ignore the muscles and only know the movement » In the frontal plane, The exercices are symmetric because we do not know the role of the asymmetry concavity convexity. In the sagittal plane, the anterior flexion increase the rotation, therefore we have to strengthen in a neutral position. No body building which concerns the superficial muscle structure.
The 24 hours of the back : adaptation of the scoliosis to the environment and of the environment to the scoliosis	Control of the sitting position when listening and writing according to the morphotype Dealing with the school bag	
Stimulate the maturation and the balancing postural system	Proprioceptiv rehabilitation kyphotisation from : Feet sensors, ocular sensors, cutaneous sensors	Some patients have a postural reflex when there is an unbalance situation, which leads to a worsening of the scoliosis

Physiological valorisation Stimulate the global mobilisation of the spine in an automatic way	Sport practice Coordination of the gesture, harmony of the move	
Psychological valorisation Well being and self confidence	To be upbeat with the scoliosis « The scoliosis is not a disease but a symptom»	

2.3. Lyon Brace Indications.

2.3.1. Magnitude of the curves :

- 20/30° a reducer plastered brace during a month, the orthesis must be wore at night. Weaning at the end of the statural growth.
- 31/40° two plastered braces lasting one month and wearing of the orthesis 20 hours a day. Weaning one year after the end of the statural growth.
- 41/50° Two plastered brace lasting two months each and wearing of the orthesis 23 hours out of 24. Weaning 18 months after the end of the statural growth.
- > à 50° it is possible to realise a Lyon treatment waiting for surgery. Weaning two years after after the end of the statural growth.

2.3.2. Children age:

The fragility of the thorax before the ephebic growth leads us to choose the Milwaukee brace. The best indication concerns the infantile and juvenile scoliosis. When the statural growth is over and waiting for the bone maturity we can use non adjustable Chenau brace.

2.4. Contra indications to bracing

Juvenile and infantile scoliosis to avoid a tubular thorax.

Sever thoracic lordosis which treatment is usually surgical. The waiting treatment with Lyon brace will be focalized on the lumbar curve to limit as much as we can the fusion of the lumbar vertebras.

Major psychological reactions.

The Lyon conservative treatment is the most elitist, but when the child and the family accept the plastered brace, the compliance is maximal.

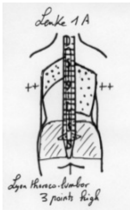
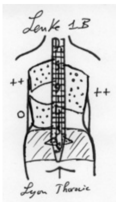
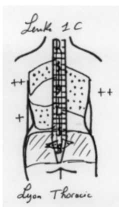
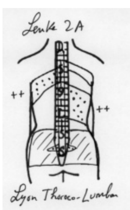
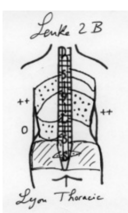
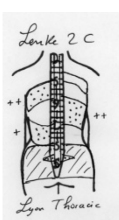
3. Brace design – blue print.

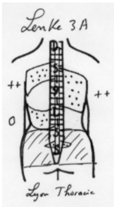
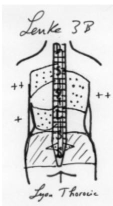
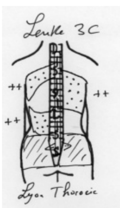
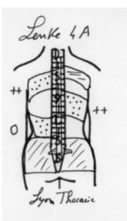
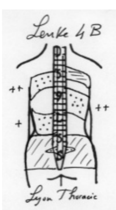
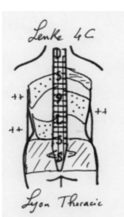
We will use Lenke's classification. To every 14 types of curves one specific blue print is going to match.

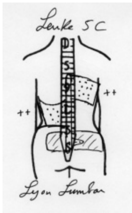
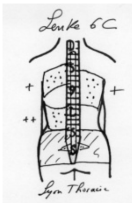
In a case of electronic moulding according to Orten's process, the specific blue prints are corrected automatically. (see Table 2) The specific modifications: erase, cut, surfacing, reload, smoothing, are done automatically.

The bending of the bars in the sagittal plane will be suitable according to the sagittal pattern.

Table 2. Blue print according to Lenke's classification

1A 		**Lyon thoraco-lumbar** **3 points high** **Without axillary balance support**	Right Thoraco-lumbar Push T5-L2 Left Thoracic Push T4-T7
1B 		**Lyon thoracic** **With lumbar stop** **Without axillary balance support**	Right Thoraco-lumbar Push T5-L1 Left Lumbar stop L1-L4 Left Thoracic Push T4-T8
1C 		**Lyon thoracic** **With lumbar drive** **Without axillary balance support**	Right Thoraco-lumbar Push T5-L1 Left Lumbar Drive L1-L4 Left Thoracic Push T4-T8
2A 		**Lyon thoraco-lumbar** **3 points high**	Right Thoraco-lumbar Push T8-L2 Left Thoracic Push T5-T7 Right axillary balance support
2B 		**Lyon thoracic** **With lumbar stop**	Right Thoracic Push T8-L1 Left Lumbar Stop L1-L4 Left Thoracic Push T5-T8 Right axillary balance support
2C 		**Lyon thoracic** **With lumbar drive**	Right Thoracic Push T8-L1 Left Lumbar Drive L1-L4 Left Thoracic Push T5-T8 Right axillary balance support

3A 		**Lyon thoracic** **With lumbar stop** **Without axillary balance support**	Right Thoracic Push T5-T12 Left Lumbar Stop L1-L4 Left Thoracic Push T4-T7
3B 		**Lyon thoracic** **With lumbar drive** **Without axillary balance support**	Right Thoracic Push T5-T12 Left Lumbar Drive L1-L4 Left Thoracic Push T4-T7
3C 		**Lyon thoracic** **With lumbar push** **Without axillary balance support**	Right Thoracic Push T5-T12 Left Lumbar Push L1-L4 Left Thoracic Push T4-T7
4A 		**Lyon thoracic** **With lumbar stop**	Right Thoracic Push T8-T12 Left Lumbar Stop L1-L4 Left Thoracic Push T4-T7 Right axillary balance support
4B 		**Lyon thoracic** **With lumbar drive**	Right Thoracic Push T8-T12 Left Lumbar Drive L1-L4 Left Thoracic Push T4-T7 Right axillary balance support
4C 		**Lyon thoracic** **With lumbar push**	Right Thoracic Push T6-T12 Left Lumbar Push L1-L4 Left Thoracic Push T4-T7 Right axillary balance support

5C 		**Lyon lumbar** **3 points low**	Left Ilio-lumbar Push T12-L4 Right Thoracic Push T7-T12 Right Trochanteric Hemi Circle
6C 		**Lyon thoracic** **With thoracic drive** **Without axillary balance support**	Left Lumbar Push T12-L4 Right Thoracic Drive T6-T12 Left thoracic Drive T4-T8

4. Long term follow up results.

4.1. Main results

We bring forward the results of 1228 complete treatments checked 2 years after the weaning of the brace. [2][3][4][7]

The most frequent curves are Lenke's 3 and 4 : 35%
The Lenke curves 5 : 30%.
The Lenke curves 1 and 2 thoraco-lumbar : 25%.
The Lenke curves 1 et 2 thoracic : 10%.

During the treatment of a scoliosis the height growth is in average of 11 cm. The weight taken is usually around 5 kgs. The vital capacity gets 10% better during the treatment.

Figure 7. Angular stabilization

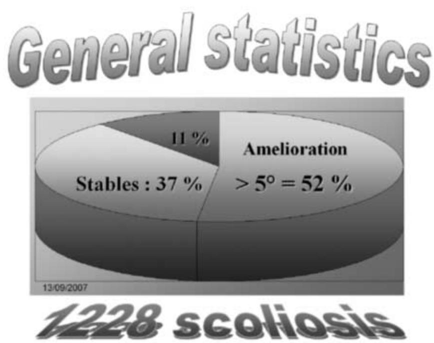


Figure 8. Effectiveness of Lyon Brace

11% of the curves got worse by more than 5°according to the initial curves, that is to say an Effectivity Index of 0.89. (see Figures 7 & 8)

Those global results can be modulated according to the localization of the curves:
- At the thoracic level the Effectivity Index: 0,8
- At the thoraco-lumbar level: Effectivity Index: O,88
- At the lumbar level : Effectivity Index : 0.97

The rib hump is reduced by 50% on average with, as for the curve, a better moulding for the lumbar curves. (see Figure 9)

Figure 9. Aurélia 14 years at the beginning of the treatment – rib hump 30mm – Cobb T11-L4 35°
Last follow up at 28 years : 12 years after weaning – rib hump 10 mm – Cobb 23°

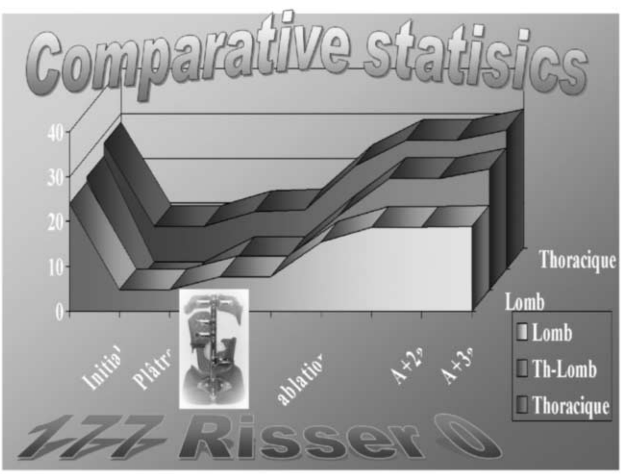


Figure 10. Mean angular results when Lyon brace begins before Risser 0

A group of 117 patients whose treatment started when the Risser sign was 0, was isolated.
The global progressive angular curve can be superimposed on the statistic general curve. The Effectivity Index is 0,74. (see Figure 10)

4.2. The failures.

We will consider as real failures the curves which have been operated or which justify a surgical indication.

2% concerning scoliosis with an initial curve below 45°

4% concerning scoliosis with a treatment which started with a Risser 0.
22% concerning scoliosis with an initial angle above 45°

5. Brace evaluation and critic

The patient is assessed every 6 months, through treatment period. The assessment includes the following:

- Size, weight, vital capacity thanks to the spirometer.
- Classical clinical check up used for scoliosis without any orthesis.
- The radiography of the spine in standing full frontal position is realized without any brace 6 months after the start of the orthesis.

The precise tightening of the shell is indicated during the control and so is the wearing of the orthesis.

The physiotherapy is adapted according to the progression of the clinical check-up.

Conclusion

Almost sixty years after the beginning of the Lyon Brace management, we can confirm its effectiveness.

Progressively, we specified the indications related to the Lyon Brace and we managed to make the all treatment ambulatory even for the realization of the plastered brace.

Nowadays, the electronic moulding enables a precise realization according to Lenke's classification.

The Lyon Brace Management seems to give the best chances to the child and the success seems guaranteed for the medical team

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Treatment of Early Adolescent Idiopathic Scoliosis Using the SpineCor System

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Abstract .The purpose of this prospective observational study was to evaluate the effectiveness of the Dynamic SpineCor System for adolescent idiopathic scoliosis in accordance with the standardized outcome criteria proposed by the Scoliosis Research Society Committee on Bracing and Nonoperative Management. The SpineCor System is the first and only truly dynamic brace, which provides a progressive correction of Idiopathic Scoliosis from 15º Cobb angle and above. The new therapeutic approach is based on a new concept upon the etiology and pathogenesis of idiopathic scoliosis; a pathology of the neuro-musculoskeletal system in growth and maturation. This prospective observational study was carried out on a group of 639 patients (92.3% females) having idiopathic scoliosis treated with the SpineCor brace.

Five hundred and eighty three patients met the criteria for inclusion, and 234 patients were still actively being treated. Overall, 349 patients have a definitive outcome. All girls were premenarchal or less than 1 year postmenarchal. Assessment of brace effectiveness included (1) percentage of patients who have 5 degrees or less curve progression, and percentage of patients who have 6 degrees or more progression; (2) percentage of patients who have been recommended/undergone surgery before skeletal maturity; (3) percentage of patients with curves exceeding 45 degrees at maturity (end of treatment); and (4) Two-year follow-up beyond maturity to determine the percentage of patients who subsequently underwent surgery. Successful treatment (correction, >5 degrees, or stabilization, ±5 degrees) was achieved in 259 (74.2%) of the 349 patients from the time of the fitting of the SpineCor brace to the point in which it was discontinued (or at the time of the surgery). Fifty one immature patients (14.6%) required surgical fusion while receiving treatment. Eight mature patients out of 298 (2.7%) required surgery within 2 years of follow-up beyond skeletal maturity. The conclusion drawn from these findings is that the SpineCor brace is effective for the treatment of adolescent idiopathic scoliosis. Moreover, positive outcomes are maintained after 2 years because 151 (93.2%) of 162 patients stabilized or corrected their end of bracing Cobb angle up to 2 years after bracing.

Key Words: adolescent idiopathic scoliosis, conservative treatment effectiveness, SpineCor system, standardized outcome criteria

Concept

The new therapeutic approach is based on a new concept upon the etiology and pathogenesis of idiopathic scoliosis; a pathology of the neuro-musculoskeletal system in growth and maturation.

In order to obtain an accurate diagnosis, that would specify a particular class and subclass for the patient, the evaluation combines a clinical exam, radiological and postural evaluation.

A specific corrective movement is performed, and the brace is applied according to the SpineCor Assistant Software instructions. The moderate tension in the elastic bands allows the repetition and amplification of the corrective movements as the child undertakes everyday activities. This results in a progressive curve reduction. To obtain a neuro-muscular integration of the new strategy of movement, the minimum duration of treatment is 24 months. Because of the progressive changes, absence of external support during the treatment and intact muscles, there is no loss of correction after the brace discontinuation.

Physical therapy is not a necessity in the SpineCor program. However, when the patient is willing to undergo a physio program or a faster consolidation of the curve is desired, the specific SpineCor physiotherapy program is considered. For the patients at the beginning of the treatment, the physio is carried out with the brace on; for the patients in the weaning period the exercises are done without the brace, to reinforce the muscles responsible for each corrective movement; which are specific for each type of curve.

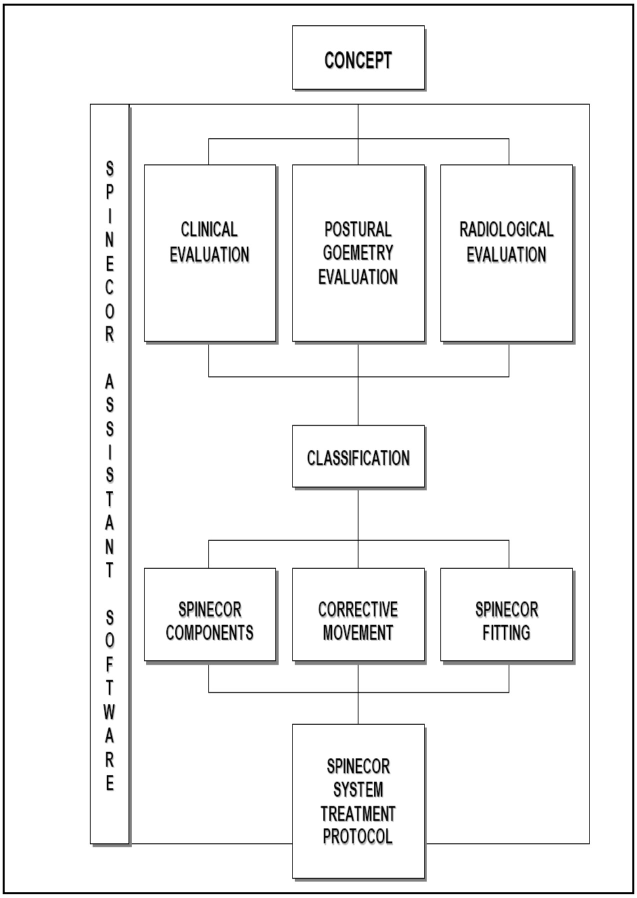
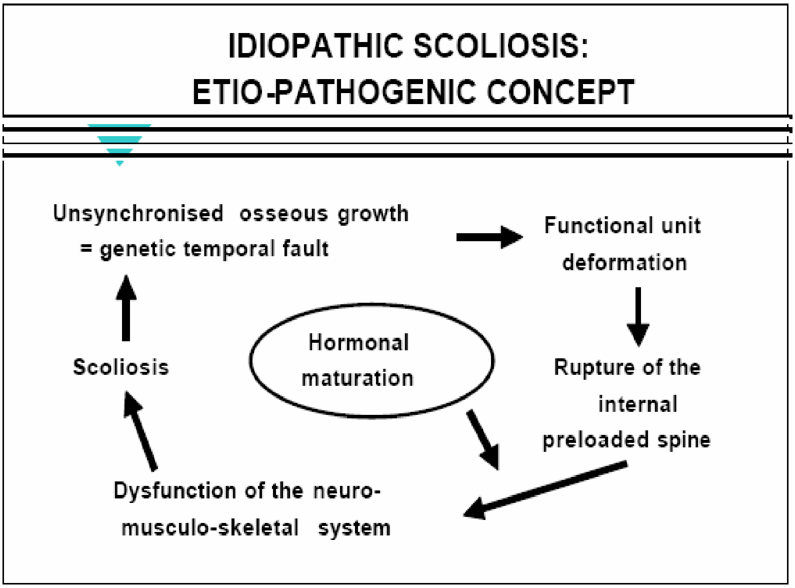


