THE EFFECTIVENESS OF SELECTIVE THORACIC FUSION FOR TREATMENT OF ADOLESCENT IDIOPATHIC SCOLIOSIS: A SYSTEMATIC REVIEW

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THESIS DECLARATION

I, Nathan Eardley-Harris certify that this work contains no material that has been accepted for the award of any other degree or diploma in any university or any other territory institution, and, to the best of my knowledge and belief, contains no material previously published or written by any other person, except where due reference has been made in the text.

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1 May 2017

SUMMARY

Scoliosis curves have a proven complex deformity, consisting of a three-dimensional deformity involving the coronal, sagittal and rotational planes. For many years, spinal surgeons have been debating whether a more rigid and straighter spine or a mobile and less straight spine provides better outcomes. The premise of selective thoracic fusion is that after fixation of the primary thoracic curve, there is spontaneous coronal correction of the unfused lumbar curve. Thus, the thoracic curve can be exclusively fused to allow for a more mobile lumbar spine. The objective of this review was to assess the effectiveness of selective thoracic fusion as a form of treatment in adolescent idiopathic scoliosis (AIS). This was compared with all other forms of operative management for major structural thoracic curves.

A comprehensive and exhaustive literature search was conducted for studies that included children aged 10-18 years with adolescent idiopathic scoliosis curve with a thoracic component that is described as structural, treated with selective fusion of the thoracic curve with no distal fusion lower than L1. Congenital, neuromuscular or syndromic causes were excluded. All studies needed a minimum follow-up of 2 years. Radiological outcomes measured were main thoracic curve, compensatory lumbar curve, coronal balance, thoracic kyphosis, lumbar lordosis, sagittal balance, thoracic apical vertebral rotation, lumbar apical vertebral rotation. Clinical outcomes included quality of life surveys, pulmonary function and complications.

A total of 373 studies were retrieved for review with 339 studies excluded after reading the full article for clearly not meeting the inclusion criteria of the review. Two reviewers independently assessed the 34 studies for methodological quality.

Eight studies were eligible for inclusion in a meta-analysis comparing selective thoracic fusion via the anterior or posterior approach. There was no significant difference between approaches for the outcomes measured except for post-operative lumbar lordosis. The anterior approach had a 4.29 (95% CI: 1.5, 7.05) degree lower post-operative lumbar lordosis than the posterior approach.

Two studies were eligible for inclusion for descriptive analysis of comparing compensated

curves against decompensated or imbalanced curves post-operatively with no obvious difference between groups with the exception of a worsening sagittal balance in the coronally decompensated group.

Two studies were eligible for inclusion for meta-analysis of comparing selective thoracic fusion in Lenke B vs Lenke C curves, with no difference in groups between the outcomes measured.

Thirty-three studies were eligible for inclusion for meta-analysis of effectiveness of selective thoracic fusion in adolescent idiopathic scoliosis. Selective thoracic fusion was significant in changing the main thoracic curve, compensatory lumbar curve, and thoracic kyphosis post-operatively. Selective thoracic fusion did not have a significant effect on changing the coronal balance, lumbar lordosis, sagittal balance, thoracic apical vertebral rotation or lumbar apical vertebral rotation.

The highest reported complication was coronal decompensation which was reported in 23.1% (95% CI: 15.1, 32.1%).

Pulmonary function and quality of life were poorly reported and therefore little conclusions could be made, besides a return to respiratory baseline and adequate quality of life following surgery.

Unfortunately, due to the lack of high level evidence in the form of RCTs and using the best available evidence which mainly consisted of retrospective case series, only weak conclusions can be drawn into the true effect of selective thoracic fusion. Further prospective uniform trials will be needed to increase the level of evidence available in this topic area.

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CHAPTER ONE: INTRODUCTION

Background

Scoliosis is defined as a lateral curvature of the spine of at least 10 degrees.[1] It can be broadly categorized into structural or non-structural curves. Non-structural curves typically allow normal mobility on bending and are usually non-progressive in nature. Non-structural curves are hypothesized to be a product of the body's instinctive nature to provide truncal balance.[2] However, some non-structural curves may progress to structural curves over time and therefore need continued observation during ages of growth. Structural curves are characterized by their fixed deformity even on bending. Due to the permanent nature of physiological and morphological change of the vertebral bodies and ligaments, structural curves will usually progress as the patient matures, usually at 1 degree per year after maturity.[3]

Scoliosis can also be commonly categorized into three broad categories based on aetiology. These include; neuromuscular, congenital and idiopathic.

Neuromuscular causes include neuropathic pathology such as cerebral palsy or poliomyelitis or myopathic pathology such as muscular dystrophy.[3,4]

Congenital includes deformity secondary to abnormal bone development such as failure of formation or failure of segmentation, abnormal spinal cord development such as myelodysplasia scoliosis or mixed causes such as myelomeningocoele which usually results in bony deformity with paralysis.[3,4]

Other less common causes include an association with neurofibromatosis, mesenchymal disorders such as Marfan's syndrome, a sequelae of trauma or transient structural curves secondary to irritative pathology such as tumours.[4]

Of these categories, idiopathic is by far the most common, and is a diagnosis of exclusion. Idiopathic can be further broken down into categories based on age of onset. Infant scoliosis presents usually prior to 4 years of age, juvenile from ages 4 to 9, and adolescent which occurs between 10 years old and skeletal maturity. Adolescent idiopathic scoliosis (AIS) accounts for 80-85% of cases.[4,5] AIS has a prevalence of 0.15 to 3 percent in the population however 0.3% of the population will ever have curves that progress over 30 degrees.[6] AIS commonly affects females more than males with the most common pattern involving a thoracic curve to the right.[3]

Idiopathic adolescent scoliosis is a complex disease and the aetiology remains unknown. It is likely that it a combination of genetic, environmental and lifestyle factors of which are still unknown.[3,7]

The understanding of scoliosis curves has grown with research with current developments suggesting a more complex deformity, consisting of a three-dimensional deformity involving the coronal, sagittal and rotational axial planes.[7-9] As bone growth during skeletal immaturity is accelerated by distraction at the growth plate and reduced by compression at the growth plate, the normal physiological curvature of the spine causes the ventral part of the spine to have compressive force acting on it, and the dorsal part of the spine to have distracting force on it.

Current theories are that axial plane deformity is the primary structural force in the scoliosis deformity rather than coronal curves.[10] As the vertebral bodies rotate in the axial plane, the ventral and dorsal components of the spine grow discordantly, which over time leads to a change in the coronal plane (ventral spine becoming the concave portion of the curve).[7]

Each curve (of which there may be many in one patient) can be described with an apex (the vertebra with the greatest lateral distance from the centre of the spine) and the two vertebrae at the end of the curve (named the end vertebrae). The Cobb angle, measured by the intersection of parallel lines from the endplates of the superior and inferior end vertebrae, is the standard way of quantifying the magnitude of scoliosis curves.[11,12]

Major or primary curves are the largest abnormal curves as classified by the Cobb angle. These curves are almost always structural. In addition, secondary or tertiary curves are described as structural if the Cobb angle cannot be reduced to below 25 degrees, on side bending radiographs.[2,13]

Current treatment modalities

For many years spinal surgeons have been debating whether a more rigid and straighter spine or a mobile and less straight spine provides better outcomes.[13] The treatment for AIS can include both an operative and non-operative approach. However when the Cobb angle is above 40^0, the likelihood of curve progression is high and surgical treatment is warranted.[14]

Although technology has advanced, the primary goals for operative management have remained constant. The primary goals of surgical treatment in AIS should be to optimize coronal and sagittal correction and avoid further curve progression. This involves not only correction of the major primary curve but also any minor (secondary) curves, while maintaining adequate thoracic kyphosis and lumbar lordosis. Ideally, a balance should be struck between fusing the lowest number of mobile segments and properly correcting the existing deformity. This is where selective spinal fusion has a role to play.

Selective thoracic fusion

The premise of selective thoracic fusion is that after fixation of the primary thoracic curve, there is spontaneous coronal correction of the unfused lumbar curve.[15] Thus the thoracic curve can be exclusively fused to allow for a more mobile lumbar spine.[13,15] This has been described in studies since the 1950s.[16,17]

However, since then, results have varied greatly in the extent of spontaneous lumbar correction. Studies have shown that the degree of spontaneous correction of the lumbar spine is somewhat close to the correction of the thoracic curve; however the extent of optimal correction that can be achieved is uncertain.[18-21]

The alternative to selective thoracic infusion involves complete fusion of both the primary thoracic and secondary lumbar curve in a consecutive series. This can be done via either an anterior or a posterior approach and instrumentation. Complete fusion gives better correction of both curves. It also diminishes the risk of coronal decompensation, adding on phenomenon, junctional kyphosis and eventual revision surgery.[13] However this needs to be calculated against the risk of sagittal decompensation, increased risk of lumbar degeneration and chronic back pain, all of which seem to be more prevalent in patients with fusion of both curves.[22]

The posterior approach

Posterior spinal fusion has been the gold standard of scoliosis fixation for many years.

Harrington published his work in 1962 which showed his progression with instrumentation of spinal fusion.[23] Prior to this spinal fusion was performed without instrumentation and often needed serial casting and bracing, often with a high failure rate. He utilized the posterior approach to instrument the spine with two Harrington rods without fusion. Hooked to the transverse processes, one rod caused curve correction by distraction of the concave side of the curve. He further developed a compression Harrington rod to be used on the convex side of the curve, but even then, post-operative bracing or casting was still needed. The issue with Harrington instrumentation was its single plane correction and therefore the inability to maintain proper sagittal curve magnitude which led to the creation of “flatback syndrome”.[24]

Luque in 1982, showed the effectiveness of a method utilizing segmental spinal curve control with sublaminar wires and flexible pre-contoured rods. Unfortunately the wires pass through the spinal canal and therefore were reported with a greater risk of neurological damage than other systems (either from insertion, scarring or development of epidural haematomas).[25]

From 1984, the method of spinal fusion changed from a single direction distraction hook with the Harrington system to multisegmental hook systems combined with posterior fusion.[24] Instrumentation examples include the Cotrel-Dubousset system which pioneered improvements in segmental spinal instrumentation with derotation of the vertebrae, then the development of the Texas Scottish Rite Hospital system, Isola, The Universal Spine System, Alici Spinal instrumentation, and Moss-Miami instrumentation. These instrumentation systems allowed finer control over curve correction, allowed the sagittal plane to also be corrected and allowed earlier post-operative mobilisation and no bracing. These work by a combination of rod rotation manoeuvres, and applying compression on the convex side to avoid distraction forces.[24] The rods are attached to the spine via a variety of methods such as hooks, wires or pedicle screws. Despite the coronal and sagittal improvement of curves with this new generation of instrumentation there is still no definitive proof that they help correct the axial component of the deformity.[26]

Posterior spinal fusion is usually performed in the prone position with a posterior midline incision. There is dissection down to the spinous processes and then laterally to reveal the transverse processes. Subperiosteal dissection is performed to spare the neurovascular bundles to the paraspinal muscles. The spinous processes and facet joints are removed with the bone potentially saved for use in bone grafting at a later step. The required vertebrae are instrumented either with wires, pedicle screws or hooks and then possible bone grafting is placed to the facet joints and surrounding areas.[23]

The posterior approach while being described as stable and reliable does have its disadvantages. The disadvantages to the posterior approach have been described as infection, substantial blood loss, prominent instrumentation in thin patients, damage to posterior musculature, worsening of the lumbar curve following fusion, failure to correct kyphosis and the presence of the crankshaft phenomenon in skeletally immature patients.[27,28]

The anterior approach

While originally used as a staging procedure to help with increase curve correction in posterior spinal fusion or as an adjunct procedure to help prevent the crankshaft phenomenon, anterior spinal fixation has now become the main treatment of surgical fixation in scoliosis for some surgeons. The theory of successful anterior fusion is that the anterior annulus fibrosis provides the majority of the torsional stiffness of the spine, therefore by the removal of the discs provides a loss of torsional stiffness of 90% compared with 30% by removal of the posterior spinal structures.[10]

Dwyer first used anterior approach in 1964 for treatment of scoliosis consisting of screws and cables.[29] The problems with this method included a high pseudoarthrosis rate, higher level of thoracic kyphosis and a high rate of instrument breakage.[30]

Zielke in 1976[31] described a method of anterior spinal fusion with stronger rods and screws to aid in compression and reduce the problems associated with Dwyer instrumentation. This method did reduce the pseudoarthrosis rate compared to the Dwyer instrumentation, it was still higher than posterior fusion, and still did have a kyphogenic effect on the thoracic curve.[30] Since then the addition of solid anterior segmental spinal fixation such as the

Kaneda system, the Isola system, Moss-Miami system and Cotrel-Dubousset system the fixation has become more rigid with a lower rate of pseudoarthrosis, less kyphogenic effect and some rod rotation manoeuvres are able to be applied. This has come at a cost of implant bulkiness compared to the Zielke system.[27,32]

Anterior spinal fusion is usually performed in the lateral position. An incision is made over the rib of the superior vertebral level to be fused. The rib is either removed or moved to allow access into the thoracic cavity. The lateral position allows the great vessels to fall away from the concavity of the curve. The pleura and the retroperitoneal space is incised and ligation or clipping of the intercostal and lumbar vessels occurs. A posterior flap is flipped back to costovertebral joints; whilst an anterior joint flap flipped to see anterior vertebral body. The intervertebral disc is removed in its entirety making sure to maintain the posterior longitudinal ligament. The removed rib may be used for bone graft between the vertebral bodies as instrumentation occurs either by single or double rod instrumentation. Usually the pleura is sutured closed and a chest drain is placed.[27,32]

Advantages of anterior spinal fusion include the need for a shorter fusion length and saving motion segments therefore lowering the risk of low back pain and degenerative changes caudal to the fusion, increased vertebral body derotation ability, less bulky instrumentation, spared posterior paraspinal musculature, shortens the spinal column decreasing the risk of traction injury to the spinal cord, and better thoracic kyphosis restoration. The disadvantages have also been described which include high rate of implant breakage, screw pullout, potential for inducing a kyphosis at the instrumented levels, higher rates of pseudoarthrosis, and greater perioperative morbidity such as its effect on pulmonary function and ipsilateral upper extremity function with axial girdle muscle dissection.[33-36] Other complications have been described including risk of atelectasis, pleural effusion, pneumonia, pneumothorax, chylothorax, damage to great vessels, brachial plexus neuropraxia, post-sympathectomy neuralgia, and post-thoracotomy syndrome.[36]

Recently a minimally invasive anterior approach has been explored utilizing video-assisted thoracoscopy to place fixation and apply curve correction. The process is similar to the anterior spinal fusion outlined earlier however has its access to the thoracic cavity by usually 4 small endoscopic ports placed at strategic sites depending on the level of fusion.[37]

This has been praised for its potential advantages of better cosmesis, and faster rehabilitation. This however comes at the price of a steep learning curve. [28,33-35,37]

The Classification of Scoliotic Curves and the Debate of Selective Thoracic Fusion

Moe was the first to report that selective thoracic fusion was effective in thoracic curves in 1958. He made a classification of 4 types of curves that he had identified with type 2 being a double curve however on bending with greater flexibility of the lumbar curve. He stressed the importance of the neutral and stable vertebra and using fusing a vertebra above and below the curve to solidify fixation.[16]

In 1983 King and Moe published results which classified curves into one of 5 types which later became the basis on which treatment was decided.[17,38] The study also showed that selective thoracic fusion as a treatment entity was successful in specific curves. They concluded that fusion to the stable vertebra will give the most reliable curve correction.[17]

King type I curves are double curves that cross the midline, with the lumbar curve larger and less flexible than the thoracic. King type II curves are also double curves that cross the midline, with the thoracic curve larger and less flexible than the lumbar. King type III curves are single thoracic curves in which the lumbar curve does not cross the midline. King type IV curves are long thoracic curves in which L5 is centred over the sacrum but L4 tilts. King type V curves are double structural thoracic curves with T1 convexly tilted.[17]

Of major debate however was the King type II curve or false double major. It was in these curves that if selective thoracic fusion was undertaken and there was a structural component to the lumbar curve, there was a high risk of coronal decompensation and imbalance. This was especially seen in greater proportions with the transition from single distraction forces to segmental rod rotation manoeuvres.

The magnitude of the lumbar curve which can be treated with selective thoracic fusion has also come under debate with studies showing satisfactory results with curves under 40-50 degrees only.[39,40]

The guidelines determined by King and Moe in 1983 were for use with Harrington instrumentation. However with the introduction of more powerful fixation methods, the inter-observer and intra-observer reliability started to decrease[41,42] along with the curve correction ability.

Lenke in 1992 published work which helped to further redefine the King classifications by distinguishing between a King type II curve and a true double major curve.[43] By the addition of additional parameters such as magnitude ratio, apical vertebral rotation and translation ratio, Lenke could suggest when a selective thoracic fusion would be beneficial. By this addition of this new criteria some King type II curves would actually be classed as double major curves and therefore require fusion of both curves.

Type	Proximal Thoracic	Main Thoracic	Thoracolumbar/Lumbar	Curve type
1	Non-structural	Structural (Major)	Non-structural	Main thoracic

2	Structural	Structural (Major)	Non-structural	Double thoracic
3	Non-structural	Structural (Major)	Structural	Double major
4	Structural	Structural (Major)	Structural	Triple major
5	Non-structural	Structural	Structural (Major)	Thoracolumbar/ Lumbar
6	Non-structural	Structural	Structural (Major)	Thoracolumbar/ lumbar – main thoracic

Lumbar modifier	Lumbar apical vertebra	Thoracic Kyphosis modifier	Thoracic Kyphosis (T5-T12)
A	CSVL bisects between pedicles	-	<10 degrees
B	CSVL bisect pedicle	N	10-40 degrees
C	CSVL lies medial to pedicle	+	>40 degrees

Table 1. The Lenke classification for AIS[2].

In 2001, Lenke et al[2] reported a classification for AIS (see Table 1) that has been able to identify those patients who may benefit from a selective spinal fusion (1C, 2C, 5C). A three-tiered approach is used with the Lenke classification system involving curve type, lumbar modifier and sagittal modifier. Firstly, the curves of the spinal column (proximal thoracic, main thoracic and thoracolumbar/lumbar) are classified as structural or non-structural based on side-bending radiographs. A lumbar modifier (A, B, C) based on the distance from the central sacral vertical line and the lumbar apical vertebra is applied. Further classification is then undertaken measuring the kyphosis of the thoracic curve T5-T12 (-, N, +).

Lenke proposed that a selective thoracic fusion could be undertaken when the primary curve is structural and the compensatory lumbar curve is non-structural and that additionally certain radiological and clinical criteria were met. Radiological criteria included a thoracic to thoracolumbar/lumbar curve ratio of 1.25 in regards to Cobb angle, apical vertebral translation and apical vertebral rotation. These are all objective markers that can be accurately measured on plain radiographs, with good inter-and intra-observer reliability.[2] The clinical criteria include a high right shoulder or level shoulders, thoracic trunk shift greater than lumbar waistline asymmetry and scoliometer measurements in the thoracic curve 1.2 times that of the lumbar curve.[15]

However all surgeons do not routinely accept these treatment guidelines. It has been reported that only 49-67% of experienced surgeons are performing a selective thoracic fusion in Lenke 1C curves.[44,45] This may be due to the fear of complications (of which the rates are relatively unknown) and well as misunderstanding of how much correction can be achieved by the un-fused compensatory lumbar curve.

