Spinal mobility, muscle strength and function in patients with idiopathic scoliosis

Different aspects on long term outcome

Karin Romberg

Department of Health and Rehabilitation
Institute of Neuroscience and Physiology
Sahlgrenska Academy, University of Gothenburg

UNIVERSITY OF GOTHENBURG

Gothenburg 2019

Cover illustration: Luc Tuymans, Bend Over, 2001, Oil on canvas, 60 x 60 cm,.Private collection, London

Spinal mobility, muscle strength and function in patients with idiopathic scoliosis – Different aspects on long term outcome

Karin.Romberg@gu.se

ISBN 978-91-7833-670-8 (PRINT)
ISBN 978-91-7833-671-5 (PDF)
http://hdl.handle.net/2077/60767

Printed in Gothenburg, Sweden 2019
Printed by BrandFactory

"Life is like riding a bicycle. To keep your balance, you must keep moving".

Albert Einstein

Spinal mobility, muscle strength and function in patients with idiopathic scoliosis

Different aspects on long term outcome

Karin Romberg

Department of Health and Rehabilitation, Institute of Neuroscience and Physiology
Sahlgrenska Academy, University of Gothenburg
Gothenburg, Sweden

ABSTRACT

Introduction: The long-term physical function outcome in patients treated for idiopathic scoliosis (IS) during childhood and adolescence has not been fully explored. In addition, there is a lack of studies where different methods to measure pulmonary function are validated in patients with early onset scoliosis. The aims of this thesis were to evaluate the outcome in terms of spinal mobility, trunk muscle endurance, back pain and function, thoracic mobility and its relation to pulmonary function and ribcage deformity in patients with IS in a long term perspective and also to evaluate the criterion validity of different methods for measuring pulmonary function in middle-aged patients with early onset idiopathic scoliosis (EOS) and to establish if any of those methods could be a valid, easy to perform and inexpensive tool to use in clinical practice.

Patients and methods: In *study I*, 237 patients with adolescent idiopathic scoliosis (AIS), either brace treated (BT) (n=102) or surgically treated (ST) (n=135) attended a follow-up. Their spinal mobility and trunk muscle endurance were evaluated and questionnaires covering their general and disease specific quality of life, as well as present back function and pain were used. An age- and sex-matched control group without scoliosis (n=100) was randomly selected. In *study II*, 106 patients with EOS (BT n=57, ST n=49) treated during childhood and adolescence. Their thoracic mobility (range of motion of the thoracic spine, thorax expansion and breathing movements) and its relation to pulmonary function and ribcage deformity (curve size and trunk deformity) was evaluated and their results compared to reference values. In a subgroup of 33 patients respiratory muscle strength was evaluated. In *study III*,

116 EOS patients (BT n=63, ST n=53), were evaluated in terms of spinal mobility and trunk muscle endurance. They were compared to 40 patients with untreated AIS, and to the AIS patients from study I. In *study IV*, the validity of five methods measuring pulmonary function was evaluated in 33 EOS patients.

Main results: *Study I*, lumbar spinal mobility and trunk muscle endurance were reduced in both BT and ST patients with AIS. For the ST patients a greater lumbar spinal mobility as well as better trunk muscle endurance were found to correlate with better measures of physical function. For the BT patients a reduced lumbar spine range of motion (ROM) was found to correlate with higher pain intensity, and larger extension of both lumbar and all over the body pain. *Study II*, thorax expansion and breathing movements were significantly reduced in both BT and ST patients with EOS. The respiratory muscle strength was significantly lower only in the ST patients when compared to reference values. The results of a multivariate analysis revealed that the strongest factors explaining total lung capacity (TLC) % of predicted were gender, brace model and smoking habits. *Study III*, spinal mobility and trunk muscle endurance were similar in BT patients with EOS and untreated patients with AIS. The BT patients with EOS were significantly more mobile and had longer trunk muscle endurance than the BT patients with AIS. The ST patients with EOS were neither weaker nor stiffer than the ST patients with AIS. The degree of total lumbar ROM was found to affect back function in the ST group with EOS. *Study IV*, there were strong correlations between the vital capacity (VC) measurements by plethysmography and the measurements by handheld spirometer, CT scan and thorax expansion for middle-aged patients with EOS.

Conclusions: For braced as well as operated patients with AIS, lumbar spinal mobility and muscle endurance were reduced more than 20 years after completed treatment. The self-reported physical function was however, not severely restricted.

In patients with EOS, BT as well as ST, thorax expansion and breathing movements were reduced more than 20 years after completed treatment. TLC values as a measurement of pulmonary function was influenced by gender, brace model, smoking habits, thorax expansion and curve size at start of treatment. Patients with scoliosis should therefore be strongly advised not to smoke.

For braced EOS patients, at mean 26.5 years after completed treatment, both spinal range of motion and trunk muscle endurance were similar to that of untreated AIS patients. The EOS patients, despite a significantly longer bracing period, were more mobile and had longer muscle endurance than the braced AIS patients. The operated EOS patients were neither weaker nor stiffer than the operated AIS patients, despite somewhat longer fusions in the EOS group.

There were strong correlations between VC measured by spirometry by plethysmography and measurements by a handheld spirometer, CT scan, and thorax expansion for middle-aged patients with EOS. Therefore, thorax expansion and handheld spirometer, both cheaper and less time-consuming, can be useful tools for early detection of reduction of pulmonary function during daily clinical practice.

Keywords: idiopathic scoliosis, long-term outcome, spinal mobility, trunk muscle endurance, back function, thoracic mobility, pulmonary function, validity

ISBN 978-91-7833-670-8 (PRINT)
ISBN 978-91-7833-671-5 (PDF)

http://hdl.handle.net/2077/60767

SAMMANFATTNING PÅ SVENSKA

Skolios är en krökning i sidled av ryggraden med en Cobbvinkel på minst 10 grader. Tidig debut av skolios före 10 års ålder innebär en ökad risk för försämrad lungfunktion. Debut efter 10 års ålder är den vanligaste formen. Behandling under barndomen och ungdomen sker med stel plastkorsett eller steloperation av ett flertal ryggkotor. Det saknas till stor del långtidsresultat av fysisk funktion hos dessa patienter. Det saknas också validering av olika metoder som mäter lungfunktion hos patienter med tidigt debuterad skolios. Syftet med denna avhandling är att i ett långtidsperspektiv utvärdera ryggrörlighet, uthållighet i bålmuskulatur, ryggsmärta och funktion, bröstkorgsrörlighet relaterat till lungfunktion och bröstkorgsdeformation hos patienter med idiopatisk skolios (idiopatisk=okänd orsak) samt att utvärdera validiteten hos olika metoder för att mäta lungfunktion hos medelålders patienter med tidigt debuterad skolios och bedöma ifall det finns mätmetoder som både är valida samt är lätta och billiga att använda i den kliniska vardagen.

Studie I: Minst 20 år efter avslutad behandling undersöktes 237 patienter (102 korsettbehandlade, 135 opererade) med skoliosdebut efter 10 års ålder. Rörligheten i ryggen och uthålligheten i bålmuskulaturen utvärderades, samt ryggspecifikt livskvalitetformulär, och jämfördes med en frisk kontrollgrupp. Rörligheten i lumbalryggen och uthålligheten i bålmuskulaturen var nedsatt hos båda patientgrupperna. Deras självrapporterade fysiska funktion uppvisade däremot ingen betydande nedsättning.

Studie II: Minst 26 år efter avslutad behandling undersöktes 106 patienter (57 korsettbehandlade, 49 opererade) med skoliosdebut före 10 års ålder. Rörligheten i bröstryggen, thoraxexpansion och andningsrörelser undersöktes och jämfördes med referensvärden. I en subgrupp med 33 patienter undersöktes styrkan i andningsmuskulaturen. Thoraxexpansion och andningsrörelser var nedsatt hos båda patientgrupperna. Styrkan i andningsmuskulaturen var signifikant lägre bara hos de opererade patienterna jämfört med referensvärden. En multivariat analys visade att de starkaste faktorerna för att förklara den totala lungkapaciteten (TLC% predicted) var kön, korsett typ och rökvanor. Patienter med skolios bör därför starkt avrådas från att röka.

Studie III: Minst 26 år efter avslutad behandling undersöktes 116 patienter (63 korsettbehandlade, 53 opererade) med skoliosdebut före 10 års ålder. Rörligheten i ryggen och uthålligheten i bålmuskulaturen utvärderades och jämfördes med resultaten från grupper med obehandlade och behandlade patienter med sent debuterad skolios. Ryggrörlighet och uthållighet i bålmuskulaturen hos den korsettbehandlade gruppen visade sig vara likartad jämfört med den obehandlade och bättre jämfört med de korsettbehandlade med sen debut, trots att gruppen med tidig debut var korsettbehandlade längre tid. Den opererade gruppen hade ungefär samma resultat som den opererade gruppen med sen debut, trots att gruppen med tidig debut hade något längre steloperationer.

Studie IV: Hos 33 patienter med tidigt debuterad skolios mättes lungfunktionen med spirometri (pletysmograf), CT, spirometri (handhållen), andningsrörelser (RMMI) och thoraxexpansion. Det visade sig finnas starka samband mellan mätningarna med spiromteri (pletysmograf) som är ”gold standard” och mätningarna med CT, spirometri (handhållen) och thoraxexpansion. Spirometri (handhållen) och thorax expansion är valida, billiga och icke tidsödande metoder, användbara i den dagliga praktiken för att tidigt upptäcka nedsatt lungfunktion.

LIST OF PAPERS

This thesis is based on the following studies, referred to in the text by their Roman numerals.

I. Danielsson A. J, Romberg K, Nachemson A. L. Spinal range of motion, muscle endurance, and back pain and function at least 20 years after fusion or brace treatment for adolescent idiopathic scoliosis: a case control study. Spine. 2006;31(3):275-83.

II. Romberg K, Fagevik Olsén M, Kjellby-Wendt G, Lofdahl Hallerman K, Danielsson A. Thoracic mobility and its relation to pulmonary function and ribcage deformity in patients with early onset scoliosis – a long-term follow-up. Accepted for publication in Spine Deformity.

III. Romberg K, Danielsson A, Fagevik Olsén M, Kjellby-Wendt G. Spinal mobility and muscle function in middle-aged patients treated for early onset idiopathic scoliosis – compared with untreated and treated adolescent onset patients. To be submitted.

IV. Romberg K, Johnsson Å. A, Danielsson A, Fagevik Olsén M, Kjellby-Wendt G. Validity of five methods to measure the pulmonary function in patients with early onset scoliosis. To be submitted.

Reprints were made with permission from the publishers.

CONTENT

ABBREVIATIONS IV
1 INTRODUCTION 1
SCOLIOSIS 3
Definition 3
Epidemiology and etiology 3
Classification 6
IDIOPATHIC SCOLIOSIS 7
Natural history 8
TREATMENT OF SCOLIOSIS 9
Conservative treatment 9
Surgical treatment 10
FUNCTION AND OUTCOME MEASURES IN SCOLIOSIS 12
Spinal range of motion, trunk muscle endurance, back function and pain 12
Pulmonary function, thoracic mobility, and respiratory muscle strength 13
Validity and reliability of measurements 14
GAPS IN KNOWLEDGE 16
2 AIMS OF THE THESIS 17
3 PATIENTS AND METHODS 18
STUDY POPULATION 18
METHODS 24
Examination of the spinal deformity 24
Examination of the pulmonary function 24
Validation of pulmonary measurements 25
Evaluation of spinal mobility 25
Evaluation of trunk muscle strength 28
Evaluation of thoracic mobility and respiratory muscle strength 29
Questionnaires 31

PROCEDURES STUDY I-IV ... 33
ETHICS ... 34
STATISTICAL ANALYSES ... 35
4 SUMMARY OF RESULTS ... 36
STUDY I ... 36
STUDY II ... 39
STUDY III ... 42
STUDY IV ... 43
5 DISCUSSION ... 45
SPINAL RANGE OF MOTION, MUSCLE STRENGTH AND FUNCTION ... 45
THORACIC MOBILITY AND RESPIRATORY MUSCLE STRENGTH ... 47
VALIDITY OF METHODS MEASURING PULMONARY FUNCTION ... 49
STRENGTHS AND LIMITATIONS ... 50
CLINICAL RELEVANCE ... 52
6 CONCLUSIONS AND FUTURE PERSPECTIVES ... 53
CONCLUSIONS ... 53
FUTURE PERSPECTIVES ... 54
7 ACKNOWLEDGEMENT ... 55
8 REFERENCES ... 57

ABBREVIATIONS

AIS	Adolescent idiopathic scoliosis
AP	Anterior-posterior
BT	Brace treated
C	Cervical
CI	Confidence Interval
CT	Computed tomography
CTR	Control group
EOS	Early onset idiopathic scoliosis
FVC	Forced vital capacity
FEV1	Forced expiratory volume in one second
HRQL	Health related quality of life
IS	Idiopathic scoliosis
L	Lumbar
MIP	Maximal inspiratory pressure
MEP	Maximal expiratory pressure
ODI	Oswestry Disability Index
RMMI	Respiratory movement measuring instrument
ROM	Range of motion
RV	Residual volume
SD	Standard deviation
ST	Surgically treated
T	Thoracic
TLC	Total lung capacity
VC	Vital capacity

1 INTRODUCTION

In the ancient world, as far back as 3500 BC, works of religion, philosophy and myths refer to images of spinal deformity (1). A fresco of boxing boys dated 1600 BC in Akrotiri, Greece is the first image recognizable as a spinal disorder, spondylolisthesis, by modern medical standards (1). The first systematic description of the anatomy and pathology of the human spine was written by Hippocrates (460-370 BC) in ancient Greece (1). He introduced the terms kyphosis and scoliosis and described diagnosis and treatment of those deformities. The term scoliosis had general meaning in his works and was used to describe all spinal deformities (1). Hippocrates and another well-known physician of antiquity, Galen of Pergamon (130-200 AD) recommended extension treatment for spinal deformities based on fundamental principles still valid today (1). Thus this type of treatment with extension of the spine has remained in use through the centuries in various forms (2).

The first supportive braces used to treat spinal deformities were developed in the 16th century (3). Prior to the development of the removable orthoses, nonoperative treatment of scoliosis was attained by correcting casts (3). When it became understood that bracing until skeletal maturity was required to prevent progression of the scoliosis the modern era of brace treatment began (3). The Milwaukee brace, also called CTLSO (cervicothoracolumbosacral orthosis), was developed in 1946 as a nonoperative treatment of adolescent idiopathic scoliosis (AIS) with the aim to prevent progression of the curve and to avoid surgery (4-7). This was the first brace that proved to be effective in controlling the curve and altering the natural history of curves 20˚-39˚ (7). The Milwaukee brace was designed with suprastructures such as mandibular and occipital distraction (8). Several other different kinds of braces exist and have been in use over the years such as the Wilmington brace, the Charleston brace and the Cheneau brace (9-12). The Boston bracing system was introduced in 1971 by Hall and Miller (13). The Boston brace, a pre-fabricated underarm brace without suprastructures, also called TLSO (Thoracolumbosacral orthosis), became widely used and is, if worn 22 hours a day, successfully preventing progression of the curve (8, 14-16). The Providence night time brace, worn at least 8 hours every night, was developed in the 1990s due to poor compliance with the full time bracing and came more widely into use in the early 2000s (17).

In the modern era the surgical treatment of scoliosis had been via surgical spinal fusion supplemented by the turnbuckle cast until the 1950s (18). The polio epidemics in the early 1950s lead to many cases of neuromuscular scoliosis (19). Paul Harrington, confronted with many polio patients with scoliosis and decreased pulmonary function, was acknowledged to be the first to use a hook-rod system for spinal correction and to support fusion (19). In the 1950´s surgical treatment with Harrington rods, hooks, extension and fusion of the spine came into use worldwide and proved lasting results (20). During the following decades surgical methods have been further developed and refined.