Figure 1. The SpineCor system approach



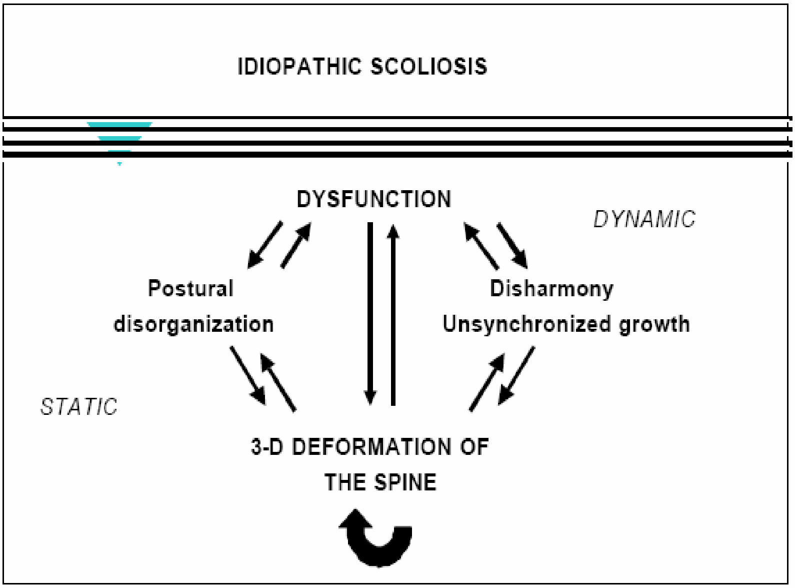


Figure 2. Ethiopatogenic hypothesis

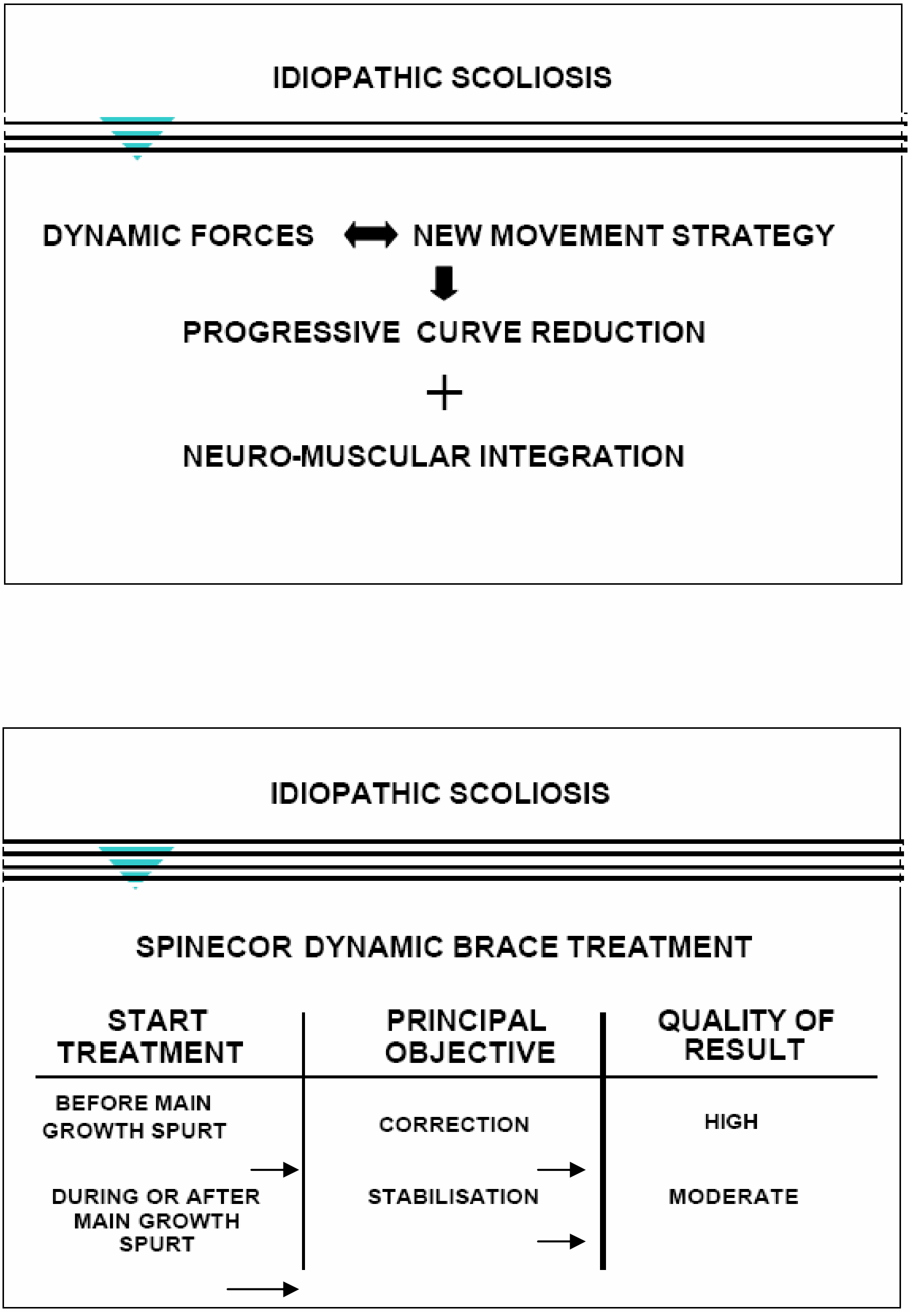


Figure 3. Therapeutic approach and treatment strategy

Radiological classification

The conventional classification of idiopathic scoliosis is based on a radiological evaluation in the P/A view and different types are identified according to the position of the apex without any consideration of the sagittal view. This classification provides only partial information even though scoliosis is known as a three-dimensional deformation of the spine associated with postural disorganization. When comparing x-rays among patients classified as the same, several differences in the morphological aspect of the curvature and other characteristics may be noted. Clinically, the differences in posture for these patients are obvious enough to reconsider if they are indeed of the same type of scoliosis. This has lead to the development of subclasses of the conventional classification of scoliosis patients. A classification that reflects the three-dimensional deformation of the spine and the associated postural disorganization is therefore essential. Observation of specific parameters, by combining frontal and sagittal x-rays, in order to get the maximum 3D information is involved.

- Tilt / rotation / version for each vertebra
- Tilt / rotation / version for the shoulder girdle / thorax / pelvic girdle
- P/A and lateral shift
- Modifications in the sagittal plane of the thoracic, thoracolumbar and lumbar segments
- Anteversion / retroversion / antepulsion / retropulsion

Indications

The SpineCor System was designed for the treatment of Idiopathic Scoliosis only (from 15º and above). Its efficacy for treating neuromuscular, neurological or other types of scoliosis is unknown and generally non Idiopathic Scoliosis is contraindicated.

SpineCor Components

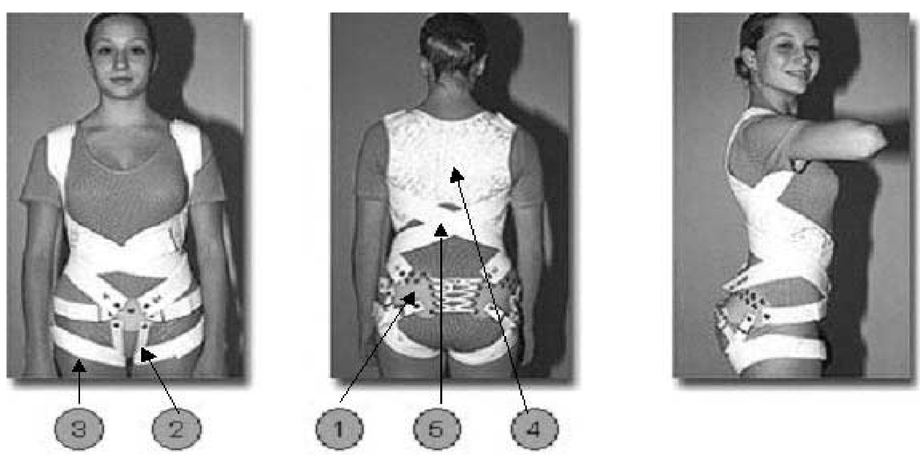


Figure 4.

The SpineCor Dynamic Corrective Brace is made up of two sections:

- The first section consists of the pelvic base (1), the crotch bands (2) and the thigh bands (3). Its role is to act as an anchoring point and support for the actions applied to the patient's trunk by the corrective elastic bands.
- The second section consists of the bolero (4) and the corrective elastic bands (5). This is the part designed to make the correction of the scoliosis curve. The fitting of the corrective bands is specific for each patient and depends on the type of curve.

SpineCorTreatment

- The SpineCor® brace is worn for 20 hours per day. The 4-hour out of the brace period should be taken in two or more intervals during the least active part of the day. The brace must be worn while sleeping.
- The length of treatment will depend on the severity of the curve, age at start of treatment and its evolution, but it is always a minimum of 24 months for adolescent scoliosis. Juvenile cases require much longer treatment period.
- To optimise the dynamic effect of the brace, patients are encouraged to perform any type of sport wearing the brace (except for swimming).
- Patients may be suggested to undergo a specific SpineCor Physiotherapy Program in order to complement the action of the SpineCor brace.
- A shoe lift may be also prescribed at the time of brace supply. All shoe lifts should be sole and heel, not just heel, and must be worn during all activities

Prognosis

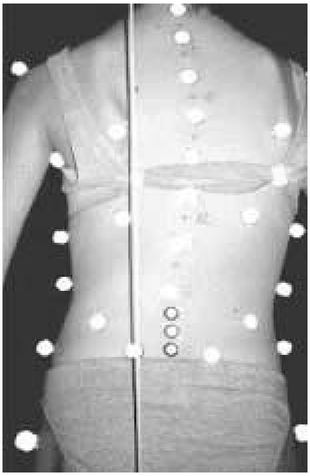
To really change the natural progression of idiopathic scoliosis, it is essential to reduce the curvature enough to eliminate the negative impacts of abnormal biomechanics and growth.

Therefore it is possible to achieve a complete or almost complete correction of moderate curves, if the treatment is started before the main growth spurt (before Risser 1 and menarche). In curves over 30° of Cobb angle, or when the treatment started during or after the main growth spurt, the goal is a stabilization of the deformity. The therapeutic success is possible in more than 80 %(stabilization or correction of the curve) of cases.

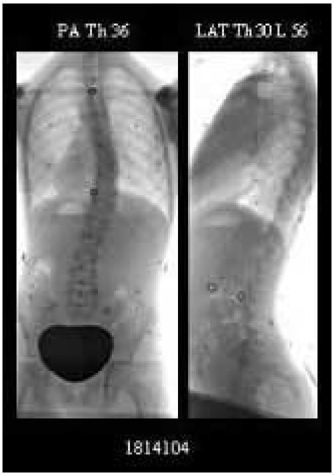
Case study

Before treatment

This case study follows the treatment of an adolescent female patient with idiopathic scoliosis whose initial presentation at 9.5 years and Risser 0 was with a 36º right thoracic curve.



Patient - 9 ½ years old - 36º
Clinical Aspect before treatment



Patient - 9 ½ years old - 36º
Radiological aspect before treatment

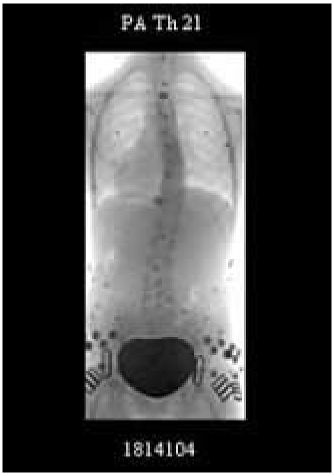
After evaluation of the patient's radiological, clinical and postural data, she was classified as a Right Thoracic Type 1 according to the SpineCor classification.

Each SpineCor classification has a specific corrective movement strategy for progressive curve reduction. In the case of Right Thoracic Type I, the corrective movement is counter clockwise rotation of the thorax and clockwise rotation of the shoulder girdle.

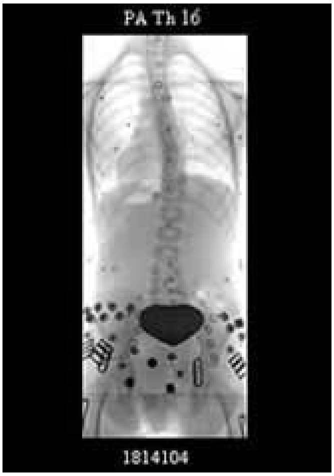
Corrective Movement
Right Thoracic Type 1

Wearing SpineCor Brace Set-up
for Right Thoracic Type 1

Treatment review

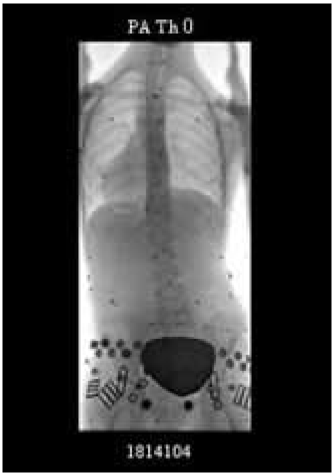


Day of Brace Fitting - 21º



One Month in Brace - 16º

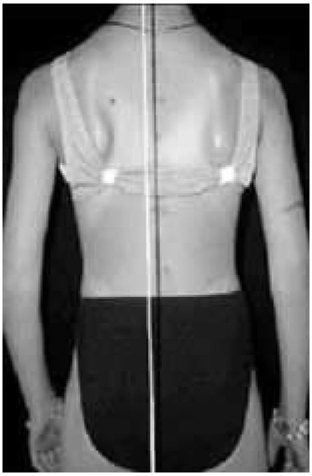
6 Months in Brace - 4º



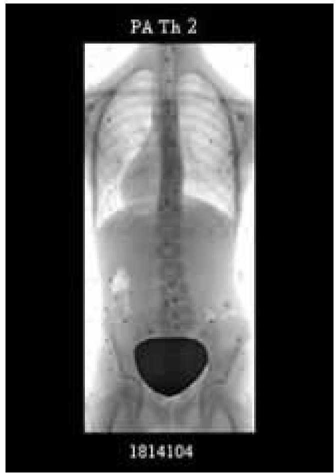
13 Months in Brace - 0º

After treatment

Patient's postural correction and Cobb angle reduction have been maintained three years post bracing.



Clinical aspect after treatment



15 Months of Brace Treatment - 2º
Radiological aspect after treatment

Material and Methods

The studied population:

This prospective observational study was carried out on a group of 639 patients (92.3% females) having idiopathic scoliosis treated with the SpineCor brace.

Radiographic analysis

The initial pre-therapeutic radiograph uses a digital technique where the irradiation is half as much as that of a standard radiographs [11]. The initial evaluation included a postero-anterior and lateral X-ray without brace within a maximum of one month before the brace was fitted. The following X-ray controls were always administered with the SpineCor brace and shoe lift if prescribed following the same schedule: the first control on the day of the fitting and at 4-6 weeks, then every 5 months until weaning. The lateral X-rays were obtained once a year. At the end of the treatment, the controls were continued at 6 months, one year and once every year. These evaluations were performed without brace.

Criteria

Inclusion criteria were as follows:

- Idiopathic scoliosis diagnosis and radiological confirmation of absence of significant pathological malformation of the spine

- Risser 0, 1, 2 or 3
- Initial Cobb angle equal to or above 15°
- Initial Cobb angle equal to or less than 40°
- No prior treatment for scoliosis

Exclusion criteria were as follows:

- Presence of a congenital malformation of the spine, spina bifida aperta or spondylolisthesis
- Neuromuscular scoliosis
- Postural scoliosis

Skeletal maturity is considered when Risser 4 or more is reached. The United States grading system [14] for Risser sign was used in this study. Respecting the criteria mentioned above, we needed to exclude some patients from the actual study. **583** patients respected the inclusion criteria, 234 (40.1%) did not completed the treatment by brace at the time of the analysis and 51 immature patients required surgical fusion while receiving treatment. Lead up to 298 patients who had reached skeletal maturity at the end of bracing. Out of this cohort of patients, 162 patients had 2 years and 69 patients had 5 years follow-up post-bracing.

Description of the bracing system and treatment protocol

The Dynamic SpineCor brace, developed in 1992-93, use a specific Corrective Movement© depending of the type of the curve [2]. Curve classification was based on the classification presented by Ponseti and Friedman [13]. The specific Corrective Movement© is performed, and the brace is applied according to the SpineCor Assistant Software instructions. In order to be effective and to obtain a neuromuscular integration of the movement through active biofeedback, the brace must be worn 20 hours a day for a minimum of 24 months. Generally, the brace is stopped at skeletal maturity (at least Risser 4) or after 2 years of regular menstruation.

Statistical analysis

Success was defined as either an improvement of more than 5° or stabilization of ± 5° of the scoliosis curvature. An aggravation of the spinal curvature of more than 5° was defined as worsening. The outcome data were analyzed in four ways as suggested by the SRS Committee on Bracing and Nonoperative Management [10].

Results

349 patients had a definite outcome, 51(14.6 %) required surgical fusion while receiving treatment and 298 finished the treatment by brace.

From the 298 patients, 279 girls and 19 males, had reached skeletal maturity at the end of bracing. The average age at initiation of brace (n=298) was 12.8 ±1.9 years (range 6.6-16.5). Patients wore the brace an average of 2.4 ± 1 year with an average age at the time of brace discontinuation of 15.4 years. 162 patients had 2 years and 69 patients had 5 years follow-up post-bracing. The evolution of the mean Cobb angle of these patients is shown in Table 1.

Table 1. Average Cobb angles for all structural curves at various points during and after treatment by the SpineCor brace

SPINECOR BRACE					
	Begining of treatment*	In brace*	End of treatment*	2 years post-bracing†	5 years post-bracing◊
Mean Cobb angle (°)	26.3 ± 6.8	19.2 ± 11.1	22.9 ± 11.5	21.4 ± 12.0	17.9 ± 10.4
Number of patients (n)	298	298	298	162	69

*298 patients who had completed the treatment by brace at skeletal maturity
†162 patients who had 2 years follow-up after the end of bracing
◊69 patients who had 5 years follow-up after the end of bracing

Assessment of brace effectiveness includes all of the following:

1. *Percentage of patients who have 5º or less curve progression and the percentage of patients who have 6º or more progression at skeletal maturity*

137 patients (46.0%) out of 298 stabilized their Cobb angle (±5º) at skeletal maturity at the end of bracing, 122 patients (40.9%) corrected their initial Cobb angle and 39 patients (13.1%) had 6º or more progression of their initial Cobb angle. Successful treatment, as defined above, was achieved in 86.9% of SpineCor brace patients.

With post-brace treatment follow-up observation (Table 2), the treatment success rate at 2 years was 93.2% (n=162), comparing the end of bracing Cobb angle to the one at 2 years post-bracing. 133 patients out of 162 stabilized their Cobb angle and 18 patients still improved from the time the braces were discontinued up to 2 years follow-up. After 5 years post-bracing, success was achieved in 95.6% (n=69) of the time, comparing the Cobb angle at the end of bracing to the one after 5 years post-bracing.

2. *Percentage of patient who have had surgery recommendation/undergone before skeletal maturity*

51 immature patients (14.6 %) out of 349 who respected the inclusion criteria and who had a definite outcome (298 + 51), required surgical fusion while receiving

treatment. The average curve magnitude at bracing in this particular group was 32.7° ±6.1° (range: 17-41°). General indication for fusion in all patients was progression of primary curve of more than 60° in thoracic region and 45° in thoracolumbar and lumbar region.

3. *Percentage of patients who progressed beyond 45° at maturity*

Seven patients out of the 298 patients who had a definite outcome (2.3 %) had documented progression of curve beyond 45° at maturity. Surgery was required for 3 of these patients.

4. *2-years follow-up beyond maturity to determine the percentage of patients who subsequently undergo surgery*

Eight mature patients out of 298 (2.7%) require surgery after weaning of the brace.

5. *Curve magnitude*

To study the effect of curve magnitude on outcome (see Table 2)

Table 2. Treatment success in relation to scoliosis curvature

Success of treatment with brace	n	Percentage of success (%)
Beginning – End of treatment*	298	86.9
End of treatment- 2 years follow-up†	162	93.2
End of treatment- 5 years follow-up◊	69	95.65

*298 patients who had completed the treatment by brace at skeletal maturity

†162 patients who had 2 years follow-up after the end of bracing

◊69 patients who had 5 years follow-up after the end of bracing

Discussion

The primary objective of this study was to perform an evaluation of the long-term outcome results of the prospective cohort of patients who completed the treatment with the SpineCor brace. Moreover, we wanted to compare the effectiveness of the SpineCor brace to rigid braces, particularly; Boston brace [3,4], Wilmington brace [5], Milwaukee brace [6], Charleston brace [7,14] and the Rosenberger brace [8].

To assess the effectiveness of a nonsurgical treatment of scoliosis, it is important to evaluate efficacy of bracing in patients who are at greatest risk of progression. All types of curves were treated with the SpineCor brace as well as both genders.

A previous study was published in 2007 in Journal of Pediatric Orthopaedics [1] on the first 493 patients from the same data bank used for this present study. The actual study expands upon this by taking in consideration standardized outcome criteria published by the SRS Committee in 2005 [10]. The preliminary study in 2007 revealed that on the 47 patients who had a minimum post-treatment follow-up of 2 years, 10.7% continued the correction of their initial Cobb angle even after the weaning of the brace, 85% stabilized their Cobb angle and only 4.3% worsened by more than 5º(that represents a total of 95.7% of success). The recent results go in a similar direction. Indeed, this study reveals that the orthopedic treatment was a success for 93.2 % of the 162 patients having a minimal post-bracing follow-up of 2 years, comparing the end of bracing Cobb angle to the one at 2 years post-bracing. Of these, 18 patients (11.1%) corrected their Cobb angle and 133 patients (82.1%) had stabilization. As reported by Montgomery and collaborators [15], a follow-up of 2 years is sufficient to foresee progression after weaning from the brace. The results are even more encouraging if we look in the long turn. There are 69 patients who now have 5 years post-treatment follow-up. Permanent correction was achieved in 28.9 % of the cases (20 patients), stabilization in 66.6% (46 patients) and only 4.4% (3 patients) progression of the curve, comparing the end of bracing Cobb angle to the one at 5 years post-bracing. Finally, success was achieved for 95.6% of the 69 patients having a post-bracing follow-up of 5 years, comparing the end of bracing Cobb angle to the one at 5 years post-bracing. These data suggest it is possible to maintain in long term, the correction or stabilization obtained during the treatment by brace.