Complications of Selective Thoracic Fusion

Another goal of surgical intervention is the need to avoid complications. Examples of complications of selective spinal fusion include: junctional kyphosis, coronal imbalance, adding-on and revision surgery.[19,46,47] Junctional kyphosis is described as kyphosis of over 10 degrees more than pre-operative measurements. This is measured by the angle between the inferior end plate of the highest instrumented vertebrae and the superior end plate of the vertebra two levels higher. Coronal decompensation is when the distance between the C7 plumb line and the central sacral vertical line is greater than 2 centimetres. The common pattern with post-operative coronal decompensation is progression of the unfused lumbar curve below the selective thoracic fusion needing extension of fusion into the lumbar region. It has many factors cited as risk factors including overcorrection of the thoracic curve, inappropriate choice of fusion level, incorrect identification of curve pattern, lumbar magnitude and stiffness and apical vertebral relative translation and rotation.[48,49] The adding-on phenomenon is described as progression or extension of the primary curve after fusion.[18]

The crankshaft phenomenon has been described by Dubousset in 1989[50] in skeletally immature patients (Risser score 0) who receive posterior fusion. Essentially the anterior vertebral body continues to grow and rotate around a fused and stable posterior column, and deformity recurs. It has been recommended that combined anterior and posterior fusion be used in patients with Risser score 0.[51]

Definition and Terms Used

In spinal surgery multiple radiological definitions apply to measurements and outcomes. These can be universally accepted however sometime small variations do exist. The following terms are defined below:

Major or Primary curve is defined as the largest abnormal curve as defined by the Cobb angle.

A minor or secondary curve is defined as the other deforming curves over 10 degrees as defined by the Cobb angle. These curves can either be structural or non-structural depending on their configuration while bending.

A structural curve is defined as a deformity that does not correct itself to under 25 degrees on bending radiograph. This can include a major or minor curve.

Cobb angle is defined as the angle formed between a line from the superior end plate of the superior end vertebra and the inferior end plate of the inferior end vertebra. Alternatively it can also be measured as the angle between perpendicular lines from the superior end plate of the superior end vertebra and the inferior end plate of the inferior end vertebra. It does not comment on vertebral rotation.

End vertebra is defined as the vertebra with maximal tilt towards the apex of the curve. It is useful in measuring the cobb angle.

Apical vertebra is defined as the vertebra or disc that is most rotated or farthest deviation from the centre of the vertebral column.

Stable vertebra is defined as the furthest cephalad vertebra that is bisected by the central sacral vertical line (CSVL).

Neutral vertebra is defined as the vertebra with no evidence on rotation on standing posteroanterior radiographs. Measured by checking that the pedicles are in symmetrical positions.

Lowest instrumented vertebra is defined as the most inferior vertebra that is fused with instrumentation.

Central Sacral Vertical Line (CSVL) is defined as a vertical line that is drawn perpendicular to a tangential line across the top of the iliac crests. It should bisect the sacrum.

C7 plumb line is defined as a vertically dropped plumb line from the centre of the C7 vertebral body parallel to the lateral edge of the vertical radiograph.

Coronal balance is measured as the distance between the C7 plumb line and the CSVL. A distance over 20mm usually indicates coronal imbalance and decompensation (if occurs post-operatively). A C7 plumb line to the right of the CSVL indicates positive coronal balance and a C7 plumb line to the left indicates negative coronal balance.[52]

Sagittal balance is measured on the sagittal radiograph as the distance between C7 plumb line and the posterosuperior aspect of the S1 vertebral body. A distance over 20mm usually indicates sagittal imbalance. A C7 plumb line anterior to the S1 vertebral body indicates positive sagittal balance.[52]

Apical vertebral translation is measured on the coronal radiograph from the centre of the apical vertebra to the CSVL.

Apical vertebral translation ratio is the ratio between the thoracic apical vertebral translation and the lumbar apical vertebral translation. A ratio over 1.2 is recommend for suitability for selective thoracic fusion.[15]

Apical vertebral rotation is a measure of how great the rotation of the apical vertebra is. It is described in the Lenke classification using the Nash-Moe method.[53] The Nash-Moe method is where each of the apical vertebra is bisected by an imaginary line and then each half is segmented into thirds. Rotation is quantified (from 0 to 4) based on the location of the convex-side pedicle in relation to those segments. If the pedicle is in the outer third, rotation is scored as 0 or neutral, grade 1 is where the pedicle is touching the outer third line, grade 2 is when the pedicle is in the middle third, grade 3 is when the pedicle is seen in the inner third, and grade 4 when the pedicle crosses the midline (see figure 1). The other method used to classify rotation is the Perdriolle method.[54] A mark is placed at the lateral borders of the vertebra and a vertical line through the convex pedicle. A torsion meter is placed on the film lined up with the lateral borders of the vertebra and the rotation is measured with the pedicle line.

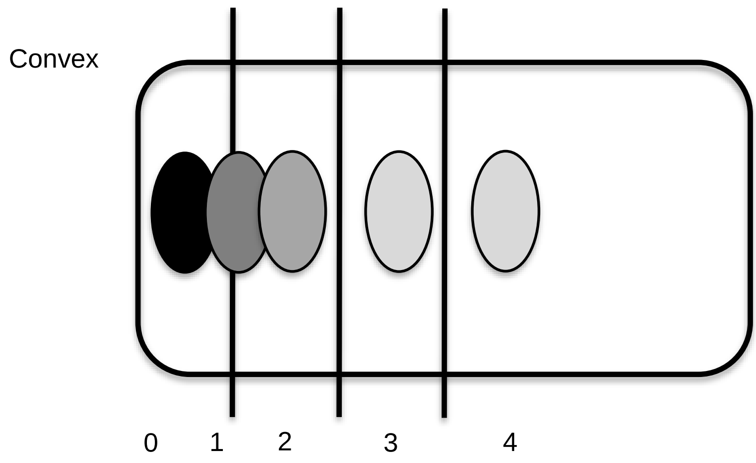


Figure 1. Nash-Moe method of measuring rotation.[53] Circles represent the convex pedicle location.

Apical vertebral rotation ratio is the ratio between the thoracic apical vertebral rotation and the lumbar apical vertebral rotation. A ratio over 1.2 is recommended in selective thoracic fusion.[15]

Lumbar lordosis is measured on the sagittal radiograph as the angle between the superior end plate of L1 or sometimes inferior endplate of T12 and the inferior endplate of L5 or the superior endplate of S1 by the same method as the Cobb angle.[55]

Thoracic kyphosis is measured on the sagittal radiograph as the angle between the superior endplate of T5 to the inferior endplate of T12 by the same method as the Cobb angle.

Thoracolumbar angle is measured on the sagittal radiograph as the angle between the superior endplate of T10 to the inferior endplate of L2 by the same method as the Cobb angle. It can also be measured from the superior endplate of T11 to the inferior endplate of L1. Normal range is under 10 degrees.[56]

Risser index is a marker used to estimate the skeletal maturity of the patient. Grades 0 to 5 denotes ossification of the iliac crest laterally to medially.

Context of the Review

A search of PubMed, the Cochrane Library, PROSPERO and the JBI Databases of Systematic Reviews and Implementation Reports found one article claiming to be a meta-analysis assessing the effectiveness of selective thoracic fusion.[57] However this review by Winter et al.[57] in 2003, only provided descriptive data on six studies and did not follow rigorous systematic review methods in terms of searching, selecting, appraising and synthesising studies. Given the lack of systematic reviews on this topic to guide practice, the aim of this review was to evaluate and critically appraise available evidence on selective thoracic fusion to provide a suitable estimate of the radiological and functional outcomes of this type of surgical intervention as well as the approximate complication rate to give patients correct information prior to their providing their informed consent.

The scope of this review will look at selective thoracic fusion as a treatment modality and its effectiveness for treatment of adolescent idiopathic scoliosis.

Evidence Synthesis

Research evidence and literature in surgery has become more popular over the last decade in evidence-based health care (EBHC). EBHC is integration of best research evidence with clinical expertise and patient values. The increase in production of medical publication in recent years has meant that there is a plethora of medical information ranging from peer-reviewed high-quality research journals to medical sites offering consumer information. The clinician is facing higher difficulty in keeping up with the latest emerging research findings[58,59] as well as to sort through to find good quality research to aid in decision making which can be further compounded with individual studies reporting unclear and often contradictory results. Therefore a systematic review may be more important to clinicians to aid in decision making.[60]

Healthcare and scientific literature has a long tradition of narrative reviews where experts collaborate in existing knowledge and publish findings in the form of summaries. These summaries are then used to inform theory or draw conclusions and are called literature reviews or critical reviews. Reviews contain publication and selection biases and have a lack of assigning weight to the where the evidence lies. Too much weight is given to large studies without attention to the quality of the study.[61,62] Therefore, more structured more critical exploration of relevant data to provide assessment, inform and change practice is needed.

Justification of Review Approach

I have chosen to conduct this research in the form of a systematic review with meta-analysis to determine the effectiveness of selective thoracic fusion. Systematic review is a form of secondary research synthesis of multiple high-level and quality studies which combine data in order to deliver it in an efficient manner. Meta-analysis employs additional statistical techniques to provide a synthesis from pooled data.[63] These aim to critically appraise and pool all available research to produce a set of implications or to guide the direction of future research. Research in the fields of spine surgery, and Orthopaedics is largely observational and it is not always possible to apply the principles of a randomised controlled trial (RCT) to answer a clinical question or to assess the effectiveness of an intervention.[63,64] However, reviews of observational studies are still important to pool data and provide a summary of the best available evidence.

A credible meta-analysis or systematic review is one in which the aim and question should be clearly identified prior to the conduct of the review. Eligibility criteria for study selection should be established prior to the process of identifying, and retrieving articles. A credible systematic review should have a protocol that is clearly stated, ideally following the guidelines from Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[65] and published in known protocol databases such as PROSPERO.[66] The search strategy should be sensitive, specific and systematic and include multiple search databases. Two independent reviewers should critically appraise each study with a proven checklist. The use of forest plots should be used in meta-analyses where appropriate and heterogeneity should be explained. A funnel plot to assess the influence of publication bias can be performed. A summary of findings table using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach[67] should also be included in a credible systematic review.[63,68]

A review article of meta-analyses in spine surgery done by Evanview and colleagues[68] has recently been published. They searched for meta-analyses in spine surgery finding 132 eligible meta-analyses for inclusion. They graded each meta-analysis in regards to their credibility (as determined by the Users' guide)[69] and their completeness of reporting (determined by the PRSIMA guidelines).[65] The mean number of satisfactory Users' guide items in each meta-analysis was only 3 of 7, with the majority of studies failing criteria on reporting possible explanations between-study differences in results (95%), presenting results ready for clinical application (82%), addressing confidence in effect estimates (82%), and reproducible selection and assessments of studies (65%). The mean number of PRSIMA items in each meta-analysis was 18 of 27. The majority of studies failed to report search terms (61%), how bias was assessed (69%), and whether risk of bias assessments were study or outcome specific (96%).

A strength of this systematic review lies in the methodology of JBI meta-analysis of statistics assessment and review instrument (MAStARI) applied for critical appraisal and data extraction from studies.

Objectives, inclusion criteria and methods were specified in advance and published in a protocol[70], and registration number CRD42016032771 in PROSPERO.[71]

Assumptions and Limitations of Approach

Systematic review and meta-analysis provides good quality evidence however, it is assumed that the studies themselves are of high quality and that meta-analysis has been conducted where statistically and clinically appropriate. The quality of a systematic review is dependent on the level of evidence of the primary studies. Primary studies in spine surgery are often of low level of evidence, therefore the conclusion drawn from this review cannot exceed the level of the studies reviewed. There was also a relative difficulty in including non-published studies mainly due to identification of such studies. Another barrier to inclusion of studies was the failure of responses from authors and study co-ordinators to provide additional information.

CHAPTER TWO – METHODOLOGY AND METHOD

Review questions/objectives

Broadly the overall objective of this review was to identify the effectiveness of selective thoracic fusion as a treatment modality for patients with adolescent idiopathic scoliosis.

Specifically, this review aims to identify the effectiveness of the treatment in regard to radiological parameters as well as clinically measured outcomes.

Inclusion criteria

Types of Studies

This review considered both experimental and epidemiological study designs including randomized controlled trials, non-randomized controlled trials, quasi-experimental, before and after studies, prospective and retrospective cohort studies, case control studies and analytical cross-sectional studies for inclusion.

As it was expected that due to the topic area there would be a low number of randomised controlled trials this review also considered descriptive epidemiological study designs including case series and descriptive cross-sectional studies for inclusion. However, any such study involving less than five patients treated with selective thoracic fusion was excluded, as it was deemed too low powered a study.

Types of participants

This review included patients with adolescent idiopathic scoliosis, typically aged from 10 to 18 years old who had a scoliosis curve with a thoracic component that is described as structural (as described by the Lenke classification).[2] During the search phase it was noted that many studies were found prior to the Lenke classification formation, therefore the King classification was also used to identify those with structural thoracic curves (mainly King type II). In addition, Lenke 1A and 2A curves only have a single thoracic curve by definition and no great compensatory lumbar curve and therefore never require fusion into the lumbar spine. As this was felt that it would give a biased result for the compensatory lumbar curve correction, studies involving purely Lenke 1A or 2A curves were excluded. All studies needed a minimum 2 years of follow-up for inclusion. Those patients with congenital, neuromuscular or syndromic causes for their scoliosis or any previous spinal fusion were excluded. Studies including patients with adult idiopathic scoliosis were excluded.

In addition where full patient data was published or raw data obtained, patients from studies were included or excluded based on their demographics. This included Lenke 1A or Lenke 2A curves which were excluded, patients who were not between the ages of 10 or 18 years were excluded and those undergoing selective thoracic fusion but with lowest instrumented vertebra (LIV) lower than L1 were excluded. All included patient's data extracted from the raw data for each study were then re-analysed to find a new mean and standard deviation where appropriate. This represents a change from our previously published protocol but was done in order to gather the greatest number of patients.

If the study did not provide individual patient data and no raw data was able to be obtained from the authors, and the study had a mean age of patients of under 18, but the age range included patients over 18 but under 30, the study was discussed for inclusion or exclusion between at least two of the authors. Studies that had this issue were included if they had specifically included patients with 'adolescent idiopathic scoliosis'. The patient groups were thought similar as the diagnosis was the same (adolescent idiopathic scoliosis) but may have only reached a surgical indication following their 18th birthday (either through progression of curve, functional issues or cosmetic concerns).

Types of interventions

This review considered studies that evaluate fusion of the thoracic curve with distal fusion ending no lower than L1. Both anterior and posterior approaches were included, however any patient who received both anterior and posterior fusion was excluded. All forms of instrumentation for fusion such as pedicle screws, hooks and rods was included. This was compared where possible to any other surgical fusion for a structural thoracic curve. This includes studies that compare selective and non-selective spinal fusion in the same article, or selective spinal fusion only, but not non-selective spinal fusion only.

Types of Comparators

This review considered comparators, such as non-selective spinal fusion versus selective thoracic fusion. Effectiveness of selective thoracic fusion was compared and analysed as a change from pre-operative values to post-operative values. Other comparisons were made between the anterior and posterior approach and instrumentation, Lenke lumbar modifier B and Lenke lumbar modifier C curves. This was altered from our original published protocol.

Types of Outcomes

This review considered studies which reported on both clinical and radiological outcomes.

Radiological outcomes included (1) main thoracic curve cobb angle magnitude and correction, (2) compensatory lumbar curve cobb angle magnitude and correction, (3) post-operative coronal balance and change, (4) thoracic kyphosis curve magnitude and change, (5) lumbar lordosis curve magnitude and change, (6) post-operative sagittal balance and change and (7) apical vertebral rotation. This represents a change from our previously published protocol.[70]

Clinical outcomes included function and quality of life surveys, complication rates and respiratory function. Quality of life surveys included the scoliosis research society-22 (SRS-22), SRS-24, or SRS-30. Complication rates included the rates of coronal imbalance and decompensation, sagittal imbalance and decompensation, junctional kyphosis, adding on or revision surgery.

Search Strategy

The search strategy aimed to find both published and unpublished studies. A three-step search strategy was utilized in this review. An initial limited search of Pubmed and Scopus was undertaken followed by an analysis of the text words contained in the title and abstract, and of the index terms used to describe the article. A second search using all identified keywords and index terms was then undertaken across all included databases. Thirdly, the reference list of all identified reports and articles was searched for additional studies. Only studies published in English were considered for inclusion in this review. No exclusion of articles based on publication year occurred.

The databases that were searched included:

PubMed

EMBASE

CINAHL

Scopus

The Cochrane Central Register of Controlled Trials (CENTRAL)

Web of Knowledge

The following grey literature databases were searched:

Mednar

ProQuest Theses and Dissertations

Grey Source

Index to Theses

Libraries Australia

Keywords that were searched:

Scoliosis

Fusion, spinal fusion, spinal fusions, spine fusion, spine fusions, spine surgery, spinal surgery, spondylodesis, spondylodeses, spondylosyndesis, spondylosyndeses, arthrodesis, surgical approach, spine fusion implant, spinal fusion implant

Thoracic, thoracic spine, thorax, thoracic vertebra*.

Informed by the findings from the initial exploratory searches, further key words were identified and a detailed search strategy developed and implemented for each database. The search strategies used to search databases is listed in Appendix I.

Using the search strategy, records were identified from the above-mentioned databases. The results from each database search were electronically important into a citation manager (EndNote X7), where the results from all the databases were pooled together into a single library.

Assessment of methodological quality

Papers selected for retrieval were assessed by two independent reviewers for methodological validity prior to inclusion in the review using standardised critical appraisal instruments from the Joanna Briggs Institute Meta-Analysis of Statistics Assessment and Review Instrument (JBI-MAStARI) (Appendix II). Consistency between reviewers was met by strict adherence to the critical appraisal instrument descriptions. Any disagreements that arose between the reviewers was resolved through discussion and therefore a third reviewer was not needed.

Standardised JBI Critical Appraisal Checklist for Randomised Control/Pseudo-randomised trial was used for two studies, standardised JBI Critical Appraisal Checklist for Comparable Cohort/ Case Control was used for no studies and standardised JBI Critical Appraisal Checklist for Descriptive/ Case Series was used for thirty-two studies. (Appendix II).

Data collection

Data was extracted from papers included in the review using the standardised data extraction tool from JBI-MAStARI (Appendix III) plus additional data recorded in an excel spreadsheet. The data extracted included specific details about the interventions, populations, study methods and outcomes of significance including pre-operative, immediately post-operative and at last follow up values. The authors of the included studies were contacted when important data was missing, however no results were returned or shared.

Data synthesis

Analysis was conducted on all main outcomes where possible. Where data was homogenous in terms of their methodological and clinical nature we performed meta-analysis. The available studies comparing anterior versus posterior approach were pooled in statistical meta-analysis using REVMAN v5.3. In addition, further studies comparing Lenke lumbar modifier B curves against Lenke lumbar modifier C curves was also pooled for meta-analysis. Effectiveness of selective thoracic fusion was pooled for meta-analysis with comparison of pre-operative and final follow-up values. Subgroup analysis was conducted in regards to the operative approach. Complications were pooled in single-arm statistical meta-analysis using OpenMeta[Analyst] v10.12. Continuous data that was collected using the same scale, the weighted mean differences (WMD) and standard deviation was calculated. For data collected using different scales, the standardised mean differences (SMD) was calculated. Heterogeneity was assessed using standard Chi square and I^2 test. Meta-analysis was performed where possible but was not conducted when there was no recorded data from that study or where only one study measured the outcome or measured the outcome in different ways. For meta-analysis of continuous data a random-effects model was chosen as the results of the meta-analysis are intended to be generalised.[72]

Where statistical pooling was not possible, the findings were presented in narrative form including tables and figures to aid in data presentation. Forest plots were used to aid in the presentation of results. A GRADE (Grading of Recommendations Assessment, Development and Evaluation) summary of findings table was used to convey the confidence in the body of evidence related to main outcomes of the review.

Dichotomous data was going to be pooled and analysed for meta-analysis and presented with relative risk and/or odds ratios and their associated 95% confidence intervals however no data presented in the studies could be pooled for presentation.