Long-term studies are necessary to evaluate the treatment of growing individuals. However, there are several problems in performing these studies, for instance difficulty in following patients over decades, study costs, evolving and changing treatments. Even though a number of long-term follow-up studies of patients treated for idiopathic scoliosis (IS) have been published (21-29) there is a need to further study the long term effects concerning spinal range of motion and trunk muscle endurance and their effect on pulmonary function and back function.

SCOLIOSIS

Definition

Scoliosis is defined as a three dimensional deformity of the spine with a lateral bending on the radiograph of at least 10 degrees Cobb angle (30), in conjunction with an axial rotation component, as stated by the Scoliosis Research Society (SRS) (31).

Scoliosis can be either functional or structural and this thesis will focus on structural scoliosis. Structural scoliosis means there is an alteration in the shape of the vertebra which leads to a rotational deformity of the spine (32). A deformity in the thoracic spine also leads to a deformation of the chest and therefore pulmonary function may be affected (33). The etiology of structural scoliosis can be classified into either neuromuscular, congenital, related to various syndromes, iatrogenic or idiopathic (32). The term idiopathic scoliosis, meaning that the etiology is unknown, was introduced by Kleinberg in 1922 (34) and is applied when it is not possible to find a specific disease that causes the deformity (31).

Epidemiology and etiology

In about 20% of cases scoliosis is secondary to other pathological processes and in 80% scoliosis is idiopathic (31). Early onset idiopathic scoliosis (EOS) and adolescent idiopathic scoliosis (AIS) affect the growing spine in children and adolescents. There is also an adult form of scoliosis that occurs after skeletal maturity and is defined as a spinal deformity with a Cobb angle of more than 10˚ in the frontal plane (35). However, in this thesis only idiopathic scoliosis with early onset and adolescent onset is discussed. Research into the topic has focused on many different areas and has shown a complex pathophysiology (36). Although idiopathic scoliosis may be divided into infantile, juvenile or adolescent based on the time of onset, most of the research has focused on adolescent idiopathic scoliosis (AIS). No single cause for the development of idiopathic scoliosis has been identified and the consensus is that the etiology is multifactorial (30, 36, 37). Factors likely to be related to the development of idiopathic scoliosis (IS) are genetic factors, abnormal biomechanical forces, neurophysiologic predisposition, hormonal factors (melatonin, oestrogen), growth hormone, connective tissue abnormality, muscle structure and vestibular function (36, 37).

Hereditary factors play a role in the etiology of IS and were described by Garland as early as in the 1930s (38). The present understanding is that IS has a polygenic background and is probably due to a diversity of genetic risk variants ranging from very rare to very common in the general population (39). Still, other unknown factors might also be important for the development of the disorder (40). An estimation of heritability of scoliosis studied in data from the Swedish Twin Registry showed that only 38% of the variance in the likelyhood of developing scoliosis is due to additive genetic effects and 62% due to environmental effects (40). Adolescent idiopathic scoliosis (AIS) with a Cobb angle of 10 degrees or more occurs with a prevalence of 2-3% (65% girls). Approximately 0.3% develop a curve size of more than 30 degrees and require treatment with brace or surgery (90% girls).

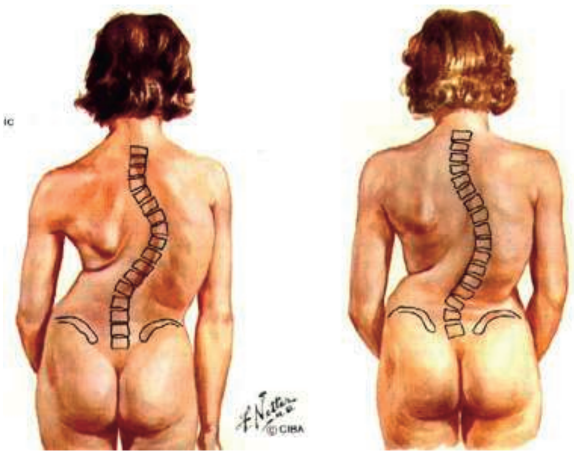


*Figure 1***.** Thoracic curve and thoraco-lumbar curve.

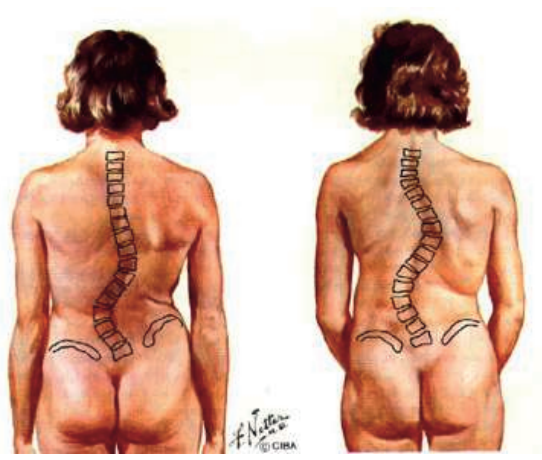


Figure 2. Lumbar curve and double primary curve.

Classification

Curve type

There are several systems to classify scoliosis. Cobb was the first to describe structural and non-structural curves, major and minor curves and accordingly guidelines for treatment in 1948 (41). Thirty-five years later King and Moe presented a classification system for AIS, based on the experience of the surgical treatment, where five curve types were defined (42). With the aim to help predict treatment when planning surgery Lenke presented a classification system for scoliosis and described six curve types as structural or non-structural and also used lumbar spine modifier and thoracic sagittal modifier to classify the curve type in 2001 (43).

Curve pattern

The manifestation of scoliosis is divided into single, double or triple curves and classification according to location is either thoracic (apex between Th2 and Th11-Th12 disc), thoracolumbar (apex between Th12 and L1) or lumbar (apex between L1-L2 disc and L4-L5 disc), determined by the apex (30, 32) (Figure 1-2).

Curve size

Classification according to curve size can be described as mild scoliosis (up to 20˚), moderate scoliosis (21˚-35˚), moderate to severe scoliosis (36˚-40˚), severe scoliosis (41˚-50˚), severe to very severe scoliosis (51˚-55˚) and very severe scoliosis (56˚ or more) (31). The angle of the scoliosis is measured using the Cobb method on a standing frontal radiograph. The measurement error of this measuring method is approximately 5˚ when measured manually, but somewhat less with computer assisted measurement (31).

Time of onset

Idiopathic scoliosis can be divided into infantile (0-3 years of age), juvenile (4-9 years of age) and adolescent (from 10 years to end of growth), based on the time of the onset (44, 45). Today the terms early onset and late onset, meaning onset before and after the age of ten, are commonly used. If the individual is skeletally mature at the time of the diagnosis the deformity will be defined as adult scoliosis (31, 35). However, in this thesis only scoliosis with early onset and adolescent onset is discussed.

IDIOPATHIC SCOLIOSIS

Early onset

Early onset idiopathic scoliosis (EOS) is defined as a spinal deformity with onset before the age of ten (46). Less than 16% of the patients with scoliosis have the diagnose EOS. Among the younger children the proportion between girls and boys is approximately the same, but among the older the proportion girls to boys is 8:1. In the 1960´s long term studies of the prognosis of scoliosis was considered poor with decrease of pulmonary function and shortened life span (47, 48). In 1992 a study of mortality in idiopathic scoliosis established that untreated EOS patients run a significantly increased risk for respiratory failure and premature death (49). This is probably due to restricted lung development during childhood which results in lower number of alveoli and also to altered biomechanics of the rib cage (50, 51). When EOS increases to a large curve size this results in chest deformity with subsequently reduced chest- and lung volume (33). A long term follow up showed that more than 20 years after completed treatment with brace or surgery the pulmonary function was preserved in most of the patients (25). However, reduced pulmonary function was obvious among the individuals with onset before the age of six who had undergone surgery due to severe curves (25). Reduction in pulmonary function before treatment was the strongest predictor for pulmonary function long time after treatment (25).

Adolescent onset

Adolescent idiopathic scoliosis is the most frequent type of idiopathic scoliosis. It affects 1-3% of children aged 10-16 years, 85% of them girls (52). Most untreated adult patients with AIS who have moderate curve size after skeletal maturity can function well and live an acceptable life in terms of work and family although back pain is more frequent (23, 53, 54). Large thoracic curve size may be associated with pulmonary symptoms but does not lead to increased mortality (23, 53, 54). The treatment aims of AIS therefore tend to be cosmetic rather than life saving.

Natural history

The natural history of a condition can be defined as the progression of a disease process in an individual over time and in absence of treatment and it provides us knowledge of the adult consequences of that entity (55).

Curve progression before skeletal maturity depends on curve related factors. Bunnell studied the risk factors for predicting curve progression of IS before skeletal maturity and determined gender, curve pattern, curve severity, age at diagnosis, menarche and Risser sign as risk factors (56).

In the 1960s long term studies of the prognosis of scoliosis was considered poor with decrease of pulmonary function and shortened life span (47, 48). In 1992 a study of mortality in idiopathic scoliosis established that untreated EOS patients run a significantly increased risk for respiratory failure and premature death (49). Patients, younger than nine years of age, with proximal thoracic deformity who need fusion of more than four segments are at the risk for developing restrictive pulmonary disease (57). To delay definitive surgery the use of brace or growing instrumentation delaying may prove beneficial in maintaining pulmonary health (58, 59).

Most of the untreated adult patients with AIS who have moderate curve size after skeletal maturity can function well and lead an acceptable life in terms of work and family although back pain is more frequent (23, 53, 54). Large thoracic curve size may be associated with pulmonary symptoms but does not lead to increased mortality (23, 53, 54).

TREATMENT OF SCOLIOSIS

Conservative treatment

Brace treatment

Brace treatment of scoliosis is still the only documented effective non-operative treatment. The aim is to prevent progression of the curve and alter the natural history of scoliosis. Brace treatment is initiated when the curve size is 25˚-35˚ and the full-time brace is worn 22-23 hours a day until skeletal maturity. The Milwaukee brace came into use in 1954 and was the first brace that proved to be effective in controlling the curve and altering the natural history of curves 20˚ to 39˚ (7). The Milwaukee brace also called CTLSO (cervico thoracolumbosacral orthosis) was designed with suprastructures such as mandibular and occipital distraction (8). The Boston bracing system was introduced in 1971 (13). The Boston brace, a pre-fabricated underarm brace without suprastructures also called TLSO (Thoracolumbosacral orthosis) became widely used and is, if worn 22 hours a day, successfully preventing progression of the curve (8, 14-16).

Poor compliance with full time bracing led to search for a more acceptable alternative. Climent and Sanchez (60) found that the night time braces had the least negative effect on psychosocial functioning, sleep disturbance, back pain, back flexibility and body image. The Providence night time brace was developed in the 1990s and came more widely into use in the early 2000s. This brace achieved a greater correction or overcorrection of the curve and should be worn at least 8 hours every night (17). It was initially used in patients with thoracolumbar or lumbar curves and 74% did not progress more than 5˚ (17). The Providence nighttime brace has been evaluated and proved to be equally efficient as full-time braces (17, 61, 62).

However, there are some studies showing poor results of brace treatment (63-65). There is a lack of uniformity of the parameters in the different bracing studies which obstructs reliable and valid comparisons. Scoliosis Research Society (SRS) Committee on Bracing and Nonoperative Management emphasizes the need for guidelines in bracing studies and the importance to define consistent parameters for inclusion criteria and to define consistent parameters to evaluate the effectiveness of brace treatment of AIS patients (66).

Figure 3. Milwaukee brace.

Figure 4. Boston brace.

Exercises

The best-known exercise treatment for scoliosis is the Schroth method. This treatment with specific postural correction, correction of breathing patterns and correction of postural perception was developed by a German physiotherapist named Katharina Schroth in the 1920s (67). This method and a few others, such as SEAS (Scientific Exercise Approach to Scoliosis), have been evaluated and effects on mild curves suggested although the evidence have been considered insufficient and more research is needed (68-72).

Surgical treatment

When the curve size in growing children or adolescents has progressed to a Cobb angle of 40˚-50˚ the patient will usually be surgically treated. Curve magnitude, curve pattern, skeletal maturity, risk of progression, clinical deformity and symptoms are also indications for surgery (73). The first method with long-lasting results was surgery with the Harrington instrumentation with long rods, hooks at the upper and lower ends and a posterior spinal fusion (20).

The correction of the scoliosis was about 50% and postoperatively a Milwaukee brace was worn for 6-12 months. The current gold standard for surgical treatment of patients with AIS is posterior spinal fusion with pedicle screws (74-76). This method allows a three-dimensional correction of the deformity (75). The correction of the scoliotic curve is about 80%, no brace is needed postoperatively and consequently considerably fewer restrictions for the patients (74-77). Nowadays patients are able to return to some level of sport about 6 months after spinal surgery (78). Back pain and health related quality of life (HRQL) was evaluated in patients with AIS and showed improvement five years after posterior spinal fusion with pedicle screws compared to untreated patients (79). Their HRQL was similar to that of a healthy control group in all domains except function (79).

Figure 5. Harrington rod.

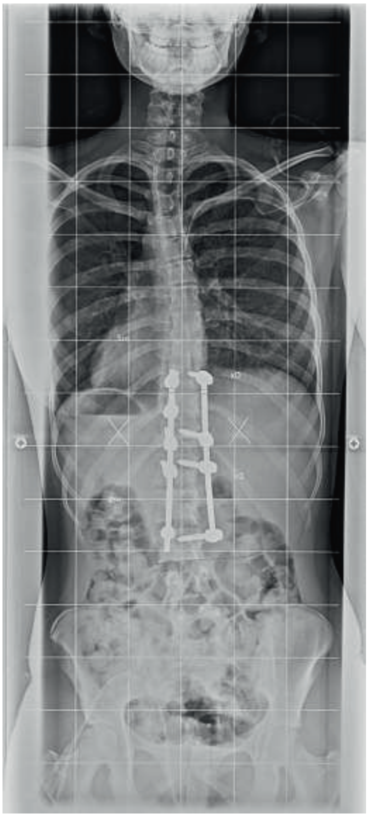


Figure 6. Expedium instrumentation.

FUNCTION AND OUTCOME MEASURES IN SCOLIOSIS

Spinal range of motion, trunk muscle endurance, back function and pain

Spinal range of motion

Mobility of the joints in the spine depends on anatomic structures and the flexibility of ligaments and discs (80). Mattson et al. (81) found that the overall joint flexibilities in girls with scoliosis were not larger than in the control group. The forward flexion in the scoliotic girls was more reduced than in the nonscoliotic control group (81). The effect of scoliosis on the range of motion (ROM) of different planes is important knowledge for evaluation of patient function. Eyvazov et al. (82) found that coronal curve severity is associated with reduced axial and coronal ROM. On the contrary, Galvis et al. (83) found that AIS patients did not have a reduced sagittal or coronal mobility, they had a greater mobility, especially in the segments directly above and below the apex. In surgically treated patients Engsberg et al. (84) found that range of motion was reduced in the fused as well as in unfused regions of the spine. These patients were however 12-18 years old and the tests were performed 12-24 months after surgery (84). Poussa et al. (80) found no change of the general spinal flexibility in girls with scoliosis. Wren et al. (85) examined the relationship between spine morphology, spine flexibility and idiopathic scoliosis and found that girls with scoliosis have smaller vertebrae relative to intervertebral disc height compared to girls without scoliosis. They also found the lateral bending to be associated with smaller vertebrae and taller intervertebral discs (85).

Trunk muscle endurance

The trunk muscles are very important for maintaining the stability of the lumbar spine. The function of the stabilizing trunk muscles have proved to have association with back pain (86). Studies have shown that when back pain is present the function is affected more negatively in the deep fibers of lumbar multifidus than in the superficial fibers or erector spinae (87). The thoracic paraspinal muscles were found to be less active and the lumbar paraspinal muscles showed higher activity when measured by surface electromyography after spine fusion (88).