Although earlier report indicated that Milwaukee brace [16] could afford some lasting reduction in the degree of spinal curvature, subsequent studies with longer follow-up demonstrated that, following the cessation of brace treatment, curves that had demonstrated some correction at the end of bracing with classical rigid braces tended to continually increased toward the pre-treatment magnitude [3,5,6,17]. In the study of Noonan and colleagues [6], 63% of the 88 patients wearing the Milwaukee brace were classified as a failure. They defined 3 types of failure: 1) increased 5º or more from initial bracing to the time that the patient stop wearing the brace, 2) underwent a surgery or had a structural curve of more than 50º at the time of the follow-up and 3) major curve progressed 10º or more from initial bracing to time to follow-up. Noonan et al shown that 27 patients (31%) had an arthrodesis; of these 18 patients (67%) had curve progression while they wore the brace, and 9 (33%) had progression of the curve after a trial of intentional weaning. We notice this lost of correction over-time with other braces such as Wilmington and Boston braces. In the study of Gabos et al [5], 22% out of 55 patients demonstrated an increased in the curve of ≥5º between the end of bracing with the Wilmington brace and the time of final follow-up (mean of 14.6 years after the completion of treatment). Besides, 13% demonstrated an increase in the curve of ≥5º between the end of bracing and the time of final follow-up that resulted in a curve that was ≥5º greater than the deformity measured at the time of the initial treatment. Katz and Durrani [3] conducted a retrospective study on 51 patients with AIS treated with the Boston brace for curve ranging between 36º and 45º. At the time of brace discontinuation, 31 patients (61%) were judged treatment success. With follow-up observation, an additional 8 patients progressed beyond 5º, and a total of 16 patients (31%) required surgical correction. Olafsson et al [4] studied a population of AIS patients wearing the Boston but with smaller curves (22 to 44º curve magnitude). They used two types of Boston braces, first one with 0º lumbar profiles and the other one with 15º lumbar profile. 50 patients completed treatment with the 0º lumbar profile brace. For this cohort of patients, mean Cobb angle at treatment start was 32 ± 6º, after bracing was 12.1 ± 7.6º, after weaning 25.4 ± 11.3° and at follow-up 29 ± 12º. Regarding the 60 patients still in treatment wearing the Boston brace with 15º lumbar profile, in one third of the case, either it remained unchanged or it increased with bracing. However, our results show that it is possible to obtain a correction of the pretreatment Cobb angle and this correction can be maintained 2 years, and even 5 years, after the end of the treatment by SpineCor brace. Actually, for the cohort of patients with 5 years post-bracing follow-up (69 patients), comparing the Cobb angle at the end of bracing to the one after 5 years follow-up, 20 patients (28.9%) still corrected their curvature, 46 patients stabilized their Cobb angle and their was only 4.4% of worsening (3 patients). With the Dynamic SpineCor brace there is no component of collapse after the end of bracing, as noted for rigid braces [5,6,17] which, by not supporting an effective musculature, may encourage the progressive collapse of the curves [2].

The purpose of any conservative treatment for AIS is to alter the natural progression of the spinal deformity. It has been shown that patient with Risser 0 or 1 have 68% incidence of progression [17]. So if we compare our results of brace treatment with the natural history of AIS, we can assume that SpineCor is efficient to alter the natural history of this pathology. Effectively, the overall success rate of 86.9% with the brace indicates that the SpineCor brace does significantly modify the predicted natural history of the disorder. If we compare our results to the ones found in the literatures, we can appreciate the positive outcome of SpineCor patients. The first published study on the clinical effectiveness of the Rosenberger brace [8] demonstrated an overall failure rate similar to untreated rates from published natural history studies. 61% out of 71 patients worsened their Cobb angle. 40 curves (56%) progressed more than 5º, 22 patients (31%) either had the surgery or met surgical criteria, and 10 patients (14%) who did not have surgery progressed greater than 10º. Trivedi and Thomson [7] had an overall success rate of 60% with the Charleston brace. On the other hand, Gepstein et al [14] achieved 80% of success (population of 85 patients) with the Charleston brace. In this study, surgery was performed in 11.8% of patients. Trivedi and Thomson only included girls in their study creating an element of selection bias, since boy seems to have more severe curves then girls [3,7]. Surprisingly, they still got poorest result even if they excluded boys compared to the Gepstein and coworkers study[13].

In summary, the SpineCor Brace is effective for the treatment of AIS. Moreover, the positive outcome appears to be maintained in the long turn. This particular finding about SpineCor brace, appears to makes him very different from the classical rigid braces in which any apparent correction obtain during treatment can be expected to be lost over time, that is after cessation of bracing [5,17]. However, futures studies that will support this finding are necessary. Upcoming studies respecting the same standardized **outcome** criteria for AIS brace studies as used in this actual study will allow valid and reliable comparison between the SpineCor brace and any others rigid braces.

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The Conservative Scoliosis Treatment
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The SPoRT (Symmetric, Patient-oriented, Rigid, Three-dimensional, active) concept for scoliosis bracing: principles and results

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Abstract. The biomechanical action of an orthesis for the conservative treatment of AIS has two goals: correction and stabilization. These goals have been pursued through very well established principles of correction, developed over the years, divided in terms of efficacy (the correct positioning of pushes, as well as through escape ways and proper drivers of the forces and stops) and acceptability (compliance, perfect body design, maximal freedom in the ADL). To achieve all these goals, the Sforzesco brace has been developed through progressive changes and verification. Finally, we discovered we had something new, and summarised it in the SPoRT acronym: Symmetric, Patient-oriented, Rigid, Three-dimensional, active. The SPoRT concept always requires a customised construction of the brace according to the patient's individual requirements. It's possible to apply CAD-CAM technologies, which usually allow us to obtain the best results in this case, but without using pre-built forms stored in databases, as is usually done. Once done, a final test must be made on the patient so as to change the first theoretical project and adapt it in the best possible way, depending on the real interaction between the body and the brace. The results that are today available on the SPoRT concept relate to the Sforzesco brace and necessarily are short-term, because the first treated patients are now reaching the third-year follow-up examination and haven't yet completed their treatments. According to first studies we can state that: tte Sforzesco brace is more effective than the Lyon brace after six months of treatment; the Sforzesco brace is equally effective as Risser Plast brace.

Keywords. adolescent idiopathic scoliosis; brace; orthosis.

1. Theoretical basis of the SPoRT concept

The biomechanical background for scoliosis correction is the "vicious cycle" concept proposed by Stokes. According to Heuter-Volkmann law saying that an increase of compressive loads on a fertile epiphysis reduces growth, while on the contrary an increase of distractive force accelerates growth, it will happen that, in a scoliotic curve, loads asymmetry will cause a growth reduction on the concavity side of vertebral plate and an increase on the convexity side. Braces should reverse it, to allow a proper growth in the concave side of the curve.

The biomechanical action of an orthesis for the conservative treatment of AIS has two goals:

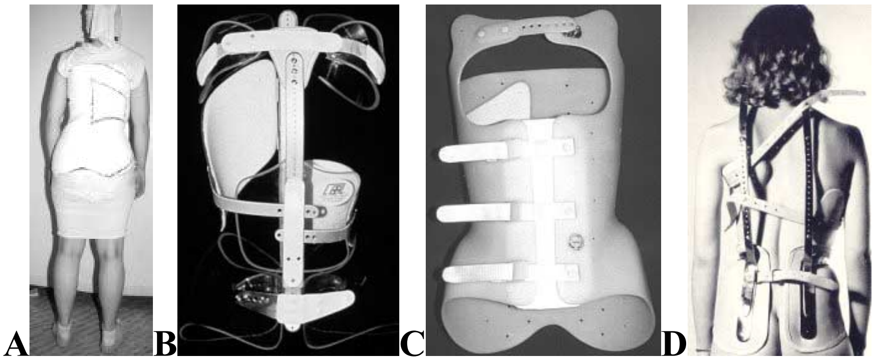

Figure 1. From a practical point of view, to develop the Sforzesco brace we started on the basis of these braces: A: Risser Plaster; B: Lyon brace; C: Sibilla brace; D: Milwaukee brace.

- the correction is obtained by external forces that, in a deformed spine, could restore the natural geometric configuration.
- the stabilization is obtained by the reduction of the forces acting on the spine and by a redistribution of residual forces and thereby avoiding their concentration in reduced areas.

The restoration of the natural configuration is always obtained, despite the differences in methods, by applying traction, lateral deflection, and derotation forces through the sagittal, coronal and transverse plane of the spine

The SPoRT concept[1, 2, 3, 4] was born while we were looking for a new brace, not for a new method of correcting scoliosis. We were searching for a way to avoid casting for our worst patients, because of the significant costs involved both at an individual (side effects including cast syndrome, skin problems, great psychological impact, no shower for months, etc.) and a social (inpatient repeated treatment) level. For that reason, we developed the new Sforzesco brace and, while applying and developing it, we ended up with a new, highly efficacious concept of bracing called SPoRT (Symmetric, Patient-oriented, Rigid, Three-dimensional, active).

From a practical point of view, we started on the basis of the following braces:

- Risser cast[5, 6, 7] (Figure 1A): Gives the highest corrections through its localised pushes and rigidity, partly due to the material and partly to the fact that it is a one-piece structure. Most of all, we tried to maintain rigidity, using for the brace only two large pieces and localizing pushes through fully modifiable inserts;
- Lyon brace[7, 8] (Figure 1B): We used to think of this brace as the most effective one for scoliosis treatment, fully based on a three-point concept, and with localised pushes on humps and curves. We maintained the material of this brace, as well as its vertical aluminium bar;
- Sibilla brace [7, 9] (Figure 1C): The highest value of this brace was in the modelling effect obtained through its symmetrical construction, which accompanies the whole body towards corrections. In the SPoRT concept this brace is maintained as a less rigid alternative to the Sforzesco one, even if modified according to new understanding and insight;

- Milwaukee brace [10, 11] (Figure 1D): This brace was not in our minds at the beginning, but we verified that the SPoRT concept reaches correction through an elongation obtained by pushing from behind but not with a traction. This allows us to maintain/restore the physiological curves while correcting scoliosis (3-D action).

From a theoretical perspective, we started this search with very well established principles of correction that we had developed over the years, such principles being divided in terms of efficacy and acceptability.

1.1. The efficacy principles of correction

They include:

- The active brace principle: The Milwaukee brace[10, 11] has historically been considered an active brace because it required the patient to escape vertically, while all other braces based on pushes were considered passive. This is theoretically correct, but a passive brace becomes more and more active as the patient is allowed (encouraged) to move freely, thus greatly increasing through his/her movements the corrective pushes against the brace (each time you try to move "incorrectly" you receive a corrective push; moreover, if the brace can serve as a neurological resetter through esteroception and proprioception, this action is greatly increased by movements)[12]. To make a brace active, it is necessary to ensure complete freedom of movement to the limbs, to have a perfect styling by the orthotist, to allow and even drive patients to perform physical activities at school and outside, and to train them through specific exercises in braced condition[12];
- Mechanical efficacy: This is achieved through the correct positioning of pushes, as well as through escape ways and proper drivers of the forces and stops, as described in the section on practical application;
- Versatility and adaptability: A perfect brace can last a maximum of two or three months due to the continuous changes in the growing child, but clearly it is not possible to change a brace with such a rhythm. This means the possibility of adapting its action through inserts in order to refine its mechanical action as continuously as desired. Moreover, pushes must be adapted when checking the brace at first wearing, because the initial project is not always confirmed by the patient's reaction and some rigid areas can require specific increases of pushes. Finally, in most important curvatures we sometimes need a couple of months before reaching the best possible correction, and many times it is necessary to adapt the brace. We think this precludes an orthosis based only on the external envelope for its action;
- Teamwork: This is seemingly only a secondary element because only very well trained CPOs, MDs, PTs and other healthcare and education professionals can achieve the best results, which are greatly increased by teamwork and thorough discussions and braces controls working together;
- Compliance: Bracing is useless without compliance. In turn, compliance is certainly due to the patient and his/her family, but also to all the previous principles and to the following acceptability principles.

1.2. The acceptability principles of correction

These principles relate to compliance as well as a human approach to the patient. They include:

- Perfect body design and minimal visibility: Patients want correction and an invisible brace. Therefore, to make the brace visible you must carefully justify it and be sure that it's really necessary. In our experience, this can be minimised and while checking the brace for the first time. This is our chief concern, so the patient understands that we are on his/her side. Afterwards, we can require everything necessary.
- Maximal freedom in the ADL (Activities of Daily Life): This is part of the active principle (movements), but it also means comfort. It must be possible to walk, run, sit, carry, wash, exercise and so on, freely or with the smallest degree of limitation possible. Any unavoidable limitation must be explained and motivated to the patient. SPoRT concept braces allow total freedom of movement for the limbs while requiring trunk movements only inside the brace, so as to be corrective;
- Assumption of responsibility: This way you run risks with adolescents, but it's possible to achieve much better results. That means, for example, freedom in the strength of closure and/or in taking out the brace through an anterior opening, and so on;
- Cognitive-behavioural approach by the entire professional team: "Explain and you will obtain (useful behaviours and increased compliance)." This is true in adults, but it's even truer in adolescents.

2. SPoRT brace concept

To achieve all these goals, the Sforzesco brace has been developed through progressive changes and verification, and consequently the Sibilla brace has been modified (and the Risser cast and Lyon braces abandoned) in order to achieve the SPoRT concept of correction. The starting point was rigidity and an almost complete exoskeleton that is totally adherent and symmetrical according to the theoretical shape that the patient's body would have had without scoliosis. In practice, this is accomplished by reducing the space where there are pathological prominences and allowing room where there are undue depressions. This way, it is the deformity that creates pushes and spaces within this external envelope. The fact that this brace is a complete symmetrical wrap has added another key point since the beginning, which we called humility: there would have been pushes and spaces even if we had not considered this important in theory. In this way, we made ourselves ready to learn from the brace and gradually understood the concept of "drivers," as is explained in the practical section. Afterwards, pushes are inserted. These are considered in a fully three-dimensional manner. Because three-dimensionality is too complex to be easily understood [13, 14], we split the different 3-D actions. However, since the beginning we have been very careful about each plan and curve, and in regard to total spinal morphology without conflict. Finally, we discovered we had something new, and summarised it in the SPoRT acronym, whose meaning is:

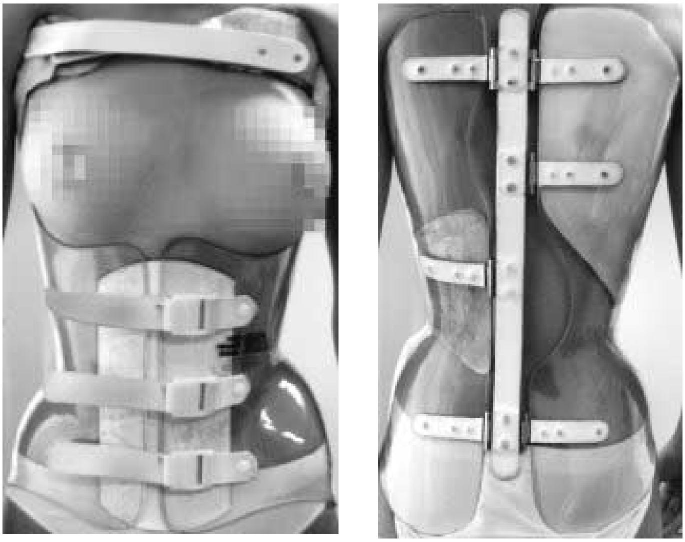

Figure 2. The Sforzesco brace has its own design, generally appreciated by patients, in particular if they already used another brace.

- Symmetric: On the outside the brace is almost perfectly symmetrical, according to the starting hypothesis we have just explained. This was a good beginning, but it was gradually overcome as we furthered our understanding of the brace action. Nowadays, the external construction is not so symmetrical, even if it is grossly maintained to reduce visibility and preserve as much as possible a theoretically perfect body shape.
- Patient-oriented: This brace is not visible, according to the acceptability principle. What patients care most about is having a brace that will be seen as little as possible, not to have less material on. This is why they would always choose a TLSO instead of a Milwaukee brace[15], even if the first one causes the patient to feel hot during the summer. The Sforzesco brace has its own design (Figure 2), which makes it somewhat fashionable, and this is how patients feel their braces. This is the most important achievement that allows us to increase acceptability, followed by compliance and efficacy;
- Rigid: The chosen material and the fact that the brace is made in two large pieces strongly connected with aluminium allow us to achieve a high rigidity that gives rise to higher pushes than in other braces;
- Three-dimensional: The brace has a three-dimensional action on the spine, and all its features have been developed with this purpose in mind, starting from its symmetrical and sagittal physiological external appearance. This is discussed extensively in the section on practical application.
- Active: This is also a property of the brace, in the sense that the Sforzesco allows total freedom of movement for all four limbs, as well as the complete possibility of normal behavior in activities of daily life, obviously with the exclusion of trunk flexion, bending and rotation (at least from the external

point of view: inside the trunk moves only towards correction, while movements towards the progression of pathology are completely blocked).

3. Practical application of SPoRT concept

The SPoRT concept always requires a customised construction of the brace according to the patient's individual requirements. In the opinion of Sibilla [9, 7], bracing is a meal served according to a "menu à la carte" in which one chooses all the elements needed to achieve the best individual result. It's possible to apply CAD-CAM technologies, which usually allow us to obtain the best results in this case, but without using pre-built forms stored in databases, as is usually done. Orthotists must directly shape the scanned trunk according to the patient's requirements, and the physician can check this first draft before final carving. Once done, a final test must be made on the patient so as to change the first theoretical project and adapt it in the best possible way, depending on the real interaction between the body and the brace. This check is made using eyes and hands because one single change is usually not enough, and because it isn't possible to perform repeated radiographs to verify what has been done.

3.1. Elements of SPoRT braces

The brace is developed in consideration of the following key points:

- Foundation: Like a building, at the base of the brace we need a fix point, which is the pelvis. On one hand, this is a theoretical concept because the pelvis is not a fixed point. On the other hand, proximally applied pushes will always produce counter-pushes on the pelvis, and provided that the brace does not rotate in any 3-D direction on the pelvis, pushes will be correctly applied. If the brace decompensates (i.e., it rotates or it flexes in an antero-posterior or lateral direction), this can be corrected by pushing on the pelvis or by changing pushes on the spine so as to regain a balanced action;
- Construction: The brace must be carefully constructed on the sagittal plane, because once built it will not be possible to truly and effectively change this configuration;
- Pushes: The brace is a somewhat rough instrument. We try to refine it as much as possible, but current research does not allow us to be as precise as we would like. Usually, we develop a project of correction and then check and change it on the patient. These thoughts and our experience have led us to believe that pushes are not points as conceived by others but are areas developed according to curvature characteristics;
- Escapes: These are crucial, and are conceived according to curvature characteristics and desired correction. Therefore, they must be considered three-dimensionally. Braces built according to the SPoRT concept seemingly lack escapes because they finish with drivers so as to allow the most important one -- vertical escape;
- Drivers: These are the areas that control and drive pushes and escapes to obtain the real 3-D action so as to avoid wrong deviations with respect to the desired correction, as well as over-pushes or over-escapes;
- Stops: These are commonly referred to as counter-pushes.

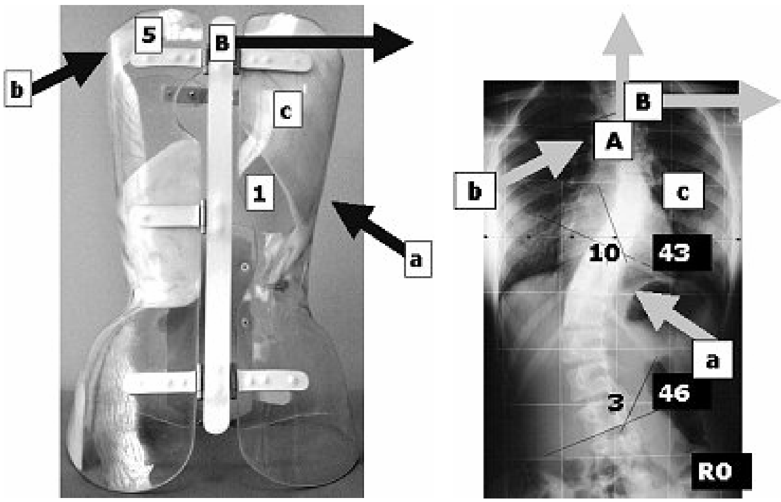

Figure 3. Action of deflection according to SPoRT concept for thoracic scoliosis in the posterior-anterior and radiographic views. Pushes (lower-case letters), escapes (upper-case letters), drivers (numbers) and stops (numbers) are explained in the text. Black letters refer to pushes, drivers and stops on the surface considered, while white letters to controlateral surfaces: e.g. in the lateral view of the brace of next figure the push "a" and the stop "7" are on the right side of the brace (controlateral surface), while all the others are on the left side of it (surface represented).