CHAPTER THREE - RESULTS

Description of the search and selection process

A total of 14, 959 citations were identified from the search strategy from each database (see Appendix I). After removal of 6,815 duplicates, 8,144 citations were screened by title and abstract. The screening process involved viewing the title and abstract of each citation and excluding those that clearly did not meet the inclusion criteria. 7,771 citations were excluded based on title and abstract with 373 articles remaining for full text screening. After full text review of the 373 articles, 34 were thought to match the inclusion criteria for critical analysis. No studies were excluded based on critical analysis. This left 34 articles for inclusion in the systematic review.

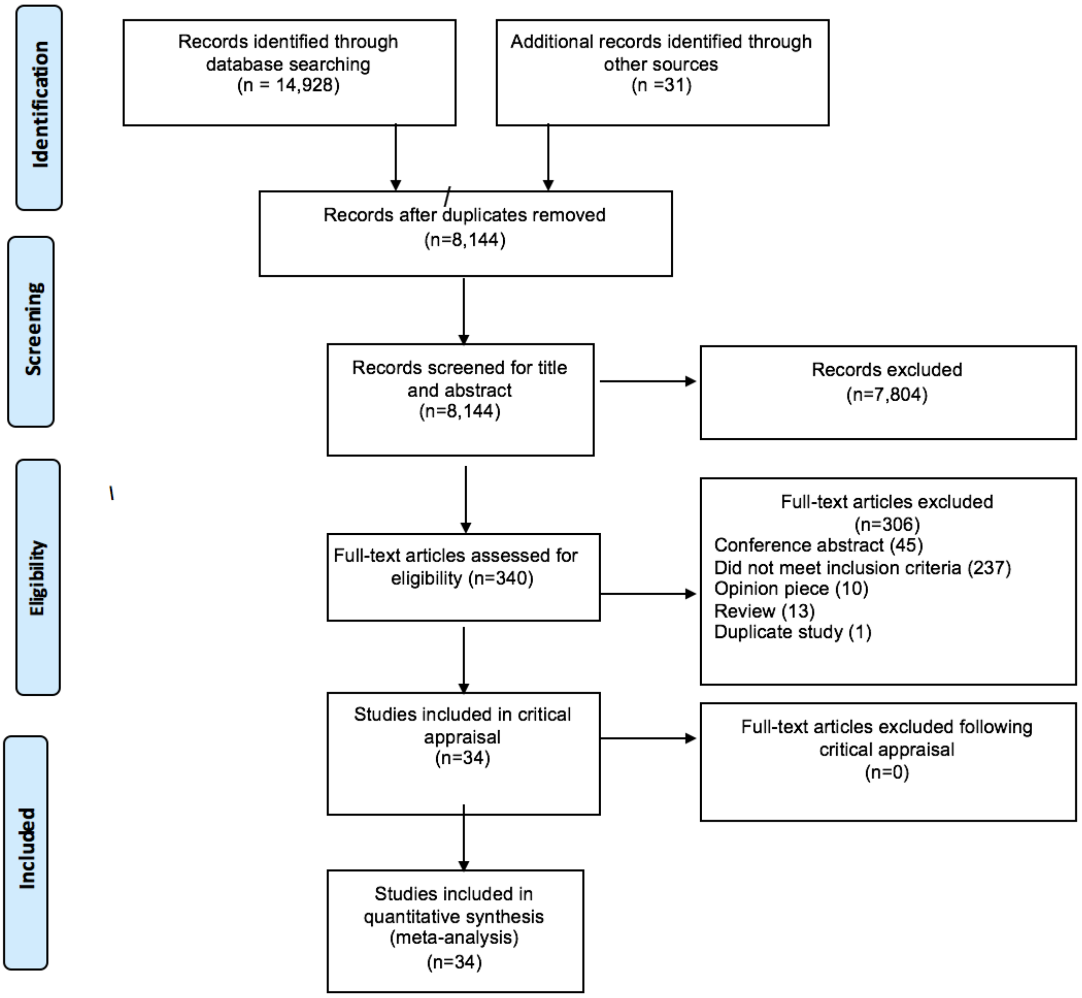


Figure 2: Flow diagram of study selection process

Description of Included Studies

The included studies were completed across the world with nineteen performed in the United States of America (USA), three from Germany, two from Australia, two from China, one from Japan, one from Korea, one from Singapore, one from Austria, one from Hong Kong, one from Brazil, one from Netherlands, and one from Denmark. The number of patients included in the studies utilizing selective thoracic fusion ranged from 6 patients[19] to 251 patients.[73] Studies were found across a large timeframe ranging from 1998[56] to 2015.[74]

Eight included studies[22,34,37,49,73,75-77] had comparisons made between anterior and posterior approach. Two studies[48,56] included comparisons between coronal balanced and coronal decompensated patients. Two studies[49,76] included comparisons between Lenke B and Lenke C curves. One study[78] included comparisons between patients with trunk shift and those without. Five studies[9,79-82] compared instrumentation types (hooks vs pedicle screws vs hybrid) or techniques (segmental, consecutive fixation, direct vertebral rotation, and simple rod rotation), These studies were not eligible for meta-analysis as they were all heterogeneous in their comparison groups. One study[47] compared the effect of different vertebral levels using lowest instrumented vertebra. One study[83] compared selective thoracic fusion against non-selective spinal fusion.

Interestingly there were minimal studies found during our searching process that investigated functional outcomes. There were only two studies[28,84] that involved pulmonary function testing, and only six studies[22,28,33,82,85,86] that involved a quality of life survey. Every included study involved radiological outcomes.

The two included prospective trials included a study by Gotfryd et al.[80] from 2013. There were 46 patients that were randomized equally in a multicentre trial to receive either pedicle screws in the usual Cotrel-Dubousset technique or strategic pedicle screws on the side of the concavity except for the apical vertebra with alternate pedicles in the side of the convexity. The surgeon and patient were not blinded to the intervention. Outcomes included proximal thoracic, main thoracic and compensatory lumbar curve correction, change in thoracic kyphosis and thoracolumbar lordosis, change in thoracic and lumbar AVT and clavicular inclination. There were 2 complications, one with a non-infected seroma, and the other with coronal decompensation.

The second prospective trial included a study by Tao et al.[87] from China. It involves a prospectively randomized study of 36 patients in each treatment arm. Patients were treated with posterior selective thoracic fusion with LIV determined based on the end vertebrae and neutral vertebra in one group, and patients in the other group were treated with posterior selective thoracic fusion with LIV determined by a protocol based on the apical vertebral position. Those treated with posterior selective thoracic fusion with LIV determined by the apical vertebral position were included in the systematic review for analysis. The second group was excluded due to lowest instrumented vertebrae out of the inclusion criteria.

Multiple outcomes were measured including thoracic cobb angle correction, thoracic kyphosis, thoracolumbar lordosis, LIV tilt and coronal balance. 2 patients developed coronal decompensation.

Behensky et al[48] in 2007 retrospectively reviewed the role of selective thoracic fusion in double major curves with 3rd generation instrumentation. All 36 patients treated in the multicenter study across the two United Kingdom and Austrian hospitals that underwent selective thoracic fusion with Lenke 3C between 1995 and 2000 were included. Traditionally these were treated with a non-selective fusion of both curves. All 36 patients had a posterior approach and were instrumented with Cotrel-Dubousset instrumentation in 21 patients and Universal Spine System in 15. 10 patients (28%) had coronal decompensation. There was a high correlation between the C7 plumb line coronal deviation and the derotation of the lumbar apical vertebrae in lumbar supine side-bending in a post-hoc analysis.

Chang et al.[86] also tried to predict the outcome of selective thoracic fusion in double major curves with Lenke lumbar modifier C. Their study retrospectively looked at 32 patients treated at a single institution in Missouri, in the USA with 5 to 24 years of follow-up. 37.5% of their patients had suboptimal results at latest follow-up. 5 patients had coronal decompensation, 4 patients had worsening lumbar apical vertebral translation, 5 patients had thoracolumbar kyphosis, 1 patient had worsening of lumbar apical vertebral rotation and 2 patients had greater lumbar curves than pre-operatively. 2 patients required revision surgery within 5 years (one at 6 weeks for coronal decompensation and one after two years for adding-on phenomenon). Most significant difference was immediately post-operative with higher amounts of standing lumbar lordosis corresponding with a better outcome (P=0.02). They concluded that not all curves can be adequately treated with selective thoracic fusion. Findings would confirm the notion that overcorrection of the thoracic curve in selective thoracic fusion can be dangerous to overall outcome. If the thoracic curve is overcorrected, perhaps the lumbar curve is unable to straighten in proportional fashion due to limitations in overall flexibility.

In 2013, Demura et al.[83] retrospectively reviewed patients with Lenke 1C AIS in his multicenter study in the USA. Of these 71 patients, 53 were treated with selective thoracic fusion and 18 with non-selective spinal fusion. The purpose of the study was to investigate the level of coronal decompensation in Lenke 1C curve and how that related to selective thoracic fusion. Of the 21 patients treated with selective thoracic fusion that were coronally imbalanced pre-operatively, 9 remained coronally imbalanced at 2 years post-operatively. However of the 32 patients who were balanced pre-operatively, 10 patients had experienced coronal decompensation at the 2-year post-operative mark. The authors concluded that they would still perform selective thoracic fusion to maintain lumbar mobility however will need to acknowledge the risk of coronal decompensation and ultimately the specific surgical plan will need to be tailored to each individual.

In 2004, Dobbs et al.[49] compared anterior and posterior selective thoracic fusions. They reported results of 56 and 44 patients that were treated with selective thoracic fusion via the anterior and posterior approaches respectively. All patients had AIS with curves classified as 1B, 1C, 2B or 2C. There was no statistical difference between anterior or posterior approaches in terms of spontaneous lumbar curve correction. Outcomes included the correction of thoracic and lumbar cobb angle, correction of lumbar AVT, correction of coronal balance and the presence of coronal decompensation. One patient with lumbar modifier B and four patients with lumbar modifier C showed signs of post-operative coronal decompensation. They also developed from a stepwise linear regression analysis to develop a formula to predict the change in lumbar compensatory curve.

Dobbs and colleagues[79] retrospectively reviewed 66 patients in Missouri, USA. All patients had AIS with Lenke lumbar modifier C and were treated with selective thoracic fusion via the posterior approach with Cotrel-Dubousset instrumentation. The study compared those patients treated with only hook constructs versus those with mainly pedicle screw constructs. Outcomes measured were correction of thoracic and lumbar cobb angle, correction of thoracic and lumbar AVT and the correction of coronal balance. At long-term follow-up, there was a difference in coronal decompensation between the 2 groups. More patients experienced coronal decompensation in the hook group rather than the screw group. In addition, pedicle screw constructs resulted in better thoracic correction and spontaneous lumbar correction when compared to the hook only construct.

In 2004, Edwards et al.[22] retrospectively compared the radiological results of selective thoracic fusion. Forty-four patients with AIS with Lenke 1C or 2C curves were included in the study. He compared those who underwent anterior fusion, with those who underwent posterior fusion and those who underwent a dual approach. The 15 who underwent an anterior approach and the 26 that underwent a posterior approach were included in our study, however the 3 patients that underwent a dual approach were excluded from our study. Outcomes included correction of thoracic and lumbar cobb angle, correction of coronal balance, correction of lumbar AVT and 41/44 patients responded with a quality of life survey (SRS-24). Selective thoracic fusion using the anterior approach was reported to have better main thoracic and compensatory lumbar post-op curve correction and fewer fusion levels involved. 26 patients showed evidence of coronal decompensation, however most were more imbalance prior to their operation. No patients required revision surgery or experienced adding-on. 81% of patients claimed that they were satisfied with their surgery.

Engsberg and his colleagues[75] compared gait and spinal range of motion in anterior and posterior fusion. Six patients treated with posterior fusion and 10 patients treated with anterior fusion and were eligible for inclusion in our study after removal of patients based on lowest instrumented vertebra and Lenke 1A or 2A curves. This is the only study to look at the gait pattern of post-operative selective thoracic fusion patients. Other outcomes measured included range of motion of the spine, and correction of thoracic cobb angle. There were no differences in gait speed or coronal or sagittal plane parameters in either group post-operatively. Globally range of movement was reduced regardless of instrumentation approach, however the results seemed to favour the anterior approach.

Frez et al.[88] reported a study of 24 patients in their hospital in Hong Kong. All patients had AIS with King type II curves and were treated with posterior instrumentation with Harrington rods, Luque rods and spinous process wiring. The lumbar curve correction was compared between patients with LIV ending at T12 versus those with LIV ending at L1. Outcome measured were thoracic and lumbar curve correction, thoracic and lumbar AVT correction, trunk shift, shoulder tilt, pelvic obliquity, coronal and sagittal balance, thoracic kyphosis, thoracolumbar lordosis and lumbar lordosis. No statistically significant differences in coronal or sagittal cobb angles was noted between the two groups.

Goshi et al.[19] reported in 2004 about the efficacy of translational corrective techniques using Isola (Depuy Spine, [J&J], Raynham, MA) instrumentation. They performed a retrospective review of adolescent and adult patients with idiopathic scoliosis who underwent selective posterior fusion. Of the patients, 14 were classed as AIS, however only 6 were eligible for inclusion based on age, fusion level and curve type. Outcomes that were measured include thoracic and lumbar curve correction, coronal balance, T1 vertebral tilt, lowest instrumented vertebra tilt, pelvic obliquity, sagittal balance, thoracic kyphosis and lumbar lordosis.

In 2000, Graham et al.[84] reported a prospectively collected multicenter study to see the effect of open anterior spinal surgery on pulmonary function tests in 51 patients. Patients with AIS did pulmonary function tests pre-operatively, 3 months, 1 year and minimum 2 years following their spinal fusion. Besides pulmonary function tests, other outcomes measured was correction of thoracic cobb angle and change in thoracic kyphosis. There was an initial decline in the absolute and percent-predicted values of forced vital capacity (FVC), forced expiratory volume in 1 sec (FEV_1) and total lung capacity (TLC) at 3 months post-operatively, however these returned to baseline at the 2-year post-operative mark.

Haber and colleagues[33] from the USA reported their study in 2012. They aimed to look at the long-term efficacy of thoracic AIS treated with the Kaneda Anterior Scoliosis System (KASS; Depuy Acromed, Raynham, MA). They had 16 patients treated with the anterior KASS with 13 of those patients eligible for inclusion in our systematic review. Outcomes measures were treatment failure and main thoracic cobb angle correction. There were 3 of the 13 patients with treatment failure defined as the need for revision surgery or progression of the main thoracic curve to over 50 degrees. Distal adding-on of the curve deformity seemed to be the primary problem.

A prospective multicenter review reported by Ilgenfritz and colleagues[89] in 2013 looked at the natural history of the un-instrumented compensatory curve. Twenty-four patients with Lenke 1C curves and 21 patients with Lenke 5C curves were treated with selective thoracic fusion and selective lumbar fusion respectively. The 24 patients treated with selective thoracic fusion were eligible for inclusion in our systematic review. They aimed to identify the natural history of the compensatory lumbar curve with 5 year post-operative results. The outcomes measured were thoracic and lumbar curve correction, thoracic kyphosis, lumbar lordosis, apical vertebral rotation, and coronal balance. They concluded that in both selective thoracic fusion and selective lumbar fusion that the un-instrumented curves adjusted to match the magnitude of the instrumented primary curve and didn't progress between 1 and 5 years.

In 1999, Kamimura et al.[90] reported a review of their 17 patients with AIS treated with the Zielke ventral derotation system for anterior fusion. All patients had a minimum of 3-years follow-up. Measured outcomes were proximal thoracic, main thoracic, and lumbar curve cobb angle correction, apical vertebral rotation and translation, T1 tilt and translation, end vertebra tilt, thoracic kyphosis and lumbar lordosis. Back deformity was assessed using a topographic body scanner. There were 3 cases of rod failure and breakage, 2 with no consequence on curve and 1 with increase in cobb angle by 10 degrees.

Kim and colleagues[91] reported their retrospective review in 2007. Forty-two patients with Lenke 1 AIS were treated with anterior instrumentation done via video-assisted thoracoscopic surgery (VATS). The aim of the study was to evaluate the surgical outcomes of VATS anterior instrumentation on sagittal plane profile. Outcomes measured were main thoracic cobb angle correction, coronal balance, thoracic kyphosis, lumbar lordosis, and proximal and distal junctional angle. 4 patients experienced implant related issues, 2 with broken caps, 1 rod failure and 1 screw pull-out.

Lenke et al.[76] published a retrospective review of his patients with AIS in 1999. He aimed to evaluate the curve correction possible with anterior selective thoracic fusion versus posterior selective thoracic fusion. Anterior thoracic fusion was used in 70 patients compared with 53 patients treated with posterior thoracic fusion. Outcomes measured were main thoracic and compensatory lumbar cobb curve correction.

In 2013, Liljenqvist et al.[92] reported a retrospective review of 28 patients from Germany. All patients were diagnosed with AIS and were treated with anterior selective thoracic fusion. They aimed to analyse the results of anterior selective thoracic fusion using a dual rod technique. Outcomes were thoracic and lumbar curve correction, thoracic and lumbar AVT and AVR, shoulder and coronal balance, trunk shift and thoracic kyphosis. Two patients experienced coronal decompensation post-operatively.

A retrospective review published by Liu et al.[81] in 2014 looked at the results on the sagittal profile of selective posterior thoracic fusion. Forty-two patients with Lenke 1 AIS were instrumented with either pedicle screws or a hybrid construct in their institution in China. Outcomes were coronal balance, proximal junctional angle, thoracic kyphosis, thoracolumbar junctional angle, distal junctional angle, and lumbar lordosis.

Lonner and colleagues[28] published a retrospective study in 2006 comparing thoracoscopic spinal fusion with posterior spinal fusion. Twenty-eight patients with Lenke 1 AIS were treated with thoracoscopic assisted anterior selective thoracic fusion which was compared with 23 patients with Lenke 1 AIS treated with non-selective posterior fusion. The thoracoscopic group were eligible for inclusion in our systemic review. Outcomes measured were thoracic curve correction, coronal balance, tilt angle of upper instrumented vertebra, thoracic kyphosis, operative time, estimated blood loss, transfusion rate, length of hospital stay and intra-operative complications. In addition, pulmonary function both pre-operatively and post-operatively was measured for both groups along with the outcomes of the SRS-22 questionnaire for quality of life. There were 5 complications in the thoracoscopic group including 1 pneumothorax, 1 mucous plug, 2 broken rods and 1 screw pull-out which eventually required revision. Post-operatively FVC and FEV_1 diminished in both groups but more so in the thoracoscopic group, however at time of follow-up there was no significant differences between the two groups. Mean SRS-22 scores improved post-operatively in the thoracoscopic group but remained stable in the posterior fusion group.

In 1998, McCance et al.[56] published a retrospective study of a consecutive serious of 67 cases of King II AIS. All 67 patients treated with selective thoracic were analysed to evaluate the long-term coronal and sagittal balance with the treatment. Patients were divided into 2 groups based on their post-operative coronal balance (between 47 coronal balanced patients and 20 coronal decompensated patients). Measured outcomes were thoracic and lumbar curve correction, T1 to CSVL and T12 to CSVL distance, clavicle level, thoracic kyphosis, lumbar lordosis and sagittal balance.

Mladenov et al.[9] reported their retrospective study from Germany in 2011. They looked to compare the effect of direct vertebral derotation on the sagittal balance after selective thoracic fusion. Patients with Lenke 1 curves were either treated with simple rod rotation technique (13 patients), or direct vertebral derotation techniques (17 patients). Outcomes measured included thoracic curve correction, coronal balance, thoracic kyphosis, lumbar lordosis, sagittal balance. They found a significant hypokyphotic effect on the thoracic spine with direct vertebral derotation compared with simple rod rotation technique.