Back function and pain

Adults with idiopathic scoliosis have a higher prevalence of back problems than nonscoliotic individuals (89). Juvenile or adolescent onset, type of treatment, preoperative brace treatment or sex were not related to the prevalence of back problems (89). In most of the follow-ups back function was considered to be at a satisfactory level (23, 90, 91). Danielsson et al evaluated back pain and function in AIS patients 22-23 years after treatment (27, 28). A larger number of surgically treated patients experienced pain compared to control group but the effect on daily life and function was minimal (27). The brace treated patients had more thoracic or lumbar pain than the controls although the effect on daily life and function also here was minimal (28). Neck problems and back problems more often coexist in individuals with scoliosis (92). Misterska et al. (93) evaluated back and neck pain and function in female AIS patients 23 years after treatment with Milwaukee brace using various disability scales including a revised Oswestry Low Back Pain Disability Index (ODI) and found significant restrictions in everyday activities due to pain in the low back and neck regions. An association between back pain and curve progression was also found in the latter study (93).

Pulmonary function, thoracic mobility, and respiratory muscle strength

Pulmonary function

The progression of the three-dimensional scoliotic deformity leads to a deformity of the rib cage with subsequent reduced chest- and lung volume (33). The deformed chest leads to reduced thoracic mobility and also to increased work of breathing. It has been shown in long term studies that patients with early onset scoliosis run an increased risk of respiratory failure and premature death if they are left untreated (49). It has been shown that the majority of patients have preserved pulmonary function in EOS patients who were followed up more than 20 years after treatment with brace or surgery (25). Patients with scoliosis onset before the age of six who had been surgically treated due to severe curves had the most manifest reduction of pulmonary function (25). The strongest predictor for pulmonary function in the middle-age was reduced pulmonary function before treatment (25). Long term studies in patients with adolescent idiopathic scoliosis found that both brace treated patients and surgically treated patients gradually increased their pulmonary function up to 25 years after treatment (94).

Thoracic mobility

A large curve size results in rib cage deformity where the distorted chest reduces thoracic mobility (33). The treatment of scoliosis during childhood and adolescence, with brace wearing for several years or with spinal fusion might also contribute to a decreased mobility of the rib cage. Rib cage mobility is often evaluated by measurement of the capacity to expand the thorax during maximal breathing at the level of the fourth rib and at the level of the Xiphoid process (95-97). This method of measuring thorax expansion has proved to be reliable (98, 99). Another method to evaluate rib cage mobility is by measuring the changes in the anterior-posterior diameter of the thorax during breathing with Respiratory Movement Measuring Instrument (RMMI) (100, 101). The RMMI has been used to evaluate the rib-cage mobility in patients with ankylosing spondylitis, in patients diagnosed with sensory hyper-reactivity and after cardiac surgery (102-104).

Respiratory muscle strength

The maximal range of motion in the rib cage is associated with the strength in the respiratory muscles. During forced inspiration the diaphragm, the external intercostal muscles and other accessory muscles contract causing the rib cage to expand and the lung volume to increase (105). During forced expiration the abdominal muscles and the internal intercostal muscles contract which leads to compression of the rib cage and reduction of the lung volume (105). The maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) is a non-invasive method to evaluate respiratory muscle strength (106, 107).

Validity and reliability of measurements

The concepts of validity and reliability are essential for high quality in quantitative research. Validity is defined as the extent to which a concept is accurately measured in a quantitative study and reliability is defined as the extent to which a research instrument consistently has the same results if it is used in the same situation on repeated occasions (108). Heale and Twycross (108) describe three kinds of validity: a) the content validity that describes to which extent a research instrument accurately measures all aspects of a construct, b) the construct validity that describes to which extent a research instrument measures the intended construct, and c) the criterion validity that describes to which extent a research instrument is related to other instruments that measures the same variables. Reliability relates to the consistency of a measurement (108). Internal consistency describes to which extent all the items on a scale measure one construct, stability, using test-re-test, describes the consistency of results and equivalence the consistency among level of agreement between two or more users (108).

GAPS IN KNOWLEDGE

In patients treated for AIS there is a lack of knowledge about the long-term effects concerning spinal range of motion, trunk muscle endurance, and back function. Particularly as they relate to the type of treatment given and comparing people with AIS to a matched control group or reference values.

In patients with EOS the spinal range of motion, trunk muscle endurance and back function long-term after treatment have not previously been evaluated. Evaluation of correlations between estimation of lung volumes, thorax expansion, measurement of breathing movements with RMMI and traditional spirometry are not yet conducted.

There is also a lack of comparisons of the long-term effects for the different groups of patients with early onset before the age of ten and with adolescent onset after the age of ten and the different treatment options and compared to untreated AIS patients and matched controls or reference values.

Several follow-up studies have been published, but there is still a need for further evaluation of aspects such as pulmonary function, spinal mobility, muscle endurance and back function. It is also important to compare measuring methods in order to find, valid, available and easy to perform methods for regularly evaluating patients in clinical practice.

2 AIMS OF THE THESIS

The overall aim of this thesis is to evaluate different aspects of spinal function and respiratory function, with long-term follow-ups, in patients with idiopathic scoliosis with debut before skeletal maturity.

The specific aims are:

To determine the long-term outcome in terms of spinal mobility and trunk muscle strength and their possible correlations to back pain and function in patients with AIS earlier treated with brace or surgery.

To evaluate the relationship between thoracic mobility, rib-cage deformity and pulmonary function in patients with EOS previously treated with brace or surgery.

To evaluate spinal mobility and trunk muscle endurance in patients with EOS treated with brace or surgery and to compare them with patients with AIS who are untreated or treated with brace or surgery.

To evaluate the criterion validity of different methods for measuring pulmonary function in a group of middle-aged patients with EOS earlier treated with brace or surgery. In addition, to establish if any of the methods evaluated to measure pulmonary function could be a valid, easy to perform and inexpensive tool to use in clinical practice.

3 PATIENTS AND METHODS

STUDY POPULATION

Patients were identified from the Gothenburg Scoliosis Data Bank, constructed in the 1970s, which contains information about all patients with scoliosis, treated from the mid1960´s at the Department of Orthopaedics at the Sahlgrenska University Hospital in Gothenburg, Sweden. All patient groups were consecutive (Table 1).

Table 1. Study population of paper I-IV.

	AIS	EOS	untreated AIS	Normal population
Paper I	BT n=102 ST n=135			n=100 control group
Paper II		BT=57 ST=49		
Paper III	BT n=102 ST n=135	BT n=63 ST n=53	n=40	
Paper IV		n=33 subgroup (BT n=16 ST n=17)		

Adolescent idiopathic scoliosis treated with brace or surgery (paper I and paper III)

All patients with AIS treated with brace or surgery between 1968 and 1977 were identified. The total number of patients was 156 surgically treated and 127 brace treated. The material has previously been described in several papers (26-28, 109-111).

Inclusion criteria:

1) Diagnosis of adolescent idiopathic scoliosis. No other related disorders or major anomalies of the spine.
2) Patients treated with either a) a brace (BT) or b) surgery
    a. Starting brace treatment from January 1, 1968 and completing treatment not later than December 31 1977. Brace treatment during at least 12 months; only patients who completed the treatment were included.
    b. Surgical treatment between January 1, 1970 and December 31, 1976.
3) Treatment performed and completed at the Department of Orthopaedics at Sahlgrenska Hospital, Gothenburg.
4) Treatment completed before the patient was 21 years old.
5) A minimum of 20 years passed since completed treatment.
6) Patients had to reside in the middle and southern part of Sweden at the time of the follow up for practical and economical reasons. Six patients (five ST and one BT) which fulfilled the inclusion criteria were excluded due to this reason (Table 2).
7) Four ST patients and seven BT patients were lost to the physiotherapy examination of the follow up due to logistical reasons.

Table 2. Number of surgically treated (ST) or brace treated (BT) AIS patients included in the follow up. n (%)

	ST	BT
Attended the current follow up	142 (91)	110 (87)
Excluded from radiographic analysis	3 (2)	1 (1)
No PT examinations due to logistic reasons	4 (3)	7(6)
PT examination	**135 (86)**	**102 (80)**
Only questionnaire answered and returned	4 (3)	6 (5)
Refused attendance	3 (2)	4 (3)
Diseased (not related to scoliosis)	2 (1)	0 (0)
Not traced	5 (3)	7 (5)
Total number of consecutive patients	**156**	**127**
Females	145 (93)	122 (96)
Males	11 (7)	5 (4)

For brace treatment (BT) a standard Milwaukee brace with superstructure and pelvis girdle (5) was used until 1974 and thereafter a Boston brace (112). The brace was worn 22-24 hours daily until skeletal maturity.

The surgically treated (ST) patients were operated using the Harrington technique (20). Between 1970 and 1973 a two-stage technique was used (113) and after 1973 a one stage procedure (114). The ST patients were postoperatively braced for a period of time ranged from 6 to 12 months.

Control group (Paper I):

One hundred persons with the same distribution of sex (90 females, 10 males) and age (mean 40 years, range 35-45) as the patients , were randomly selected through the Swedish Postal Registry, previously described (26). They were all living in Gothenburg near and represented a balanced mixture of urban and rural living conditions comparable to the patients. The only exclusion criterion was significant scoliosis or previous back surgery.

Early onset scoliosis treated with brace or surgery (Paper II and paper III)

All patients with EOS treated with brace or surgery between 1966 and 1994 were identified and 179 consecutive patients were invited to participate in the follow up (Figure 7).

Inclusion criteria:

1) Diagnosis of idiopathic scoliosis before the age of ten
2) Start of treatment between 1966 and 1992.
3) Treatment with brace for at least six months or surgical treatment. Treatment completed no later than at skeletal maturity.
4) No other related disorders or anomalies of the spine
5) More than ten years since skeletal maturity or since surgery

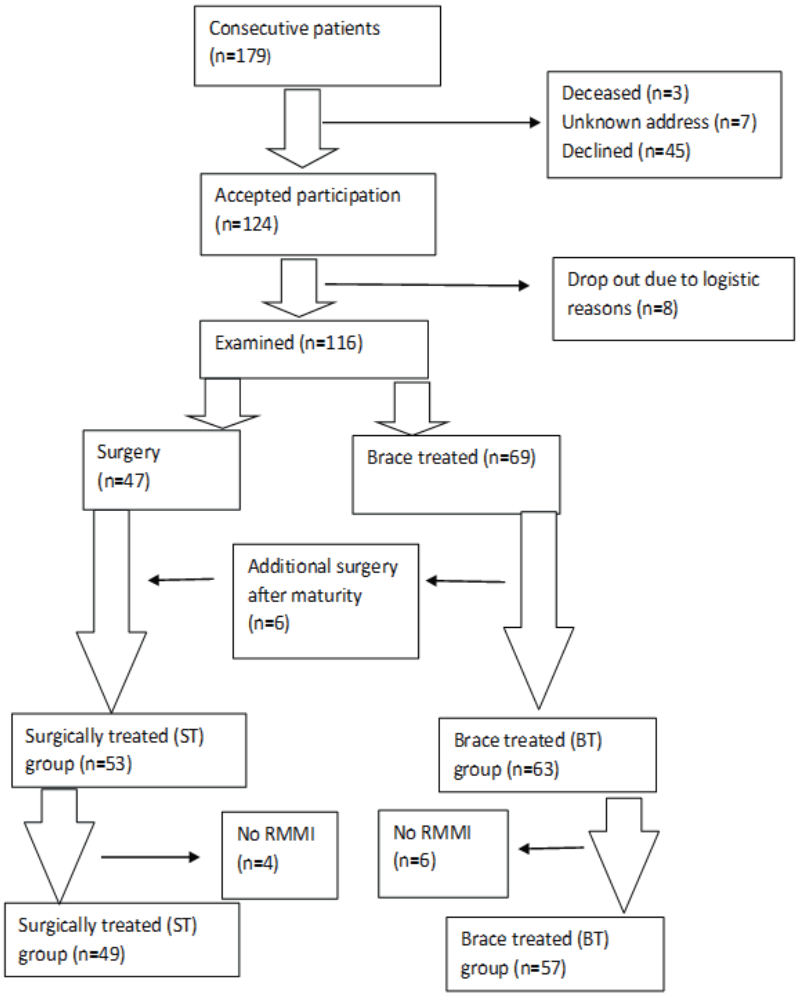


Figure 7. EOS patients included in paper II and III.

Out of the 179 consecutive patients 124 (69%) accepted the invitation to participate in the follow up. Fifty-five (31%) patients did not attend or complete the follow up, more specifically three patients were deceased, seven could not be located, one did not respond, one did not complete the examination, and 43 declined the invitation to participate. Another eight patients dropped out due to logistical reasons.

One hundred and six patients were examined in study II, forty- nine of them surgically treated and fifty-seven brace treated. The surgically treated group includes six patients who were brace treated but had additional surgery after skeletal maturity. Forty-nine (86%) of the BT patients were female and 38 of the ST (78%).

One hundred and sixteen patients were examined in study III. Fifty-three of them were surgically treated and sixty-three were brace treated. The surgically treated group includes six patients who were brace treated but had additional surgery after skeletal maturity. Fifty-four (86%) of the BT patients were female and 42 of the ST (79%).

Early onset scoliosis subgroup (paper II and paper IV)

Forty patients out of the 106 earlier examined early onset patients accepted an invitation to a follow up three to five years after the initial follow-up. Seven of these patients were lost to follow up due to logistic reasons. Thirty-three patients were examined, twenty-two women and eleven men. Sixteen of the patients were brace treated only until skeletal maturity and seventeen of them were treated with surgery before skeletal maturity.

Untreated patients with adolescent idiopathic scoliosis (paper III)

Sixty-five patients with untreated AIS had solely been observed as the intention to treat

This group of patients were prospectively recruited during their adolescence, as part of an earlier study, while under observation (15).

Inclusion criteria:

1) Diagnosis of idiopathic scoliosis after the age of ten.
2) Thoracic or thoracolumbar curve with a moderate curve size between 25˚ and 35˚.

Patients who progressed 6˚ or more during observation underwent treatment with brace or surgery, depending on curve size and residual growth.

These 65 patients were later invited to a long-term follow-up. Out of the 65 observed patients thirteen received brace treatment, six underwent surgery and another six did not attend the follow up. Forty untreated patients were therefore examined at the current follow-up (115).

METHODS

Examination of the spinal deformity

Trunk deformity was measured by use of a Bunell scoliometer (116). The scoliometer shows a good measurement reproducibility (116). The validity of the scoliometer is not sufficient enough for using the method alone for determining diagnosis and management, though it can be used as a screening device (116). The curve size of the scoliosis was measured using the Cobb method on full standing posterior anterior digital roentgenograms (41). Different measurement procedures to determine the Cobb angle show high degrees of reliability, with a tendency to slightly better agreement of digital procedures than manual (117).

Examination of the pulmonary function

Spirometry by body plethysmography

Forced vital capacity (FVC) and Forced expiratory volume in one second (FEV_1) was measured by spirometry by a pressure- differences method (Jaeger ®Masterscope) and Total Lung Capacity (TLC) with a body plethysmograph (Sensormedics Vmax® Encore system (Yorba Linda CA, USA) (118). The measurements were conducted in a sitting position in a standardized manner (118). The values for FVC, FEV_1 and TLC were presented as the percent of predicted values related to age, height and gender according to Quanjer (118, 119). When the measurements are conducted in a standardized manner the reliability and validity are good (118). The values were also corrected to loss of height due to scoliosis (120).