The construction (sagittal shaping) of the brace almost always changes according to the curve, even if there are individual variations:

- Lumbar scoliosis: The construction must be in lordosis, and with this objective we need an antiversion of the pelvis with a retro-positioning of the upper trunk over the apex of lordosis, while the abdomen must also be allowed to escape anteriorly;
- Thoraco-lumbar scoliosis: This must usually be in lordosis, which is due to the tendency of this curve to evolve in junctional kyphosis. In this case, the apex of lordosis must coincide with T12-L1;
- Thoracic scoliosis: This must be almost always in kyphosis, which is achieved through the previously described good construction in lordosis and through an important retro-positioning of the higher trunk so as to use the force of gravity to induce the spine to posteriorly “sit” in the given space while superiorly shaping the brace in an anterior direction.

3.2. Correction of a thoracic scoliosis

Because general brace action according to the SPoRT concept is too complex to be adequately described in these few pages, we will now give a complete example of the means to correct a thoracic scoliosis. The figures have been obtained from an actual case, so they do not always totally coincide with the theoretical description. However, as already stated, theory is always and continuously changed according to individual needs and reactions to the brace.

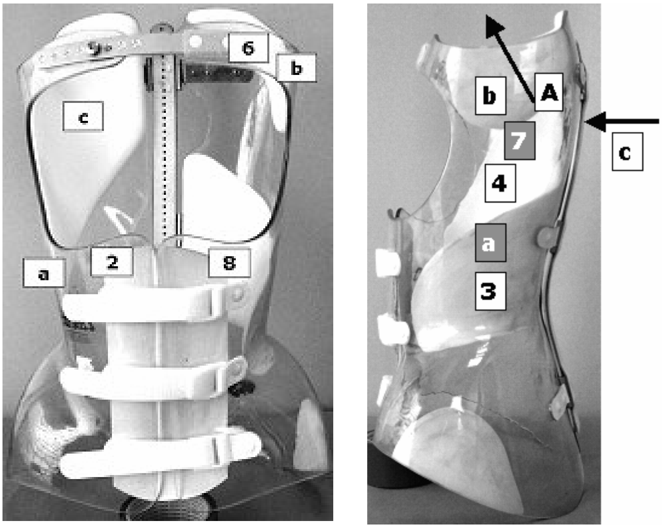

Figure 4. Action of deflection according to SPoRT concept for thoracic scoliosis in the anterior-posterior and lateral views.

Terminology is defined according to a posterior-anterior radiograph. Accordingly, convexity and concavity refer to the considered scoliosis curve, not to trunk protuberances. This means that the convex side posteriorly coincides with posterior rib hump and anteriorly with rib depression, while the concave side coincides with anterior rib hump and posterior depression.

3.2.1. Action of deflection

The mechanisms needed to achieve deflection (Figures 3 and 4) action are:

- Lateral distal convex push (a): This is obtained through brace modelling and a direct pad; to reach the spine using the ribs it is necessary to have posterior (1) and anterior (2) convex drivers, while the counter-push is given by the lumbar lateral stop (3). This push drives the spine to the anterior-superior escape (A) through the concave lateral driver (4), which does not allow a direct lateral shift;
- Lateral proximal concave push (b): This is obtained by maintaining the brace high under the axilla through brace modelling and a direct pad. Again, to avoid rib flexion and apply the push to the spine we need the posterior (5) and anterior (6) superior concave drivers as well as the counter-push of the thoracic lateral stop (7). The spine is driven to the anterior-superior escape (A) and also to the convex-superior escape (B);
- Posterior convex push (c): The main action of this push is derotation, but it also becomes deflexion due to the thoracic lateral stop (7), which allows a straightening (flattening) of the ribs with no lateral space but only medial space; and the anterior superior (6) and inferior (8) concave drivers, which avoid an anterior escape. Again, in terms of deflection the spine is driven to

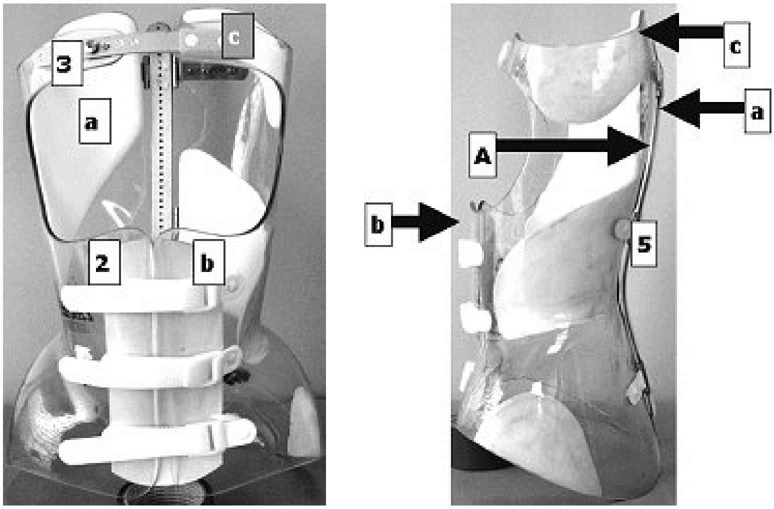

Figure 5. Action of derotation according to SPoRT concept for thoracic scoliosis in the anterior-posterior and lateral views.

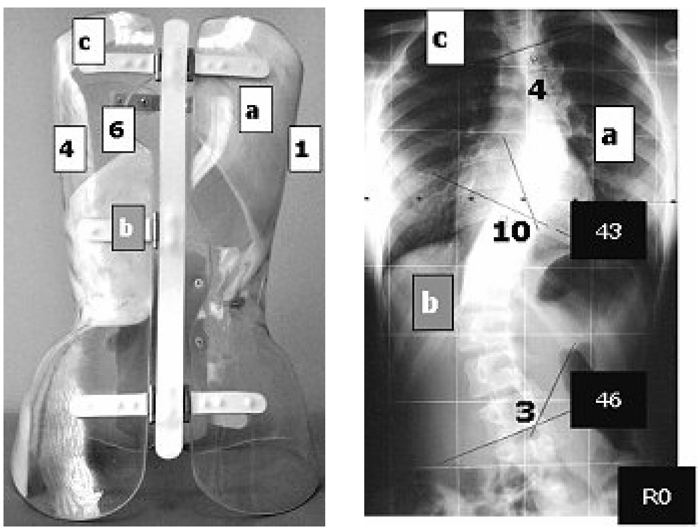

Figure 6. Action of derotation according to SPoRT concept for thoracic scoliosis in the posterior-anterior and radiographic views.

the anterior-superior escape (A) through the concave lateral driver (4), which does not allow a direct lateral shift.

3.2.2. Action of derotation

The mechanisms needed to achieve derotation action are:

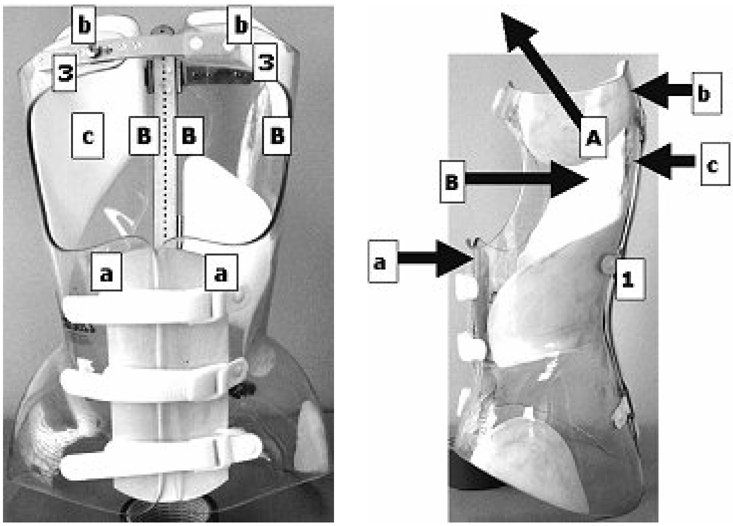

Figure 7. Action of kyphotisation according to SPoRT concept for thoracic scoliosis in the anterior-posterior and lateral views.

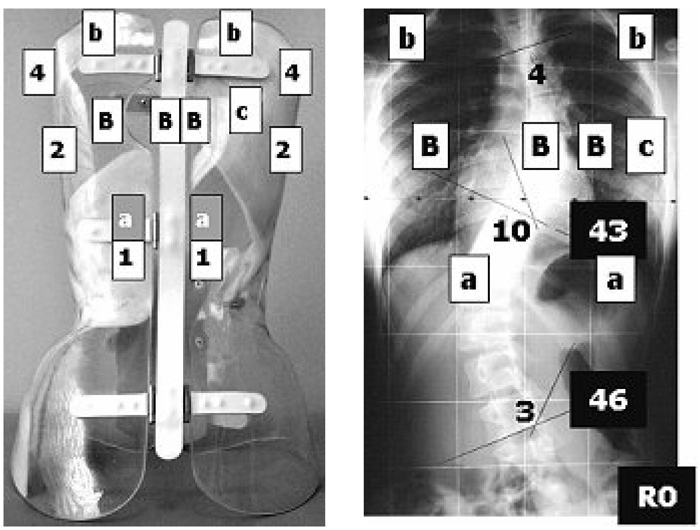

Figure 8. Action of kyphotisation according to SPoRT concept for thoracic scoliosis in the posterior-anterior and radiographic views.

- Posterior convex push (a): This works through the thoracic lateral stop (1) and the posterior (5) and anterior (6) superior concave drivers, which really represent stops so as to avoid an anterior uncontrolled buckling of the spine (Figure 5); Anterior-inferior concave push (b): It joins the posterior convex push in a couple of forces posteriorly transmitted through the concave lateral driver (4). The lumbar posterior stop (5) avoids a posterior buckle of the spine;

- Posterior concave escape (A): This is the only escape for this correction, even if it does not allow over-derotation due to the posterior concave driver (4) that, once reached, transforms the forces towards the anterior-superior escape considered in the deflexion action (Figure 6);
- Superior concave push (c): The combined actions of previously reported forces almost always cause a contra-rotation of the upper girdle towards concavity, which must be controlled through this push (whose action is mainly towards kyphotisation) whenever necessary.

3.2.3. Action of kyphotisation

This is mainly realised through brace construction, but it is also achieved through other mechanisms as follows:

- Anterior-inferior bilateral pushes (a): They posteriorly decompensate the upper trunk, creating a lordosis through the lumbar posterior bilateral stops (1) but also facilitating the formation of kyphosis (Figure 7);
- Superior bilateral push (c): Once posteriorly unbalanced, the spine must be superiorly flexed to create kyphosis. The combined actions of previously reported forces almost always cause a contra-rotation of the upper girdle towards concavity, which must be controlled through this push (whose action is anyway mainly towards kyphotisation) whenever necessary (Figure 8);
- Posterior convex push (c): Again, the main action of this push is derotation, but it also becomes kyphotisation when it is allowed an adequate paravertebral escape to the medial side of the hump, together with the thoracic lateral drivers (2) that allow a straightening (flattening) of the ribs with no lateral space but only medial space; and the anterior superior (6) and inferior (8) concave drivers, which avoid an anterior escape. Again, in terms of deflection the spine is driven to the anterior-superior escape (A) through the concave lateral driver (4), which does not allow a direct lateral shift.

3.2.4. Correction of a thoraco-lumbar scoliosis

The pushes are:

- Posterior convex, with derotation and lordosis actions;
- Lateral distal convex, with deflection action;
- Lateral proximal concave, with deflection action;
- Anterior bilateral, with lordosis action.

The escapes include:

- Vertical, with deflection action;
- Posterior concave, with derotation action.

The drivers are:

- Lateral median-proximal convex;
- Lateral median-distal concave;
- Anterior submammary convex;
- Anterior bilateral;
- Posterior proximal concave;
- Posterior distal convex;
- Posterior convex (escape).

- Correction of a lumbar scoliosis

3.2.5. Correction of a lumbar scoliosis

The pushes are:
- Posterior paravertebral convex, with derotation and lordosis actions;
- Lateral over-iliac convex, with deflection action;
- Lateral proximal concave, with deflection action;
- Anterior proximal bilateral, with lordosis action.

The escapes include:
- Superior-posterior, with deflection and lordosis actions;
- Posterior concave, with derotation action;
- Lateral convex, with deflection action.

The drivers are:
- Lateral over-iliac concave;
- Anterior bilateral;
- Posterior concave (escape).

3.2.6. Correction of a high thoracic scoliosis

The pushes are:
Posterior convex, with derotation and kyphosis actions;
Lateral distal convex, with deflection action;
Lateral proximal concave on C6-7 through a rigid hemi-collar;
Anterior concave or convex, as needed.

4. Results

4.1. Scientific results

The results that are today available on the SPoRT concept relate to the Sforzesco brace and necessarily are short-term, because the first treated patients are now reaching the third-year follow-up examination and haven't yet completed their treatments. At an anecdotal level (not confirmed by formal studies), we can already state that results are at least maintained over time, according to what is reported below on the basis of preliminary results.

4.1.1. The Sforzesco brace is more effective than the Lyon brace after six months of treatment

We conducted a prospective cohort study[3, 2] (Sforzesco brace, SPoRT correction concept) with a matched retrospective control group (Lyon brace, three-point correction concept) on thirty patients aged thirteen years and with curves of 38° Cobb. It was a study on the "best available practice," because the proposed brace was considered the best at the moment of treatment execution. The Sforzesco brace obtained higher mean radiographic improvements (-10° Cobb vs. -5°), as well as a better cosmetic appearance of the flanks and shoulders, without the negative impact on kyphosis determined by the Lyon brace. In terms of Cobb degrees, in the Sforzesco group 80% of patients improved and none worsened, while the Lyon group had respective results of 53% and 13%. We did not notice a difference in regard to humps.

4.1.2. Sforzesco brace equally effective as Risser plaster brace

Currently, the Risser plaster brace is also proposed by the Scoliosis Research Society (SRS) as the most effective tool for the conservative treatment of adolescent idiopathic scoliosis. We conducted a prospective cohort study[4] with a retrospective control group on forty-one patients aged four years and with curves of 40° CobbEighteen were treated with the Risser plaster brace and thirty-three with the Sforzesco brace. It was a study on the "best available practice," because until 2002 plaster had been our standard treatment for the largest curves, while since the midpoint of 2004 we have systematically used the Sforzesco brace. The verification was scheduled at eighteen months, when the corrective phase of the treatment has finished (twelve months) and the first follow-up examination is available with complete clinical and radiographic data. The Sforzesco was shown to be more effective at reducing the thoracic curve, and its results were superimposable for the other regions. The Risser plaster brace was shown to be more effective on the thoracic hump and in regard to the cosmetic appearance of the flanks, but it also caused a serious kyphosis reduction. Considering the decrease of personal (quality of life) and social costs (outpatient treatment for brace, while plasters always require some kind of hospitalisation, at least in day-hospital), today we have a plastic brace that can take the place of the Risser plaster brace.

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The Boston Brace System Philosophy, Biomechanics, Design & Fit

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Abstract. The Boston Brace System developed in the early 1970's by Dr John Hall and Bill Miller, CPO, is a logical, multidisciplinary approach to the treatment of idiopathic scoliosis. The Brace itself is but one component of the Brace system. The clinical team consists of patient, family, orthopedist, orthotist, physical therapist and nurse. Each team member needs to have a working knowledge of each others discipline, and educate the patient on his/her roll of the treatment plan. If the patient is not educated and understands the process, the logic behind the process and the critical roll they play- then the whole system has been compromised. The Boston Brace itself is one of the most widely studied orthosis used in the conservative management of scoliosis. It has been shown that orthotist training and skill, as well as the ability to assess and modify the fit in 3D have a positive influence on patient outcome. This chapter will discuss the philosophy, biomechanics, design, fit and adjustments necessary for a successful outcome. By following the basic tenants of the system, and maintaining the patient focus, the goal of having a stable spine in adulthood can be obtained. It takes a team effort. This outline will take about how to construct and evaluate the orthosis to maximize fit and function.

Keywords. Boston Brace, adolescent idiopathic scoliosis, brace design, orthosis

Philosophy

The Boston Brace System developed in the early 1970's by Dr John Hall and Bill Miller, CPO, is a logical, multidisciplinary conservative approach to the treatment of idiopathic scoliosis. Initial designed to replace the leather girdle of the Milwaukee orthosis, Miller and Hall found that by removing the super structure for certain curves, the Cobb reduction improved[1]. They started with lower curves; and then, as their competence with the system improved, they systematically addressed higher level curves [1-5]. Today, the Boston, and its various designs, is used to treat most curves from T6 apex to L4. It is designed to be a full time (16 hrs/day or more) wearing system. Studies show 50% reduction of the curve is generally received while standing, this correction, has been shown to increased in a TLSO design when the patient is supine.[3, 5-8].

The clinical team is the basic tenant of success. Below is an outline of the system that will follow the patient from initial diagnosis through the treatment plan until skeletal maturity/discharge.

It all begins with the patient and family. They are the centre of the team and plan. As the child develops, both physically and mentally so too does the program need to develop. We use the term dynamic, this system, since its inception, has been just that, both in brace design, and in adjusting our approach to meet the needs of the patient and family.

The clinical team consists of the patient, family, orthopaedist, orthotist, physical therapist and nurse. Each team member needs to have a working knowledge of each others discipline, and educate the patient on his/her roll in the treatment plan. If the patient is not educated and understands the process, the logic behind the process and the critical roll they play- then the whole system may be compromised [4, 9].

The Boston Brace

To understand the biomechanics and design it is important to become familiar with the terms and define the components of the orthosis and their function.

The base orthosis itself (the module) is made of copolymer plastic, thickness decided by patient size. Generally there is an aliplast lining, periodically an unlined orthosis is fabricated. However, the waist section needs to be lined for comfort. Standardized symmetrical modules were original to the Boston Brace System [4, 10]. The advantage in terms of saving the patient from being molded, and fabrication time is obvious. Many sizes have been added to our original library. Some patients due to body proportions or boney prominences may need a custom “module” fabricated. This can be achieved by taking a series of measurements and utilizing a cad machine to carve a custom module, or modifying an existing mold to match the measurements. For those presenting with boney prominences about the pelvis a mold or cast of the patient is utilized to capture their shape. The term, “Custom module” describes this to differentiate it from the standardized module. This module, whether standardized or custom is the starting point from which the blueprint will be traced to design the individual orthosis. Sagittal plane contours, an increase in the standard lordosis and a prokyphotic design have been a part of the evolution. Figure 1 shows a Boston module[4].

Figure 1. Boston Module

There are terms we use to describe the orthosis as shown in Figures 2 and 3. It is important to note, that each trim line or plastic extension has a purpose, other wise it is unnecessary and therefore should be removed. It truly is a modular system in that the components can be adjusted or removed depending on need and clinical findings.