Morr and colleagues[82] retrospectively reviewed their cohort of 40 patients with Lenke 1 AIS. All their patients underwent selective thoracic fusion however 20 were treated with thoracic pedicle screws at every level and 20 patients were treated with every level on concave side and skipped levels on the convex side of the curve. They aimed to determine the number of implants needed for best correction and outcome. Outcomes measured included proximal thoracic, main thoracic and lumbar curve correction, thoracic kyphosis, thoracolumbar junction angle, lumbar lordosis, apical vertebral body rib ration, and apical rib spread difference. Clinical outcomes were measured by the SRS-22 questionnaire. A cost analysis done based on pedicle screw cost and operating room time was also done. There was no difference between the two in terms of radiological outcome however the skip level group was significantly cheaper.

A retrospective radiographic study was performed by Na et al.[93] and published in 2010. They reviewed 28 patients with AIS that were treated by anterior selective thoracic fusion. They aimed to review the proximal lumbar curve flexibility compared with the whole lumbar curve flexibility in patients with AIS. Outcomes measured included correction of main thoracic, lumbar, proximal lumbar and distal lumbar curves, and coronal balance. They concluded that the proximal lumbar curve became more lordotic or mobilised post-operatively while the distal lumbar curve became less lordotic or became stabilised.

Newton and colleagues[73] in 2010 published their retrospective review based on a multicenter prospective database. They aimed to review the sagittal profile of AIS patients surgically treated. A total of 251 patients were included in the study with 97 patients having an open anterior approach, 71 having a thoracoscopic assisted approach and 83 patients had a posterior spinal fusion. Outcomes measured included thoracic kyphosis and lumbar lordosis. They concluded that anterior fusion was associated with added thoracic kyphosis and lumbar lordosis whereas posterior fusion was associated with decreased thoracic kyphosis and lumbar lordosis at 2 years post-operatively.

Patel et al.[77] in 2008 aimed to be able to predict the effect of selective thoracic fusion and the approach on the spontaneous lumbar curve correction in Lenke B and C curves. The study compared 132 patients treated with anterior selective thoracic fusion with 44 patients treated with posterior selective thoracic fusion in a multicentre study. Thoracic and lumbar curve correction, and thoracic and lumbar apical translation and rotation were measured as outcomes. They concluded that the lumbar curve correction was independent of surgical approach but correlated with pre-operative lumbar curve flexibility and thoracic curve correction.

In 2005, Potter and colleagues[34] published their results of a multicentre retrospective review. They aimed to compare the curve correction of anterior selective thoracic fusion with posterior selective thoracic fusion. At total of 40 patients were enrolled in the study with 20 in each group. All patients had Lenke 1 AIS. Due to some exclusion of patients with lowest instrumented vertebral down to L2 or Lenke 1A curves, 14 patients treated with the anterior approach and 11 patients treated with the posterior approach were eligible for inclusion in our systematic review. Outcomes included proximal thoracic, main thoracic, and lumbar curve correction, rib hump deformity, apical rib spread difference and apical vertebral body-rib ratio. They concluded that posterior fusion gave superior thoracic curve correction and rotation correction.

Schulz et al.[94] tried to define the optimal postoperative coronal parameters after selective thoracic fusion. In 2014, they published the results of their multicentre retrospective review of prospective data. A total of 106 patients with Lenke 1C to 4C curves were included. Outcomes included thoracic and lumbar curve correction. They concluded that a lumbar curve of less than 45 degrees that decreased to under 25 degrees on bending leads to optimal outcomes with selective thoracic fusion. In addition, they outlined that an optimal post-operative outcome is a lumbar curve of less than 26 degrees, coronal balance under 2cm, deformity-flexibility quotient less than 4, lumbar correction over 37% and trunk shift less than 1.5cm.

Studer and colleagues[74] published results from our local institution in 2015. A retrospective review was done on 16 patients with AIS treated with selective thoracic fusion and 14 patients treated with selective lumbar fusion. The 16 patients treated with selective thoracic fusion were eligible for our systematic review. The outcomes measured included correction of proximal thoracic, main thoracic and lumbar curves, change in thoracic and lumbar AVR and AVT, coronal balance, sagittal balance and lumbar sacral take off angle. Four patients showed post-operative adding-on and three patients developed post-operative coronal decompensation.

In 2011, Takahashi and colleagues[47] published results of a multicentre, prospectively collected trial which was retrospectively reviewed. They aimed to review how selection of the lowest instrumented vertebra (LIV) relative to the stable vertebra (SV) and end vertebra (EV) affected the post-operative results of patients treated with selective thoracic fusion. A total of 172 patients with Lenke 1B, 1C or 3C AIS were treated with selective thoracic fusion. They were divided into 3 groups based on the relative position of the SV and EV; 93 patients had their SV below their EV, 66 patients had their SV and EV at equal vertebral levels, and 13 patients had their EV below their SV. Outcomes measured included thoracic and lumbar curve correction, and coronal balance. They concluded that when the SV was below the EV, the LIV should be placed one vertebral level distal to the SV. When the SV and EV were at equal levels, the LIV should be selected one level distal to the SV.

Van Rhijn et al.[95] reported their study on selective thoracic fusion in 2002. They aimed to evaluate how the lumbar curve corrects following selective thoracic fusion. A retrospective study was done on 27 patients with King type II AIS treated with selective thoracic fusion, of which 23 patients were eligible for inclusion in our systematic review (4 excluded based on age at surgery or LIV). Outcomes were correction of thoracic and lumbar cobb angles, thoracic kyphosis, lumbar lordosis and L4 tilt. They concluded that the correction of the lumbar curve is not dependent on the degree of correction of the thoracic curve.

Wang et al.[78] published two studies in 2012. One was included in our systematic review and the other was excluded due the inability to exclude the same patient population. The first one was published in *Spine* (Phila Pa 1976) and aimed to identify the causative factors for post-operative trunk shift in Lenke 1C curves. 44 patients with Lenke 1C AIS treated with posterior selective thoracic fusion were retrospectively reviewed and divided into two groups based on whether they had experienced trunk shift. 30 patients did not experience trunk shift. Outcomes included correction of thoracic and lumbar curve, correction of thoracic AV to T1 distance, lumbar AVT and position of LIV. They found that both LIV selection and thoracic to lumbar curve magnitude ratio were highly correlated with the onset of trunk shift.

In 2004, Wong et al.[37] retrospectively reviewed 31 patients with AIS who underwent selective thoracic fusion. They aimed to compare the efficacy of thoracoscopic anterior selective thoracic fusion with standard posterior selective thoracic fusion. Of which only 8 patients fused posteriorly and 10 patients fused anteriorly were eligible for inclusion in our systematic review, mainly due to LIV or age inappropriateness. Outcomes were thoracic curve correction, thoracic kyphosis, lumbar lordosis, operating time, ICU stay days, hospital stay, days requiring parenteral analgesia and blood loss. There was no significant difference between the two groups in terms of scoliosis correction.

Yong et al.[85] published a report on 24 patients with Lenke 1C AIS treated with anterior thoracoscopic selective thoracic fusion. The aim of the study was to report the action of the compensatory lumbar curve. Outcomes were the correction of thoracic and lumbar curves, thoracic kyphosis, coronal balance, T1 tilt angle, and shoulder balance. Clinical outcomes were measured using the SRS-24 questionnaire. No patients had a significant change in kyphosis or coronal decompensation.

Excluded studies

Wang and colleagues[96] second study was published in *The Spine Journal* and aimed to investigate how spinal alignment changes after selective thoracic fusion. A total of 29 patients with Lenke 1C AIS were treated with posterior selective thoracic fusion to assess spinal alignment. Outcome measures included thoracic and lumbar curve correction, coronal balance, T1 translation, thoracic AVT, LIV translation, vertebral translation below LIV. 20 patients were coronally decompensated immediately post-operatively however only 11 remained imbalanced at 2 years post-operatively. Communication was attempted with the authors to clarify whether the same patient group was used for both studies however no reply was returned, and therefore the second study published by Wang et al.[96] was excluded.

Methodological quality

From the search and selection process, 34 studies were critically appraised by two independent reviewers to assess methodological quality prior to inclusion in the review. There were no disagreements.

There were 2 randomized controlled trials (RCT), and 32 retrospective case series.

The results of the quality assessment using the JBI-MAStARI appraisal tool for randomized controlled trials in presented in table 2. The results of the quality assessment using the JBI-MAStARI appraisal tool for retrospective case series is presented in table 3.

Of the included prospective studies they were generally of good quality with both studies scoring a minimum of 7/10 for the appraisal questions. Both studies were unclear whether they blinded the patients, however in view of the subject matter it is likely that they had seen their post-operative radiographs and therefore were not blinded. Both studies did not have the assessor blinded, as the treatment arm would have been noticeable on the radiographs used to assess its efficacy.

The included case series were overall of good quality. All studies scored a minimum of 5/9 on the appraisal questions, with the majority scoring 7/8. No studies were based on a random or pseudorandom sample. Most studies did not clarify whether data on patients that withdrew from the study was reported, however due to their retrospective nature and clearly defined inclusion criteria in regards to follow-up, if they were lost to follow up, it is likely they were never included in the population group.

Citation	Year	Type	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Score
Gotfryd[80]	2013	RCT	Y	U	Y	Y	N	Y	Y	Y	Y	Y	8/10
Tao[87]	2011	Randomised prospective	Y	U	N	Y	N	Y	Y	Y	Y	Y	7/10

Table 2: Critical appraisal results for prospective randomised studies.
Y=Yes; N = No; U = Unclear, N/A = Not applicable
See Appendix II for Question breakdown

Citation	Year	Type	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Score
Behensky[48]	2007	Retrospective	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8
Chang[86]	2010	Retrospective	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8
Demura[83]	2013	Retrospective	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8
Dobbs[79]	2006	Retrospective	N	Y	N	Y	Y	Y	N/A	Y	Y	6/8
Dobbs[49]	2004	Retrospective	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8
Edwards[22]	2004	Retrospective	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8
Engsberg[75]	2003	Prospective	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8
Frez[88]	2000	Retrospective	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8

Goshi[19]	2004	Retrospective	N	Y	Y	Y	Y	Y	N	Y	Y	7/9
Graham[84]	2000	Prospective	N	Y	Y	Y	Y	Y	U	Y	Y	7/9
Haber[33]	2012	Retrospective	N	Y	Y	Y	Y	Y	Y	Y	Y	8/9
Ilgenfritz[89]	2013	Prospective	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8
Kamimura[90]	1999	Retrospective	N	Y	Y	Y	N/A	Y	N/A	Y	Y	6/7
Kim[91]	2007	Retrospective	N	Y	Y	Y	N/A	Y	N/A	Y	Y	6/7
Lenke[76]	1999	Retrospective	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8
Liljenqvist[92]	2013	Retrospective	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8
Liu[81]	2014	Retrospective	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8
Lonner[28]	2006	Retrospective	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8
McCance[56]	1998	Retrospective	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8
Morr[82]	2015	Retrospective	N	Y	N	Y	Y	Y	N/A	Y	Y	6/8
Mladenov[9]	2011	Retrospective	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8
Na[93]	2010	Retrospective	N	Y	Y	Y	N/A	Y	N/A	Y	Y	6/7
Newton[73]	2010	Retrospective	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8
Patel[77]	2008	Retrospective	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8
Potter[34]	2005	Retrospective	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8
Schulz[94]	2014	Retrospective	N	Y	Y	Y	N/A	Y	N/A	Y	U	5/7
Studer[74]	2015	Retrospective	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8
Takahashi[47]	2011	Retrospective	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8
Van Rhijn[95]	2002	Retrospective	N	Y	Y	Y	N/A	Y	N/A	Y	Y	6/7
Wang[78]	2012	Retrospective	N	Y	N	Y	Y	Y	N/A	Y	Y	6/8
Wong[37]	2004	Retrospective	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8
Yong[85]	2012	Retrospective	N	Y	Y	Y	Y	Y	N/A	Y	Y	7/8

Table 3: Critical appraisal results for case series.
Y=Yes; N = No; U = Unclear, N/A = Not applicable
See Appendix II for Question breakdown

Findings of the review

Anterior selective thoracic fusion versus posterior selective thoracic fusion

Eight retrospective case series[22,34,37,49,73,75-77] directly compared anterior instrumentation with posterior instrumentation for selective thoracic fusion for adolescent idiopathic scoliosis. The anterior group was made up of 475 patients with mean age 14.7 (range 10.4–18). Three studies identified as open anterior surgery, one used thoracoscopically assisted anterior surgery, and four did not specify anything more than the anterior approach. The posterior group was made up of 275 patients with mean age 14.2 (range 10.4-18.7). All 8 studies used an open posterior approach with a variety of implants.

Post-operative main thoracic curve

	Anterior			Posterior				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Dobbs 2004	32.6	9	56	36.2	12	44	15.6%	-3.60 [-7.86, 0.66]
Edwards 2004	32.3	8.86	15	41.7	9.1	26	14.2%	-9.40 [-15.09, -3.71]
Engsberg 2003	31.5	8.76	10	33.8	8.33	6	11.2%	-2.30 [-10.90, 6.30]
Lenke 1999	24	11.7	70	36	14	53	15.3%	-12.00 [-16.66, -7.34]
Patel 2008	24	10	132	26	11	44	16.2%	-2.00 [-5.67, 1.67]
Potter 2005	27.2	6.46	14	20.36	6.36	11	14.9%	6.84 [1.78, 11.90]
Wong 2004	16.8	7.45	10	18.675	7.82	8	12.7%	-1.88 [-8.99, 5.24]
Total (95% CI)			**307**			**192**	**100.0%**	**-3.53 [-8.21, 1.14]**

Heterogeneity: $Tau^2 = 31.64$; $Chi^2 = 33.89$, df = 6 ($P < 0.00001$); $I^2 = 82\%$
Test for overall effect: $Z = 1.48$ ($P = 0.14$)

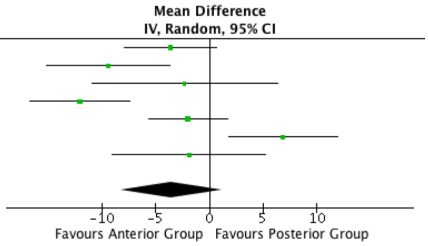


Figure 3: Main thoracic curve (º) at a minimum of 2 years post-operatively in anterior approach selective thoracic fusion vs posterior approach selective thoracic fusion.

Post-operative main thoracic curve was available for analysis in 7 studies[22,34,37,49,75-77] including 499 patients which is shown in figure 3. The meta-analysis shows that there was not a significant difference in post-operative main thoracic curve magnitude between the two groups (p= 0.14). The anterior group had a smaller post-operative main thoracic curve by 3.53 degrees as evidenced by a weighted mean difference of -3.53 (95% CI: -8.21, 1.14). There was statistically significant heterogeneity (p<0.00001) and the I^2 value of 82% indicates that between study variation is considerable. This heterogeneity is likely due to the large range of pre-operative thoracic curves included in all the studies.

Studies not included in meta-analysis

Newton et al.[73] was not included in the meta-analysis as it failed to report on post-operative main thoracic curve results.

Main thoracic curve correction

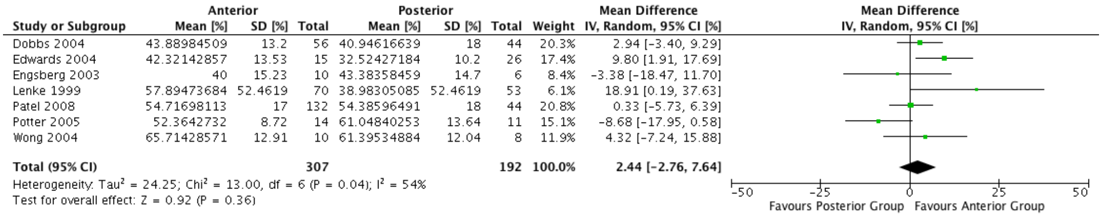


Figure 4: Main thoracic curve correction (%) in anterior approach selective thoracic fusion vs posterior approach selective thoracic fusion.

Thoracic curve correction was evaluated in 7 studies[22,34,37,49,75-77] that all included 499 patients. The anterior approach group had a weighted mean difference of 2.44% (95% CI: -1.03, 5.47) increase in main thoracic curve correction when compared to the posterior approach. However, the meta-analysis showed that there was no statistically significant difference in thoracic curve correction between the two groups (p=0.18). There was statistically significant heterogeneity (p= 0.04) and I^2 value of 54% indicates that there may have been substantial heterogeneity between studies. Lenke 1999[76] did not provide standard deviations of the post-operative main thoracic curve correction but instead gave a p value. The standard deviation for the table was calculated using the p value and the formula given from the Cochrane Handbook for Systematic Reviews of Interventions.[97]

Studies not included in meta-analysis

Newton et al.[73] was not included in the meta-analysis as it failed to report on post-operative main thoracic curve results.

Post-operative compensatory lumbar curve

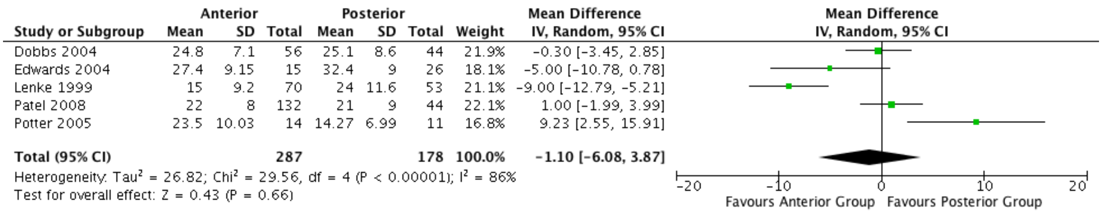


Figure 5: Compensatory lumbar curve (°) at a minimum of 2 years post-operatively in anterior approach selective thoracic fusion vs posterior approach selective thoracic fusion.

Post-operative lumbar curve was reported in 5 studies[22,34,49,76,77] involving 465 patients. The anterior approach group had a weighted mean difference of 1.10 degree (95% CI: -6.08, 3.87) smaller curves post-operatively at final follow-up. However, the meta-analysis showed that there was no statistically significant difference between the two groups (p=0.66). There was statistically significant heterogeneity (p<0.00001) and the I^2 value of 86% implies considerable study variation, which may be explained from a large range of pre-operative lumbar curve values.

Studies not included in meta-analysis

Engsberg et al.[75], Newton et al.[73] and Wong et al.[37] were all unable to be included in the meta-analysis as they failed to report on post-operative compensatory lumbar curve results.

Compensatory lumbar curve correction

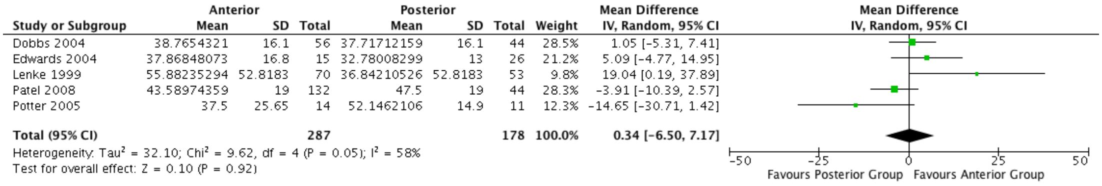


Figure 6: Compensatory lumbar curve correction (%) in anterior approach selective thoracic fusion vs posterior approach selective thoracic fusion.

Lumbar curve correction was evaluated in 5 studies[22,34,49,76,77] that included 465 patients. Overall there was no statistically significant correction (p=0.92) of the compensatory lumbar curve between the anterior or posterior approach. Weighted mean difference was 0.34% (95% CI: -6.50, 7.17) more correction in the anterior group compared to the posterior group. There was statistically significant heterogeneity (p=0.05) and I^2 value of 58% indicating that there may have been substantial heterogeneity between studies. Lenke[76] did not provide standard deviations of the post-operative main thoracic curve correction but instead gave a p value. The standard deviation for the table was calculated using the p value and the formula given from the Cochrane Handbook for Systematic Reviews of Interventions.[97]

Studies not included in meta-analysis

Engsberg et al.[75], Newton et al.[73] and Wong et al.[37] were all unable to be included in the meta-analysis as they failed to report on post-operative compensatory lumbar curve results.