Spirometry by handheld spirometer

An EasyOne® (ndd Medical Technologies, MA, US) electronic handheld spirometer was used to measure the Vital Capacity (VC). When the measurements are conducted in a standardized manner the reliability and validity are good (118). The measurements were conducted in a standardized manner in supine position in order to able to compare to volume measured by Computed Tomography (CT) (118).

Computed tomography

Lung volumes, TLC and Residual Volume (RV), were measured with CT using a CT Discovery CT750HD (GE Healthcare, Milwaukee, WI, USA). Imaging parameters were helical scan with tube voltage of 100kV, tube current 10-80mA with Automatic Exposure Control, rotation time 0.4 s and pitch 0.98. Reconstructed image slice thickness was 0.6 mm and the patients were measured in a standardized manner in supine position with arms above their heads. One CT scan was conducted in maximal inspiration and one in maximal expiration. Automated segmentations of lung volumes were executed by one observer with a commercially available software Thoracic VCAR on an AW Workstation (both from GE Healthcare, Milwaukee, WI, USA) with manual corrections if necessary. Measurements with inspiratory and expiratory helical CT have been shown to have good reliability and validity (121).

Validation of pulmonary measurements

The criterion validity refers to the extent to which scores on a particular instrument relate to a gold standard. The criterion validity is regarded as a positive rating if the correlation with the gold standard is at least 0.70 (122). Spirometry by body plethysmography is the current gold standard for measuring lung volumes. The results of the measurements of VC by handheld spirometer, VC by CT, ribcage mobility by thorax expansion and respiratory movements by RMMI were correlated to the gold standard.

Evaluation of spinal mobility

Cervical range of motion

Flexion, extension, lateral bending and rotation was evaluated with a Myrin Inclinometer with the individual in a sitting position (123). The validity and reliability of this measuring instrument has been evaluated and considered to be good (123).

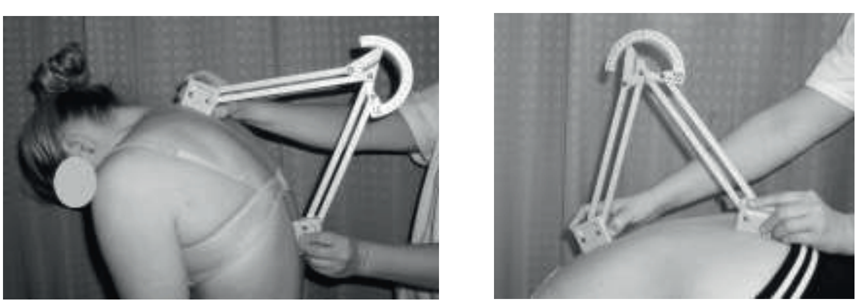
Thoracic range of motion

Thoracic rotation was measured with a Myrin inclinometer with the individual sitting on a stool with the arms folded across the stomach and with a compass, placed on the forearms, showing the extreme positions (124). The repeatability of this test has been tested and the correlation coefficients approximately estimated to 0.9 (125).

The total thoracic range of motion was measured with the Debrunner kyphometer (126) (Figure 8 a). The subject is measured in standing position and is asked to bend the head down and bend the upper part of the spine as much as possible in order to assess the thoracic flexion. For measurement of the thoracic extension the subject is asked to bend the upper part of the spine backwards. The total thoracic range of motion from maximal flexion to maximal extension was measured between the disc spaces of T2-T3 and T11-T12 (126). The intrarater reliability for measurements of thoracic range of motion using the Debrunner kyphometer was 0.56-0.63 and the interrater reliability was 0.69-0.83 (127).

Lumbar range of motion

The total lumbar range of motion was measured with the Debrunner kyphometer (126) (Figure 8 b). The individual is measured in a standing position and is asked to bend forward as far as possible in order to assess the lumbar flexion. For measurement of the lumbar extension the subject is asked to bend backwards as far as possible. The total lumbar range of motion from maximal flexion to maximal extension was measured between T11-T12 and S1-S2 (126). The intrarater reliability for measurements of lumbar range of motion using the Debrunner kyphometer was 0.84-0.89 and the interrater reliability 0.87-0.93 (127).



a b

Figure 8. Thoracic (a) and lumbar (b) measurements with the kyphometer.

Anterior flexion

The Schober test was performed with the person in standing position (128). A mark was inked on the skin at the lumbosacral junction and further marks were inked 10 cm above and 5 cm below the first mark. The distance between the upper and lower skin mark was measured with a tape when the individual was asked to bend forward maximally (128). This test was previously found to have a coefficient of variation of 4.8% (129).

Backward bending

The backward bending was measured with a tape measure and with the subject standing straight, with heels together and arms in a neutral position (130). The spinous process of C7 and the level of posterior superior iliac spine were marked with ink on the skin, the person was asked to bend backwards maximally and the excursion between the initial and final distances was measured (130). The reliability has previously been tested and considered acceptable (130).

Lateral bending

The lateral bending was measured with a tape measure and with the subject standing in a neutral position with feet 20 cm apart (131). The positions of the fingertip of the middle fingers were marked on the thighs and marked again during maximal lateral bending and the distance between the marks were measured with the tape (131). The intraobserver and interobserver reproducibility have previously been studied and considered acceptable (131).

Fingertip-floor-distance

The distance between fingertip and floor was measured with a tape measure. The subject was bending forward maximally with the knees straight and feet together and the distance between the middle fingers and the floor was measured (129). This test has previously proved to be reproducible (129).

Evaluation of trunk muscle strength

Trunk flexor endurance

To evaluate the endurance of the trunk flexors the modified Kraus-Weber test was performed (132) (Figure 9). The test was conducted with the subject in a supine position with raised legs with 90° flexion of the hip and knee joints. The persons were asked to maintain this position for as long as possible, not exceeding a five-minute limit. This test has previously been evaluated and considered to have high reliability and reproducibility (132).

Trunk extensor endurance

To evaluate the endurance of the trunk extensors the modified Sorensen test was performed (132) (Figure 10). The test was conducted with the subject in a prone position with a small pillow under the lower abdomen. The subjects were asked to the sternum off the floor and to maintain this position for as long as possible, not exceeding a five-minute time limit. This test has previously been evaluated and considered to have a high reliability and reproducibility (132).

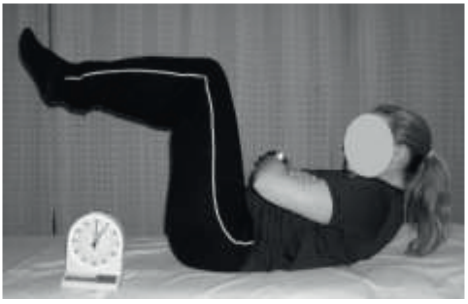


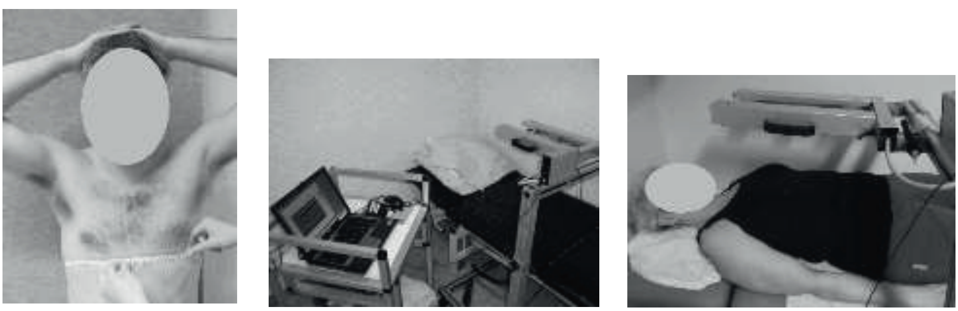
*Figure 9***.** Trunk flexor endurance.

Figure 10. Trunk extensor endurance.

Evaluation of thoracic mobility and respiratory muscle strength

Thorax expansion

The ability for the chest cage to expand the thorax was measured with a measuring tape at maximal inspiration and maximal expiration (95-97) (Figure 11 a). The thorax expansion was measured at the level of the xiphoid process and at the level of the fourth rib with the subjects standing erect with their hands on their heads. They were instructed to first make as large an inhalation as possible and "make themselves as big as possible" and the to exhale maximally and "make themselves as small as possible"(95, 97). Thorax expansion is the difference in circumference between maximal inspiration and maximal expiration measured with the measuring tape (95-97). The reliability has previously been studied and proven to be satisfactory if the same tape is used and the same person measures (98, 99).



a *b* *c*

Figure 11. Thorax expansion (a), RMMI (b, c.).

Breathing movements

Breathing movements were measured as the changes in the anterior-posterior diameter of the thorax during deep breathing with the Respiratory Movement Measuring Instrument (RMMI) in a supine position on a treatment bench (101) (Figure 11 b-c). This measuring device consists of a mobile rack with six laser diodes in three pairs, adjustable to the length of each participant's torso. The six laser distance sensors of the instrument have an accuracy of 0.0003 mm.

The laser diodes are arranged bilaterally at the level medial to each subject's armpit folds, and lateral to the xiphoid process and the umbilicus, and can therefore register the amplitude of the breathing movements. These signals were converted from analogue to digital by the data acquisition system and relayed to a computer program (100, 101, 133, 134). The subjects were instructed to close their eyes and to inhale deeply through the nose and exhale through the mouth without breath holding. The reliability and validity of RMMI has been valuated and it was found to be a reliable instrument for clinical practice as well as for research (133, 134). The breathing movements have previously been evaluated and considered symmetrical and did not change significantly with increasing age (101).

The breathing movements of each individual in the study group were adjusted to the direction of the scoliosis i.e. either the convex or the concave side. Breathing movements were analysed as the sum of movements on both sides on all six positions and on the upper thoracic and abdominal positions.

Respiratory muscle strength

The respiratory muscle strength was evaluated with measurements by Maximal Inspiratory pressure (MIP) and Maximal Expiratory Pressure (MEP) in a sitting position (107) (Figure 12). This noninvasive measurement tool has previously been evaluated and considered to be reliable and valid (135). The subjects performed three MIP and three MEP tests and the tests with the highest scores were recorded and analysed.

Figure 12. Measurements by MIP and MEP.

Questionnaires

SF-36

As general Health-Related Quality of Life (HRQL) questionnaire, measuring the physical, social and mental components, SF-36 was used. Each subscale scores from 0 to 100, where 100 is the best function. The subscale Physical function (PF) and the physical component summary score have been presented in study I. This questionnaire is widely used and the validity has been evaluated and considered good (136, 137).

Oswestry low back pain Disability Index (ODI)

Oswestry low back pain Disability Index (ODI) is a disease specific quality of life questionnaire used for the evaluation of general back function (138). The subject answers ten questions on activities that are back-dependent, scored and summarized. The scoring system is graded from 0-100, where 0 is the least possible disability (138). There are five different grades of disability, of which the lowest, a score up to 20, is considered being a normal back function (138). The test-retest reliability has previously been evaluated and found to have a good test-retest reliability (139).

Physical activity during work and leisure time

For information about the level of physical activity during work and leisure time questions from a questionnaire described by Rosengren and Orth-Gomer (140) were used:

Physical activity during work:

1 = Sedentary

2 = Light work with some physical activity

3 = Relatively heavy work

4 = Heavy manual work

Physical activity during leisure time:

1 = Mainly sedentary

2 = Light exercises and training minimum 4 hours per week

3 = Regular training and exercise

4 = Serious training and competitive sports

For the purpose of the analyses, patients that had activity level 3 or 4 of either activity were grouped together as “more” active in paper I. In paper III activity level 1-2 and activity level 3-4 were grouped together.

Pain drawing

Pain drawing was rated by a grid dividing the body into 216 body sections. A quantification of the pain was conducted by calculating a Total Body Area Score through counting the number of cells that were marked on the pain drawing (141).

Questions about smoking habits

The patients were asked questions about their smoking habits and were thereafter classified into either ”never-smokers” or “ever-smokers” (current/ex-smokers).

PROCEDURES STUDY I-IV

Table 3. Procedures study I-IV.

Variable	**Measured by**	**I**	**II**	**III**	**IV**
Spinal deformity					
Trunk deformity	Bunell scoliometer	x	x	x	
Curve size	Post anterior roentgenogram	x	x	x	x
Pulmonary function					
TLC	plethysmograph		x		x
FVC	plethysmograph		x		x
FEV_1	plethysmograph		x		
RV	plethysmograph				x
VC	Handheld spirometer				x
TLC	CT in max inspiration				x
RV	CT in max expiration				x
Spinal mobility					
Cervical ROM	Myrin inclinometer	x		x	
Thoracic ROM	Debrunner kyphometer	x	x	x	
Thoracic rotation	Myrin inclinometer	x		x	
Lumbar ROM	Debrunner kyphometer	x		x	
Lateral flexion	Measuring tape	x		x	
Anterior flexion	Measuring tape	x		x	
Backward bending	Measuring tape	x		x	
Fingertip-floor distance	Measuring tape	x		x	
Trunk muscle endurance					
Trunk flexors	Modified Kraus-Weber	x		x	
Trunk extensors	Modified Biering-Sörensen	x		x	
Thoracic mobility					
Breathing movements	RMMI		x		x
Thorax expansion	Measuring tape		x		x
Resp muscle strength					
Insp muscle strength	MIP		x		
Exp muscle strength	MEP		x		
Questionnaires					
Physical function	SF-36	x			
General back function	ODI	x			x
Physical activity	Questionnaire	x			x
Pain	Pain drawing	x			
Pain	VAS (0-10)	x			
Smoking habits	Questions		x		

ETHICS

Ethical approval for all studies included in the thesis have been obtained from the Human Research Committee at the Medical faculty, Gothenburg University, Gothenburg, Sweden #259-96, 1996-05-29, #081-07, 2007-06-29, #636-03, 2003-12-31, #732-12, 2012-10-08, and are described in the separate papers. The patients were included after verbal and written information and signed consent. There was no conflict of interest.

Internal ethical considerations

Internal ethics refers to research ethics and a researcher has to make sure that everything is done to prevent false results. I have examined all patients in the studies, handled the data and performed most of the statistical analyses myself. It would be preferable that it would not be the same person who examines the patients and handles data, however this might also be an advantage due to the fact that I am familiar with the measurements and results and know which values are in the normal range.

To avoid errors studies data were monitored by two people of which one was a nurse who was independent of the trial.

External ethical considerations

External ethics refers to ethics towards the patients to do the right thing and not to cause them harm. Sending an invitation letter to a patient and reminding them of the treatment they went through as children or adolescents may have caused distress for some of them.

On the other hand, many of them appreciated the opportunity to check their status. The fact that scoliosis is a hereditary disease makes many of them even more interested in the research for the sake of their children.

How many examinations and how long time they will take to accomplish is also a strain for the patients that we have to consider.

An important matter to consider is the effect of exposition to radiation. Adult patients treated for AIS have been reported to have a five times higher frequency of cancer compared to healthy controls (142).

STATISTICAL ANALYSES

For descriptive analysis mean, SD, median, range and 95% confidence interval was used.

For analytic statistics Mann-Whitney U test for comparison between two groups, Kruskal Wallis test for comparison between three groups, Fisher's exact test for proportion between two groups were used.

Spearman rank correlation (r_s) was used for correlation analysis and correlation was defined as little, if any (r_s<0.35), low (r_s=0.26-0.49), moderated (r_s=0.50-0.69), high (r_s=0.70-0.89) and very high (r_s=0.90-1.00) (143).

The different statistical analysis used in the studies are presented in table 4.

Table 4. Statistical analysis in Paper I-IV.