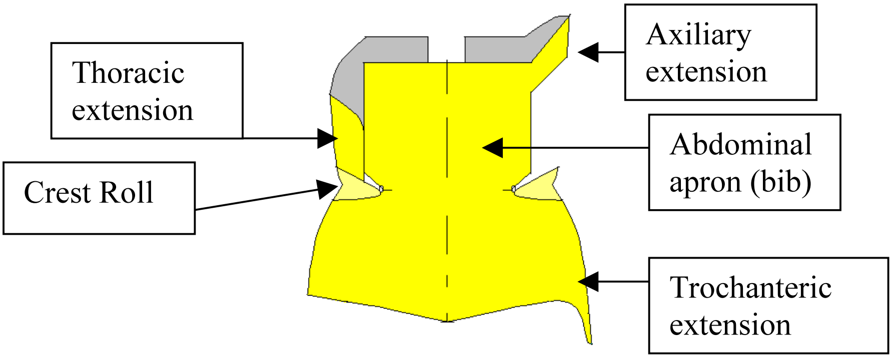


Figure 2. Compliments of the Boston Brace Europe Bracing Manual

The axiliary extension refers to the portion of the orthosis situated just under the arm. Its purpose is to contact the lateral aspect of the upper thoracic ribs to generate a pure medial force. It works to shift the upper portion of the thoracic curve and improve balance in the decompensated patient. No anterior or posterior radius should remain.

The abdominal Apron refers to the anterior portion of the brace that extends enough laterally and superiorly to contain the abdomen and covers the margins of the ribs and xyphoid. Care is taken not to have rib impingement. This section is usually flat in the frontal plane to allow the torso to shift within the orthosis. The radius at both lateral aspects is tight so that a transition can be made between the anterior and lateral section. This is important when removing plastic to generate a window or relief opposite the thoracic extension. There is to be no radius left so as to not impede the lateral transition of the off centred body segment. Also, the anterior lateral section adjacent to the thoracic extension should be trimmed or cut to disconnect it from the thoracic extension. This affords the bib some flexibility to encourage derotation to the thoracic spine, ease donning and doffing, and minimize pulmonary compromise while wearing the orthosis. This trim begins at the lateral quarter sections of the apron and continues to the superior boarder of the thoracic extension [22].

The trochanter extension is designed to extend over one greater trochanter for the purpose of providing balance and improved leverage to the working of the lumbar pad [11]. In the early development of the Boston Brace, it was found that the patients were able to over power a low profile orthosis since it did not have the super structure of the Milwaukee neck ring. It was found that by placing an extension over the greater trochanter, this increased the leverage and provided a neutral posture of the patient. Through study of this extension, it was found to be most effective on the side to which the patient was decompensated and the tilt of L5 [4]. There are always exceptions to any findings, we can report trends and guidelines. When presented with such a scenario, simply leave both extensions and allow the clinical finding to determine which extension provides best balance [8]. Then simply remove the other [12] trochanteric extension. A Boston Brace will only have one extension over the trochanter. The opposite side needs to clear the troch to provide a true relief to maximize its effectiveness.

The iliac crest roll is made of several layers of foam and should be positioned at the anatomical waist crease. Care is taken so that it does not impede on the iliac crest or lower rib. Its main purpose is to help maintain a pelvic tilt by providing a solid lock of the pelvis. It also assists in preventing brace migration (superiorly, inferiorly) as well as providing a slight distraction between the iliac crest and the inferior costal margin.

The thoracic extension is designed to generate a force at the apex and below of a thoracic

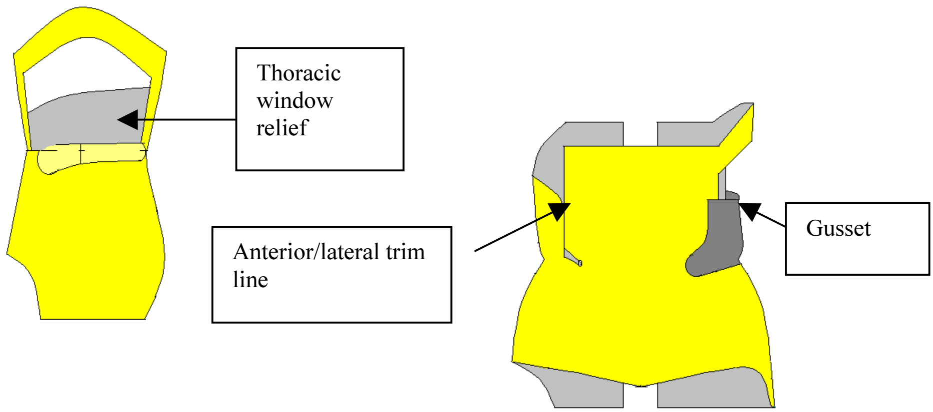


Figure 3. Compliments of the Boston Brace Europe Manual

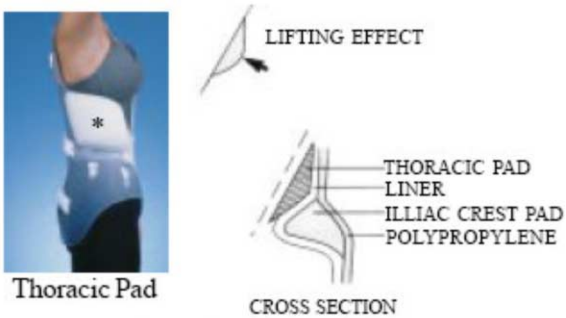
curve [13], and to increase leverage of the lumbar pad in a thoracolumbar curve, or a lumbar curve where the patient is significantly decompensated. The side of the extension is dictated by the individual vertebral tilt and decompensation. Following the same logic as the trochanter extension, if in question, leaves the extension and if the patient is out of balance, then it can be removed. Only one thoracic extension, if needed, remains on the finished orthosis.

The height of the extension is dictated by the blueprint. Its height corresponds to the rib of the apical vertebrae. As the orthosis moves from posterior to anterior, care is taken to follow the slope of the rib. If additional force is needed, a thoracic pad is added to the inside of the orthosis along the thoracic extension.

The Thoracic window or relief is directly opposite the thoracic extension and pad. Ideally the height extends a minimum of one rib higher than the extension. All radii must be removed to ensure a large enough opening exist so as to not impede breathing and to allow for a linear shift of the torso. Inferiorly, the window extends to the crest roll. At times, tissue impingement may occur, or in the case of excessive tissue displacement, an unsightly bulge may exist. In these cases an elastic gusset is added over the window to provide a slight counter force and improve cosmesis.

There are three main pads that are utilized in the Boston System. Their function is to provide an increased force on the curve. These are added to the inner surface of the orthosis so they can generate increased pressure, and are easily adjusted. If the in brace x-ray reveals the pad(s) is in the incorrect position, it is easily removed and adjusted. The pads are named by the section of the orthosis to which they are attached.

The Thoracic pad is designed to provide an upward lateral force. The full thickness of the pad should not extend beyond the anterior/posterior lateral aspects of the brace [23]. This pad is skived to have an upwardly directed force. A custom pad, or adjustments to the inside surface of the pad is made to ensure even pressure through out. Care is needed to not malform the ribs in the case of younger patients who may have years of brace wear ahead of them.



[4]

Figure 4. Compliments of Boston Brace Manual

The Lumbar Pad is designed and placed in the orthosis to apply pressure to the paraspinal muscles at the level of the apex of the curve and below. The pad can extend as high as T12. If L4 or L5 are to be included the pad thickness should be tapered to reduce the risk of bridging between the gluteus and the lumbar regions, thereby decreasing the pressure and effecting results. Laterally, the pad extends into the posterior lateral third of the orthosis as shown in figure 5. There is a small extension that will taper into the crest roll. The lumbar pad should provide an anterior medially directed force, so care is taken to ensure the posterior lateral aspect has full thickness of the pad. Figure 6 shows various shapes of the lumbar pad [4].

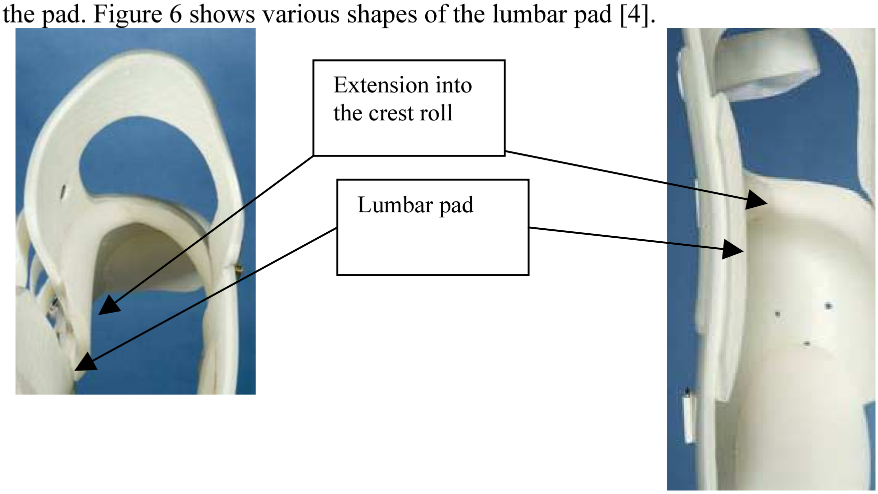


Figure 5.

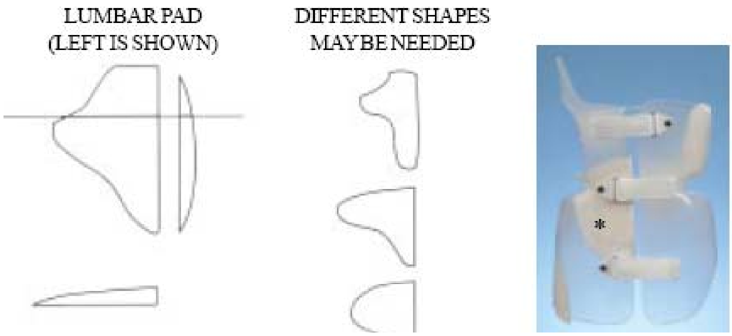


Figure 6. Compliments of the Boston Brace Manual [4]

The Trochanter Pad as shown in figure 7 is used to help increase the leverage of the lumbar pad and axiliary extension. Thickness is dictated by patient presentation at the time of fitting. Typically it varies from ¼ to ½ inch.

Figure 7. Compliments of the Boston Brace Manual

Now that we are familiar with the components of the orthosis, we can now define the various styles of braces that make up the Boston Brace system. It is important to note that the style of brace is named for the highest component of the brace, not the curve itself. Many times a lumbar brace design is used in the treatment of a thoracolumbar curve.

Boston Lumbar Brace: the highest component is the lumbar pad. This style is used for lumbar and or thoracolumbar curves. It usually will have a trochanteric extension with pad, Lumbar pad. (See Figure 8)

Figure 8. Boston Lumbar Brace

Boston Thoraco-Lumbar Brace: the highest component is the thoracic extension. This style is used for lumbar curves where the patient is decompensated, and thoracolumbar curves. This style usually consists of a trochanteric extension with pad, lumbar pad, and thoracic extension, with or without pad [4]. (See Figure 9)

Figure 9. Boston Thoracolumbar Brace

Boston Thoracic Brace: the highest component is the axiliary extension. This style is used for thoracic curves, double major curves, and lumbar and thoracolumbar curves when the patient is decompensated. Future study is needed to quantify decompensation as well as curve flexibility to help with design selection. Today, the blueprint along with the orthopaedist an orthotist experience are used in the decision process. It usually consists of a trochanteric extension with pad, a lumbar pad, thoracic extension and pad, axiliary extension [4]. (See Figure 10)

Figure 10. Boston Thoracic Brace

Over the years, the standard module for scoliosis has been modified and redesigned for ease of fitting, potentially better [17] compliance, and better management of the spine in the sagittal plane. . The Boston Brace scoliosis module is designed with a moderate degree of lumbar and pelvic flexion (15 degrees measured on the external surface of the module). This has been a basic Boston Brace principle since its inception and is a fundamental part of the design of the Boston Brace. By flexing the lumbar spine and pelvis a better grip can be obtained on the pelvis itself and a more stable foundation is made available for the rest of the brace [4]. By placing the lumbar spine in flexion, the mid-section of the lumbar spine moves posteriorly where it is more accessible to lateral and derotating pressure. Also its noted that by reducing lordosis we also obtain a reduction in the lateral deviation of the curve [17].

It is important to note at this juncture, that a reduction of thoracic kyphosis due to the reduction of lumbar lordosis was of concern early on in the use of the Boston design. Physical therapy was always stressed to help stretch the hip flexors and to teach the patients how to obtain a pelvic tilt [15, 16]. They also worked on over all balance and improved posture both in and out of the brace. A design change also helped maintain a pro kyphotic posture, and proved to be as effective and more comfortable by the patient [17]. The posterior superior trim line, in this author's opinion plays a critical roll in promoting kyphosis and will be discussed later in this writing [18].

The orthotist draws a brace blueprint for each patient regardless of module. The blueprint allows the orthotist to convert the module to an individual orthosis. The patients x-rays are required to draw the blueprint. The brace blueprint focuses attention on the status of individual vertebra and we believe allows for a much more accurate design and placement of pads. Experience and mathematical modelling dictates that pad pressure should be at the apex of the curve and below for nearly all deformities [13, 19]. This is achieved in the lumbar spine by placing a properly shaped pad at full thickness at the apical lumbar vertebrae. The lumbar pad can be a high as T12. However, care is to be given so to design, so as to not interfere with the T11 or T10 rib. In the thoracic spine, the pad corresponds to the rib of the apical vertebrae. The slope of this extension needs to follow the slope of the rib. Radiographic markers placed at the full thickness of the pads allow the in-brace x-ray to reveal their placement. Adjustments are then made if necessary to maximize placement within the orthosis.

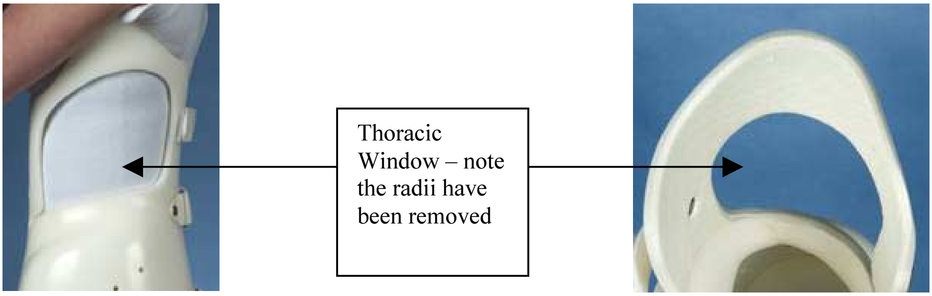


Figure 11. Thoracic Window

In order to maximize the force of each pad a relief is made in the orthosis on the contralateral side directly opposite the pad. In the lumbar spine, the lumbar pad acts to laterally shift and derotates the lumbar spine. Directly opposite the lumbar pads a heat relieve is made to encourage derotation. The lateral shift is to a neutral opposition. This coupled with a reduction of lordosis helps reduce a lumbar curvature. The thoracic pad has a window cut out on the contralateral side as shown in figure 11, the window is void of any radii so as not to impede shift of the segment in need of correction. The height of this relief is ideally one rib higher than the apical rib being acted upon by the thoracic pad. Both axiliary and trochanteric extensions have relief opposite by virtue of the brace design.

The Blueprint

To create a Blueprint you must do the following:

1. Orient the x-ray and mark the spinous process of S1, draw a centre line from this point parallel to the side of the x-ray.
2. Find a “degree value” for each vertebra by drawing a line along the inferior edge of each vertebra across the centre line, and measuring the angle between this line and the centre line.
3. Measure a degree value for every vertebra.
4. Locate the “Null” point (apex) of the curve (the level at which the degree values change from right to left or vise versa). This point is used to determine the upper level of the pad placement.
5. Locate the L2-L3 disc space and draw a line perpendicular to the centre line. This is the level of the iliac crest rolls. (all vertical distances are marked from this line).
6. Determine the tilt of L5. If L5 is tilted, draw in a trochanter extension covering the trochanter on the same side to which L5 tilts. If L5 is not tilted, a trochanter extension is not required, the exception to this rule is when the patient has a stiff thoracic curve that is unbalanced to one side, then consider a trochanter extension to the unbalanced side.
7. If a lumbar pad is required, draw the pad on the x-ray. Lumbar pad “full thickness” is measured from the level of the lumbar null point and for each vertebra with a degree value below. The position from x-ray to brace is marked relevant to the crest roll line. A tapered border of approximately ¾” is drawn beyond the full thickness border of the pad.

8. If a thoracic extension/pad is required, draw the extension/pad on the x-ray. The thoracic extension/pad is drawn as a medially directed force upwards at the rib corresponding to the null vertebra and downwards to the centre of the iliac crest roll.
9. If an axillary extension is required, draw the extension on the x-ray. The axillary extension is drawn as a medially directed force and an opposing force to the thoracic extension. The upper limit of the extension is determined by the highest vertebra tilting into the concavity of the thoracic curve. The lower limit is drawn at the rib corresponding to one vertebral level superior to the thoracic null point [4].

Below figure 12 shows the final steps of the blueprint. Note centre sacral line, in yellow. This patient is decompensated to the left and L5 is angled to the left, so our trochanteric extension is on the let hand side. The Lumbar curve null point is L2-L1 disk space, so the lumbar pad extends to L2, tapering to L1. We need to be conscious of the 3D aspect of this curve, so the lumbar pad extends into the posterior lateral aspect of the orthosis. The pad is depicted as extending beyond the null point (Red line), this is to ensure a smooth transition into the orthosis and that the full thickness of the pad is at the null point. The thoracic pad extends to the rib corresponding to the apical vertebrae. Note the taper of the pad. This is to provide an upwardly directed force. This pad is designed to sit in the lateral aspect of the orthosis.

With the Blueprint in place, we now can shape our pads to match the blue print. The lumbar pad shape is dictated not only by the null point, but if the null is L1 or L2, attention must be paid to the shape and slope of the lower ribs. The downward slope of the superior edge of the pad must be such so as not to impede or influence the lower rib. Particularly if the corresponding vertebrae has an angulation opposite that of the treated lumbar vertebrae.

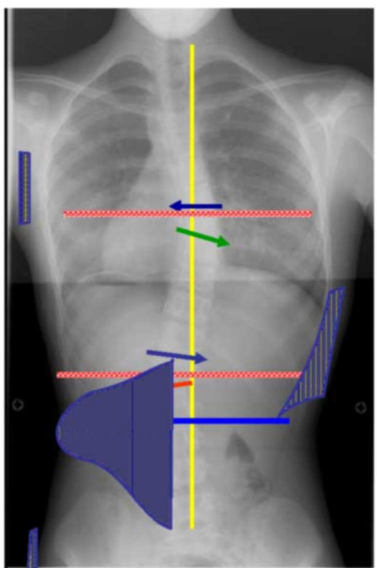


Figure 12. Completed x-ray Blueprint

Trimline for the orthosis are based off the blueprint. The anterior trimlines are typically at the level of the xyphoid superiorly and sitting comfort inferiorly. Care is taken to not impede the ribs and to make sure the Anterior Superior Iliac spines are encapsulated for pelvic control, and room for growth. Laterally be sure to encompass the trochanter where needed, and clearance of at least 1cm for the contralateral trochanter. The slope of the line from the trochanter to posterior is dictated by pelvic development. For patients with a more mature pelvic shape, try to encapsulate more tissue. This helps reduce impingement and is more cosmetic under clothing. Both issues this author feels may help with compliance. Superiorly the lateral trim line of the thoracic extension is dictated by the blueprint. The axiliary extension is by patient's shape. Care is taken on the transition from anterior bib to axiliary, this bridge needs to remain wide enough to maintain or provide enough surface area to reduce the pressure. This bridge is intended to provide a force coupling with the posterior aspect of the orthosis.

Fitting the Orthosis

This appointment with the patient brings with it many emotions. As orthotist it is our responsibility to ease the patients concerns, and provide an open environment to provide a comfort zone for the family and patient to express their concerns. The first part of the appointment is show and tell. Explaining why the orthosis looks the way it does, how it is put on, and more importantly, how to take it off. Explain that adjustments will need to be made as far as the trimlines are concerned. Let the patient know the goal is for them to become independent in donning and doffing. Also that toileting should not be impeded with the orthosis. We start with the patients back toward us, our knees just touching the patients from the back. This causes the patient to flex slightly at the knee, inducing a pelvic tilt. The orthosis is placed on the torso; the waist crease is palpated on the patient, and let them know this is where the crest roll should be situated. Proper donning and wearing of the orthosis can not be reviewed enough. Letting the patient know that their job, donning correctly, is imperative for the pads to be in the proper position, and being most effective.