Post-operative coronal balance

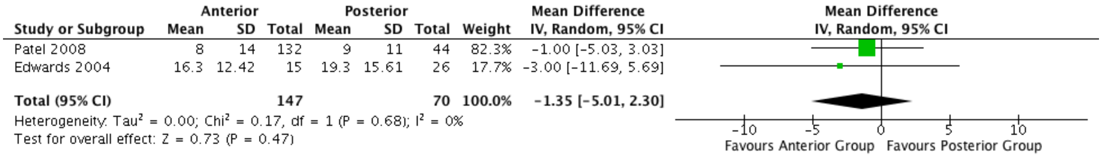


Figure 7: Coronal balance(mm) at a minimum of 2 years post-operatively in anterior approach selective thoracic fusion vs posterior approach selective thoracic fusion.

Figure 7 shows the coronal balance at final follow up in the two studies[22,77] that reported post-operative coronal balance of 217 patients. Mean coronal balance is in millimetres from midline. Both studies had their mean coronal balance as acceptable or balanced. Overall there was no statistically significant change in post-operative coronal balance between patients treated with anterior instrumentation compared with posterior instrumentation ($p=0.47$). The weighted mean difference in coronal balance was the anterior approach group was 1.35mm (95% CI: -5.01, 2.30) closer to midline that the posterior approach group. There was no significant heterogeneity ($p=0.68$), and I^2 indicates there is no important heterogeneity (0%).

Studies not included in meta-analysis

Dobbs et al.[49], Engsberg et al.[75], Lenke et al.[76], Newton et al.[73], Potter et al.[34] and Wong et al.[37] were unable to be included in analysis due to a lack of reported data on the coronal balance of patients.

Change in coronal balance

The change in coronal balance was unable to be analysed in meta-analysis due to lack of standard deviation reported by Patel[77], therefore only leaving one study with change in coronal balance reported. The mean coronal balance change reported in the two studies[22,77] was 3.3mm and -1.0mm in the anterior group and -1.1mm and 0mm in the posterior group respectively.

Post-operative thoracic kyphosis

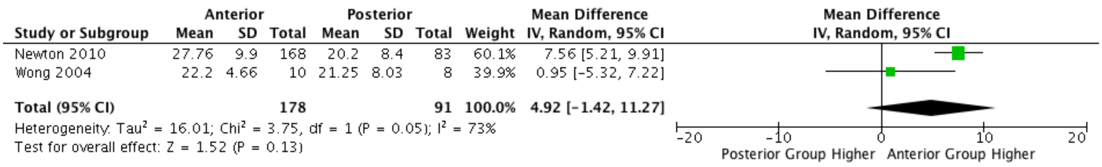


Figure 8: Thoracic kyphosis (°) at a minimum of 2 years post-operatively in anterior approach selective thoracic fusion vs posterior approach selective thoracic fusion.

Figure 8 shows the post-operative thoracic kyphosis magnitude in degrees. Two studies[37,73] reported on the post-operative thoracic kyphosis in 269 patients. Both studies had thoracic kyphosis curves within acceptable ranges. There was no statistically significant difference between the two groups ($p=0.13$) with the anterior approach having a weighted mean difference of 4.92 degrees greater thoracic kyphosis (95% CI: -1.42, 11.27) compared with the posterior group. There was significant heterogeneity between the two studies ($p=0.05$) and an I^2 of 73% implies a considerable variation in studies.

Studies not included in meta-analysis

Dobbs et al.[49], Edwards et al.[22], Engsberg et al.[75], Lenke et al.[76], Patel et al.[77] and Potter et al.[34] were unable to be included in the meta-analysis due to lack of reported data on the thoracic kyphosis.

Change in thoracic kyphosis

	Anterior			Posterior				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Newton 2010	7.86	10.7	168	-2.8	11.4	83	58.6%	10.66 [7.72, 13.60]
Wong 2004	4.9	11.36	10	5.375	9.27	8	41.4%	-0.47 [-10.01, 9.06]
Total (95% CI)			**178**			**91**	**100.0%**	**6.05 [-4.69, 16.80]**

Heterogeneity: $Tau^2 = 49.05$; $Chi^2 = 4.79$, df = 1 (P = 0.03); $I^2 = 79\%$
Test for overall effect: Z = 1.10 (P = 0.27)

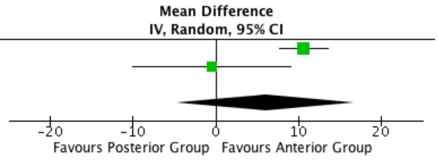


Figure 9: Change in thoracic kyphosis (º) with selective thoracic fusion in the anterior approach vs posterior approach.

Figure 9 shows the change in thoracic kyphosis angle in degrees. Only two studies[37,73] were available for comparison involving 269 patients. Overall there was no statistically significant change in thoracic kyphosis between anterior and posterior instrumentation (p=0.27) implied by the weighted mean difference of 6.05 degrees (95% CI: -4.69, 16.80) higher increase in thoracic kyphosis in the anterior group compared to the posterior group. There was statistically significant heterogeneity between groups (p=0.03) further supported by the I^2 of 79% signifying considerable study variation.

Studies not included in meta-analysis

Dobbs et al.[49], Edwards et al.[22], Engsberg et al.[75], Lenke et al.[76], Patel et al.[77] and Potter et al.[34] were unable to be included in the meta-analysis due to lack of reported data on the thoracic kyphosis.

Post-operative lumbar lordosis

	Anterior			Posterior				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Newton 2010	62.01	11.4	168	57.59	11.5	83	83.5%	4.42 [1.40, 7.44]
Wong 2004	45.4	5.62	10	41.75	8.38	8	16.5%	3.65 [-3.12, 10.42]
Total (95% CI)			**178**			**91**	**100.0%**	**4.29 [1.54, 7.05]**

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.04$, df = 1 (P = 0.84); $I^2 = 0\%$
Test for overall effect: Z = 3.05 (P = 0.002)

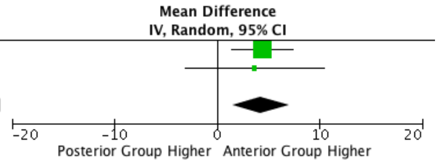


Figure 10: Lumbar lordosis (º) at a minimum of 2 years post-operatively in anterior approach selective thoracic fusion vs posterior approach selective thoracic fusion.

There were two studies[37,73] involving 269 patients available for comparison of post-operative lumbar lordosis, shown in figure 10 and measured in degrees. Overall there was a statistically significant difference (P=0.002) in post-operative lumbar lordosis between the two approaches. There was weighted mean difference of 4.29 degrees (95% CI: 1.54, 7.05) increase in the post-operative lumbar lordosis in the anterior group compared with the posterior group. However all post-operative values in both groups fell within the acceptable range for lumbar lordosis. There was no statistically significant (p=0.84) heterogeneity between studies and the I^2 was 0% signifying no important study variance.

Studies not included in meta-analysis

Unfortunately, Edwards et al.[22] reported on the post-operative lumbar lordosis in their anterior group however did not included the standard deviations or a P value and did not report the lumbar lordosis of the posterior group therefore this study was excluded from meta-analysis.

Dobbs et al.[49], Engsberg et al.[75], Lenke et al.[76], Patel et al.[77] and Potter et al.[34] were unable to be included in the meta-analysis due to lack of reported data on the lumbar lordosis.

Change in lumbar lordosis

	Anterior			Posterior				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Newton 2010	3.01	8.9	168	-5.61	9.7	83	60.5%	8.62 [6.14, 11.10]
Wong 2004	0.3	11.95	10	2	8.84	8	39.5%	-1.70 [-11.31, 7.91]
Total (95% CI)			**178**			**91**	**100.0%**	**4.55 [-5.34, 14.43]**

Heterogeneity: $Tau^2 = 40.42$; $Chi^2 = 4.15$, df = 1 (P = 0.04); $I^2 = 76\%$
Test for overall effect: Z = 0.90 (P = 0.37)

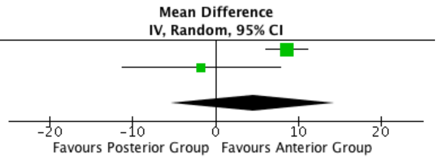


Figure 11: Change in thoracic kyphosis (º) with selective thoracic fusion in the anterior approach vs posterior approach.

Figure 11 shows the change in lumbar lordosis curve post-operatively in degrees. Two studies[37,73] were available for meta-analysis involving 269 patients. There was no statistically significant difference between the two groups (p=0.37). The weighted mean difference was 4.55 degrees (95% CI: -5.34, 14.43) higher increase in lumbar lordosis with the anterior approach compared with the posterior approach. There was a statistically significant (p=0.04) heterogeneity between the two studies, also confirmed by the I^2 of 76% implying considerable study variance.

Studies not included in meta-analysis

Unfortunately, Edwards et al.[22] reported on the post-operative lumbar lordosis in their anterior group however did not included the standard deviations or a p value and did not report the lumbar lordosis of the posterior group therefore this study was excluded from meta-analysis.

Dobbs et al.[49], Engsberg et al.[75], Lenke et al.[76], Patel et al.[77] and Potter et al.[34] were unable to be included in the meta-analysis due to lack of reported data on the lumbar lordosis.

Post-operative sagittal balance

No studies included post-operative results on sagittal balance and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Change in sagittal balance

No studies included post-operative results on sagittal balance and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Post-operative apical vertebral rotation

No studies included post-operative results on apical vertebral rotation and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Change in apical vertebral rotation

No studies included post-operative results on apical vertebral rotation and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Quality of life

One study by Edwards et al.[22] included data on quality of life using the SRS-24 scale. Their results showed that there was near identical (anterior approach group total score 95, posterior approach group total score 94) quality of life (as deemed by SRS-24 score) between the two approaches.

Pulmonary function tests

No studies included data on pulmonary function tests and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Complications

Edwards et al.[22] included complications reporting that coronal decompensation occurred in 8 cases in the anterior approach compared to 13 cases in the posterior approach. As only one study was included, meta-analysis was not possible, and therefore we cannot draw any conclusions about approach leading to superior complication rate.

Compensated vs decompensated patients

Two studies[48,56] directly compared the results of patients who were coronally compensated post-operatively with those that were coronally decompensated post-operatively. However meta-analysis could not be performed due to lack of standard deviations reported by McCance et al.[56] The reported outcomes are described below:

Post-operative main thoracic curve

Both studies[48,56] reported pre-operative and post-operative main thoracic curve magnitudes. McCance et al.[56] reported that main thoracic curve went from 56 degrees (no range given) in the 47 patients in the compensated group to 35 degrees (no range given) post-operatively, in their study whereas the 20 patients in the decompensated group went from 57 degrees pre-operatively (no range given) to 32 degrees post-operatively (no range given). This represents a post-operative main thoracic curve magnitude of 3 degrees less with the compensated group.

Behensky et al.[48] reported that main thoracic curve went from 56 degrees (+/- 7) in the 26 patients in the compensated group to 27 degrees (+/-7) post-operatively, in their study whereas the 10 patients in the decompensated group went from 62 degrees pre-operatively (+/- 13) to 37 degrees post-operatively (+/-10). This represents a post-operative main thoracic curve magnitude of 10 degrees less with the compensated group. This was noted to be statistically significant using parametric testing (p=0.04).[48]

Main thoracic curve correction

Both studies[48,56] were eligible for descriptive analysis for main thoracic curve correction.

McCance et al.[56] reported that the main thoracic curve correction was 37.5% (no range given) or 21 degrees (no range given) in the 47 patients in the compensated group compared to the 20 patients in the decompensated group which had correction of 43.86% (no range given) or 25 degrees (no range given). This represents a main thoracic curve correction of 6.36% less with the compensated group.

Behensky et al.[48] reported that the main thoracic curve correction was 51.79% (+/-12) or 29 degrees (+5.28) in the 26 patients in the compensated group compared to the 10 patients in the decompensated group which had correction of 40.32% (+/-12) or 25 degrees (+5.28). This represents a main thoracic curve correction of 11.47% more with the compensated group. This was noted to be not statistically significant using parametric testing (p=0.05).[48]

It is unlikely that there is a statistical or clinical significant change in main thoracic curve correction between compensated or decompensated curves.

Post-operative compensatory lumbar curve

Both studies[48,56] reported pre-operative and post-operative compensatory lumbar curve magnitudes. McCance et al.[56] reported that compensatory lumbar curve went from 44 degrees (no range given) in the 47 patients in the compensated group to 31 degrees (no range given) post-operatively, in their study whereas the 20 patients in the decompensated group went from 45 degrees pre-operatively (no range given) to 32 degrees post-operatively (no range given). This represents a post-operative compensatory lumbar curve magnitude of 1 degrees less with the compensated group.

Behensky et al.[48] reported that compensatory lumbar curve went from 42 degrees (+/- 10) in the 26 patients in the compensated group to 28 degrees (+/-11) post-operatively, in their study whereas the 10 patients in the decompensated group went from 47 degrees pre-operatively (+/- 5) to 36 degrees post-operatively (+/-9). This represents a post-operative compensatory lumbar curve magnitude of 8 degrees less with the compensated group. This was noted to be not statistically significant using parametric testing (p=NS).[48]

Compensatory lumbar curve correction

Both studies[48,56] were eligible for descriptive analysis for compensatory lumbar curve correction. McCance et al.[56] reported that the compensatory lumbar curve correction was 29.55% (no range given) or 13 degrees (no range given) in the 47 patients in the compensated group compared to the 20 patients in the decompensated group which had correction of 28.89% (no range given) or 13 degrees (no range given). This represents a compensatory lumbar curve correction of 0.66% more with the compensated group.

Behensky et al.[48] reported that the compensatory lumbar curve correction was 33.33% (+/-21) or 14 degrees (+4.62) in the 26 patients in the compensated group compared to the 10 patients in the decompensated group which had correction of 23.40% (+/-20) or 11 degrees (+4.62). This represents a compensatory lumbar curve correction of 9.93% more with the compensated group. This was noted to be not statistically significant using parametric testing (p=NS).[48]

Although both studies showed higher compensatory lumbar curve correction in the compensated group, the difference is very small. Therefore, It is unlikely that there is a statistical or clinical significant change in compensatory lumbar curve correction between compensated or decompensated curves.

Post-operative coronal balance

Both studies[48,56] reported post-operative coronal balance data. McCance et al.[56] reported that coronal balance went from -9.2mm (no range given) in the 47 patients in the compensated group to -8.7mm (no range given) post-operatively, in their study whereas the 20 patients in the decompensated group went from -13mm pre-operatively (no range given) to -27.2mm post-operatively (no range given). This represents a post-operative coronal balance of 18.5mm closer to midline with the compensated group.

Behensky et al.[48] reported that coronal balance went from -8.0mm (+/- 9) in the 26 patients in the compensated group to -12mm (+/-9) post-operatively, in their study whereas the 10 patients in the decompensated group went from -7mm pre-operatively (+/- 6) to -27mm post-operatively (+/-8). This represents a post-operative coronal balance of 15mm closer to midline with the compensated group. This was noted to be statistically significant using parametric testing (p=0.003).[48]

As coronal decompensation is defined as post-operative coronal balance more than 20mm from midline, it is expected the decompensated group had a greater post-operative coronal balance in both studies. This is likely to be both clinically and statistically significant in both studies.

Change in coronal balance

Both studies[48,56] reported coronal balance change data. McCance et al.[56] reported that coronal balance moved 0.5mm (no range given) closer to midline in the 47 patients in the compensated group in their study whereas the 20 patients in the decompensated group moved 14.2mm (no range given) away from midline. This represents a coronal balance change difference of 13.7mm closer to midline with the compensated group.

Behensky et al.[48] reported that coronal balance moved 4.0mm (no range given) away from midline in the 26 patients in the compensated group, in their study whereas the 10 patients in the decompensated group moved 20mm (no range given) away from midline. This represents a difference in coronal balance change of 16mm closer to midline with the compensated group. This was noted to be statistically significant using parametric testing (p=0.003).[48]

As coronal decompensation is defined as post-operative coronal balance more than 20mm from midline, it is expected the decompensated group had a greater post-operative coronal shift away from the midline in both studies. This is likely to be both clinically and statistically significant in both studies.

Post-operative thoracic kyphosis

Both studies[48,56] reported pre-operative and post-operative thoracic kyphosis curve magnitudes. McCance et al.[56] reported that thoracic kyphosis went from 24 degrees (no range given) pre-operatively in the 47 patients in the compensated group to 28 degrees (no range given) post-operatively, in their study whereas the 20 patients in the decompensated group went from 24 degrees pre-operatively (no range given) to 20 degrees post-operatively (no range given). This represents a post-operative thoracic kyphosis difference of 8 degrees more with the compensated group.

Behensky et al.[48] reported that thoracic kyphosis went from 27 degrees (+/- 11) in the 26 patients in the compensated group to 25 degrees (+/-6) post-operatively, in their study whereas the 10 patients in the decompensated group went from 36 degrees pre-operatively (+/- 16) to 31 degrees post-operatively (+/-8). This represents a post-operative thoracic kyphosis difference of 6 degrees less with the compensated group. This was noted to be not statistically significant using parametric testing (p=NS).[48]

Both groups had post-operative thoracic kyphosis values within the accepted range.

Change in thoracic kyphosis

Both studies[48,56] were eligible for descriptive analysis of thoracic kyphosis change.

McCance et al.[56] reported that the change in thoracic kyphosis was 4 degrees more (no range given) in the 47 patients in the compensated group compared to the 20 patients in the decompensated group which had change of 4 degrees less (no range given). This represents a thoracic kyphosis change difference of 8 degrees more with the compensated group.

Behensky et al.[48] reported that the change in thoracic kyphosis was 2 degrees less (no range given) in the 26 patients in the compensated group compared to the 10 patients in the decompensated group which had change of 5 degrees less (no range given). This represents a thoracic kyphosis change difference of 3 degrees more with the compensated group. This was noted to be not statistically significant using parametric testing (p=NS).[48]

It is unlikely that there is a statistical or clinical significant difference in the change in thoracic kyphosis between compensated or decompensated curves.

Post-operative lumbar lordosis

Both studies[48,56] reported pre-operative and post-operative lumbar lordosis values.

McCance et al.[56] reported that lumbar lordosis went from 56 degrees (no range given) pre-operatively in the 47 patients in the compensated group to 52 degrees (no range given) post-operatively, in their study whereas the 20 patients in the decompensated group went from 60 degrees pre-operatively (no range given) to 70 degrees post-operatively (no range given). This represents a post-operative lumbar lordosis difference of 18 degrees less with the compensated group.

Behensky et al.[48] reported that lumbar lordosis went from 40 degrees (+/- 10) in the 26 patients in the compensated group to 41 degrees (+/-8) post-operatively, in their study whereas the 10 patients in the decompensated group went from 44 degrees pre-operatively (+/- 17) to 45 degrees post-operatively (+/-8). This represents a post-operative lumbar lordosis difference of 4 degrees less with the compensated group. This was noted to be not statistically significant using parametric testing (p=NS).[48]

Both groups had post-operative lumbar lordosis values within the accepted range.[98] Interestingly both studies had lower post-operative lumbar lordosis in the compensated group. It is possible that with decompensation of the coronal balance, the lumbar lordosis secondarily increases, however it is hard to draw a statistical or clinical significance with the level of evidence provided by only these two studies.