	I	**II**	**III**	**IV**
Mean, SD	x	x	x	x
Confidence interval 95%			x	x
Mann-Withney non-parametric U test	x	x	x	x
Kruskal Wallis test			x	
Fisher's exact test	x	x	x	x
Spearman rank correlation coefficient	x	x	x	x
Multivariate linear regression		x		
Bland Altman test for analyzing level of agreement				x
Criterion validity				x

4 SUMMARY OF RESULTS

STUDY I

The main findings in this study were that more than 20 years after completed treatment the lumbar spinal mobility and trunk muscle endurance were reduced in both brace treated and surgically treated AIS patients. For the surgically treated AIS patients a greater lumbar spinal mobility as well as a higher trunk muscle extensor and flexor endurance were found to be correlated with better measures of physical function (SF-36 and ODI). No such correlations were found for the braced patients. For the brace treated patients a reduced lumbar spinal mobility was found to correlate with higher pain intensity, larger extension of lumbar pain, and larger extension of pain all over the body.

Table 5. Spinal range of motion and trunk muscle endurance in 102 patients brace treated (BT) and 135 patients surgically treated (ST) for AIS and 100 controls (CTR). Mean, (SD) [range].

	BT n=102	ST n=135	CTR n=100	p-value BT vs. CTR	p-value ST vs. CTR
Cervical spine range of motion					
Flexion (˚)	71.4 (9.8) [45-90]	69.9 (9.7) [45-90]	76.3 (9.3) [50-90]	0.0003	<0.0001
Extension (˚)	66.7 (12.8) [35-90]	62.1 (11.4) [25-90]	66.9 (10.8) [40-90]	0.83 (NS)	0.0038
Lateral flexion to the right (˚)	40.0 (5.9) [25-50]	37.8 (6.2) [20-60]	41.3 (6.3) [25-60]	0.59 (NS)	<0.0001
Lateral flexion to the left (˚)	40.2 (5.3) [25-50]	36.9 (7.2) [20-75]	40.6 (5.8) [30-60]	0.57 (NS)	<0.0001
Rotation to the right (˚)	76.2 (9.4) [40-90]	71.0 (10.7) [30-90]	75.7 (9.7) [45-90]	0.71 (NS)	0.0006
Rotation to the left (˚)	75-9 (10.5) [30-90]	72.0 (10.1) [20-90]	76.7 (9.2) [40-90]	0.80 (NS)	<0.0001
Thoracic spine range of motion					
Total thoracic ROM (˚)	28.4 (9.6) [8-60]	14.4 (9.6) [0-50]	28.2 (8.2) [11-52]	0.87 (NS)	<0.0001

Rotation to the right (˚)	76.2 (9.4) [40-90]	71.0 (10.7) [30-90]	75.7 (9.7) [45-90]	0.71 (NS)	0.0006
Rotation to the left (˚)	75.9 (10.5) [30-90]	72.0 (10.1) [20-90]	76.7 (9.2) [40-90]	0.80 (NS)	<0.0001
Lumbar spine range of motion					
Total lumbar ROM (˚)	54.7 (23.6) [8-97]	34.4 (17.4) [0-70]	87.3 (12.3) [56-113]	<0.0001	<0.0001
Distance fingertips-floor (cm)	7.0 (9.6) [0-39]	12.3 (12.2) [0-49]	4.1 (7.0) [0-30]	0.028 (NS)	<0.0001
Flexion (cm)	5.6 (1.8) [2-20]	3.6 (1.5) [0-7]	6.4 (1.1) [2-9]	<0.0001	<0.0001
Extension (cm)	3.3 (1.6) [0-9]	1.5 (1.1) [0-6]	4.9 (1.8) [1-10]	<0.0001	<0.0001
Lateral flexion to the right (cm)	15.0 (3.3) [6.24]	8.0 (2.8) [2-15]	18.5 (3.8) [10-28]	<0.0001	<0.0001
Lateral flexion to the left (cm)	16.2 (3.5) [4-24]	9.1 (3.1) [2-17]	18.6 (3.9) [2-28]	<0.0001	<0.0001
Trunk muscle endurance					
Trunk flexors (sec)	106.1 (78.8) [6-300]	104.7 (85.9) [9-300]	151.9 (91.7) [13-3000]	<0.0001	<0.0001
Trunk extensors (sec)	169.8 (97.0) [4-300]	140.1 (107.4) [9-300]	238.2 (83.6) [8-300]	<0.0001	<0.0001

Spinal range of motion

For both ST and BT the ROM of the lumbar spine was significantly decreased compared to the controls. The ST patients had a lumbar ROM reduction of 61% and the BT patients 37%. The ST patients had significantly reduced thoracic as well as cervical ROM compared to the controls. Also, the fingertip-floor distance was reduced in the ST patients compared to controls (Table 5).

Comparison between the two treated groups showed that the ST patients were significantly stiffer than the BT patients with a significantly less thoracic ROM and lumbar ROM as well as fingertip-floor distance. There were no significant differences found between the groups concerning the cervical ROM.

The total length of the fusion affected the lumbar mobility negatively, but neither cervical ROM nor Thoracic ROM was affected. ST patients with a fusion ending at L3 or above had a better lumbar ROM compared to patients with a more caudally ending fusion.

Trunk muscle endurance

Trunk muscle endurance for both trunk flexor and trunk extensor muscles was significantly lower compared to the controls for both ST group (with 31% and 41%) and BT group (with 30% and 29%). There were no significant differences between the ST and BT groups. The trunk muscle endurance was not affected by the distal level of fusion (Table 5).

Back Pain/Function and correlation with spinal range of motion and strength

The ST patients with higher trunk extensor and flexor muscle endurance or a better lumbar ROM correlated with a better physical function, as measured by the Physical functioning subscale and Physical Component Summary score of SF-36 as well as ODI.

For the BT patients there were no correlations with functional measurements found. Yet, reduced lumbar ROM was found to correlated with a respectively higher pain intensity, larger extent of lumbar pain and larger extent of pain all over the body (Total Body Area Score).

STUDY II

The main findings in this study were that the thoracic mobility was significantly reduced at mean 26.5 years after completed treatment in both BT and ST patients with EOS and that reduced thoracic mobility did not influence TLC as strongly as gender, brace model and smoking habits.

Table 6 Total thoracic range of motion measured by Kyphometer and thorax expansion in BT and ST patients with EOS and compared to reference values. Mean, (SD), range.

	BT (n=57)			ST (n=49)		
	Measured value	Reference value	p-value	Measured value	Reference value	p-value
Total thoracic ROM, °	39.7 (8.9) 23.0-62.0	28.2 (8.2)	<0.001	15.2 (8.1) 0-37.0	28.2 (8.2)	<0.001
Xiphoid process level (mm)	46.8 (19.4) 10.0-90.0	60.4 (0.5)	<0.001	39.8 (19.1) 5.0-80.0	59.1 (0.7)	<0.001
Fourth rib level (mm)	41.8 (17.4) 10.0-100.0	-	-	39.5 (17.8) 10.0-90.0	-	-

The thoracic ROM was significantly larger in the BT group ($p<0.001$) and significantly less in the ST group ($p<0.001$) compared to the reference values. The BT group had a significantly larger ($p<0.001$) thoracic ROM than the ST group (Table 6).

The measurements of thorax expansion at the level of the xyphoid process were significantly smaller compared to the reference values ($p<0.001$). There was no significant difference between the BT and ST patients ($p=0.53$) (Table 6).

Table 7. Maximal breathing movements measured by RMMI (adjusted to the direction of the scoliosis) in BT and ST patients with EOS and compared to reference values. Mean, (SD), range.

	BT (n=57)			ST (n=49)		
RMMI (mm)	Measured value	Reference value	p-value	Measured value	Reference value	p-value
Upper thoracic convex	7.32 (7.52) 1.23-45.72	17.69 (0.03)	<0.001	7.54 (7.16) 0.94-38.74	17.68 (0.34)	<0.001
Upper thoracic concave	7.07 (7.85) 1.14-49.21	18.09 (0.16)	<0.001	7.16 (7.19) 0.86-36.59	18.11 (0.14)	<0.001
Lower thoracic convex	5.32 (5.29) 0.72-33.25	16.84 (1.56)	<0.001	5.65 (6.57) 1.31-33.10	17.22 (1.87)	<0.001
Lower thoracic concave	5.33 (6.26) 0.66-41.66	16.53 (1.30)	<0.001	5.73 (5.40) 1.48-28.24	16.84 (1.56)	<0.001
Abdominal convex	9.18 (8.54) 1.55-41.60	18.25 (2.58)	<0.001	8.57 (5.95) 1.68-25.15	18.87 (3.10)	<0.001
Abdominal concave	8.54 (8.94) 1.04-44.70	18.52 (2.50)	<0.001	7.89 (5.79) 1.40-27.75	19.13 (3.02)	<0.001

The respiratory movements measured by the RMMI during deep breathing were significantly smaller in both BT and ST groups compared to reference values ($p<0.001$). There were no significant differences between the BT and ST groups (Table 7).

Table 8. Respiratory muscle strength measured in a subgroup of 33 patients and compared to a control group (CTR) of 40 individuals.

	BT (n=16)	CTR (n=40)	p-value	ST (n=17)	CTR (n=40)	p-value
MIP, cm water	78.1 (32.6) 9.0-123-0	88.7 (28.6) 23.0-147.0	n.s.	59.3 (23.4) 22.0-103.0	88.7 (28.6) 23.0-147.0	0.001
MEP, cm water	112.8 (34.4) 39.0-169.0	118.4 (29.8) 61.0-195.0	n.s.	94.2 (28.1) 57.0-149.0	118.4 (29.8) 61.0-195.0	0.007

The respiratory muscle strength evaluated in the subgroup was significantly reduced to 67% of MIP and 79% of MEP reference values in the ST group. This was not found for the BT group. There were no significant differences between the BT and ST groups (Table 8).

Multivariate analysis

A multivariate linear regression model explaining TLC as per cent of predicted values, as a measurement of pulmonary function was influenced by gender, brace model, smoking habits, thorax expansion and curve size at start of treatment. The reduced thoracic mobility did not influence TLC as strongly as gender, brace model and smoking habits.

STUDY III

The main findings in study III were that at mean 26.5 years after completed treatment spinal ROM and trunk muscle endurance were similar in BT EOS patients and untreated AIS patients. The BT EOS patients were significantly more mobile and had significantly longer trunk muscle endurance than the BT AIS patients, despite being in a brace for longer time. The ST EOS patients were neither weaker nor stiffer than the ST AIS patients despite somewhat longer fusions in the EOS group. The degree of total lumbar ROM was found to affect back function in the ST EOS group.

Spinal range of motion

The BT EOS patients had significantly larger total thoracic ROM (mean 40˚) compared to both untreated AIS patients (mean 34˚, $p<0.05$) and BT AIS patients (mean 28˚, $p<0.001$). The total lumbar ROM of the BT EOS group (78˚) was reduced by 10˚ compared to untreated AIS patients, but significantly better than the BT AIS patients (54˚, $p<0.001$). The total thoracic ROM of the ST EOS group was similar to that of the ST AIS group, but the total lumbar ROM was significantly less in the ST AIS group (34˚ vs. 55˚, $p<0.001$). The total lumbar ROM was therefore evaluated according to the lowest level of the fusion. EOS patients with fusion down to L1/above or to L2/below, had significantly better lumbar ROM than equivalent AIS patients.

Trunk muscle endurance

The trunk muscle endurance of trunk flexors and extensors did not differ significantly between the BT and ST EOS patients. Only the EOS ST patients had less trunk flexor endurance compared to untreated AIS patients (125 sec, vs. 158 sec., $p<0.05$). The BT EOS patients had longer endurance of both trunk flexors and trunk extensors compared to the BT AIS patients (140 sec. vs. 106 sec., $p=0.002$ and 255 sec. vs. 170 sec., $p<0.001$).

Back pain and function

The majority of the EOS patients (86%) reported a normal function (score ≤20) as measured by ODI. There were no significant differences compared to AIS BT or ST groups. The level of physical strain during work and leisure time showed no significant differences between the EOS groups or between the EOS groups and the AIS groups.

STUDY IV

The main findings in study IV are that there is a good agreement between the measurements by plethysmography and CT (figure 13-14) and there are strong correlations between spirometry by plethysmography (gold standard) and the measurements by handheld spirometer, CT scan and thorax expansion for middle-aged patients with early onset scoliosis. Thorax expansion and handheld spirometer are therefore found to be two less expensive and less time consuming, useful tools for early detection of reduction of pulmonary function during daily clinical practice (Table 9).

Table 9. Correlation between the measurements of VC by body plethysmograph ("gold standard") with Spirometry, CT, Thorax expansion and RMMI.

n=33	VC by body plethysmography (sitting)	
	Correlation coefficient	p-value
VC by handheld spirometer (supine)	0.82	≤0.001
VC (TLC-RV) by CT (supine)	0.74	≤0.001
Rib cage mobility (upper and lower) by thorax exp	0.70	≤0.001
Respiratory movements (sum) by RMMI	0.29	0.18

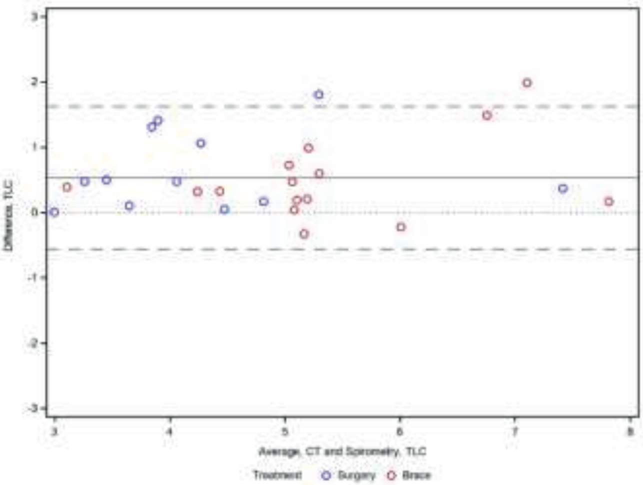


Figure 13. Bland-Altman plots for TLC are depicted for the measurements with CT and plethysmography.

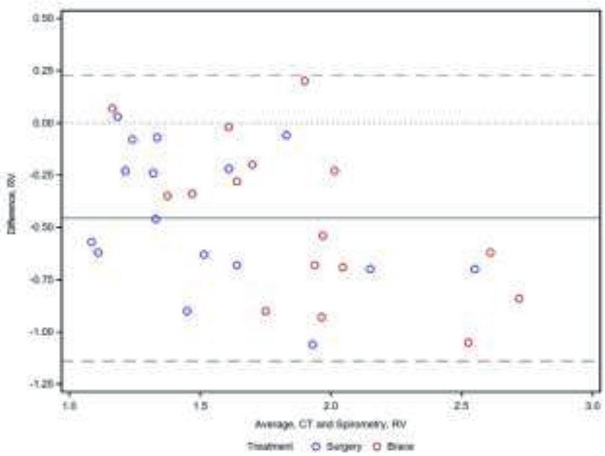


Figure 14. Bland -Altman plots for RV are depicted for the measurements with CT and plethysmography.

5 DISCUSSION

In the work with the studies included in this thesis we evaluated the long-term outcome of physical function in patients with idiopathic scoliosis in studies I-III and the validity of instruments measuring pulmonary function in study IV.

SPINAL RANGE OF MOTION, MUSCLE STRENGTH AND FUNCTION

In study I, consisting of 237 patients with adolescent idiopathic scoliosis lumbar spinal mobility was reduced in both BT and ST patients compared to controls. Comparing the two treated groups the ST patients were significantly stiffer than the BT in thoracic range of motion, lumbar range of motion as well as fingertip-floor distance. In several other studies patients fused with Harrington instrumentation have been found to have reduced lumbar range of motion (21, 77, 84, 144, 145). The total length of the fusion affected the lumbar mobility negatively in the present study; however the fingertip-floor distance was not affected. This good functional mobility despite a stiff spine indicates that the lost mobility of the fused spine might have been taken over by increased motion by the hip joint or increased length of hamstrings muscles.