Land marks are then palpated to ensure no impingement is occurring. This too follows a logical progression. Starting posteriorly, inferior then superior, laterally, then anterior. Anteriorly we need to be sure we are not impinging the chest, and when sitting, the orthosis just touches the thighs.

The opening of the orthosis is important to make sure the pads are positioned and providing the proper vectors .At initial fit, an opening of 4 – 6 cm is acceptable, the goal will be to reduce his opening during weaning to 3.5cm, or the width of L5.

Always step back and view the patient. Check for balance in all three planes. Coronally, we want the orthosis straight, the patients head over the pelvis, and the shoulders level. Sagittaly, we want to see the head in line with the pelvis. The patient maybe leaning anteriorly, have them flex at the knee, if this reduces the anterior posture, then they need to stretch their hip flexors. Encourage them to do the exercises provided by physical therapy, or encourage them to see a therapist for evaluation and treatment. In the transverse plane, the shoulders should be neutral. In higher thoracic curves, or those with significant rotation, the shoulder girdle maybe rotated in counter rotation to the thoracic curve. This should have been noted in the initial evaluation and extension above or to the spine of the scapulae should be incorporated into the orthosis [18]. If not this extension can be added to the orthosis, and removed at a latter date.

Review donning and doffing and place a starting and goal line on the straps. The patient is educated on how the tissue will be displaced inside the orthosis and as with increase wear time, the straps will become lose and be able to be tightened with our the patient feeling any tighter.

A follow up should be set for a check before x-ray. Presently we are reviewing our brae check appointments to see if there is a difference in the initial x-ray. Since this initial x-ray usually dictates successful outcome. Currently we have this as part of our protocol. At brace check we are encouraged if the patient is wearing the orthosis for the appointment. We then ask wear time, if any issues. We then review how the orthosis is donned to see the "real world" picture of how the orthosis is being worn. We then address any issues at that time.

The check Before X-Ray:

The check before x-ray appointment is to review the brace program. Not just to see how the orthosis is being worn. Donning is important. How is the patient's posture? Are they in balance in all three planes? If the patient's posture is not balanced, adjustments need to be made. Note the series of photos in fig13. The blueprint suggests a left trochanteric extension with pad is necessary; however the orthosis is tilted to the left. The trochanter pad is removed, the orthosis remains out of balance, removable of the troch allows the orthosis to be balanced, and the patient is balanced as well. What are the reported hours worn? Are they doing there hip flexor stretches? See how the overall pressure of the pads is. The lumbar pad should be in complete contact with the paraspinal musculature. Even though the patient is at the goal mark, can we increase or wear the orthosis tighter? Note figure below. Fig 14 We are able to tighten the orthosis beyond the initial goal mark. If so, we may need to trim ¼ - ½ inch from each side of the opening, or as in the next figure, we can add a "belly pad". This is ¼ to ½ inch aliplast added to the anterior section of the orthosis. It is skived on all four sides. (note: the hinge depicted is for teaching purposes only).
This will allow the orthosis to be positioned properly on the patient. Once the adjustments are complete and the patient is comfortable and balanced review the wear time and donning with the patient. Currently we are reviewing the benefits of the check before x-ray as part of the protocol. Frequent contact and a review of wearing schedules as well as an additional opportunity to answer patient questions or concerns we feel, anecdotally, has a positive influence on compliance.

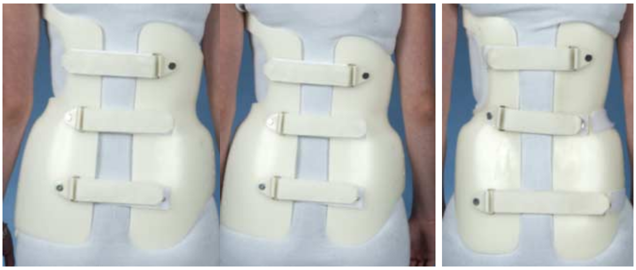


Figure 13. Effects of a left Trochanteric extension on balance when not needed

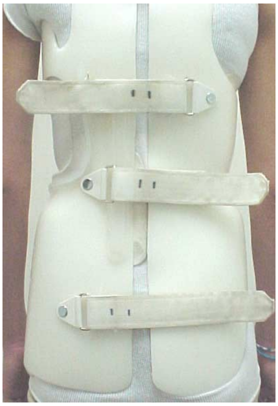


Figure 14. Well worn orthosis that has closed down due to tissue displacement

Interpreting the in brace x-ray:

The in brace x-ray is a valuable tool to assess not only brace design, but enable us to discuss with the patient how their curve has responded to bracing. As with all previous steps, a logical thought process must be followed to endure that proper adjustments will be made.

A centre sacral line is drawn on the in brace x-ray to assess overall balance. Marty Carlson and Keith Smith have pointed out in there studies, that we can be fooled into thinking that a curve has reduced in Cobb, but the balanced spine is now out of balance. Our goal is to have curve reduction and to stop progression of the curve all while maintaining balance of the spine. Cobb the curve and see how they compare to the previous x-ray. There have been various reports on the amount of reduction necessary in order to be successful in our bracing program. The average reduction, according to Dr Emans study was 50%, however when in the research he was able to look at apical vertebrae Dr Emans,[3, 20] look at reduction by apex with variations from – to -. We need to be aware of the factors that influence the reduction.[21]

If the orthosis or curve is out of balance, we need to see if a trochanteric extension was used, if there was a pad or not, if decompensated to the side opposite of the pad and extension, remove the pad and or extension in an attempt to allow the spine to move back into balance. If decompensated to the same side as the trochanteric extension and or pad, is it enough, or do we have an axiliary extension on the opposite side, is it needed? Is the thoracic extension too much with pad? Each presentation and finding needs to be addressed individually and adjusted logically to provide reduction and balance to the curve. Curve apex, rotation, flexibility,

Measure the Cobb angle and compared to previous. If reduction and or balance are not ideal we need to assess the overall fit of the orthosis and how it is donned. The waist crease is marked by the rivets and chafe of the middle strap. By consistently placing this strap at the centre of the crest roll, we can easily see where the brace is positioned on the patient. Also view the chafe, it should be flat in the coronal plane, if not the orthosis may be rotated and not providing the proper vectors for treatment. View the distance between chafe and strap rivet for all straps. Is the orthosis on tight enough? Wearing it too lose may not yield a positive result.

View the position of the lumbar pad. Radiographic markers should be place at full thickness of the pad along the edge of the orthosis. Ideally these markers should be along the transverse processes. Adjust accordingly. The thoracic pad also has markers placed along the apex of the pad at the edge of the extension. See if we have contact with the apical rib. Depending on the radiograph and its clarity, you may be able to view the window and determine its height. Height if the axiliary extension should be noted as well.

The findings will dictate the course of action and the conversation with the patient. Whether it is reviewing donning or asking is this how it is typically worn and therefore the pads need to be adjusted for segment length, the conversation occurs with the patient as to what we found and what we need to adjust. Patient involvement through out the process is the key and needs to be part of each part of the program.

The Boston System has continued to evolve and will do so as we learn more about the etiology and treatment efficacy of bracing. We look forward to the future and playing a roll in developing its landscape.

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Section IX

Study of the Surface After Brace Application

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T.B. Grivas (Ed.)
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Cosmetic Outcome after Conservative Treatment of Idiopathic Scoliosis with a Dynamic Derotation Brace

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Abstract. Improved cosmesis is a major concern for the adolescents with Idiopathic Scoliosis (IS). We hypothesized that if we correct the rotation simultaneously to the lateral curvature of the spine with a dynamic brace we may decrease the asymmetry of the back and ultimately improve the cosmetic appearance of the scoliotic child.

Thirty six scoliotic children (32 girls and 4 boys) with a mean age of 13.9 (range 12-17) years, a mean Cobb angle of 28,2° (range 19-38°) and a mean ATI 7,8° (range 4°-17°) were studied. The examined children were divided in 3 subgroups according to the curve type. All children wore the Dynamic Derotation Brace (DDB), which is a modified Boston brace with antirotatory blades, for 23 hours per day, for a minimum duration of 2 years. The ATI was assessed using the Pruijs scoliometer at baseline and at the end of treatment.

ATI was improved statistically significant in the thoracolumbar ($p<0.01$) and lumbar region ($p<0.013$) of double curves and in the thoracolumbar ($p<0.018$) and lumbar region ($p<0.027$) of thoracolumbar curves. ATI improvement in the thoracic region was not statistically significant either in double curves ($p<0.088$) or in thoracolumbar curves ($p<0.248$). For right thoracic curves, ATI improvement was not statistically significant for all the examined regions.

The above findings indicate that in double and thoracolumbar curves, a deforming torsional force is present, blocked by the antirotatory action of the blades of the DDB, and seems to be more active in the "lower" spine.

In conclusion, DDB improves the cosmetic appearance of the back of IS children with all but right thoracic curves.

Keywords. Idiopathic scoliosis, conservative treatment, surface deformity, Angle of Trunk Inclination, Dynamic Derotation Brace, cosmetic outcome in Idiopathic Scoliosis

Introduction

Improved cosmesis is a major concern for the adolescents with Idiopathic Scoliosis (IS) [1]. Traditionally, conservative treatment with a brace aims at prevention of curve progression beyond surgical limits, and its effectiveness is evaluated by radiographic measurements, namely the Cobb angle and vertebral rotation. The patient satisfaction, the cosmetic appearance of the back and the overall quality of life have recently been introduced as important factors in evaluation of the conservative treatment effectiveness.

The typical cosmetic appearance of the back in children with IS, is back asymmetry and is usually the first noticed sign. A simple method to quantify back asymmetry is by measuring the Angle of Trunk Inclination (ATI) with the use of scoliometer. Improvement of ATI should be one of the primary goals of conservative treatment in IS.

Back asymmetry is mainly the clinical expression of rib cage deformity and spinal column 3-D deformity, including vertebral rotation. Any attempt to improve the cosmetic result should focus on correction of both the scoliotic curve and the rotation. If the corrective forces are applied to a relatively immature skeleton, it could theoretically improve the rib cage asymmetry and result in a better cosmetic appearance.

It is known that the Dynamic Derotating Brace (DDB) acts by the application of corrective forces to the scoliotic curve, but additionally derotates the spine with its metallic antirotatory blades which are attached on the posterior surface of it [2]. We hypothesized that if we correct the rotation simultaneously to the lateral curvature of the spine with a dynamic brace we may decrease the asymmetry of the back and ultimately improve the cosmetic appearance of the scoliotic child.

Material-Method

Thirty-six scoliotic children treated conservatively with a DDB are included in the study. Most of them were detected through the school-screening program. All the patients wore the brace for 23 hours per day for a minimum duration of 2 years.

According to the curve type they were divided into three groups: In the *first group* there were 20 children, 17 girls and 3 boys, with a double curve (right thoracic with a compensatory lumbar), a mean age 12.3 years old (range 10-17) and a mean follow up time of 28 months (range 24-34). The mean thoracic Cobb angle was 23.2° (range 10°-35°) and a mean lumbar 21.2° (8°-30°) respectively. Mean ATI in the thoracic, thoracolumbar and lumbar region was 6.1° (range 0°-15°), 6.6° (0°-10°) and 3.2° (0°-10°) respectively (see Table 1**).** In the *second group* there were 6 children, all girls with a right thoracic curve and a mean age of 13.8 years (range 12-15) and a mean follow up was 25 months (range 24-28). Mean thoracic Cobb angle was 25° (range 22°-31°). Mean ATI in thoracic, thoracolumbar and lumbar region was 4.5° (range 0°-8°), 6° (2-10°) and 5.3° (3°-8°) respectively (see Table 1**).** In the *third group* there were 10 children, 9 girls and 1 boy, with a thoracolumbar curve and a mean age of 13.5 years (range 12-17) and a mean follow up time of 29 months (range 24-36). The mean Cobb angle was 24° (range 20°-38°). Mean ATI in thoracic, thoracolumbar and lumbar region was 5.4° (range 0°-15°), 3.6° (6°-17°) and 4.2° (0°-14°) respectively (see Table 1).

DDB is a modified underarm TLSO - Boston brace with antirotatory blades, which act as springs, maintaining constant correcting forces at the pressure areas of the brace

Table 1. The three groups of the 36 studied scoliotic children with the Cobb angle and ATI measurements at baseline. Th: Thoracic region, Tl: Thoracolumbar region, Lu: Lumbar region.

	No of pts	Curve type	Mean age (years)	Mean Cobb angle (degrees)	Mean ATI (degrees)			Mean Follow Up (months)
					Th	Tl	Lu	
Group I	20	Double	12.3 (10-17)	Th 23.2 (10-35) Lu 21.2 (8-30)	6.1 0-15	6.6 0-10	3.2 0-10	28 (24-34)
Group II	6	Right Thoracic	13.8 (12-15)	25 (22-31)	4.5 0-8	6.0 2-10	5.3 3-8	25 (24-28)
Group III	10	Thoraco lumbar	13.5 (12-17)	24 (20-38)	5.4 0-15	3.6 6-17	4.2 0-14	29 (24-36)

and produce at the same time movements in opposite directions of the two side halves of the brace. The derotating metallic blades are attached to the rear side of the brace corresponding to the most protruding part of the thorax (hump) or the trunk of the patient. They become active when their free ends are located underneath the opposite side of the brace and the brace is tightened. The forces applied by the derotating blades are added to the side forces exerted by the brace aiming in both the correction of the spinal and the correction of the rotational deformities of the chest and the trunk. [2].

The effect of DDB on the cosmetic appearance of the back was assessed by measuring ATI at thoracic, thoracolumbar and lumbar region of each curve using the Pruijs scoliometer at baseline and at the end of treatment.

Correlations were determined by the Pearson correlation coefficient, with $p<0.05$ considered significant. The SPSS v.12 was used for the statistical analysis.

Results

In *group I,* at the end of treatment, the mean ATI in the thoracic, thoracolumbar and lumbar region in standing position was 4.4^o (range 0^o-10^o), 3.1^o (0^o-10^o) and 0.9^o (0^o-5^o) respectively. ATI improvement was statistically significant in thoracolumbar ($P<0.01$) and in lumbar region ($p<0.013$) but not in thoracic region ($p<0.088$) (see Table 2).

In *group II,* at the end of treatment, the mean ATI in the thoracic, thoracolumbar and lumbar region in standing position was 3.8^o (range 0^o-7^o), 4^o (0^o-8^o) and 3.5^o (2^o-5^o). ATI improvement in group II was not statistically significant for all the examined regions (see Table 2).

In *group III,* at the end of treatment, the mean ATI in the thoracic, thoracolumbar and lumbar region in standing position was 4.4^o (range 0^o-10^o), 2.3^o (0^o-15^o) and 3.4^o (0^o-13^o) respectively. In standing position ATI improved statistically significant in thoracolumbar ($p<0.018$) and in lumbar region ($p<0.027$) but not in thoracic region ($p<0.248$) (see Table 2).

Table 2. Statistical significance of ATI improvement. SS: Statistically significant, NSS: Non statistically significant.

	Thoracic ATI	Thoracolumbar ATI	Lumbar ATI
Group I	p<0,088 (NSS)	p<0,01 (SS)	p<0,013 (SS)
Group II	p<0,180 (NSS)	p<0,066(NSS)	p<0,066 (NSS)
Group III	p<0,248 (NSS)	p<0,018(SS)	p<0,027 (SS)

A graph of ATI improvement at the three examined regions of the back in the three groups of scoliotic children is shown in Figure 1.

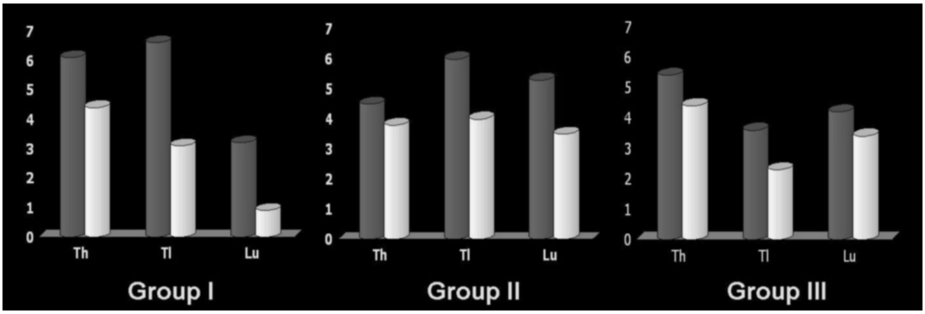

Figure 1. A graph showing ATI improvement at the three examined regions of the back in the three groups of scoliotic curves. *Grey bar*: Mean ATI at baseline, *White bar*: ATI at the end of treatment. ATI is measured in degrees. Th: Thoracic region, Tl: Thoracolumbar region, Lu: Lumbar region.

Discussion

The efficacy of the various orthotic devices is controversial [3, 4, 5]. There are studies in the literature where the results documented that bracing altered the natural history of IS by preventing curve progression [3], or by reducing the number of patients requiring surgery [4]. Other authors believe that there is lack of data to support brace management of IS and they are questioning the necessity of school screening due to the uncertainty of the efficacy of treatment with a brace, stating that early detection may not necessarily prevent curve progression and the need for surgical intervention [5].

The issue of corrective forces and how these forces should be applied on a scoliotic curve in order to achieve maximum correction is not new [6]. Different types of braces are using different principles of correction [6]. A very common mistake is to correct the lateral curvature of the spine without correcting the rotation of the trunk. Furthermore, a proper designed brace could be ineffective when applied by orthotists or physicians who are not following the above principles. Therefore, in order to evaluate the effectiveness of brace treatment we need to establish some quality criteria and not include all braces as a whole and subjectively comment about their efficacy [6].

The forces applied by the derotation blades of the DDB are added to the lateral forces applied by the brace resulting in both the correction of the spinal curvature and the correction of the rotation of the trunk. DDB is an “aetiologic” brace [2] because it overcomes the deforming forces of spiral composite muscle trunk rotator, which has been integrated by the Nottingham theory for IS pathogenesis [7, 8]. The essential feature of this theory is a failure of control of cyclical rotations in the spine during gait [9]. For mild and moderate curves, which after a successful conservative treatment remain below 45^{o} is unlikely to affect the health status [10], but they always have a cosmetic impact on the scoliotic patient. Therefore the effect of a brace on cosmesis is crucial in evaluating the results of conservative treatment.

A previous study revealed that DDB has a positive effect on correction for the majority of curves treated conservatively [2] and can change the natural history of IS, by improving both the Cobb angle and the vertebral rotation. The present study shows that although DDB as a dynamic brace is very effective, it is able to improve significantly the ATI of the thoracolumbar and lumbar region, while the effectiveness on the thoracic ATI is relatively poor.

One possible explanation is that the antirotatory blades of the DDB are very likely to create an antirotatory force and block the deforming torsional action of the asymmetrically acting spiral composite muscle trunk rotator in the thoracolumbar and lumbar spine. The deforming rotatory forces which are generated by the asymmetric action of a component of the above described spiral composite trunk rotator muscle are probably involved in the pathogenesis of IS in the “lower” spine, while for the “upper” spine there must be some other factors, such as the rib cage which through a different unknown mechanism may initiate the deformity [11]. The counter-action of the antirotatory blades of the DDB to the above rotation-inducing system on the thoracolumbar and lumbar spine makes some aetiological implications that neuromuscular factors are involved in the aetiology of IS.

The findings of the present study revealed the limitations of DDB in improving cosmesis at the thoracic region although it is very effective in improving the Cobb angle. An effective brace should ideally correct both the Cobb angle and the surface deformity of the back, in order to achieve both radiological correction and patient satisfaction.