Change in lumbar lordosis

Both studies[48,56] were eligible for descriptive analysis of lumbar lordosis change. McCance et al.[56] reported that the change in lumbar lordosis was 4 degrees less (no range given) in the 47 patients in the compensated group compared to the 20 patients in the decompensated group which had change of 10 degrees more (no range given). This represents a lumbar lordosis change difference of 14 degrees more with the decompensated group.

Behensky et al.[48] reported that the change in lumbar lordosis was 1 degrees more (no range given) in both the 26 patients in the compensated group and the 10 patients in the decompensated group. This was noted to be not statistically significant using parametric testing (p=NS).[48]

It is unlikely that there is a statistical or clinical significant difference in the change in lumbar lordosis between compensated or decompensated curves.

Post-operative sagittal balance

Both studies[48,56] reported post-operative sagittal balance data. McCance et al.[56] reported that sagittal balance went from -26.0mm (no range given) in the 47 patients in the compensated group to -28.0mm (no range given) post-operatively, in their study whereas the

20 patients in the decompensated group went from -19.0mm pre-operatively (no range given) to -41.0mm post-operatively (no range given). This represents a post-operative sagittal balance of 13.0mm closer to midline with the compensated group.

Behensky et al.[48] reported that sagittal balance went from -5.0mm (no range given) in the 26 patients in the compensated group to -12.0mm (no range given) post-operatively, in their study whereas the 10 patients in the decompensated group went from -7.0mm pre-operatively (no range given) to -16.0mm post-operatively (no range given). This represents a post-operative coronal balance of 4.0mm closer to midline with the compensated group. This was noted to be statistically significant using parametric testing (p=0.09).[48]

It is possible that with decompensation of the coronal balance, the sagittal balance also secondarily worsens, however it is hard to draw a statistical or clinical significance with the level of evidence provided by only these two studies. This is further supported by the fact that both the compensated and decompensated groups in the study reported by McCance et al.[56] reported sagittal balance that would be deemed unacceptable.

Change in sagittal balance

Both studies[48,56] reported sagittal balance change data. McCance et al.[56] reported that sagittal balance moved 2.0mm (no range given) away from the midline in the 47 patients in the compensated group in their study, compared with the 20 patients in the decompensated group which moved 22.0mm (no range given) away from the midline. This represents a coronal balance change difference of 20.0mm closer to midline with the compensated group, which is likely to be clinical and even possibly statistically significant.

Behensky et al.[48] reported that sagittal balance moved 7.0mm (no range given) away from midline in the 26 patients in the compensated group, in their study whereas the 10 patients in the decompensated group moved 9.0mm (no range given) away from midline. This represents a difference in coronal balance change of 2.0mm closer to midline with the compensated group. This is unlikely to be either clinically or statistically significant.

Post-operative thoracic apical vertebral rotation

No studies included post-operative results on apical vertebral rotation and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Change in thoracic apical vertebral rotation

No studies included post-operative results on apical vertebral rotation and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Post-operative lumbar apical vertebral rotation

No studies included post-operative results on apical vertebral rotation and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Change in lumbar apical vertebral rotation

No studies included post-operative results on apical vertebral rotation and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Quality of Life

No studies included data on quality of life and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Pulmonary Function

No studies included data on pulmonary function tests and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Complications

No studies included data on complications and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Lenke lumbar modifier B vs Lenke lumbar modifier C

Two studies directly involving 165 patients compared the results of patients with Lenke B curves (113 patients) against those with Lenke C curves (52 patients). They each had 2 treatment arms, with patient results separated into subgroups of anterior or posterior instrumentation.

Post-operative main thoracic curve

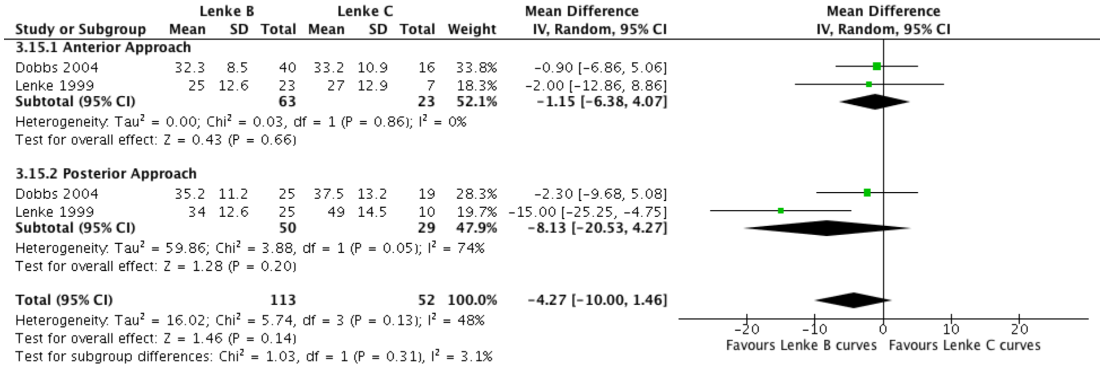


Figure 12: Main thoracic curve (º) at a minimum of 2 years post-operatively following selective thoracic fusion in Lenke lumbar modifier B curves vs Lenke lumbar modifier C curves.

Both studies[49,76] reported results on post-operative main thoracic curve in 165 patients. Using the anterior approach there was a weighted mean difference of -1.15 degrees (95% CI: -6.38, 4.07) between Lenke B and Lenke C curves. This did not reach statistical significance (p=0.66). There was no significant heterogeneity (p=0.86) and I^2 score of 0% signifies little study variance. Using the posterior approach there was a weighted mean difference of -8.13 degrees (95% CI: -20.53, 4.27). This also did not reach statistical significance (p=0.2). There was significant heterogeneity between studies (p=0.05) and I^2 was 74% which would signify substantial study variance. Overall there was no statistically significant difference between the post-operative values of the main thoracic curves (p=0.14). Lenke B curves had a weighted mean difference of -4.27 degrees (95% CI: -10.00, 1.46) compared to their Lenke C comparators. There was no statistically significant (p=0.13) heterogeneity between the two studies, also confirmed by the I^2 of 48% implying moderate study variance.

Main thoracic curve correction

Lenke et al.[76] was unable to be included in meta-analysis because although a value of correction was given, there was no range or P value to calculate the standard deviation for inclusion, therefore their results are described below.

Dobbs et al.[49] reported that the main thoracic curve correction was 42.8% (+/-13.7) or 24.2 degrees (+/-8.3) in the 40 patients in the Lenke B anterior approach group compared to the 16 patients in the Lenke C anterior approach group which had correction of 46.6% (+/-9.6) or 29.3 degrees (+/-8.2). This represents a main thoracic curve correction of 3.8% less with the Lenke B group.

Dobbs et al.[49] reported that the main thoracic curve correction was 41.9% (+/-19.1) or 25.4 degrees (+/-12.2) in the 25 patients in the Lenke B posterior approach group compared to the 19 patients in the Lenke C posterior approach group which had correction of 39.7% (+/-17.0) or 24.7 degrees (+/-11.8). This represents a main thoracic curve correction of 2.2% more with the Lenke B group.

Lenke et al.[76] reported that the main thoracic curve correction was 54.5% (no range given) or 30.0 degrees (no range given) in the 23 patients in the Lenke B anterior approach group compared to the 7 patients in the Lenke C anterior approach group which had correction of 58.5% (no range given) or 38 degrees (no range given). This represents a main thoracic curve correction of 4.0% less with the Lenke B group.

Lenke et al. [76] reported that the main thoracic curve correction was 42.4% (no range given) or 25.0 degrees (no range given) in the 25 patients in the Lenke B posterior approach group compared to the 10 patients in the Lenke C posterior approach group which had correction of 26.9% (no range given) or 18.0 degrees (no range given). This represents a main thoracic curve correction of 15.5% more with the Lenke B group.

All groups have very similar main thoracic correction rates between Lenke B and Lenke C curves, with the exception of the one treatment arm in the study by Lenke et al. [76] Therefore it is unlikely that there is a statistical or clinical significant change in main thoracic curve correction between Lenke B or Lenke C groups.

Post-operative Compensatory Lumbar curve

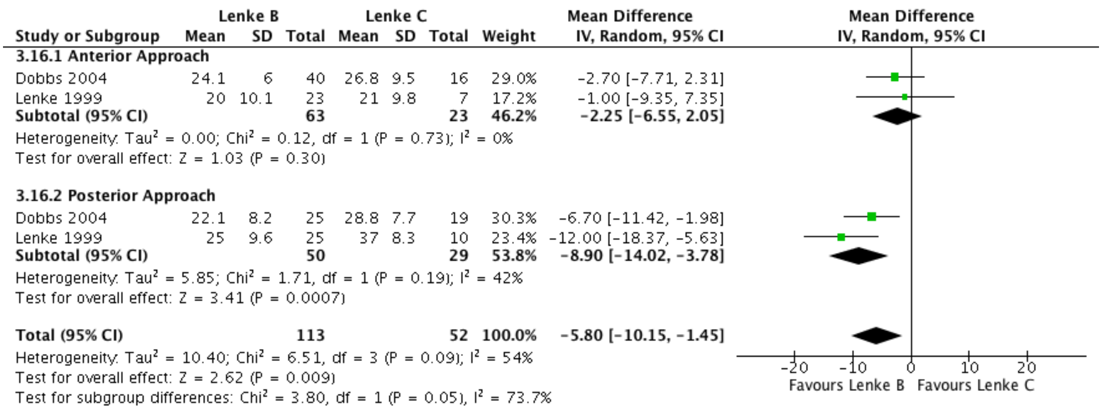


Figure 13: Compensatory lumbar curve (º) at a minimum of 2 years post-operatively following selective thoracic fusion in Lenke lumbar modifier B curves vs Lenke lumbar modifier C curves.

Both studies[49,76] reported results on post-operative compensatory lumbar curve magnitude in 165 patients. Using the anterior approach there was a weighted mean difference of -2.25 degrees (95% CI: -6.55, 2.05) between Lenke B and Lenke C curves. This did not reach statistical significance (p=0.30). There was no statistically significant heterogeneity (p=0.73) and I^2 score of 0% signifies little study variance. Using the posterior approach there was a weighted mean difference of -8.90 degrees (95% CI: -14.02, -3.78). This was statistically significant (p=0.0007). There was no statistically significant heterogeneity between studies (p=0.19) and I^2 was 42% which would signify moderate study variance. Overall there was statistically significant difference between the post-operative values of the compensatory lumbar curves (p=0.009). Lenke B curves had a weighted mean difference of -5.80 degrees (95% CI: -10.15, -1.45) compared to their Lenke C comparators. This is however expected as the classification of a Lenke B or Lenke C curve is dictated by the position of the lumbar apical vertebrae and therefore a larger curve pre-operatively is more likely to be a Lenke C curve. There was no statistically significant (p=0.09) heterogeneity between the two studies, also confirmed by the I^2 of 54% implying moderate study variance.

Compensatory lumbar curve correction

Lenke et al.[76] was unable to be included in meta-analysis because although a value of correction was given, there was no range or P value to calculate the standard deviation for inclusion, therefore their results are described below.

Dobbs et al.[49] reported that the compensatory lumbar curve correction was 38.0% (+/-13.9) or 14.8 degrees (+/-5.7) in the 40 patients in the Lenke B anterior approach group compared to the 16 patients in the Lenke C anterior approach group which had correction of 38.4% (+/-21.7) or 18.0 degrees (+/-10.4). This represents a compensatory lumbar curve correction of 0.4% less with the Lenke B group.

Dobbs et al.[49] reported that the compensatory lumbar curve correction was 40.6% (+/-18.6) or 15.1 degrees (+/-6.8) in the 25 patients in the Lenke B posterior approach group compared to the 19 patients in the Lenke C posterior approach group which had correction of 35.1% (+/-11.7) or 15.6 degrees (+/-5.8). This represents a compensatory lumbar curve correction of 5.5% more with the Lenke B group.

Lenke et al.[76] reported that the compensatory lumbar curve correction was 45.9% (no range given) or 17 degrees (no range given) in the 23 patients in the Lenke B anterior approach group compared to the 7 patients in the Lenke C anterior approach group which had correction of 50.0% (no range given) or 21 degrees (no range given). This represents a compensatory lumbar curve correction of 4.1% less with the Lenke B group.

Lenke et al. [76] reported that the compensatory lumbar curve correction was 37.5% (no range given) or 15 degrees (no range given) in the 25 patients in the Lenke B posterior approach group compared to the 10 patients in the Lenke C posterior approach group which had correction of 30.2% (no range given) or 16 degrees (no range given). This represents a compensatory lumbar curve correction of 7.3% more with the Lenke B group.

All groups have very similar compensatory lumbar correction rates between Lenke B and Lenke C curves. Interestingly the anterior approach treatment arms had less correction in Lenke B curves, but the posterior approach treatment arms had more correction in the Lenke B curves. Therefore it is unlikely that there is a statistical or clinical significant change in compensatory lumbar curve correction between Lenke B or Lenke C groups.

Post-operative coronal balance

No studies included post-operative results on coronal balance and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Change in coronal balance

No studies included post-operative results on coronal balance and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Post-operative thoracic kyphosis

No studies included post-operative results on thoracic kyphosis and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Change in thoracic kyphosis

No studies included post-operative results on thoracic kyphosis and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Post-operative lumbar lordosis

No studies included post-operative results on lumbar lordosis and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Change in lumbar lordosis

No studies included post-operative results on lumbar lordosis and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Post-operative sagittal balance

No studies included post-operative results on sagittal balance and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Change in sagittal balance

No studies included post-operative results on sagittal balance and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Post-operative thoracic apical vertebral rotation

No studies included post-operative results on thoracic apical vertebral rotation and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Change in thoracic apical vertebral rotation

No studies included post-operative results on thoracic apical vertebral rotation and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Post-operative lumbar apical vertebral rotation

No studies included post-operative results on lumbar apical vertebral rotation and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Change in lumbar apical vertebral rotation

No studies included post-operative results on lumbar apical vertebral rotation and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Quality of Life

No studies included data on quality of life and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Pulmonary Function

No studies included data on pulmonary function tests and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Complications

No studies included data on complications and therefore this outcome was not able to be analysed using meta-analysis or descriptive analysis.

Effectiveness of selective thoracic fusion in adolescent idiopathic scoliosis

To assess the effectiveness of selective thoracic fusion we compared the post-operative values with the pre-operative values. The treatment arms of the studies were further divided into groups based on their approach (anterior, posterior or unspecified/unable to segregate). All studies that met our inclusion criteria were eligible for inclusion for meta-analysis for one or more outcome depending on the data analysed except McCance et al. which did not report any P values, standard deviations or standard errors and therefore was excluded from meta-analysis.[56] Overall there was 706 patients treated with the anterior approach with mean age of 14.8 years, 857 patients treated with the posterior approach with mean age of 14.4 years, and 281 patients treated with an unspecified approach with mean age of 14.3 years.

Main thoracic curve correction

	Pre-op			Post-op				Mean Difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**
2.1.1 Anterior Approach								
Dobbs 2004	58.1	8.8	56	32.6	9	56	3.0%	25.50 [22.20, 28.80]
Edwards 2004	56	6.92	15	32.3	8.86	15	2.4%	23.70 [18.01, 29.39]
Engsberg 2003	52.5	6.15	10	31.5	8.76	10	2.2%	21.00 [14.37, 27.63]
Graham 2000	53	10	51	24	9	51	2.9%	29.00 [25.31, 32.69]
Haber 2012	58.5	12.22	13	34.8	11.04	13	1.7%	23.70 [14.75, 32.65]
Kamimura 1999	54.8	10.5	17	23.8	10.5	17	2.1%	31.00 [23.94, 38.06]
Kim 2007	54.5	13.9	42	19.7	9.3	42	2.6%	34.80 [29.74, 39.86]
Lenke 1999	57	12.5	70	24	11.7	70	2.8%	33.00 [28.99, 37.01]
Liljenqvist 2013	61.6	8.7	28	29.3	5.1	28	2.9%	32.30 [28.56, 36.04]
Lonner 2006	48.1	5.12	28	21.9	9.09	28	2.9%	26.20 [22.34, 30.06]
Na 2010	52	0	28	18.1	0	28		Not estimable
Patel 2008	53	9	132	24	10	132	3.2%	29.00 [26.70, 31.30]
Potter 2005	57.1	5.4	14	27.2	6.46	14	2.7%	29.90 [25.49, 34.31]
Wong 2004	49	7.2	10	16.8	7.45	10	2.3%	32.20 [25.78, 38.62]
Yong 2012	53	8.4	24	24.9	5.9	24	2.8%	28.10 [23.99, 32.21]
Subtotal (95% CI)			**510**			**510**	**36.7%**	**28.82 [27.02, 30.62]**
Heterogeneity: Tau² = 6.11; Chi² = 30.04, df = 13 (P = 0.005); I² = 57%								
Test for overall effect: Z = 31.39 (P < 0.00001)								
2.1.2 Posterior Approach								
Behensky 2007 Compensated	56	7	26	27	7	26	2.9%	29.00 [25.19, 32.81]
Behensky 2007 decompensated	62	13	10	37	8	10	1.6%	25.00 [15.54, 34.46]
Dobbs 2004	61.3	9.1	44	36.2	12	44	2.7%	25.10 [20.65, 29.55]
Dobbs 2006 Hook group	64	28.399	32	51.1	136.487	32	0.1%	12.90 [−35.40, 61.20]
Dobbs 2006 Pedicle Group	62.3	29.2731	34	40.1	140.6876	34	0.1%	22.20 [−26.10, 70.50]
Edwards 2004	61.8	8.29	26	41.7	9.1	26	2.7%	20.10 [15.37, 24.83]
Engsberg 2003	59.7	9.46	6	33.8	8.33	6	1.5%	25.90 [15.81, 35.99]
Frez 2000	60.2	9.2	24	43.4	16.9883	24	2.0%	16.80 [9.07, 24.53]
Goshi 2004	48	6.07	6	16.17	5.34	6	2.3%	31.83 [25.36, 38.30]
Gotfryd 2013 Group 1	59.7	6.6	23	19.3	6.1	23	2.9%	40.40 [36.73, 44.07]
Gotfryd 2013 Group 2	57.2	10.6	23	17.8	8	23	2.5%	39.40 [33.97, 44.83]
Lenke 1999	59	12.4	53	36	14	53	2.6%	23.00 [17.97, 28.03]
Liu 2014 Hybrid group	47.6	9	21	18.8496	13.8022	21	2.1%	28.75 [21.70, 35.80]
Liu 2014 Pedicle Screw	45.4	8.1	21	14.755	13.8265	21	2.2%	30.64 [23.79, 37.50]
McCance 1998 Compensated	56	0	47	35	0	47		Not estimable
McCance 1998 Decompensated group	57	0	20	32	0	20		Not estimable
Mladenov 2011 DVD group	62.4	12	17	19.5	5.8	17	2.3%	42.90 [36.56, 49.24]
Mladenov 2011 SRR group	62.3	12.1	13	21.4	7.2	13	2.0%	40.90 [33.25, 48.55]
Morr 2015 CON Group	52.1	8.7774	20	17.3	1.8905	20	2.9%	34.80 [30.86, 38.74]
Morr 2015 SKP Group	51.7	8.7771	20	17.7	1.8905	20	2.9%	34.00 [30.07, 37.93]
Patel 2008	57	12	44	26	11	44	2.7%	31.00 [26.19, 35.81]
Potter 2005	52.27	4.43	11	20.36	6.31	11	2.7%	31.91 [27.35, 36.47]
Schulz 2004	53	11	106	24	8	106	3.1%	29.00 [26.41, 31.59]
Studer 2015	62.9	9.64	16	24	7.18	16	2.4%	38.90 [33.01, 44.79]
Tao 2011	52.47	10.83	36	14.78	8.19	36	2.7%	37.69 [33.25, 42.13]
Van Rhijn 2002	52.5	8.08	23	30.7	8.14	23	2.7%	21.80 [17.11, 26.49]
Wang 2012 No trunk shift group	56.1	10.2	30	23	49.9354	30	0.7%	33.10 [14.86, 51.34]
Wang 2012 Trunk shift	50.6	6.2	14	19.1	34.1124	14	0.7%	31.50 [13.34, 49.66]
Wong 2004	48.375	10.62	8	18.675	7.82	8	1.7%	29.70 [20.56, 38.84]
Subtotal (95% CI)			**707**			**707**	**57.7%**	**30.92 [28.27, 33.58]**
Heterogeneity: Tau² = 34.87; Chi² = 147.63, df = 26 (P < 0.00001); I² = 82%								
Test for overall effect: Z = 22.85 (P < 0.00001)								
2.1.3 Unspecified Approach								
Chang 2010	61.6	11.9	32	39.8	9.7	32	2.5%	21.80 [16.48, 27.12]
Demura 2013	49.3	7.7	53	22.3	6.8	53	3.1%	27.00 [24.23, 29.77]
Ilgenfritz 2013	49	9	24	26.46	0	24		Not estimable
Takahashi 2011 EBS	50	6	13	21	0	13		Not estimable
Takahashi 2011 SAE	51	7	66	23.46	0	66		Not estimable
Takahashi 2011 SBE	54	9	93	22.68	0	93		Not estimable
Subtotal (95% CI)			**85**			**85**	**5.6%**	**24.92 [19.92, 29.91]**
Heterogeneity: Tau² = 8.84; Chi² = 2.89, df = 1 (P = 0.09); I² = 65%								
Test for overall effect: Z = 9.78 (P < 0.00001)								
Total (95% CI)			**1302**			**1302**	**100.0%**	**29.79 [28.10, 31.47]**
Heterogeneity: Tau² = 21.89; Chi² = 199.63, df = 42 (P < 0.00001); I² = 79%								
Test for overall effect: Z = 34.60 (P < 0.00001)								
Test for subgroup differences: Chi² = 4.61, df = 2 (P = 0.10), I² = 56.6%								