The brace treated patients in the first study also had reduced lumbar mobility compared to the control group. In the BT group the reduced mobility was correlated to pain measures of both general and lumbar pain. In the ST group the reduced lumbar mobility correlated to measures of physical function.

In study III the BT patients with early onset scoliosis were found to have similar range of motion as patients with untreated AIS and significantly larger than the BT AIS patients. This was seen despite the fact that they were significantly younger at start of treatment and were braced for a significantly longer period of time.

In study I the trunk muscle endurance of trunk flexors as well as trunk extensors was significantly reduced for both BT and ST AIS patients compared to the control group. For the ST group a higher muscle endurance of both flexors and extensors correlated with better physical function measures. In a long-term follow-up Helenius et al. (77) studied 78 AIS patients surgically treated with Harrington or Cotrel-Dubousset instrumentation and found that the patients performed as well as a reference population on the tests of trunk strength. The reason for the different finding in their study and in our might be that different type of muscle tests were used. In the study by Helenius et al. repetitive tests were used and in the present study endurance tests were used (77). There was a lack of correlation between curve size and muscle strength as well as spinal mobility found in their study as well as in the present study (77).

In study III the trunk muscle endurance did not differ significantly between the BT and ST early onset groups. Only the ST patients had less trunk flexor endurance compared to the untreated AIS patients. These findings indicate that early treatment with brace is not negative regarding the endurance of the trunk muscles.

For endurance of trunk extensors, similar results were seen for the total EOS group compared to the untreated AIS group. The BT EOS group had significantly longer endurance of trunk flexors as well as extensors compared to the BT AIS group. The trunk extensor endurance was significantly longer in the EOS group compared to the AIS, but this was not the case for the trunk flexors. A possible explanation for the differences between the treated EOS and AIS groups might be that more patients with surgically treated AIS underwent their treatment during a period of long postoperative brace wearing was routine.

Although weak, correlation between trunk flexor endurance versus leisure time physical activity was found in both EOS groups. Being more active in the leisure time seems to positively affect the trunk flexor endurance in the EOS patients. Muscle endurance was found to affect back function in the surgically treated AIS group and this has also been reported by Lu et al. (88).

THORACIC MOBILITY AND RESPIRATORY MUSCLE STRENGTH

In study II, thoracic mobility was defined as range of motion of the thoracic spine, thorax expansion and breathing movements. Thorax expansion and respiratory movements were found to be significantly reduced in both brace treated and surgically treated EOS patients compared to reference values. Rib cage movements in patients with idiopathic scoliosis have previously been evaluated, with other methods, and found to be reduced according to Leong et al. (146) and Kotani et al. (147). As information about time of onset or treatment of the scoliosis is lacking in those studies, comparisons are problematic. The clinical value of a reduction less than 20 mm needs to be established before a proper evaluation on pulmonary function can be made**.**

RMMI measures the changes in the anterior- posterior diameter of the thorax during maximal breathing with the patient in the supine position on a treatment bench. The results of the left and right measurements of each subject in the study group were adjusted to the direction of the scoliosis to reflect the effect of the curve. For correlation analyses the breathing movements were analyzed as the sum of movements on both sides and on all six positions and on the upper thoracic and abdominal positions. The clinical relevance of approximately 10 mm difference compared to the reference values also needs to be further evaluated. There are no previous studies on subjects with scoliosis for comparison. However compared to other patients groups Ragnarsdottir et al. (104) reported reduced thoracic movements in patients with ankylosing spondylitis, Kristjansdottir et al.(103) found decreased abdominal movements and a difference between the right and left side three months after cardiac surgery, and Johansson et al.(102) showed reduced abdominal movement in patients with sensory hyperreactivity.

Thorax expansion ability correlated moderately with measurements of pulmonary function, curve size at follow-up or trunk deformity which was found in paper I. The results of the RMMI did not show any correlations of significance regardless if four or six measuring points were analysed. This is contradictory to Hagman et al. (148) who found a strong correlation between measured breathing movements and dynamic lung volumes. In contradiction to our study they performed their measurements with RMMI and a dynamic spirometer simultaneously and in three different body positions (148). The different positions of the body during the tests might be an explanation for the lack of correlation. On the other hand it is hard to measure in the sitting position as it is not as stable as lying supine on a bench and may therefore decrease the reliability.

In the subgroup of 33 patients in paper II respiratory muscle strength measured as MIP and MEP was significantly reduced in the ST group compared to the control group, but not in the BT group. Moderate correlations between respiratory muscle strength and pulmonary variables were found. In previous studies the respiratory muscle strength has been tested in patients with cystic fibrosis (149), chronic obstructive pulmonary disease (150) and ankylosing spondylitis (151) and different levels of associations have been reported. The study by Arikan et al. (149) reported correlations between thorax expansion and MIP and MEP similar to our findings. There is a close association between muscle strength and function and a decreased thoracic mobility was found in the patients with scoliosis. Whether these findings are results of the deformed rib cage itself or a stiffer spine after surgery or a long-standing brace treatment, is not known. Study II evaluates late additive results of both the deformity and the treatment of the deformity but does not evaluate these issues separately.

The main impairment of pulmonary function due to scoliosis and its treatment is a restriction of ventilation. Total Lung Capacity (TLC) is the key measurement to evaluate restrictive disorders of ventilation and was therefore chosen to be the main outcome of the pulmonary function in the present study. The result of the multivariate regression model, aimed to explain the TLC % predicted, showed a strong association with gender, brace model, smoking habits, thorax expansion at the level of the Xiphoid process and curve size at start of treatment in paper II. The impact of gender in lung volumes is well known, due to the fact that men in general are larger and have larger lungs than women. Regardless of our analyses using percent of predicted values, in order to eliminate gender difference, the male gender had an association with lower TLC in the present study. The type of brace was also of importance and can be explained by the use of the stiff Milwaukee brace that extends from the pelvis to the base of the skull compared to the less rigid Boston brace, which is still in use. This negative effect might be reduced in the future with more modern braces in use, such as the nighttime braces worn for fewer hours. Another factor is smoking which has a strong association to TLC% predicted values. The result that the “ever-smokers” had higher values than “never-smokers” presented a possible difficulty in evaluating the effect on the decrease of TLC related to treatment for scoliosis. The higher values of the “ever-smokers” are most probably due to the development of emphysema which has been found to increase TLC in apparently healthy smokers (152).

VALIDITY OF METHODS MEASURING PULMONARY FUNCTION

In paper IV the criterion validity of methods measuring pulmonary function was evaluated in middle-aged patients treated for EOS. It is known that middle-aged patients with EOS have a reduced pulmonary function, with a greater reduction in the ST patients more reduced compared to the BT (25). It has been emphasized that it is important to follow the patients regularly with spirometry before treatment as well as follow-ups a long time after treatment (25). The examination of pulmonary function is usually evaluated by body plethysmography. This examination is performed in a pulmonary function laboratory, where the accessibility and cost might vary due to location and capacity. Correlations between VC measured by "gold standard" spirometry by plethysmography versus handheld spirometer, CT and ribcage mobility by thorax expansion were high in study IV. This finding is in line with Debouche et al. (153) who reported a good correlation between upper and lower thorax expansion and lung function (FVC, FEV_1 and VC) in healthy individuals. This method is easy to conduct with just a measuring tape, it is also quick and costs almost nothing. The measurements with RMMI, however, did not correlated with the "gold standard" spirometry. This finding does not correspond with Hagman et al. (148) who reported strong correlations between RMMI and different lung volumes. This disparity might be explained by the fact that in the study of Hagman et al.(148) dynamic lung volumes (FEV_1, FVC) and RMMI were simultaneously evaluated in healthy individuals in three different body positions (supine, sitting on a chair, standing with the back against a wall). In study IV static lung volumes and breathing movements were evaluated, not simultaneously but on the same day, in the supine position and in patients treated for early onset scoliosis which is a restrictive lung disease.

STRENGTHS AND LIMITATIONS

Generally

This thesis is based on data from The Gothenburg, Scoliosis Database, at the Department of Orthpaedics at Sahlgrenska University Hospital, Gothenburg Sweden. This data base contains consecutive information about all patients with scoliosis at Sahlgrenska Hospital between 1966 and 1994. The availability of this unique data collection is a strength. The fact that not all of the included patients participated in the different studies due to various reasons is a limitation.

Another strength is that the physical measurements of all patients and healthy controls in all of the studies included in the thesis are performed by the same examiner.

Paper 1

This was to our knowledge the first study on long-term outcome and spinal mobility for brace treated AIS patients. The fact that this group showed a reduced lumbar spinal mobility supports the idea that the deformed spine itself might the reason for this reduction in mobility. Unfortunately, no untreated AIS patients of the same age groups and curve sizes for comparison were able to be found, which is a limitation.

Paper II

The long follow-up time of more than 100 patients with EOS is a strength. Another strength is that we have analyzed the mobility of the rib cage and its relation to TLC. This has previously not been studied.

A limitation of the study is that we did not compare the results to a matched control group. However, we used reference values consisting of corresponding groups of healthy individuals of similar age and gender. Another limitation is the small number of patients in the subgroup. Though, they were compared to an age- gender- and BMI (body mass index) -matched control group consisting of a convenience sample of healthy individuals.

Paper III

The spinal range of motion and trunk muscle endurance in patients treated for EOS has to our knowledge previously not been evaluated and compared to other groups of AIS in long term follow ups. A limitation is that we were not able to compare the results to a healthy control group. Another limitation was that the group of untreated patients were significantly younger than the other patient groups.

Paper IV

This study is the first study to evaluate the validity of these five different pulmonary measurements in patients with early onset scoliosis. All measurements were performed during the same day and all measurements, except for CT and the plethysmography, by the same examiner. A limitation is the relatively small number of patients, although the group consisted of both previously brace treated and surgically treated patients with different degrees of lung volume limitations.

CLINICAL RELEVANCE

The increased knowledge about physical function long-term after treatment is of great value for the different groups of patients with idiopathic scoliosis, as well as for their healthcare providers before choice of initial treatment and before interventions with the aim to reduce the degree of impact on physical function and pulmonary function.

The patients with scoliosis can be provided with information of probable long-term effects on physical function and be offered examination and treatment.

It is also of value for the patients in their roles as parents and their concern about their children and later grandchildren as scoliosis is known to be hereditary.

The strong correlations between ”gold standard” spirometry and the measurements by handheld spirometer and thorax expansion show that these inexpensive and less time consuming methods can be useful tools for early detection of reduction of pulmonary function during daily clinical practice. This provides an opportunity to, after an initial spirometry by plethysmography, continue to follow the patients and in case of a decrease a new spirometry by plethysmography should be conducted.

6 CONCLUSIONS AND FUTURE PERSPECTIVES

CONCLUSIONS

□ For braced as well as operated patients with adolescent idiopathic scoliosis, lumbar spinal mobility and muscle endurance were reduced more than 20 years after completed treatment. The self-reported physical function was however, not severely restricted.

□ In patients with early onset scoliosis, brace treated as well as surgically treated, thorax expansion and breathing movements measured by RMMI were reduced more than 20 years after completed treatment. TLC values as a measurement of pulmonary function was influenced by gender, brace model, smoking habits, thorax expansion and curve size at start of treatment. Patients with scoliosis should therefore be strongly advised not to smoke.

□ For braced EOS patients, at mean 26.5 years after completed treatment, both spinal range of motion and trunk muscle endurance were similar to that of untreated AIS patients. The EOS patients, despite a significantly longer bracing period, were more mobile and had longer muscle endurance than the braced AIS patients. The operated EOS patients were neither weaker nor stiffer than the operated AIS patients, despite somewhat longer fusions in the EOS group.

□ There were strong correlations between VC measured by spirometry by plethysmography and measurements by a handheld spirometer, CT scan, and thorax expansion for middle-aged patients with EOS. Therefore, thorax expansion and handheld spirometer, both cheaper and less time-consuming, can be useful tools for early detection of reduction of pulmonary function during daily clinical practice.

FUTURE PERSPECTIVES

The long-term outcome of physical function and pulmonary was evaluated more than 20 years after completed treatment. Since then other types of brace treatment as well as surgical treatment have been developed. In the future it would be of value to examine the patients before start of treatment and immediately after the end of treatment to be able to detect the need for individually designed exercises earlier.

In study II it was found that smoking habits was among strong factors explaining TLC % predicted. The effect of smoking also needs to be further evaluated in a larger number of patients.

There is also a need for further studies to establish the correlations, found in this study, between spinal mobility and trunk muscle endurance versus back function and physical activity for both brace treated and surgically treated patients.

This thesis focuses on several different aspects of function. However, the connection between the pelvic floor muscles and the stabilizing trunk muscles and the relation to pulmonary function need to be further examined.

7 ACKNOWLEDGEMENT

Först och främst vill jag framföra mitt hjärtliga tack till alla patienter och kontrollpersoner som har varit deltagare. Utan er hade det inte blivit några resultat att analysera.

I would like to thank and express my gratitude to everyone, mentioned or not, who has helped me to make this thesis possible. In particular I would like to thank:

My main supervisor and co-author Gunilla Kjellby-Wendt, RPT, PhD. Thank you for sharing your deep knowledge about spinal function, for excellent scientific support and for encouraging me during my work with this thesis.

Professor Monika Fagevik-Olsén, RPT, PhD, co-supervisor and co-author. Thank you for sharing your deep knowledge in the researchfield of pulmonary function and for excellent scientific support and encouragement.

Aina Danielsson, MD, PhD, co-supervisor and co-author. Thank you for sharing your deep knowledge about research in the area of spinal deformities and for excellent scientific support and encouragement.

Kerstin Löfdahl MD, PhD, co-author. Thank you for sharing your invaluable knowledge about respiratory function.

Åse Johnsson MD, PhD, co-author. Thank you for sharing your deep knowledge about radiology and for your quick response to questions regarding our work.

Everybody at the Department of Health and Rehabilitation, Institute of Neuroscience and Physiology at Sahlgrenska Academy, University of Gothenburg.

All my physiotherapy colleagues and co-workers at the physiotherapy department at Sahlgrenska University hospital. All my former bosses and my current bosses, Mia and Julia. My colleagues and co-workers in ROHP, thank you for always being positive and supportive.

My colleague and friend Elisabeth Brodin. Thank you for interesting conversations, good advice, support and friendship.

My colleague and fellow doctoral student Jenny Danielsbacka. Thank you for good talks and encouragement.

Everybody at the orthopaedic department. Thank you for always being positive and fun to work together with.

My former colleague Gunilla Mattsson who introduced be to the field of scoliosis.

Bengt Bengtsson and Nils-Gunnar Pehrsson for statistical support.

Kate Bramley-Moore for her invaluable language skills.

All my dear friends and relatives outside the scientific world, for showing interest in my research, for all support and for being there.

My brother Michael and brother-in-law Meir, thank you for all great conversations, support and for being there although it is "over there".

My sister Anna and niece Alice, thank you for being there, for support and for all the friendship and fun.

Most of all, my beloved Pelle (and of course Ruben and Alexander), thank you for believing in me, for your great support and all the joy you bring.

Funding

This thesis was funded in part by the Local Research and Development Board for Gothenburg and Södra Bohuslän, the region Västra Götaland, the Renée Eander Foundation for Research, Sahlgrenska Funds and Norrbacka-Eugenia institute.