Conclusion

DDB improves the cosmetic appearance of the back, more effectively in scoliotic patients with double and thoracolumbar curves, particularly in the thoracolumbar and lumbar region. The thoracic region of the above curves and the surface deformity in patients with thoracic curves seems to remain unaffected.

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Section X

Brace Treatment Outcomes

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The Conservative Scoliosis Treatment
T.B. Grivas (Ed.)
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End-growth results of bracing and exercises for adolescent idiopathic scoliosis. Prospective worst-case analysis

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Abstract *Background* In the literature the rate of surgery for AIS (Adolescent Idiopathic Scoliosis) of 30° ranges from 22.4% to 31% when braces are used, versus the natural history rate of 28.1%. When a complete conservative approach is used (braces and exercises), this rate decreases to the range of 3.8% to 7.3%. All these studies are retrospective.

Aim The aim was to evaluate the final results of a prospective set of patients treated in a center fully dedicated to a complete conservative treatment (exercises and braces) of AIS.

Materials and Methods This is an everyday clinical, retrospective study on a prospective data base. The population included 112 AIS patients, 13.2±1.8 years old, with 23.4±11.5° Cobb degrees at the start of treatment. All the patients had been treated with a full set of conservative treatments, including exercises, according to their individual needs. We used the SEAS (Scientific Exercises Approach to Scoliosis) protocol and the ISICO approach, while the orthosis used included: Risser cast, and the Lyon, Sforzesco-SPoRT, Sibilla-Chêneau and Lapadula braces. The patients had been followed up by the same physician, braces had been made and exercises had been applied by the same team. The outcomes were established for each single patient: The absolute aim was to avoid surgery, while the minimal and optimal outcomes were defined according to the starting curve. An efficacy analysis and worst-case analysis had been performed.

Results The rate of surgery was 0.9% (efficacy analysis), and 4.5% (worst case); the minimal outcomes had been obtained in 99% of patients and the optimal ones in 84%. Overall, the curves over 40°, which numbered eleven at the start of observation, were reduced to three. In total, eight patients exited the presumable area of risk in adulthood (final curve over 30°). The treatment produced a statistically significant reduction in the worst curves, and the best results have been obtained in the curves over 40°.

Conclusion Provided the use of a complete conservative approach, there is very little doubt that it is possible to reduce the rate of surgery in AIS treatment.

Keywords. adolescent idiopathic scoliosis; brace; exercises; end-growth results.

Introduction

The main treatment for AIS has for years been considered the conservative one (mainly bracing, but also exercises), while surgery was seen as the unavoidable treatment when everything before had failed, because it creates a permanent loss of function in the spine to guarantee its stability [1, 2]. Today, however, things seem to be reversed in a way. Many orthopedic surgeons think and propose that the years of disability for patients due to bracing, do not provide enough results in terms of avoiding surgery [3, 4]: At any rate, their point of view could be somehow biased due to the obvious conflict of interest [5]. Contrastingly, an increasing body of non-exclusively surgical specialists fully engaged in conservative treatment as a mean to avoid surgery, recently founded the Society on Scoliosis Orthopedic and Rehabilitation Treatment (SOSORT) [6, 7, 8]. This society includes mainly orthopedic surgeons, rehabilitation specialists and allied professionals who strive toward strengthening research and understanding in the currently understudied field of AIS conservative treatment (only 19% of the entire studies in this sector in Medline in 1999-2003) [9, 10]. In this situation, publishing prospective studies on the final results of conservative treatment, including drop-outs in the analysis [11], is crucial in order to gain more understanding compared to the natural history.

The main outcomes of conservative treatment include the avoidance of surgery and maintaining the curve at least under 50° Cobb (reduced risks of progression in adulthood) [12];the best outcome is the curve to remain under 30° Cobb, which means almost no risk of pain and progression in adulthood [13, 8]. Two natural-history studies gave rates of surgery of 16% [14] and 28% [4] in patients not treated. On the other hand, the end-growth results studies of bracing gave very sparse results, with surgery rates ranging from 5% to 46% [3]. A group of studies reviewed by Weiss [15] have been performed in very similar patients with average curves ranging between 30° and 35° Cobb, so as to be comparable with each other and with the control group proposed by Goldberg, where the rate of surgery was 28.1% in 153 patients [4]. In the conservatively treated (brace and exercises) patients these rates were 7.3% in 179 (Weiss) [16], 5.6% in 106 (Rigo) [17] and 5.5% in 328 (Maruyama) [18]. Of these studies, the only one to consider a worst-case analysis was that of Rigo: Including all drop-outs as failures, the surgery rate increased from 5.6% to 14.1% [17]. The other studies in the literature with similarly braced patients reported surgery rates of 22.4% in 1020 patients (Lonstein and Winter) [19], 25.9% in fifty-four (Fernandez-Feliberti) [20] and 31% in eighty-eight (Noonan) [21]. It seems that in the former group something serves to increase the efficacy of treatment.

There is some kind of methodological bias, which could be technical (use of exercises, interaction of brace and exercises, quality and type of bracing, excellence and completeness of the treating team beyond Medical Doctors and Orthotists, etc.) but human too (compliance, continuous involvement of patients, commitment to treatment by the therapeutic team, etc.).

Is conservative treatment able to obtain good outcome for AIS patients? To help answer this question, the aim of the present study is to evaluate the final results of a prospective set of patients in a centre fully dedicated to the conservative treatment of AIS. Data will be evaluated in terms of surgery prescription rate, but also in terms of expected outcome (good or optimal) according to the starting point of each individual patient.

Table 1. Baseline characteristics of the entire sample and the identified sub-groups. NS: not significant. NA: statistics not applicable due to the low/absent numbers in some cases

	Abbreviation	Number	M/F	Age	° Cobb	DO
Total		112	17/95	13.2±1.8	23.4±11.5	
Minor (<20°)	S	51	11/40	13.0±1.7	13.3±4.1	1
Medium (20-29°)	M	33	4/29	13.7±2.1	25.3±5.1	2
High (30-39°)	L	17	0/17	13.7±1.7	32.7±2.4	0
Major (40°>)	XL	11	2/9	15.2±1.4	45.3±4.1	1
P			NA	<0.05	<0.05	NS
End Of Treatment	EOT	108	17/91	13.6±1.9	22.5±10.9	
Drop-Outs	DO	4	0/4	11.4±0.7	27.7±13.8	
P			NA	<0.05	NS	

1. Materials and Methods

1.1. Design

This is an everyday clinical, retrospective study on a prospective database that started on September 1, 2003. The observation window considered is 40 months, from September 1, 2003 to December 31, 2006. The inclusion criteria were: diagnosis of AIS; at least 10 years of age and Risser 0, or Risser 1 to 4 at first evaluation; at least one year of treatment (to exclude simple consultations, and therapies not even begun). All patients who satisfied the inclusion criteria at the start of their own treatment have been considered in the study.

1.2. Population

The population included 112 patients, of whom 18.1% were males: They were 13.2±1.8 years old at the start of treatment. The AIS Cobb degrees were 23.4±11.5° over the entire population. The patients were divided according to the degree of curvature into four groups: Minor (S: <20°), Medium (M: 20-29°), High (L: 30-39°) and Major (XL: 40°>). Moreover, the patients were divided into two groups: patients who had reached end of treatment (EOT), defined according to the prescription of the treating physician or the satisfaction of Bunnell's criteria (15 years of age and Risser 3); and drop-outs (DO), meaning patients who discontinued treatment before reaching 15 years of age and Risser 3. All the groups' characteristics are summarized in Table 1.

1.3. Treatment

The patients had been treated on an individual basis according to their needs, and a contract was established each time with the patient and his/her family. We applied a

Table 2. Treatments required for each patient classified according to the groups considered in the study. NA: Statistics not applicable due to the low/absent numbers in some cases.

Groups	Risser cast	Plastic brace			Exercises	P
		23 hours/day	21 hours/day	18 hours/day		
Total	9	17	22	24	40	
S	2	2	3	9	35	<0.05
M	1	2	14	11	5	
L		8	5	4		
XL	6	5				
EOT	9	14	22	23	40	NA
DO		3		1		

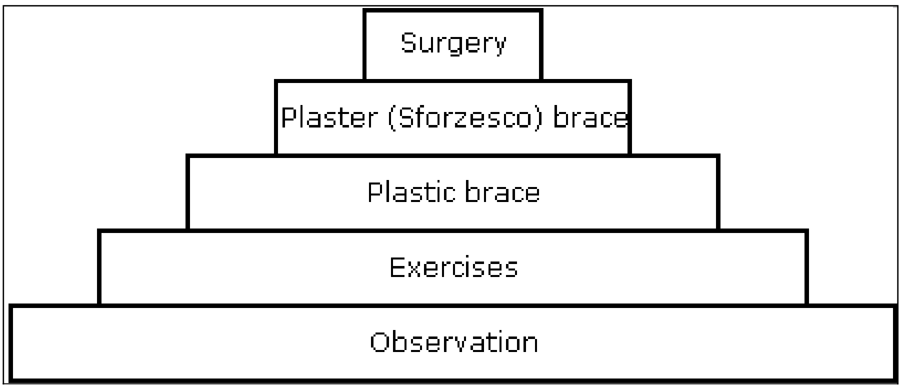

Figure1. Representation of the "step-by-step" Sibilla's theory[37,38] of treatment of scoliosis: Each step represents an increase in strength of treatment but also in requirements to patients. Good physicians are able to start from the right step, so avoiding over-treatment with higher impact on quality of life, as well as under-treatment that engenders progression.

full set of conservative treatments, including exercises, according to the "step-by-step" Sibilla's theory of treatment of scoliosis, in which each step represents an increase in the strength of treatment, but also in requirements to patients (see Figure 1).

In Table 2 we report the most aggressive treatment proposed in the entire sample and in each group. All patients have been followed up by the same physicians in our Vigevano Center, where all the exercises planned have been proposed. All the braces were made by the same orthotists in Vigevano.

1.3.1. Brace treatment

The braces we used--obviously always adapted according to the curve patterns were chosen on the basis of individual needs. They included [22]: Risser cast (see Figure 2A) and Lyon (see Figure 2B), or Sforzesco-SPoRT brace (see Figure 2C) for the most

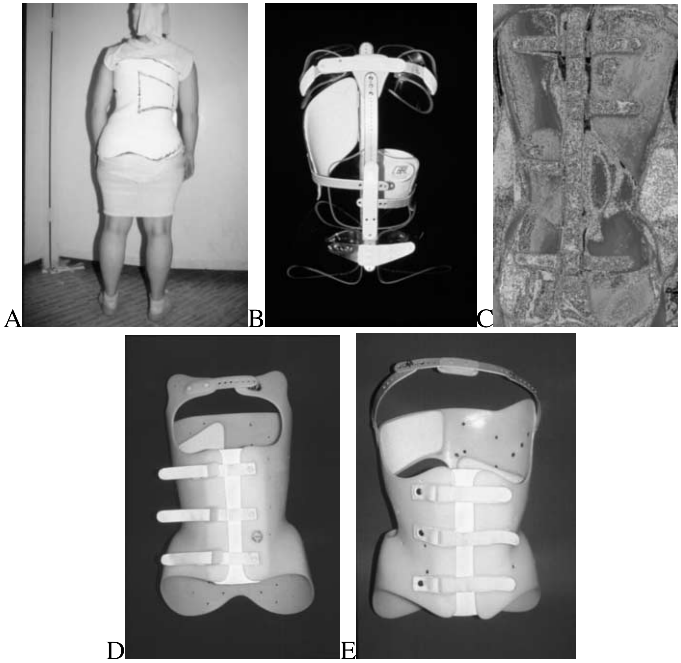

Figure 2 Different orthosis used for treatment of the patients included in this study were: the Risser cast (A) and the following braces: Lyon (B), Sforzesco-SPoRT (C), Sibilla-Chêneau (D) and Lapadula (E).

important cases. In cases where reduced forces were required, we used the Sibilla-Chêneau brace (see Figure 2D) for thoracic and double curves, and the Lapadula (see Figure 2E) for thoraco-lumbar and lumbar ones. The goal of brace treatment varied according to the degree of curvature considered, and forces (in terms of the type of brace and hours of usage) were consequently administered. The extreme cases to be considered were as follows: In mild progressive adolescent scoliosis (up to 30°-35° Cobb) that could not be caused by the brace. In such cases the chosen brace was less rigid (Sibilla or Lapadula) and had to be worn for eighteen to twenty-one hours each day until the end of the progressive period (up to Risser stage 3). The patient then entered the weaning period. In severe adolescent scoliosis (up to 45°-50° and over if the patient didn't want to be operated on or if surgery was not possible) the aim was at least to avoid progression (and surgery) and possibly to reduce the amount of curvature, which was presumed not to guarantee stability in adulthood. In these cases the brace was worn all day long for at least one year, and the most rigid ones were chosen (Risser cast and Lyon brace, or Sforzesco brace). Subsequently the wearing of the brace was gradually reduced, even if the hours were maintained up to eighteen per day until Risser stage 3. The weaning period [22] required a gradual increase in the hours without the brace while allowing the patient to be able to maintain the achieved correction. This is why we reduced the wearing of the brace by no more than two or three hours every six months, and why the stabilization exercises were considered so crucial during this period.

1.3.2. Exercise treatment

Exercises have been proposed, beyond the mere deformity, as the means to compensate--or to prevent, if possible--the secondary damages of scoliosis and brace treatment [22, 23]. Moreover, they have been prescribed to prevent scoliosis progression each time the risk of progression appeared significant and a brace could still be avoided [24]. Our aim with exercises was to avoid or at least postpone bracing, and to arrive at the end of growth with a presumably stable curvature (as far as possible from 30°, so that a maximum value between 20° and 25° has been considered acceptable) [25]. Exercises have been proposed in the following cases: evidence of scoliosis progression coming from radiographs and/or clinical changes superior to the known measurement error (5° for radiographs, 2° for Bunnell, 3 mm for hump height) [26, 27]; the starting radiographic and clinical data were near to the previously defined acceptable boundaries (i.e. approximately 15° Cobb, or 5° Bunnell, or 5 mm of hump) [24]; very high postural component, as evidenced by an important decompensation and/or by the Aesthetic Index [28]; high risks due to other known factors of progression, such as a family history of an important scoliosis, flat back, start of puberty, etc. [29, 25, 30]. When a brace had already been prescribed, exercises were always proposed in order to avoid all the side effects of bracing, to increase its function, and to allow the spine to be stable during the weaning period and when the brace was abandoned [24, 31].

The exercises were performed according to the SEAS (Scientific Exercises Approach to Scoliosis) protocol and the ISICO approach [22]. This consists of individually adapted exercises that are taught to the patients in a super-specialized structure dedicated to scoliosis treatment. The patients perform a single session of 1.5 hours every two to three months at our institute, in which they are evaluated by a physiotherapist with expertise in scoliosis, learn their own personalized exercise protocol, receive a TV record of their execution with the physiotherapist's suggestions, and engage in a meeting for family counseling in regard to scoliosis. The patients continue treatment at a rehabilitation facility near home (by themselves and/or with their parents) twice a week (forty minutes) plus one daily exercise at home (five minutes). The SEAS exercises are based on ASC (Active Self-Correction) [32], which is an active movement performed in order to achieve the maximum possible correction, the goal being to activate neuron-motor reflex corrective answers. The exercises are all performed with respect to ASC and are aiming towards spinal stabilization, the strengthening of the tonic antigravity muscles, the improvement of balance and coordination [33, 34, 35], the recovery and maintenance of physiologic sagittal curves, and full functional improvement according to the physiotherapeutic and medical evaluations. Therapists avoid increasing the spine's range of motion but instead focus mainly on spinal stability.

1.4. Outcomes

This is an everyday clinical study, so we must consider in our data analysis that the outcomes set during treatment are not standard and are usually defined case by case, according to a general medical reference setting and a criterion of acceptability of the patient and his/her family. In fact, basing our behavior on data from literature indicating the need to be as far as possible from the two recognized thresholds of scoliosis (50 degrees, i.e. the near certainty of progression in adulthood; and 30 degrees,

Table 3. Outcomes established during treatment for each single patient according to the starting curve. The absolute aim was for all patients to avoid surgery, but we also had the goal of obtaining an optimal result as stated in the table. When difficulties arise, and compliance lowers, or the curve offers higher resistance to treatment, a minimal outcome is in any cased envisaged.

		Minimal	**Optimal**	**Absolute**
S	**Minor (<20°)**	< 30°	<20°	Avoiding surgery
M	**Medium (20-29°)**		<25°	
L	**High (30-39°)**	stable	<30°	
XL	**Major (40°>)**	-5°	-10°	

i.e. possible progression) [8], and considering that risk does not mean the certainty of progression, we determined our counselling with patients and families and the choices of treatment. Accordingly, we started with fixed radiographic goals since they would presumably be the most important determinants of our patient's future [8], defined according to the starting point of treatment. These goals can be summarized in Table 3, which we use in the present study as a reference to verify the obtained results: They can be divided into absolute (avoiding surgery), minimal and optimal according to the starting point. In fact, starting with 50° curves, Risser 0 and the first signs of puberty, trying to obtain 30° at the end of treatment is almost always just a dream. On the contrary, we aim at finishing between 20° and 25° whenever possible. Given these goals, we continuously adapted ourselves to what we had obtained, as well as to how the patient behaved and felt, thus respecting the other aims as defined by SOSORT [8]. We established and constantly renewed a contract with the patient and his/her parents, who in this way were fully integrated within the rehabilitation team. This meant also obtaining some results in the most difficult patients: those who did not comply with our prescriptions for best results but nevertheless were able to reach a minimum result.

1.5. Statistical analysis

We performed two separate analyses of the data: the efficacy analysis related only to patients who completed treatment (EOT group), while in the worst-case analysis we included all patients (EOT+DO groups) and drop-outs were considered as failures. Patients have been classified as changed when their variation in Cobb degrees was at least of 5° Cobb. In the analysis of total data we considered the worst curvature of each patient and the average of patients' curvatures. We also split the results according to the topographic classification of scoliosis. We performed, according to what was appropriate, ANOVA, the Tukey-Kramer test, the paired t-test and chi-square analysis.

2. Results

At the start of treatment the patients in the XL group were, statistically speaking, considerably older than those in the other three groups, while in the DO group we had patients younger than in the EOT (see Table 1). Moreover, as expected, the treatments

Table 4. Clinical data of the four patients who dropped-out from treatment: The start picture, as well as the worst one during treatment, and the final radiographic data at the last evaluation before dropping out have been reported.

Patient	Curves	Start		Worst		Therapy			Drop-out	
		R	° Cobb	R	° Cobb	Brace	Years	Compliance	R	° Cobb
1	Thoracic	0	50	0	50	23 h	2.4	100%	0	50
	Lumbar		46		46					46
2	Thoracic	0	23	0	27	18 h	2.8	90%	2	19
	Lumbar		27		33					25
3	Thoracic	0	17	1	24	23 h	2.5	50%	3	24
	Lumbar		21		28					24
4	Thoracic	0	19	1	38	23 h	3.7	100%	2	33
	Lumbar		19		28					25

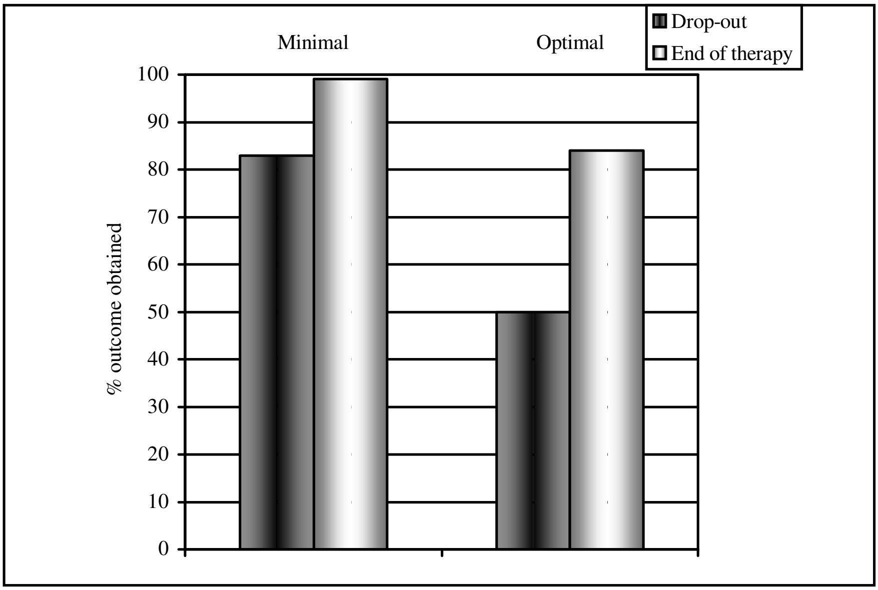

Figure 3. Percentage of patients who achieved the minimal and optimal results in the groups who reached the end of treatment, compared to those in the patients who dropped-out.

had to be more aggressive as the degree of curvature at first evaluation increased (see Table 2).