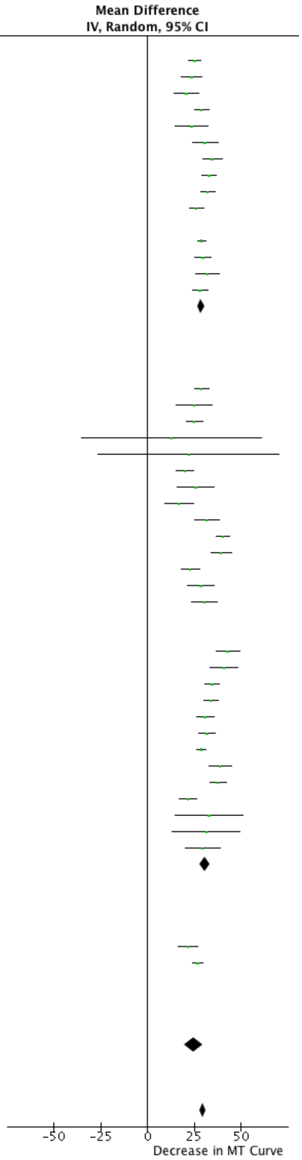


Figure 14: Effect of selective thoracic fusion on the main thoracic curve magnitude (°).

Figure 14 shows the effect of selective thoracic fusion on the magnitude of the main thoracic curve for all included studies. For each study, the mean pre-operative value in degrees and the mean post-operative value in degrees are listed. Those studies which were unable to be included for meta-analysis due to missing data are listed here but not included in patient numbers or calculated in weighted mean difference.

Of those utilizing the anterior approach there were 15 studies involving 538 patients that described the effectiveness of selective thoracic fusion on the main thoracic curve magnitude however only 14 treatment arms and 510 patients that were eligible for inclusion for meta-analysis. There was significance for difference between post-operative and pre-operative values (p<0.0001), with the weighted mean difference of 28.82 degrees (95% CI: 27.02, 30.62). There was significant heterogeneity between the studies with p value of 0.005 and I^2 of 57% signifying moderate variance of studies.

Of those using the posterior approach there were 29 treatment arms involving 774 patients which described the effectiveness of selective thoracic fusion on the main thoracic curve magnitude however only 27 treatment arms across 20 studies involving 707 patients were eligible for inclusion. There was significance for difference between pre-operative and post-operative values (P<0.00001), with the weighted mean difference of 30.92 degrees (95% CI: 28.27, 35.58). There was significant heterogeneity (p<0.00001) and was further supported by the I^2 of 84% which suggests considerable heterogeneity. Dobbs et al.[79], Frez et al.[88], Liu et al.[81], Morr et al.[82], and Wang et al.[78] did not provide standard deviations of the pre-operative or post-operative main thoracic curve but instead gave a P value. The standard deviation for the table was calculated using the P value and the formula given from the Cochrane Handbook for Systematic Reviews of Interventions.[97]

There were 4 studies involving 281 patients that either did not specify what approach was used or did not isolate the approach groups that described the effectiveness of selective thoracic fusion on the main thoracic curve magnitude however only 2 were eligible for inclusion in meta-analysis. This involved 85 patients. The weighted mean difference was 24.92 degrees (95% CI: 19.92, 29.91) which was statistically different from pre-operative values (P<0.00001). Between the two studies there was no significant heterogeneity (P=0.09) with I^2 or 65% signifying substantial study variance.

Overall, 29 studies, 43 treatment arms and 1302 patients included in the meta-analysis all reached a statistically significant difference in main thoracic curve (p<0.00001). The average weighted mean difference between pre-operatively and post-operatively was 29.79 degrees (95% CI: 28.10, 31.47). Across all studies there was significant heterogeneity (p<0.00001) and I^2 was 79% signifying substantial study variance.

Study or Subgroup	Pre-Op Mean	Pre-Op SD	Pre-Op Total	Post-Op Mean	Post-Op SD	Post-Op Total	Weight	Mean Difference IV, Random, 95% CI
2.11.1 Anterior Approach								
Dobbs 2004	58.1	8.8	56	32.6	9	56	3.0%	25.50 [22.20, 28.80]
Edwards 2004	56	6.92	15	32.3	8.86	15	2.5%	23.70 [18.01, 29.39]
Engsberg 2003	52.5	6.15	10	31.5	8.76	10	2.2%	21.00 [14.37, 27.63]
Graham 2000	53	10	51	24	9	51	2.9%	29.00 [25.31, 32.69]
Haber 2012	58.5	12.22	13	34.8	11.04	13	1.7%	23.70 [14.75, 32.65]
Kamimura 1999	54.8	10.5	17	23.8	10.5	17	2.1%	31.00 [23.94, 38.06]
Kim 2007	54.5	13.9	42	19.7	9.3	42	2.6%	34.80 [29.74, 39.86]
Lenke 1999	57	12.5	70	24	11.7	70	2.8%	33.00 [28.99, 37.01]
Liljenqvist 2013	61.6	8.7	28	29.3	5.1	28	2.9%	32.30 [28.56, 36.04]
Lonner 2006	48.1	5.12	28	21.9	9.09	28	2.9%	26.20 [22.34, 30.06]
Na 2010	52	0	28	18.1	0	28		Not estimable
Patel 2008	53	9	132	24	10	132	3.2%	29.00 [26.70, 31.30]
Potter 2005	57.1	5.4	14	27.2	6.46	14	2.8%	29.90 [25.49, 34.31]
Wong 2004	49	7.2	10	16.8	7.45	10	2.3%	32.20 [25.78, 38.62]
Yong 2012	53	8.4	24	24.9	5.9	24	2.8%	28.10 [23.99, 32.21]
Subtotal (95% CI)			**510**			**510**	**36.8%**	**28.82 [27.02, 30.62]**
Heterogeneity: Tau² = 6.11; Chi² = 30.04, df = 13 (P = 0.005); I² = 57%								
Test for overall effect: Z = 31.39 (P < 0.00001)								
2.11.2 Posterior Approach								
Behensky 2007 Compensated	56	7	26	27	7	26	2.9%	29.00 [25.19, 32.81]
Behensky 2007 decompensated	62	13	10	37	8	10	1.6%	25.00 [15.54, 34.46]
Dobbs 2004	61.3	9.1	44	36.2	12	44	2.7%	25.10 [20.65, 29.55]
Edwards 2004	61.8	8.29	26	41.7	9.1	26	2.7%	20.10 [15.37, 24.83]
Engsberg 2003	59.7	9.46	6	33.8	8.33	6	1.5%	25.90 [15.81, 35.99]
Frez 2000	60.2	9.2	24	43.4	16.9883	24	2.0%	16.80 [9.07, 24.53]
Goshi 2004	48	6.07	6	16.17	5.34	6	2.3%	31.83 [25.36, 38.30]
Gotfryd 2013 Group 1	59.7	6.6	23	19.3	6.1	23	2.9%	40.40 [36.73, 44.07]
Gotfryd 2013 Group 2	57.2	10.6	23	17.8	8	23	2.5%	39.40 [33.97, 44.83]
Lenke 1999	59	12.4	53	36	14	53	2.6%	23.00 [17.97, 28.03]
Liu 2014 Hybrid group	47.6	9	21	18.8496	13.8022	21	2.1%	28.75 [21.70, 35.80]
Liu 2014 Pedicle Screw	45.4	8.1	21	14.755	13.8265	21	2.2%	30.64 [23.79, 37.50]
McCance 1998 Compensated	56	0	47	35	0	47		Not estimable
McCance 1998 Decompensated group	57	0	20	32	0	20		Not estimable
Mladenov 2011 DVD group	62.4	12	17	19.5	5.8	17	2.3%	42.90 [36.56, 49.24]
Mladenov 2011 SRR group	62.3	12.1	13	21.4	7.2	13	2.0%	40.90 [33.25, 48.55]
Morr 2015 CON Group	52.1	8.7774	20	17.3	1.8905	20	2.9%	34.80 [30.86, 38.74]
Morr 2015 SKP Group	51.7	8.7771	20	17.7	1.8905	20	2.9%	34.00 [30.07, 37.93]
Patel 2008	57	12	44	26	11	44	2.7%	31.00 [26.19, 35.81]
Potter 2005	52.27	4.43	11	20.36	6.31	11	2.7%	31.91 [27.35, 36.47]
Schulz 2004	53	11	106	24	8	106	3.1%	29.00 [26.41, 31.59]
Studer 2015	62.9	9.64	16	24	7.18	16	2.4%	38.90 [33.01, 44.79]
Tao 2011	52.47	10.83	36	14.78	8.19	36	2.7%	37.69 [33.25, 42.13]
Van Rhijn 2002	52.5	8.08	23	30.7	8.14	23	2.7%	21.80 [17.11, 26.49]
Wang 2012 No trunk shift group	56.1	10.2	30	23	49.9354	30	0.7%	33.10 [14.86, 51.34]
Wang 2012 Trunk shift	50.6	6.2	14	19.1	34.1124	14	0.7%	31.50 [13.34, 49.66]
Wong 2004	48.375	10.62	8	18.675	7.82	8	1.7%	29.70 [20.56, 38.84]
Subtotal (95% CI)			**641**			**641**	**57.6%**	**31.00 [28.33, 33.67]**
Heterogeneity: Tau² = 35.29; Chi² = 146.95, df = 24 (P < 0.00001); I² = 84%								
Test for overall effect: Z = 22.74 (P < 0.00001)								
2.11.3 Unspecified Approach								
Chang 2010	61.6	11.9	32	39.8	9.7	32	2.5%	21.80 [16.48, 27.12]
Demura 2013	49.3	7.7	53	22.3	6.8	53	3.1%	27.00 [24.23, 29.77]
Ilgenfritz 2013	49	9	24	26.46	0	24		Not estimable
Takahashi 2011 EBS	50	6	13	21	0	13		Not estimable
Takahashi 2011 SAE	51	7	66	23.46	0	66		Not estimable
Takahashi 2011 SBE	54	9	93	22.68	0	93		Not estimable
Subtotal (95% CI)			**85**			**85**	**5.6%**	**24.92 [19.92, 29.91]**
Heterogeneity: Tau² = 8.84; Chi² = 2.89, df = 1 (P = 0.09); I² = 65%								
Test for overall effect: Z = 9.78 (P < 0.00001)								
Total (95% CI)			**1236**			**1236**	**100.0%**	**29.82 [28.12, 31.51]**
Heterogeneity: Tau² = 22.10; Chi² = 199.07, df = 40 (P < 0.00001); I² = 80%								
Test for overall effect: Z = 34.47 (P < 0.00001)								
Test for subgroup differences: Chi² = 4.73, df = 2 (P = 0.09), I² = 57.7%								

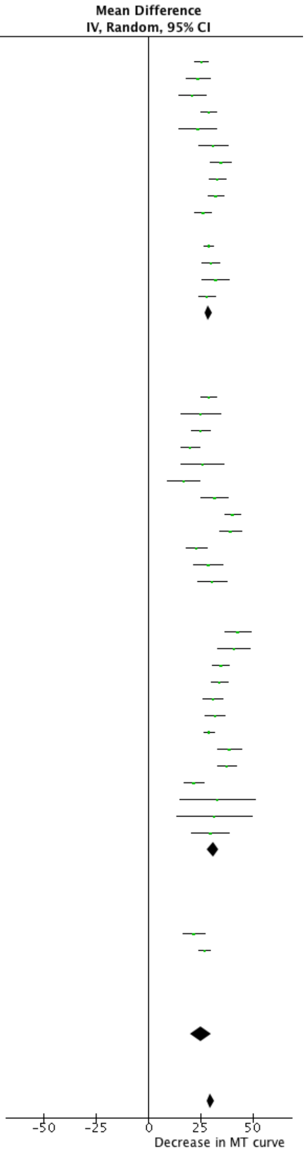


Figure 15: Effect of selective thoracic fusion on the main thoracic curve magnitude (º). Sensitivity analysis excluding Dobbs et al.[79]

Due to the extremely large standard definition calculated for the data from Dobbs et al.[79] a sensitivity analysis was done with the study excluded. The results were only minimally changed (weighted mean difference of 29.82 (95% CI: 28.12, 31.51) and therefore it was included in our main meta-analysis. This sensitivity analysis can be seen in figure 15. This did not show a significant difference between approaches (p=0.09).

Study or Subgroup	Pre-Op Mean	Pre-Op SD	Pre-Op Total	Post-Op Mean	Post-Op SD	Post-Op Total	Weight	Mean Difference IV, Random, 95% CI
2.12.1 Anterior Approach								
Dobbs 2004	58.1	8.8	56	32.6	9	56	3.2%	25.50 [22.20, 28.80]
Edwards 2004	56	6.92	15	32.3	8.86	15	2.6%	23.70 [18.01, 29.39]
Engsberg 2003	52.5	6.15	10	31.5	8.76	10	2.4%	21.00 [14.37, 27.63]
Graham 2000	53	10	51	24	9	51	3.1%	29.00 [25.31, 32.69]
Haber 2012	58.5	12.22	13	34.8	11.04	13	1.8%	23.70 [14.75, 32.65]
Kamimura 1999	54.8	10.5	17	23.8	10.5	17	2.3%	31.00 [23.94, 38.06]
Kim 2007	54.5	13.9	42	19.7	9.3	42	2.8%	34.80 [29.74, 39.86]
Lenke 1999	57	12.5	70	24	11.7	70	3.0%	33.00 [28.99, 37.01]
Liljenqvist 2013	61.6	8.7	28	29.3	5.1	28	3.1%	32.30 [28.56, 36.04]
Lonner 2006	48.1	5.12	28	21.9	9.09	28	3.0%	26.20 [22.34, 30.06]
Na 2010	52	0	28	18.1	0	28		Not estimable
Patel 2008	53	9	132	24	10	132	3.4%	29.00 [26.70, 31.30]
Potter 2005	57.1	5.4	14	27.2	6.46	14	2.9%	29.90 [25.49, 34.31]
Wong 2004	49	7.2	10	16.8	7.45	10	2.4%	32.20 [25.78, 38.62]
Yong 2012	53	8.4	24	24.9	5.9	24	3.0%	28.10 [23.99, 32.21]
Subtotal (95% CI)			**510**			**510**	**38.8%**	**28.82 [27.02, 30.62]**
Heterogeneity: $Tau^2 = 6.11$; $Chi^2 = 30.04$, df = 13 ($P = 0.005$); $I^2 = 57\%$								
Test for overall effect: $Z = 31.39$ ($P < 0.00001$)								
2.12.2 Posterior Approach								
Behensky 2007 Compensated	56	7	26	27	7	26	3.1%	29.00 [25.19, 32.81]
Behensky 2007 decompensated	62	13	10	37	8	10	1.7%	25.00 [15.54, 34.46]
Dobbs 2004	61.3	9.1	44	36.2	12	44	2.9%	25.10 [20.65, 29.55]
Dobbs 2006 Hook group	64	28.399	32	51.1	136.487	32	0.1%	12.90 [-35.40, 61.20]
Dobbs 2006 Pedicle Group	62.3	29.2731	34	40.1	140.6876	34	0.1%	22.20 [-26.10, 70.50]
Edwards 2004	61.8	8.29	26	41.7	9.1	26	2.8%	20.10 [15.37, 24.83]
Engsberg 2003	59.7	9.46	6	33.8	8.33	6	1.6%	25.90 [15.81, 35.99]
Frez 2000	60.2	9.2	24	43.4	16.9883	24	2.1%	16.80 [9.07, 24.53]
Goshi 2004	48	6.07	6	16.17	5.34	6	2.4%	31.83 [25.36, 38.30]
Gotfryd 2013 Group 1	59.7	6.6	23	19.3	6.1	23	3.1%	40.40 [36.73, 44.07]
Gotfryd 2013 Group 2	57.2	10.6	23	17.8	8	23	2.7%	39.40 [33.97, 44.83]
Lenke 1999	59	12.4	53	36	14	53	2.8%	23.00 [17.97, 28.03]
Liu 2014 Hybrid group	47.6	9	21	18.8496	13.8022	21	2.3%	28.75 [21.70, 35.80]
Liu 2014 Pedicle Screw	45.4	8.1	21	14.755	13.8265	21	2.3%	30.64 [23.79, 37.50]
McCance 1998 Compensated	56	0	47	35	0	47		Not estimable
McCance 1998 Decompensated group	57	0	20	32	0	20		Not estimable
Mladenov 2011 DVD group	62.4	12	17	19.5	5.8	17	2.4%	42.90 [36.56, 49.24]
Mladenov 2011 SRR group	62.3	12.1	13	21.4	7.2	13	2.1%	40.90 [33.25, 48.55]
Morr 2015 CON Group	52.1	8.7774	20	17.3	1.8905	20	3.0%	34.80 [30.86, 38.74]
Morr 2015 SKP Group	51.7	8.7771	20	17.7	1.8905	20	3.0%	34.00 [30.07, 37.93]
Patel 2008	57	12	44	26	11	44	2.8%	31.00 [26.19, 35.81]
Potter 2005	52.27	4.43	11	20.36	6.31	11	2.9%	31.91 [27.35, 36.47]
Schulz 2004	53	11	106	24	8	106	3.3%	29.00 [26.41, 31.59]
Studer 2015	62.9	9.64	16	24	7.18	16	2.5%	38.90 [33.01, 44.79]
Tao 2011	52.47	10.83	36	14.78	8.19	36	2.9%	37.69 [33.25, 42.13]
Van Rhijn 2002	52.5	8.08	23	30.7	8.14	23	2.8%	21.80 [17.11, 26.49]
Wang 2012 No trunk shift group	56.1	10.2	30	23	49.9354	30	0.7%	33.10 [14.86, 51.34]
Wang 2012 Trunk shift	50.6	6.2	14	19.1	34.1124	14	0.7%	31.50 [13.34, 49.66]
Wong 2004	48.375	10.62	8	18.675	7.82	8	1.8%	29.70 [20.56, 38.84]
Subtotal (95% CI)			**707**			**707**	**61.2%**	**30.92 [28.27, 33.58]**
Heterogeneity: $Tau^2 = 34.87$; $Chi^2 = 147.63$, df = 26 ($P < 0.00001$); $I^2 = 82\%$								
Test for overall effect: $Z = 22.85$ ($P < 0.00001$)								
Total (95% CI)			**1217**			**1217**	**100.0%**	**30.09 [28.34, 31.84]**
Heterogeneity: $Tau^2 = 22.26$; $Chi^2 = 186.38$, df = 40 ($P < 0.00001$); $I^2 = 79\%$								
Test for overall effect: $Z = 33.74$ ($P < 0.00001$)								
Test for subgroup differences: $Chi^2 = 1.66$, df = 1 ($P = 0.20$), $I^2 = 39.7\%$								

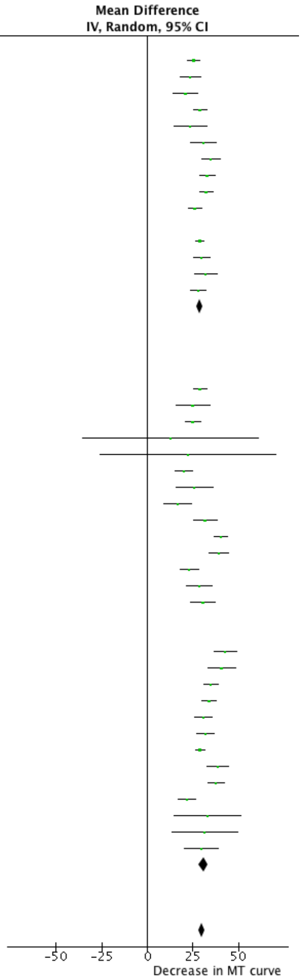


Figure 16: Effect of selective thoracic fusion on the main thoracic curve magnitude (°). Sensitivity analysis excluding those treated with unspecified approach.