8 REFERENCES

1. Vasiliadis ES, Grivas TB, Kaspiris A. Historical overview of spinal deformities in ancient Greece. Scoliosis. 2009;4:6.
2. Moen KY, Nachemson AL. Treatment of scoliosis. An historical perspective. Spine (Phila Pa 1976). 1999;24(24):2570-5.
3. Fayssoux RS, Cho RH, Herman MJ. A history of bracing for idiopathic scoliosis in North America. Clin Orthop Relat Res. 2010;468(3):654-64.
4. Blount WP. The Milwaukee brace in the treatment of the young child with scoliosis. Archiv fur orthopadische und Unfall-Chirurgie. 1964;56:363-9.
5. Blount WP. Non-operative treatment of scoliosis with the Milwaukee brace. Manitoba medical review. 1965;45(8):478-80.
6. Blount WP, Schmidt AC, Keever ED, Leonard ET. The Milwaukee brace in the operative treatment of scoliosis. The Journal of bone and joint surgery American volume. 1958;40-a(3):511-25.
7. Lonstein JE, Winter RB. The Milwaukee brace for the treatment of adolescent idiopathic scoliosis. A review of one thousand and twenty patients. The Journal of bone and joint surgery American volume. 1994;76(8):1207-21.
8. Emans JB, Kaelin A, Bancel P, Hall JE, Miller ME. The Boston bracing system for idiopathic scoliosis. Follow-up results in 295 patients. Spine (Phila Pa 1976). 1986;11(8):792-801.
9. Bassett GS, Bunnell WP, MacEwen GD. Treatment of idiopathic scoliosis with the Wilmington brace. Results in patients with a twenty to thirty-nine-degree curve. The Journal of bone and joint surgery American volume. 1986;68(4):602-5.
10. Kotwicki T, Pietrzak S, Szulc A. Three-dimensional action of Cheneau brace on thoracolumbar scoliosis. Stud Health Technol Inform. 2002;88:226-9.
11. Piazza MR, Bassett GS. Curve progression after treatment with the Wilmington brace for idiopathic scoliosis. Journal of pediatric orthopedics. 1990;10(1):39-43.
12. Price CT, Scott DS, Reed FR, Jr., Sproul JT, Riddick MF. Nighttime bracing for adolescent idiopathic scoliosis with the Charleston Bending Brace: long-term follow-up. Journal of pediatric orthopedics. 1997;17(6):703-7.
13. Hall J, Miller W, Shuman W, Stanish W. A refined concept in the orthotic management of idiopathic scoliosis. Prosthetics and orthotics international. 1975;29:7-13.
14. Donzelli S, Zaina F, Minnella S, Lusini M, Negrini S. Consistent and regular daily wearing improve bracing results: a case-control study. Scoliosis and spinal disorders. 2018;13:16.

15. Nachemson AL, Peterson LE. Effectiveness of treatment with a brace in girls who have adolescent idiopathic scoliosis. A prospective, controlled study based on data from the Brace Study of the Scoliosis Research Society. The Journal of bone and joint surgery American volume. 1995;77(6):815-22.
16. Weinstein SL, Dolan LA, Wright JG, Dobbs MB. Effects of bracing in adolescents with idiopathic scoliosis. The New England journal of medicine. 2013;369(16):1512-21.
17. D'Amato CR, Griggs S, McCoy B. Nighttime bracing with the Providence brace in adolescent girls with idiopathic scoliosis. Spine (Phila Pa 1976). 2001;26(18):2006-12.
18. Khan MJ, Srinivasan VM, Jea AH. The History of Bracing for Scoliosis. Clinical pediatrics. 2016;55(4):320-5.
19. Hasler CC. A brief overview of 100 years of history of surgical treatment for adolescent idiopathic scoliosis. Journal of children's orthopaedics. 2013;7(1):57-62.
20. Harrington PR. Treatment of scoliosis. Correction and internal fixation by spine instrumentation. The Journal of bone and joint surgery American volume. 1962;44-a:591-610.
21. Helenius I, Remes V, Yrjonen T, Ylikoski M, Schlenzka D, Helenius M, et al. Comparison of long-term functional and radiologic outcomes after Harrington instrumentation and spondylodesis in adolescent idiopathic scoliosis: a review of 78 patients. Spine (Phila Pa 1976). 2002;27(2):176-80.
22. Padua R, Padua S, Aulisa L, Ceccarelli E, Padua L, Romanini E, et al. Patient outcomes after Harrington instrumentation for idiopathic scoliosis: a 15- to 28-year evaluation. Spine (Phila Pa 1976). 2001;26(11):1268-73.
23. Weinstein SL, Dolan LA, Spratt KF, Peterson KK, Spoonamore MJ, Ponseti IV. Health and function of patients with untreated idiopathic scoliosis: a 50-year natural history study. Jama. 2003;289(5):559-67.
24. Dickson JH, Erwin WD, Rossi D. Harrington instrumentation and arthrodesis for idiopathic scoliosis. A twenty-one-year follow-up. The Journal of bone and joint surgery American volume. 1990;72(5):678-83.
25. Danielsson AJ, Ekerljung L, Hallerman KL. Pulmonary function in middle-aged patients with idiopathic scoliosis with onset before the age of 10 years. Spine deformity. 2015;3(5):451-61.
26. Danielsson AJ, Nachemson AL. Radiologic findings and curve progression 22 years after treatment for adolescent idiopathic scoliosis: comparison of brace and surgical treatment with matching control group of straight individuals. Spine (Phila Pa 1976). 2001;26(5):516-25.
27. Danielsson AJ, Nachemson AL. Back pain and function 23 years after fusion for adolescent idiopathic scoliosis: a case-control study-part II. Spine (Phila Pa 1976). 2003;28(18):E373-83.

28. Danielsson AJ, Nachemson AL. Back pain and function 22 years after brace treatment for adolescent idiopathic scoliosis: a case-control study-part I. Spine (Phila Pa 1976). 2003;28(18):2078-85; discussion 86.
29. Lange JE, Steen H, Brox JI. Long-term results after Boston brace treatment in adolescent idiopathic scoliosis. Scoliosis. 2009;4:17.
30. Burwell RG. Aetiology of idiopathic scoliosis: current concepts. Pediatric rehabilitation. 2003;6(3-4):137-70.
31. Negrini S, Donzelli S, Aulisa AG, Czaprowski D, Schreiber S, de Mauroy JC, et al. 2016 SOSORT guidelines: orthopaedic and rehabilitation treatment of idiopathic scoliosis during growth. Scoliosis and spinal disorders. 2018;13:3.
32. Düppe H, Acke Ohlin, Jeanette Engquist, and Lena Lyons. Danielssons Och Willners Barnortopedi. Helt Omarb. Nyutg.] ed. Lund: Studentlitteratur, 2007. Print.
33. Charles YP, Dimeglio A, Marcoul M, Bourgin JF, Marcoul A, Bozonnat MC. Influence of idiopathic scoliosis on three-dimensional thoracic growth. Spine (Phila Pa 1976). 2008;33(11):1209-18.
34. Kleinberg S. The operative treatment of scoliosis. JAMA Surgery. 1922;5(3):631-45.
35. Aebi M. The adult scoliosis. Eur Spine J. 2005;14(10):925-48.
36. Lowe TG, Edgar M, Margulies JY, Miller NH, Raso VJ, Reinker KA, et al. Etiology of idiopathic scoliosis: current trends in research. The Journal of bone and joint surgery American volume. 2000;82(8):1157-68.
37. Kouwenhoven JW, Castelein RM. The pathogenesis of adolescent idiopathic scoliosis: review of the literature. Spine (Phila Pa 1976). 2008;33(26):2898-908.
38. Garland HG. Hereditary scoliosis. British medical journal. 1934;1(3816):328.
39. Grauers A, Einarsdottir E, Gerdhem P. Genetics and pathogenesis of idiopathic scoliosis. Scoliosis and spinal disorders. 2016;11:45.
40. Grauers A, Rahman I, Gerdhem P. Heritability of scoliosis. Eur Spine J. 2012;21(6):1069-74.
41. Cobb J. Technique for study of scoliosis. AAOS Instructional Course Lectures. 1948:261-75.
42. King HA, Moe JH, Bradford DS, Winter RB. The selection of fusion levels in thoracic idiopathic scoliosis. The Journal of bone and joint surgery American volume. 1983;65(9):1302-13.
43. Lenke LG, Betz RR, Haher TR, Lapp MA, Merola AA, Harms J, et al. Multisurgeon assessment of surgical decision-making in adolescent idiopathic scoliosis: curve classification, operative approach, and fusion levels. Spine (Phila Pa 1976). 2001;26(21):2347-53.
44. James JI. The management of infants with scoliosis. J Bone Joint Surg Br. 1975;57(4):422-9.

45. James JI. Idiopathic scoliosis; the prognosis, diagnosis, and operative indications related to curve patterns and the age at onset. J Bone Joint Surg Br. 1954;36-b(1):36-49.
46. El-Hawary R, Akbarnia BA. Early Onset Scoliosis - Time for Consensus. Spine Deform. 2015;3(2):105-6.
47. Nachemson A. A long term follow-up study of non-treated scoliosis. Acta Orthop Scand. 1968;39(4):466-76.
48. Nilsonne U, Lundgren KD. Long-term prognosis in idiopathic scoliosis. Acta Orthop Scand. 1968;39(4):456-65.
49. Pehrsson K, Larsson S, Oden A, Nachemson A. Long-term follow-up of patients with untreated scoliosis. A study of mortality, causes of death, and symptoms. Spine. 1992;17(9):1091-6.
50. Davies G, Reid L. Growth of the alveoli and pulmonary arteries in childhood. Thorax. 1970;25(6):669-81.
51. Narayanan M, Owers-Bradley J, Beardsmore CS, Mada M, Ball I, Garipov R, et al. Alveolarization continues during childhood and adolescence: new evidence from helium-3 magnetic resonance. Am J Respir Crit Care Med. 2012;185(2):186-91.
52. Weinstein SL, Dolan LA, Cheng JC, Danielsson A, Morcuende JA. Adolescent idiopathic scoliosis. Lancet (London, England). 2008;371(9623):1527-37.
53. Danielsson AJ. Natural history of adolescent idiopathic scoliosis: a tool for guidance in decision of surgery of curves above 50 degrees. Journal of children's orthopaedics. 2013;7(1):37-41.
54. Weinstein SL. The Natural History of Adolescent Idiopathic Scoliosis. Journal of pediatric orthopedics. 2019;39(Issue 6, Supplement 1 Suppl 1):S44-s6.
55. Weinstein SL. The Importance of Natural History. Journal of pediatric orthopedics. 2019;39(Issue 6, Supplement 1 Suppl 1):S6-s9.
56. Bunnell WP. The natural history of idiopathic scoliosis before skeletal maturity. Spine (Phila Pa 1976). 1986;11(8):773-6.
57. Karol LA, Johnston C, Mladenov K, Schochet P, Walters P, Browne RH. Pulmonary function following early thoracic fusion in non-neuromuscular scoliosis. The Journal of bone and joint surgery American volume. 2008;90.
58. Karol LA. The Natural History of Early-onset Scoliosis. Journal of Pediatric Orthopaedics. 2019;39:S38-S43.
59. Harshavardhana NS, Lonstein JE. Results of Bracing for Juvenile Idiopathic Scoliosis. Spine Deform. 2018;6(3):201-6.
60. Climent JM, Sanchez J. Impact of the type of brace on the quality of life of Adolescents with Spine Deformities. Spine (Phila Pa 1976). 1999;24(18):1903-8.
61. Davis L, Murphy JS, Shaw KA, Cash K, Devito DP, Schmitz ML. Nighttime bracing with the Providence thoracolumbosacral orthosis for

treatment of adolescent idiopathic scoliosis: A retrospective consecutive clinical series. Prosthetics and orthotics international. 2019;43(2):158-62.
62. Yrjonen T, Ylikoski M, Schlenzka D, Kinnunen R, Poussa M. Effectiveness of the Providence nighttime bracing in adolescent idiopathic scoliosis: a comparative study of 36 female patients. Eur Spine J. 2006;15(7):1139-43.
63. Dickson RA, Weinstein SL. Bracing (and screening)--yes or no? J Bone Joint Surg Br. 1999;81(2):193-8.
64. Goldberg CJ, Dowling FE, Hall JE, Emans JB. A statistical comparison between natural history of idiopathic scoliosis and brace treatment in skeletally immature adolescent girls. Spine (Phila Pa 1976). 1993;18(7):902-8.
65. Goldberg CJ, Moore DP, Fogarty EE, Dowling FE. Adolescent idiopathic scoliosis: the effect of brace treatment on the incidence of surgery. Spine (Phila Pa 1976). 2001;26(1):42-7.
66. Richards BS, Bernstein RM, D'Amato CR, Thompson GH. Standardization of criteria for adolescent idiopathic scoliosis brace studies: SRS Committee on Bracing and Nonoperative Management. Spine (Phila Pa 1976). 2005;30(18):2068-75; discussion 76-7.
67. Weiss HR. The method of Katharina Schroth - history, principles and current development. Scoliosis. 2011;6:17.
68. Park JH, Jeon HS, Park HW. Effects of the Schroth exercise on idiopathic scoliosis: a meta-analysis. European journal of physical and rehabilitation medicine. 2018;54(3):440-9.
69. Negrini S, Donzelli S, Negrini A, Parzini S, Romano M, Zaina F. Specific exercises reduce the need for bracing in adolescents with idiopathic scoliosis: A practical clinical trial. Annals of physical and rehabilitation medicine. 2019;62(2):69-76.
70. Burger M, Coetzee W, du Plessis LZ, Geldenhuys L, Joubert F, Myburgh E, et al. The effectiveness of Schroth exercises in adolescents with idiopathic scoliosis: A systematic review and meta-analysis. The South African journal of physiotherapy. 2019;75(1):904.
71. Day JM, Fletcher J, Coghlan M, Ravine T. Review of scoliosis-specific exercise methods used to correct adolescent idiopathic scoliosis. Archives of physiotherapy. 2019;9:8.
72. Monticone M, Ambrosini E, Cazzaniga D, Rocca B, Ferrante S. Active self-correction and task-oriented exercises reduce spinal deformity and improve quality of life in subjects with mild adolescent idiopathic scoliosis. Results of a randomised controlled trial. Eur Spine J. 2014;23(6):1204-14.
73. Kim HJ, Blanco JS, Widmann RF. Update on the management of idiopathic scoliosis. Current opinion in pediatrics. 2009;21(1):55-64.
74. Kim YJ, Lenke LG, Kim J, Bridwell KH, Cho SK, Cheh G, et al. Comparative analysis of pedicle screw versus hybrid instrumentation in posterior spinal fusion of adolescent idiopathic scoliosis. Spine (Phila Pa 1976). 2006;31(3):291-8.