We had a total of four drop-outs, and one patient in the EOT group went to surgery. Accordingly, the rate of surgery was 0.9% in the efficacy analysis (EOT group), and 4.5% in the worst-case analysis (EOT+DO groups), where all drop-outs were included as failures. Looking individually at the patients who dropped out (see Table 4), one could raise reasonable doubts that all these patients but one would be operated on even

Table 5. Results of treatment in the total sample, as well as in the sub-groups identified according to the importance of the curve at start of treatment. Results have been listed according to the worst curve, their average, and their topographical localization.

	Total		Major (XL)		High (L)		Medium (M)		Minor (S)	
	Result	P	Result	P	Result	P	Result	P	Result	P
Worst curve	-2.8±5.7	<0.05	-8.3±6.7	<0.01	-4.2±5.5	<0.05	-3.6±4.6	<0.05	-0.8±5.3	NS
Average of curves	-2.1±5.3	NS	-5.4±6.4	<0.05	-3.1±5.7	NS	-2.5±5.1	NS	-0.9±4.9	NS
Thoracic proximal	3.5±6.5	NS	NA	NA	-0.5±3.5	NS	2.3±1.1	NS	+2.5±7.8	NS
Thoracic	-1.0±6.9	NS	-3.6±7.1	NS	-4.6±5.6	NS	-0.3±7.4	NS	+0.9±6.2	NS
Thoraco-lumbar	-3.2±6.1	NS	NA	NA	-2.0±1.4	NS	-4.2±4.7	NS	-2.9±7.0	NS
Lumbar	-2.9±6.3	NS	-10.0±5.0	<0.01	-1.1±8.1	NS	-4.0±5.8	<0.05	-0.9±5.0	NS

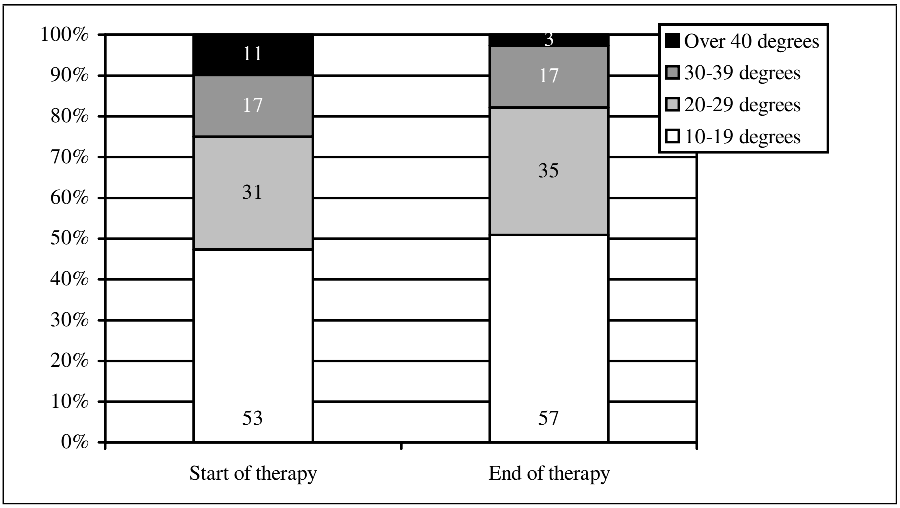

Figure 4. At the end of treatment only 3 patients were over 40 degrees of curvature (versus 11 at start), while 8 in total exit the "attention area" over 30° Cobb.

if closing the treatment at the time of drop-out (final results being obtained at the last evaluation with x-rays without brace). In this period of 3.4 years, of the study we had five major scoliosis patients who went to surgery.

According to our definition of the outcomes to be obtained in each single patient (see Table 3) the treatment produced a statistically significant reduction in the worst curvatures (with exclusion of the S group).

The minimal outcome had been obtained in 99% of patients in the group EOT (98% in the total), while the optimal outcome had been obtained in 84% (82%). The results in the DO group were much lower (see Figure 3).

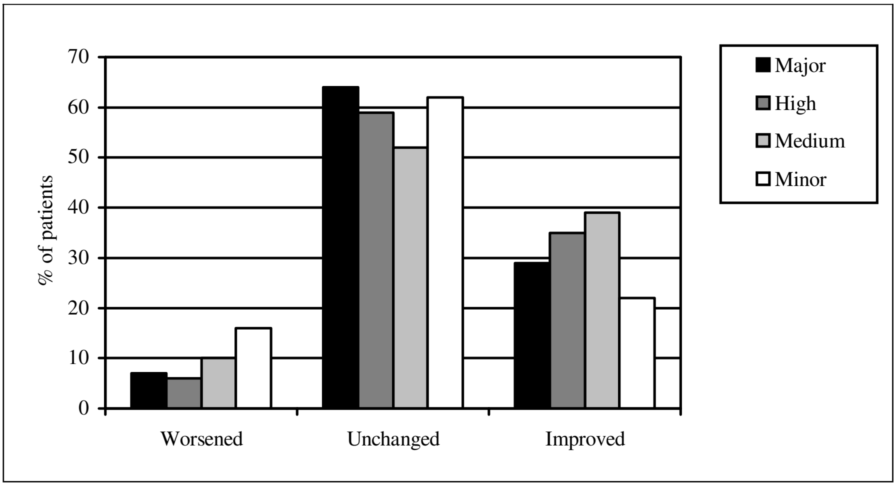

Figure 5. The worst results have been obtained in the Minor curves, where treatment was less aggressive and the aim was mainly stabilisation ; then the results increased from Medium to Major curves, even if worsened patients were in these groups always under 10%. This reveal that, when bracing is started because of the importance of the curve, orthosis obviously have better results in better curves.

Overall, the curves over 40°, which numbered eleven at the start of observation (XL group), reduced to three; in all, eight patients exited the presumable area of risk in adulthood (final curve over 30°) (see Figure 4). The treatment produced a statistically significant reduction in the worst curvatures (with exclusion of the S group). Looking at the single treated groups, the best results were obtained in the XL group, while according to the topographical distribution of curvatures, only the lumbar curvature had a reduction that proved to be statistically significant (see Table 5).

Percentage of patients who achieved the minimal and optimal results in the groups which reached the p), reduced to three; in all, eight patients exited the presumable area of risk in adulthood, compared to those in the patients who dropped-out. (final curve over 30°) (see Figure 4).

Another interesting analysis showed that the best results (larger number of patients improved) were obtained in the M group (20°-29° curves), while the number of positive results gradually decreased with increasing degree of curvature. The worst results were obtained in the S group (see Figure 5).

3. Discussion

The results presented in this study prove the efficacy of conservative treatment in reducing the surgery rate in scoliosis patients below the 28.1% that is reported in the literature of natural history [4]. In our study the average degree of curvature considered is lower (23.4°) versus 33°, but if we select only patients at least braced full-time (30.2°) the rate of surgery increases “only” to 1.9% according to the efficacy analysis and 9.1% for the worst-case one. In this case our results are consistent to those reported by other authors who apply a full conservative treatment, including exercises and not only braces, such as Weiss (7.3%) [16], Maruyama (5.5%) [18] and Rigo (5.6%) [17].

Table 6. The principles of brace treatment[22] include those of “efficacy” as well as “acceptability,” because compliance is a key factor in obtaining results.

The efficacy principles	The acceptability principles
Active brace: The patient is encouraged to move freely, thus increasing the corrective pushes against the brace. It is necessary freedom of movement to the limbs, perfect styling, and specific exercises;	**Perfect body design and minimal visibility**: Patients want correction and an invisible brace. When the brace is visible you must carefully justify it and be sure that it’s really necessary;
Mechanical efficacy: This is achieved through the correct positioning of pushes, as well as through the escape ways and proper drivers of the forces and stops;	**Maximal freedom in the Activities of Daily Life**: This is part of the active principle, but it also means comfort. Any unavoidable limitation must be motivated to the patient.
Versatility and adaptability: Changes in the growing child, and the need to adapt the pushes when checking the brace, require the continuous refinement of action.	**Assumption of responsibility**: This way you run risks with adolescents, but it is possible to achieve much better results.
Teamwork: CPOs, MDs, PTs and other allied professionals, very well trained and working together.	**Cognitive-behavioral approach** by the entire professional team.
Compliance: Bracing is useless without compliance due to the patient and family, and to these principles.	

The advantages of this study include:

- The methodological strength, greatly increased by the worst-case analysis, whereby all drop-outs are included as failures.
- The prospective design: This is, in fact, the only study where the term “drop-out” has been correctly applied, because of the prospective design, while all the others were retrospective. This is the main difference between our study and that of Rigo’s, where drop-outs were patients who did not return for the two years’ follow-up after the end of treatment, while in our case drop-outs were all patients who did not reach the end of treatment. Again, this gives more strength to the analysis.
- The outcome definition, which is totally new in the literature. In fact, we have to consider not only the surgery rate, nor we can bear in mind the reduction of curvature only. In fact, we have no interest in reducing the curvature in a patient with 16° Cobb, where we can even accept a worsening up to 8°-9° without causing such a patient any real health problem (and this is a clinical everyday reality). On the other hand, what we really want for the patients is a reduction when the curvature exceeds the range of 35°-40°.

The weak points of our study could include:

- It refers to the end of treatment, when the brace is finally taken out, with an x-ray after 48 hours without the brace, but not to a follow-up at least two years later, as in all the other studies. This could better our results to some degree, but it would reduce the overall importance of the study. In the near future we will monitor all these patients with an adequate follow-up: This was not possible now, since the database started only in 2003.

- The inclusion of low-degree scoliosis: In our opinion this is more a characteristic of our study and our clinical everyday behavior. In fact, we start treatment early, using what we consider the best, most adapted weapons for each single case, which could even serve to explain our good outcomes.
- The fact of considering only the radiographic outcomes but not the clinical ones (i.e. aesthetics, humps, sagittal plane, etc.): This will be done in the future.

The rate of surgery reported in the literature for curves of approximately 30° in studies where only braces were used ranges from 22.4% to 31% [21, 19, 20] (even if they have been claimed up to 43%-46%) [3], versus the reported natural history of 28.1% [4]. When a complete conservative approach is used, this rate decreases dramatically to the range of 3.8% to 7.3% [17, 18, 16] (with one study with a worst-case analysis whose rate was 14.1%) [17]. In our study, where the treatment approach is comparable to the last group, also results were comparable (1.9% for efficacy and 9.1% for worst-case analysis in our 30° curves). How can these different results (but comparable when grouped in two different cluster) be explained? Considering the outcome "rate of surgery," we should not neglect the insidious inherent bias due to the role of the physician who prescribes treatment. In fact, his ideas, his interpretation of the results of treatment, and the manner in which he speaks to the patient and family will greatly influence the choice of being more or less aggressive. This bias alone could almost totally explain the different results in the literature, while other justifications could be found in the failure of any of the principles of correction through bracing, being divided in terms of efficacy and acceptability (see Table 6) [22]. Particularly, a commitment to treatment greatly influences compliance.

In conclusion, provided the use of a complete conservative approach, there is very little doubt that it is possible to reduce the rate of surgery in AIS treatment.

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Quality of Life after Conservative Treatment of Adolescent Idiopathic Scoliosis

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Abstract. As an important consideration in medical care, health-related quality of life (HRQoL) refers to the patient's ability to enjoy normal life activities. When assessing the effectiveness of conservative treatment of AIS, HRQoL variables are more important than the radiographic results or pulmonary function. The present study examines the impact of conservative treatment in HRQoL of the AIS patients.

Thirty-two female patients with a mean age of 13.5 (range 12-16) years, a mean Cobb angle of 29.4° (range 21-38°) and a mean angle of trunk inclination (ATI) 7.9° (range 5°-18°) were treated with a full time application of a modified Boston brace and occasionally physiotherapy, for a minimum of 2 years. HRQoL was measured with the Brace Questionnaire (BrQ) at baseline and at the end of treatment. Correlations were determined by the Pearson correlation coefficient, with $p<0.05$ considered significant.

AIS patients scored lower in all the domains of BrQ at the end of treatment. This difference was statistically significant for the mean overall score of BrQ and for the domains of general health perception, physical functioning, emotional functioning, self-esteem and aesthetics, bodily pain and social functioning. The scores in the domains of vitality and school activity were not affected.

The HRQoL immediately after the end of conservative treatment of AIS is found to have been negatively affected. Because of limitations in study design, this finding does not necessarily implicate the conservative treatment itself, but highlights the importance of HRQoL measurement in assessing how AIS patients perceive the impact of their disease.

Keywords. Adolescent idiopathic scoliosis, health related quality of life, conservative treatment

Introduction

As an important consideration in medical care, health-related quality of life (HRQoL) refers to the patient's ability to enjoy normal life activities. HRQoL is a multi-dimensional construct composed of functional, physical, emotional, social and spiritual well-being [1] and has therefore become a leading criterion in many outcome studies alongside physical and economic factors. In the course of this development, the concept of HRQoL is clearly listed as outcome parameter in many medical societies' guidelines [2].

The aim of conservative treatment of adolescent idiopathic scoliosis (AIS) is the prevention of curve progression and the cosmetic improvement of the trunk. When assessing the effectiveness of conservative treatment of AIS, HRQoL variables such as physical and mental function, pain relief, and cosmesis are more important than the radiographic results or pulmonary function [3].

AIS is a chronic condition that affects the body configuration of the adolescent leading to certain alterations in lifestyle as a consequence. AIS itself has a quantifiable impact on several aspects of child and family functioning [4, 5]. The introduction of conservative treatment by an orthotic device, physiotherapy and/or an intensive rehabilitation program results in different psychological reactions during the initial period, such as panic [6], negative mood, depression, anger, or feelings of responsibility for illness [7, 8] and emotional disturbances of body image, self-esteem, and sexual attitudes [9, 10].

There is weak evidence in the literature regarding the impact of conservative treatment on HRQoL in patients with AIS. In the SOSORT 2005 consensus paper, it was reported that only 1.48% of studies on scoliosis included a measure of HRQoL [2]. Patients treated with a brace had a significantly higher mean score in the function / activity domain and better pain scores than patients treated surgically [11]. Danielsson et al. concluded that in conservatively treated patients, minimal pain occurred compared with normal controls [12] and that psychosocial well-being is quite good 20 years after brace or surgical treatment and is equal to the general population [13].

The present study examines the impact of conservative treatment in HRQoL of the AIS patients.

Material-Method

Thirty-two female patients, who attended the Scoliosis Clinic of the Orthopaedic Department of Thriasio General Hospital at Athens, Greece, were included in the study. They had a mean age of 13.5 (range 12-16) years, a mean Cobb angle of 29.4^o (range 21-38^o) and a mean angle of trunk inclination (ATI) 7.9^o (range 5^o-18^o). All the patients were treated conservatively with a full time application of a modified Boston brace with antirotatory blades [14], and occasionally physiotherapy. HRQoL was measured with Brace Questionnaire (BrQ) [15] at baseline and at the end of treatment. The minimum duration of conservative treatment was 2 years.

BrQ is a validated, disease specific instrument, its score ranges from 20 to 100 and higher BrQ scores mean better quality of life. It consists of eight specific domains, namely a) general health perception, b) physical functioning, c) emotional functioning, d) self-esteem and aesthetics, e) vitality, f) school activity, g) bodily pain and h) social functioning.

Correlations were determined by the Pearson correlation coefficient, with $p<0.05$ considered significant. The SPSS v.12 statistical package was used for the statistical analysis.

Results

The results from the statistical analysis are summarized in Table 1.

AIS patients scored lower in all the domains of BrQ at the end of treatment. This difference was statistically significant for the mean overall score of BrQ and for the domains of general health perception, physical functioning, emotional functioning, self-esteem and aesthetics, bodily pain and social functioning. The scores in the domains of vitality and school activity were not affected (see Table 1).

Table 1. The mean BrQ overall and domain scores (SD= Standard Deviation) at baseline and at the end of treatment and their correlations. *Correlation is significant at the 0,05 level

BrQ Domains	Mean score at baseline	Mean score at the end of treatment	Statistical significance	
General health perception	91,0 (SD 8,8)	80,0 (SD 18,9)	p value	0,000
			Pearson Correlation	0,942
Physical functioning	68,7 (SD 13,5)	55,4 (SD 15,9)	p value	0,000
			Pearson Correlation	0,921
Emotional functioning	79,4 (SD 20,3)	68,2 (SD 26,8)	p value	0,000
			Pearson Correlation	0,947
Self esteem and aesthetics	81,0 (SD 15,2)	68,0 (SD 29,7)	p value	0,000
			Pearson Correlation	0,912
Vitality	63,0 (SD22,6)	55,0 (SD 25,9)	p value	0,220
			Pearson Correlation	0,426
School activity	99,0 (SD1,8)	98,0 (SD 4,5)	p value	0,969
			Pearson Correlation	0,014
Bodily pain	88,0 (SD 10,6)	84,4 (SD 12,9)	p value	0,000
			Pearson Correlation	0,937
Social functioning	89,2 (SD 9,5)	83,1 (SD 16,3)	p value	0,020
			Pearson Correlation	0,839
BrQ overall score	85,0 (SD 10,2)	73,8 (SD 15,8)	p value	0,000
			Pearson Correlation	0,953

Discussion

AIS may lead to multiple physical and psychosocial impairments depending on its severity [16]. Unfortunately, most studies in the literature are comparing HRQoL between surgically treated AIS patients and the normal population [13, 17, 18] or between brace and surgically treated AIS patients. [13, 17, 19, 20]. There are no HRQoL measurements in untreated AIS patients and the various disease specific instruments like BrQ have not been established for healthy persons. Therefore, it is still unclear whether an impairment of the HRQoL really exists before treatment of AIS.

The results of the present study indicate that the HRQoL of AIS patients is moderately affected immediately after completion of conservative treatment. Vitality shows a low score at baseline which remains low at the end of treatment and therefore is unchanged. On the other hand school activity shows a high score both at baseline and at the end of treatment. All the other domains of the BrQ, including the BrQ overall score were deteriorated statistically significant after conservative treatment.

The present study attempts to measure HRQoL of adolescents or young adults immediately after completion of conservative treatment, and shows that it is negatively affected, although moderately. An immediate improvement in HRQoL after conservative treatment of AIS will not be seen, and is not even expected. In the course of time, and long after brace weaning, patients seem to experience HRQoL scores similar to the general population [13, 17, 21]. One possible explanation could be the production of stress which is reported during conservative treatment with orthotic devices [4, 9, 22, 23, 24]. In a previous study we found that the brace stiffness and rigidity may affect the physical functioning and vitality while its impact on emotional functioning, self-esteem, aesthetics and social functioning was limited [3].

The present study does not implicate that AIS patients' HRQoL is poor when compared to normal individuals, as this was not the scope of the study. Furthermore, it cannot distinguish whether the negative impact is the result of the AIS itself or the result of the conservative treatment. However, it would be extremely interesting to measure HRQoL longitudinally during the course of conservative treatment and to identify when this deterioration occurs and which factors are associated with it.

Conclusion

The HRQoL immediately after the end of conservative treatment of AIS is found to have been negatively affected. Because of limitations in study design, this finding does not necessarily implicate the conservative treatment itself, but highlights the importance of HRQoL measurement in assessing how AIS patients perceive the impact of their disease.

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Author Index

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