75. Lee SM, Suk SI, Chung ER. Direct vertebral rotation: a new technique of three-dimensional deformity correction with segmental pedicle screw fixation in adolescent idiopathic scoliosis. Spine (Phila Pa 1976). 2004;29(3):343-9.
76. Suk SI, Lee CK, Kim WJ, Chung YJ, Park YB. Segmental pedicle screw fixation in the treatment of thoracic idiopathic scoliosis. Spine (Phila Pa 1976). 1995;20(12):1399-405.
77. Helenius I, Remes V, Yrjonen T, Ylikoski M, Schlenzka D, Helenius M, et al. Harrington and Cotrel-Dubousset instrumentation in adolescent idiopathic scoliosis. Long-term functional and radiographic outcomes. The Journal of bone and joint surgery American volume. 2003;85-a(12):2303-9.
78. Sellyn GE, Hale AT, Tang AR, Waters A, Shannon CN, Bonfield CM. Pediatric thoracolumbar spine surgery and return to athletics: a systematic review. Journal of neurosurgery Pediatrics. 2019:1-11.
79. Helenius L, Diarbakerli E, Grauers A, Lastikka M, Oksanen H, Pajulo O, et al. Back Pain and Quality of Life After Surgical Treatment for Adolescent Idiopathic Scoliosis at 5-Year Follow-up: Comparison with Healthy Controls and Patients with Untreated Idiopathic Scoliosis. The Journal of bone and joint surgery American volume. 2019;101(16):1460-6.
80. Poussa M, Harkonen H, Mellin G. Spinal mobility in adolescent girls with idiopathic scoliosis and in structurally normal controls. Spine (Phila Pa 1976). 1989;14(2):217-9.
81. Mattson G, Haderspeck-Grib K, Schultz A, Nachemson A. Joint flexibilities in structurally normal girls and girls with idiopathic scoliosis. Journal of orthopaedic research : official publication of the Orthopaedic Research Society. 1983;1(1):57-62.
82. Eyvazov K, Samartzis D, Cheung JP. The association of lumbar curve magnitude and spinal range of motion in adolescent idiopathic scoliosis: a cross-sectional study. BMC musculoskeletal disorders. 2017;18(1):51.
83. Galvis S, Burton D, Barnds B, Anderson J, Schwend R, Price N, et al. The effect of scoliotic deformity on spine kinematics in adolescents. Scoliosis and spinal disorders. 2016;11:42-.
84. Engsberg JR, Lenke LG, Reitenbach AK, Hollander KW, Bridwell KH, Blanke K. Prospective evaluation of trunk range of motion in adolescents with idiopathic scoliosis undergoing spinal fusion surgery. Spine (Phila Pa 1976). 2002;27(12):1346-54.
85. Wren TAL, Ponrartana S, Poorghasamians E, Moreau S, Aggabao PC, Zaslow TL, et al. Biomechanical Modeling of Spine Flexibility and Its Relationship to Spinal Range of Motion and Idiopathic Scoliosis. Spine Deform. 2017;5(4):225-30.
86. Hodges PW, Richardson CA. Contraction of the abdominal muscles associated with movement of the lower limb. Phys Ther. 1997;77(2):132-42; discussion 42-4.

87. MacDonald DA, Moseley GL, Hodges PW. The lumbar multifidus: does the evidence support clinical beliefs? Manual therapy. 2006;11(4):254-63.
88. Lu WW, Hu Y, Luk KD, Cheung KM, Leong JC. Paraspinal muscle activities of patients with scoliosis after spine fusion: an electromyographic study. Spine (Phila Pa 1976). 2002;27(11):1180-5.
89. Grauers A, Topalis C, Moller H, Normelli H, Karlsson MK, Danielsson A, et al. Prevalence of Back Problems in 1069 Adults With Idiopathic Scoliosis and 158 Adults Without Scoliosis. Spine (Phila Pa 1976). 2014;39(11):886-92.
90. Andersen MO, Christensen SB, Thomsen K. Outcome at 10 years after treatment for adolescent idiopathic scoliosis. Spine (Phila Pa 1976). 2006;31(3):350-4.
91. Lange JE, Steen H, Gunderson R, Brox JI. Long-term results after Boston brace treatment in late-onset juvenile and adolescent idiopathic scoliosis. Scoliosis. 2011;6(1):18.
92. Topalis C, Grauers A, Diarbakerli E, Danielsson A, Gerdhem P. Neck and back problems in adults with idiopathic scoliosis diagnosed in youth: an observational study of prevalence, change over a mean four year time period and comparison with a control group. Scoliosis and spinal disorders. 2017;12:20.
93. Misterska E, Glowacki J, Okret A, Laurentowska M, Glowacki M. Back and neck pain and function in females with adolescent idiopathic scoliosis: A follow-up at least 23 years after conservative treatment with a Milwaukee brace. PloS one. 2017;12(12):e0189358.
94. Pehrsson K, Danielsson A, Nachemson A. Pulmonary function in adolescent idiopathic scoliosis: a 25 year follow up after surgery or start of brace treatment. Thorax. 2001;56(5):388-93.
95. Finsbäck C, Mannerkorpi K. Spinal and thoracic mobility - age-related values for healthy men and women. Nord Fysioter. 2005;9(3):136-43.
96. Moll JM, Wright V. An objective clinical study of chest expansion. Ann Rheum Dis. 1972;31(1):1-8.
97. Olsén MF, Lindstrand H, Broberg JL, Westerdahl E. Measuring chest expansion; A study comparing two different instructions. Advances in Physiotherapy. 2011;13(3):128-32.
98. Bockenhauer SE, Chen H, Julliard KN, Weedon J. Measuring thoracic excursion: reliability of the cloth tape measure technique. The Journal of the American Osteopathic Association. 2007;107(5):191-6.
99. Reddy RS, Alahmari KA, Silvian PS, Ahmad IA, Kakarparthi VN, Rengaramanujam K. Reliability of Chest Wall Mobility and Its Correlation with Lung Functions in Healthy Nonsmokers, Healthy Smokers, and Patients with COPD. Can Respir J. 2019;2019:5175949.
100. Cahalin LP, Ragnarsdottir M. Reliability, validity, and clinical utility of a novel Respiratory Movement Measurement Instrument.(Critical care--outcomes: 12: 00pm-1: 45pm). Chest. 2002;122(4):207S-S.

101. Ragnarsdottir M, Kristinsdottir EK. Breathing movements and breathing patterns among healthy men and women 20-69 years of age. Reference values. Respiration. 2006;73(1):48-54.
102. Johansson EL, Ternesten-Hasseus E, Olsen MF, Millqvist E. Respiratory movement and pain thresholds in airway environmental sensitivity, asthma and COPD. Respir Med. 2012;106(7):1006-13.
103. Kristjansdottir A, Ragnarsdottir M, Hannesson P, Beck HJ, Torfason B. Respiratory movements are altered three months and one year following cardiac surgery. Scand Cardiovasc J. 2004;38(2):98-103.
104. Ragnarsdottir M, Geirsson AJ, Gudbjornsson B. Rib cage motion in ankylosing spondylitis patients: a pilot study. Spine J. 2008;8(3):505-9.
105. Butler JE. Drive to the human respiratory muscles. Respiratory physiology & neurobiology. 2007;159(2):115-26.
106. Rochester DF. The diaphragm: contractile properties and fatigue. J Clin Invest. 1985;75(5):1397-402.
107. Sclauser Pessoa IM, Franco Parreira V, Fregonezi GA, Sheel AW, Chung F, Reid WD. Reference values for maximal inspiratory pressure: a systematic review. Can Respir J. 2014;21(1):43-50.
108. Heale R, Twycross A. Validity and reliability in quantitative studies. Evidence-based nursing. 2015;18(3):66-7.
109. Cochran T, Irstam L, Nachemson A. Long-term anatomic and functional changes in patients with adolescent idiopathic scoliosis treated by Harrington rod fusion. Spine (Phila Pa 1976). 1983;8(6):576-84.
110. Cochran T, Nachemson A. Long-term anatomic and functional changes in patients with adolescent idiopathic scoliosis treated with the Milwaukee brace. Spine (Phila Pa 1976). 1985;10(2):127-33.
111. Danielsson AJ, Wiklund I, Pehrsson K, Nachemson AL. Health-related quality of life in patients with adolescent idiopathic scoliosis: a matched follow-up at least 20 years after treatment with brace or surgery. Eur Spine J. 2001;10(4):278-88.
112. Watts HG, Hall JE, Stanish W. The Boston brace system for the treatment of low thoracic and lumbar scoliosis by the use of a girdle without superstructure. Clin Orthop Relat Res. 1977(126):87-92.
113. Nordwall A. Studies in idiopathic scoliosis relevant to etiology, conservative and operative treatment. Acta orthopaedica Scandinavica Supplementum. 1973:1-178.
114. Nachemson A, Nordwall A. Effectiveness of preoperative Cotrel traction for correction of idiopathic scoliosis. The Journal of bone and joint surgery American volume. 1977;59(4):504-8.
115. Danielsson AJ, Hasserius R, Ohlin A, Nachemson AL. A prospective study of brace treatment versus observation alone in adolescent idiopathic scoliosis: a follow-up mean of 16 years after maturity. Spine (Phila Pa 1976). 2007;32(20):2198-207.

116. Amendt LE, Ause-Ellias KL, Eybers JL, Wadsworth CT, Nielsen DH, Weinstein SL. Validity and reliability testing of the Scoliometer. Phys Ther. 1990;70(2):108-17.
117. Langensiepen S, Semler O, Sobottke R, Fricke O, Franklin J, Schonau E, et al. Measuring procedures to determine the Cobb angle in idiopathic scoliosis: a systematic review. Eur Spine J. 2013;22(11):2360-71.
118. Quanjer PH, Tammeling GJ, Cotes JE, Pedersen OF, Peslin R, Yernault JC. Lung volumes and forced ventilatory flows. Eur Respir J. 1993;6 Suppl 16:5-40.
119. Quanjer PH, Stanojevic S, Cole TJ, Baur X, Hall GL, Culver BH, et al. Multi-ethnic reference values for spirometry for the 3–95-yr age range: the global lung function 2012 equations. Eur Respiratory Soc; 2012.
120. Lindh M, Bjure J. Lung volumes in scoliosis before and after correction by the Harrington instrumentation method. Acta Orthopaedica Scandinavica. 1975;46(6):934-48.
121. Kauczor HU, Heussel CP, Fischer B, Klamm R, Mildenberger P, Thelen M. Assessment of lung volumes using helical CT at inspiration and expiration: comparison with pulmonary function tests. AJR American journal of roentgenology. 1998;171(4):1091-5.
122. Terwee CB, Bot SD, de Boer MR, van der Windt DA, Knol DL, Dekker J, et al. Quality criteria were proposed for measurement properties of health status questionnaires. Journal of clinical epidemiology. 2007;60(1):34-42.
123. Malmström E-M, Karlberg M, Melander A, Magnusson M. Zebris versus Myrin: a comparative study between a three-dimensional ultrasound movement analysis and an inclinometer/compass method: intradevice reliability, concurrent validity, intertester comparison, intratester reliability, and intraindividual variability. Spine. 2003;28(21):E433-E40.
124. Mellin G. Physical therapy for chronic low back pain: correlations between spinal mobility and treatment outcome. Scandinavian journal of rehabilitation medicine. 1985;17(4):163-6.
125. Mellin G. Method and instrument for noninvasive measurements of thoracolumbar rotation. Spine (Phila Pa 1976). 1987;12(1):28-31.
126. Öhlén G. Spinal Sagittal Configuration and Mobility: A Kyphometer Study1989.
127. Ohlen G, Spangfort E, Tingvall C. Measurement of spinal sagittal configuration and mobility with Debrunner's kyphometer. Spine (Phila Pa 1976). 1989;14(6):580-3.
128. Macrae IF, Wright V. Measurement of back movement. Annals of the Rheumatic Diseases. 1969;28(6):584-9.
129. Biering-Sorensen F. Physical measurements as risk indicators for low-back trouble over a one-year period. Spine (Phila Pa 1976). 1984;9(2):106-19.

130. Frost M, Stuckey S, Smalley LA, Dorman G. Reliability of measuring trunk motions in centimeters. Physical therapy. 1982;62(10):1431-7.
131. Mellin GP. Accuracy of measuring lateral flexion of the spine with a tape. Clinical Biomechanics. 1986;1(2):85-9.
132. Ito T, Shirado O, Suzuki H, Takahashi M, Kaneda K, Strax TE. Lumbar trunk muscle endurance testing: an inexpensive alternative to a machine for evaluation. Archives of physical medicine and rehabilitation. 1996;77(1):75-9.
133. Gunnesson IL, Olsen MF. Validity in measuring breathing movements with the Respiratory Movement Measuring Instrument, RMMI. Clin Physiol Funct Imaging. 2011;31(1):1-4.
134. Olsen MF, Romberg K. Reliability of the Respiratory Movement Measuring Instrument, RMMI. Clin Physiol Funct Imaging. 2010;30(5):349-53.
135. Dimitriadis Z, Kapreli E, Konstantinidou I, Oldham J, Strimpakos N. Test/retest reliability of maximum mouth pressure measurements with the MicroRPM in healthy volunteers. Respiratory care. 2011;56(6):776-82.
136. Sullivan M, Karlsson J, Ware JE, Jr. The Swedish SF-36 Health Survey--I. Evaluation of data quality, scaling assumptions, reliability and construct validity across general populations in Sweden. Social science & medicine (1982). 1995;41(10):1349-58.
137. Ware JE, Jr., Sherbourne CD. The MOS 36-item short-form health survey (SF-36). I. Conceptual framework and item selection. Medical care. 1992;30(6):473-83.
138. Fairbank J, Couper J, Davies J, O'brien J. The Oswestry low back pain disability questionnaire. Physiotherapy. 1980;66(8):271-3.
139. Gronblad M, Hupli M, Wennerstrand P, Jarvinen E, Lukinmaa A, Kouri JP, et al. Intercorrelation and test-retest reliability of the Pain Disability Index (PDI) and the Oswestry Disability Questionnaire (ODQ) and their correlation with pain intensity in low back pain patients. The Clinical journal of pain. 1993;9(3):189-95.
140. Rosengren A, Orth-Gomer K, Wedel H, Wilhelmsen L. Stressful life events, social support, and mortality in men born in 1933. Bmj. 1993;307(6912):1102-5.
141. Gatchel RJ, Mayer TG, Capra P, Diamond P, Barnett J. Quantification of lumbar function. Part 6: The use of psychological measures in guiding physical functional restoration. Spine (Phila Pa 1976). 1986;11(1):36-42.
142. Simony A, Hansen EJ, Christensen SB, Carreon LY, Andersen MO. Incidence of cancer in adolescent idiopathic scoliosis patients treated 25 years previously. Eur Spine J. 2016;25(10):3366-70.
143. Domholdt E. Rehabilitation research: principles and applications: Elsevier Saunders St. Louis^ eMo Mo. 2005.

144. Aaro S, Ohlen G. The effect of Harrington instrumentation on the sagittal configuration and mobility of the spine in scoliosis. Spine (Phila Pa 1976). 1983;8(6):570-5.
145. Behensky H, Krismer M, Bauer R. Comparison of spinal mobility after Harrington and CD instrumentation. J Spinal Disord. 1998;11(2):155-62.
146. Leong J, Lu W, Luk K, Karlberg E. Kinematics of the chest cage and spine during breathing in healthy individuals and in patients with adolescent idiopathic scoliosis. Spine. 1999;24(13):1310.
147. Kotani T, Minami S, Takahashi K, Isobe K, Nakata Y, Takaso M, et al. An analysis of chest wall and diaphragm motions in patients with idiopathic scoliosis using dynamic breathing MRI. Spine. 2004;29(3):298-302.
148. Hagman C, Janson C, Malinovschi A, Hedenström H, Emtner M. Measuring breathing patterns and respiratory movements with the respiratory movement measuring instrument. Clinical physiology and functional imaging. 2016;36(5):414-20.
149. Arikan H, Yatar I, Calik-Kutukcu E, Aribas Z, Saglam M, Vardar-Yagli N, et al. A comparison of respiratory and peripheral muscle strength, functional exercise capacity, activities of daily living and physical fitness in patients with cystic fibrosis and healthy subjects. Research in developmental disabilities. 2015;45-46:147-56.
150. Kim NS, Seo JH, Ko MH, Park SH, Kang SW, Won YH. Respiratory Muscle Strength in Patients With Chronic Obstructive Pulmonary Disease. Annals of rehabilitation medicine. 2017;41(4):659-66.
151. Sahin G, Calikoglu M, Ozge C, Incel N, Bicer A, Ulsubas B, et al. Respiratory muscle strength but not BASFI score relates to diminished chest expansion in ankylosing spondylitis. Clinical rheumatology. 2004;23(3):199-202.
152. Tylen U, Boijsen M, Ekberg-Jansson A, Bake B, Löfdahl C-G. Emphysematous lesions and lung function in healthy smokers 60 years of age. Respiratory medicine. 2000;94(1):38-43.
153. Debouche S, Pitance L, Robert A, Liistro G, Reychler G. Reliability and Reproducibility of Chest Wall Expansion Measurement in Young Healthy Adults. Journal of manipulative and physiological therapeutics. 2016;39(6):443-9.