A sensitivity analysis was done with the unspecified approach groups excluded. The results can be seen in figure 16. This showed that the mean weighted difference was 30.09 degrees (95% CI: 28.34, 31.84). There was no significant change between the anterior and posterior groups (p=0.20) which supports the results found in our anterior versus posterior approach meta-analysis.

Those studies not eligible for meta-analysis

Newton et al.[73] was not eligible for inclusion in meta-analysis or descriptive analysis as they did not report any post-operative thoracic curve magnitude. Na et al.[93] reported mean main thoracic curve magnitude from 52 degrees pre-operatively to 18.1 degrees post-operatively with a correction of 33.9 degrees. However, no range, p value or standard deviation was reported for inclusion in meta-analysis. Ilgenfritz et al.[89] reported correction of mean main thoracic curve as a percentage of 46%(+/- 23), however did not report absolute values of post-operative main thoracic curve magnitude and therefore could not be included for meta-analysis. Takahashi et al.[47] reported the correction of the mean main thoracic curve as 58% (+/-16) in the SBE group, 54% (+/-15) in the SAE group and 58% (+/- 18) in the EBS group however reported the P value only as non-significant between the groups and therefore was not eligible for inclusion in the meta-analysis. McCance et al. [56] reported mean main thoracic curve magnitude from 56 degrees pre-operatively to 35 degrees post-operatively with a correction of 21 degrees in their compensated group and values of 57 degrees reduced to 32 degrees with a change of 25 degrees in their decompensated group. However, no range, p value or standard deviation was reported for inclusion in meta-analysis.

Compensatory Lumbar curve correction

Study or Subgroup	Pre-op Mean	Pre-op SD	Pre-op Total	Post-op Mean	Post-op SD	Post-op Total	Weight	Mean Difference IV, Random, 95% CI
2.2.1 Anterior group								
Dobbs 2004	40.5	7.4	56	24.8	7.1	56	5.9%	15.70 [13.01, 18.39]
Edwards 2004	44.1	7.04	15	27.4	9.15	15	2.2%	16.70 [10.86, 22.54]
Kamimura 1999	31.9	9.7	17	15.9	10.5	17	1.8%	16.00 [9.20, 22.80]
Lenke 1999	34	10.5	70	15	9.2	70	4.8%	19.00 [15.73, 22.27]
Liljenqvist 2013	47.7	4.8	28	30.5	6	28	5.6%	17.20 [14.35, 20.05]
Na 2010	35	0	28	13.6	0	28		Not estimable
Patel 2008	39	7	132	22	8	132	7.7%	17.00 [15.19, 18.81]
Potter 2005	37.6	6.44	14	23.5	10.03	14	2.0%	14.10 [7.86, 20.34]
Yong 2012	43.5	5.6	24	25.4	6.6	24	4.6%	18.10 [14.64, 21.56]
Subtotal (95% CI)			**356**			**356**	**34.5%**	**17.02 [15.92, 18.13]**
Heterogeneity: Tau² = 0.00; Chi² = 3.66, df = 7 (P = 0.82); I² = 0%								
Test for overall effect: Z = 30.21 (P < 0.00001)								
2.2.2 Posterior group								
Behensky 2007 Compensated	42	10	26	28	11	26	2.3%	14.00 [8.29, 19.71]
Behensky 2007 decompensated	47	5	10	36	9	10	1.9%	11.00 [4.62, 17.38]
Dobbs 2004	40.3	8	44	25.1	8.6	44	4.5%	15.20 [11.73, 18.67]
Dobbs 2006 Hook group	49.48	51.5284	32	37.5	17.2388	32	0.3%	11.98 [-6.85, 30.81]
Dobbs 2006 Pedicle Group	44.6	53.1142	34	27.6	17.7694	34	0.3%	17.00 [-1.83, 35.83]
Edwards 2004	48.2	9.45	26	32.4	9	26	2.8%	15.80 [10.78, 20.82]
Frez 2000	40.7	6.6	24	32.2	9.7748	24	3.1%	8.50 [3.78, 13.22]
Goshi 2004	36.17	5.04	6	12.5	4.3	6	2.6%	23.67 [18.37, 28.97]
Gotfryd 2013 Group 1	36.7	8	23	17.5	9.9	23	2.7%	19.20 [14.00, 24.40]
Gotfryd 2013 Group 2	31.9	9.1	23	13.5	8.5	23	2.8%	18.40 [13.31, 23.49]
Lenke 1999	38	12.8	53	24	11.6	53	3.1%	14.00 [9.35, 18.65]
Liu 2014 Hybrid group	31	8.1	21	11.749	24.5867	21	0.7%	19.25 [8.18, 30.32]
Liu 2014 Pedicle Screw	32.1	4.6	21	12.4548	24.5867	21	0.8%	19.65 [8.95, 30.34]
McCance 1998 Compensated	44	0	47	31	0	47		Not estimable
McCance 1998 Decompensated group	45	0	20	32	0	20		Not estimable
Morr 2015 CON Group	26.3	11.2395	20	11.8	5.1156	20	2.5%	14.50 [9.09, 19.91]
Morr 2015 SKP Group	29.3	11.2395	20	13.4	5.1156	20	2.5%	15.90 [10.49, 21.31]
Patel 2008	40	8	44	21	9	44	4.4%	19.00 [15.44, 22.56]
Potter 2005	29.82	10.76	11	14.27	6.99	11	1.5%	15.55 [7.97, 23.13]
Schulz 2004	41	7	106	25	8	106	7.2%	16.00 [13.98, 18.02]
Studer 2015	41.7	7.33	16	18.3	5.47	16	3.3%	23.40 [18.92, 27.88]
Van Rhijn 2002	32.9	6.33	23	21	7.06	23	4.0%	11.90 [8.02, 15.78]
Wang 2012 No trunk shift group	41	5.7	30	22.9	19.2542	30	1.6%	18.10 [10.91, 25.29]
Wang 2012 Trunk shift	43.1	7.6	14	27.1	28.1852	14	0.4%	16.00 [0.71, 31.29]
Subtotal (95% CI)			**627**			**627**	**55.4%**	**16.24 [14.59, 17.89]**
Heterogeneity: Tau² = 6.66; Chi² = 42.81, df = 21 (P = 0.003); I² = 51%								
Test for overall effect: Z = 19.32 (P < 0.00001)								
2.2.3 Unspecified group								
Chang 2010	47.2	10.4	32	33.2	9.3	32	3.0%	14.00 [9.17, 18.83]
Demura 2013	39	5.2	53	23.1	5.5	53	7.2%	15.90 [13.86, 17.94]
Ilgenfritz 2013	40	6	24	24.4	0	24		Not estimable
Takahashi 2011 EBS	39	6	13	22.62	0	13		Not estimable
Takahashi 2011 SAE	39	8	66	22.62	0	66		Not estimable
Takahashi 2011 SBE	36	8	93	19.44	0	93		Not estimable
Subtotal (95% CI)			**85**			**85**	**10.1%**	**15.61 [13.74, 17.49]**
Heterogeneity: Tau² = 0.00; Chi² = 0.50, df = 1 (P = 0.48); I² = 0%								
Test for overall effect: Z = 16.30 (P < 0.00001)								
Total (95% CI)			**1068**			**1068**	**100.0%**	**16.39 [15.41, 17.38]**
Heterogeneity: Tau² = 2.46; Chi² = 49.07, df = 31 (P = 0.02); I² = 37%								
Test for overall effect: Z = 32.51 (P < 0.00001)								
Test for subgroup differences: Chi² = 1.79, df = 2 (P = 0.41), I² = 0%								

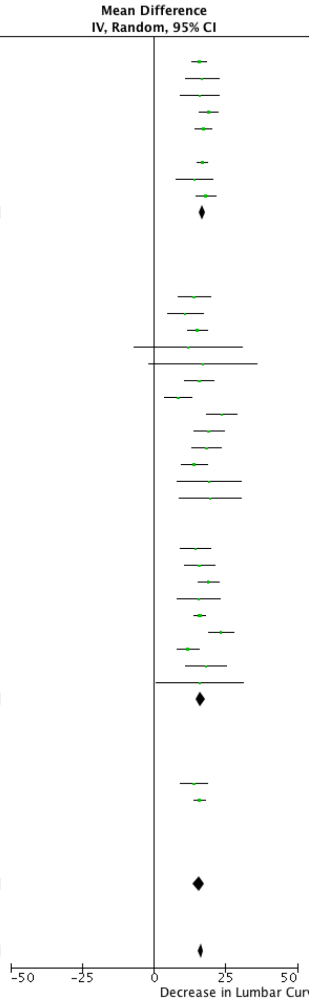


Figure 17: Effect of selective thoracic fusion on the compensatory lumbar curve magnitude (°).

Figure 17 shows the effectiveness of selective thoracic fusion on the compensatory lumbar curve magnitude. For each study, the mean pre-operative value in degrees and the mean post-operative value in degrees are listed. Those studies which were unable to be included for meta-analysis due to missing data are listed here but not included in patient numbers or calculated in weighted mean difference.

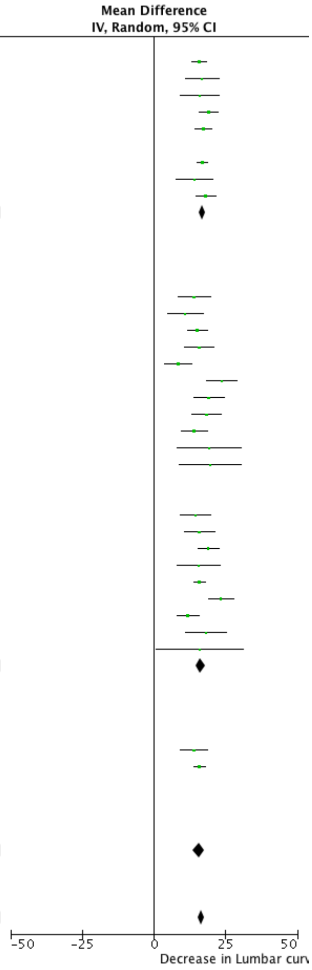
A total of 9 studies involving 384 patients reported pre-operative and post-operative compensatory lumbar curve results using the anterior approach. Included for meta-analysis using the anterior approach was 8 studies involving 356 patients. There was significant change between the pre-operative and post-operative values (P<0.00001), with the weighted mean difference of change of 17.02 degrees (95 CI: 15.92, 18.13). There was no significant heterogeneity between studies (P=0.82) with an I^2 of 0% signifying no important study variance.

Of those using the posterior approach there were 17 studies involving 694 patients that reported on compensatory lumbar curve correction with pre-operative and post-operative values. Of these 22 treatment arms across 16 studies involving 627 patients. There was statistically significant change (P<0.00001) in the lumbar curve following selective thoracic fusion with weighted mean difference of 16.24 degrees (95% CI: 14.59, 17.89). There was significant heterogeneity (P=0.003) and a I^2 of 51% indicates substantial study variance.

Dobbs et al.[79], Frez et al.[88], Liu et al.[81], Morr et al.[82], and Wang et al.[78] did not provide standard deviations of the pre-operative or post-operative main thoracic curve but instead gave a P value. The standard deviation for the table was calculated using the P value and the formula given from the Cochrane Handbook for Systematic Reviews of Interventions.[97]

There were 4 studies (with 6 treatment arms) with 281 patients that did not specify what approach was used or did not isolate the approach groups that reported effectiveness of selective thoracic fusion on the lumbar curve. Of these 2 studies involving 85 patients were eligible for inclusion in meta-analysis. The weighted mean difference was 15.61 (95 CI:13.74, 17.49) which was statistically significant (p<0.00001). There was no significant heterogeneity (P=0.48) with I^2 of 0% signifying no substantial study variance.

Overall selective thoracic fusion was effective in changing the compensatory lumbar curve. Overall, 21 studies and 30 treatment arms and 1068 patients were included for meta-analysis and all reached a statistically significant difference in compensatory lumbar curve (p<0.00001). The average weighted mean difference between pre-operative and post-operative curves was 16.39 degrees (95% CI: 15.41, 17.38). Across all studies there was significant heterogeneity (p=0.02) and I^2 was 37% signifying moderate study variance.



Study or Subgroup	Pre-op Mean	Pre-op SD	Pre-op Total	Post-op Mean	Post-op SD	Post-op Total	Weight	Mean Difference IV, Random, 95% CI
2.13.1 Anterior group								
Dobbs 2004	40.5	7.4	56	24.8	7.1	56	5.8%	15.70 [13.01, 18.39]
Edwards 2004	44.1	7.04	15	27.4	9.15	15	2.3%	16.70 [10.86, 22.54]
Kamimura 1999	31.9	9.7	17	15.9	10.5	17	1.8%	16.00 [9.20, 22.80]
Lenke 1999	34	10.5	70	15	9.2	70	4.8%	19.00 [15.73, 22.27]
Liljenqvist 2013	47.7	4.8	28	30.5	6	28	5.5%	17.20 [14.35, 20.05]
Na 2010	35	0	28	13.6	0	28		Not estimable
Patel 2008	39	7	132	22	8	132	7.5%	17.00 [15.19, 18.81]
Potter 2005	37.6	6.44	14	23.5	10.03	14	2.1%	14.10 [7.86, 20.34]
Yong 2012	43.5	5.6	24	25.4	6.6	24	4.6%	18.10 [14.64, 21.56]
Subtotal (95% CI)			**356**			**356**	**34.4%**	**17.02 [15.92, 18.13]**
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 3.66$, df = 7 (P = 0.82); $I^2 = 0\%$								
Test for overall effect: Z = 30.21 (P < 0.00001)								
2.13.2 Posterior group								
Behensky 2007 Compensated	42	10	26	28	11	26	2.4%	14.00 [8.29, 19.71]
Behensky 2007 decompensated	47	5	10	36	9	10	2.0%	11.00 [4.62, 17.38]
Dobbs 2004	40.3	8	44	25.1	8.6	44	4.6%	15.20 [11.73, 18.67]
Edwards 2004	48.2	9.45	26	32.4	9	26	2.9%	15.80 [10.78, 20.82]
Frez 2000	40.7	6.6	24	32.2	9.7748	24	3.1%	8.50 [3.78, 13.22]
Goshi 2004	36.17	5.04	6	12.5	4.3	6	2.7%	23.67 [18.37, 28.97]
Gotfryd 2013 Group 1	36.7	8	23	17.5	9.9	23	2.7%	19.20 [14.00, 24.40]
Gotfryd 2013 Group 2	31.9	9.1	23	13.5	8.5	23	2.8%	18.40 [13.31, 23.49]
Lenke 1999	38	12.8	53	24	11.6	53	3.2%	14.00 [9.35, 18.65]
Liu 2014 Hybrid group	31	8.1	21	11.749	24.5867	21	0.8%	19.25 [8.18, 30.32]
Liu 2014 Pedicle Screw	32.1	4.6	21	12.4548	24.5867	21	0.8%	19.65 [8.95, 30.34]
McCance 1998 Compensated	44	0	47	31	0	47		Not estimable
McCance 1998 Decompensated group	45	0	20	32	0	20		Not estimable
Morr 2015 CON Group	26.3	11.2395	20	11.8	5.1156	20	2.6%	14.50 [9.09, 19.91]
Morr 2015 SKP Group	29.3	11.2395	20	13.4	5.1156	20	2.6%	15.90 [10.49, 21.31]
Patel 2008	40	8	44	21	9	44	4.4%	19.00 [15.44, 22.56]
Potter 2005	29.82	10.76	11	14.27	6.99	11	1.5%	15.55 [7.97, 23.13]
Schulz 2004	41	7	106	25	8	106	7.1%	16.00 [13.98, 18.02]
Studer 2015	41.7	7.33	16	18.3	5.47	16	3.4%	23.40 [18.92, 27.88]
Van Rhijn 2002	32.9	6.33	23	21	7.06	23	4.0%	11.90 [8.02, 15.78]
Wang 2012 No trunk shift group	41	5.7	30	22.9	19.2542	30	1.7%	18.10 [10.91, 25.29]
Wang 2012 Trunk shift	43.1	7.6	14	27.1	28.1852	14	0.4%	16.00 [0.71, 31.29]
Subtotal (95% CI)			**561**			**561**	**55.5%**	**16.27 [14.57, 17.97]**
Heterogeneity: $Tau^2 = 7.26$; $Chi^2 = 42.61$, df = 19 (P = 0.001); $I^2 = 55\%$								
Test for overall effect: Z = 18.77 (P < 0.00001)								
2.13.3 Unspecified group								
Chang 2010	47.2	10.4	32	33.2	9.3	32	3.0%	14.00 [9.17, 18.83]
Demura 2013	39	5.2	53	23.1	5.5	53	7.0%	15.90 [13.86, 17.94]
Ilgenfritz 2013	40	6	24	24.4	0	24		Not estimable
Takahashi 2011 EBS	39	6	13	22.62	0	13		Not estimable
Takahashi 2011 SAE	39	8	66	22.62	0	66		Not estimable
Takahashi 2011 SBE	36	8	93	19.44	0	93		Not estimable
Subtotal (95% CI)			**85**			**85**	**10.1%**	**15.61 [13.74, 17.49]**
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.50$, df = 1 (P = 0.48); $I^2 = 0\%$								
Test for overall effect: Z = 16.30 (P < 0.00001)								
Total (95% CI)			**1002**			**1002**	**100.0%**	**16.40 [15.39, 17.41]**
Heterogeneity: $Tau^2 = 2.71$; $Chi^2 = 48.85$, df = 29 (P = 0.01); $I^2 = 41\%$								
Test for overall effect: Z = 31.77 (P < 0.00001)								
Test for subgroup differences: $Chi^2 = 1.76$, df = 2 (P = 0.41), $I^2 = 0\%$								

Figure 18: Effect of selective thoracic fusion on the compensatory lumbar curve magnitude (º). Sensitivity analysis excluding Dobbs et al.[79]

Due to the extremely large standard deviation calculated for the data from Dobbs et al.[79] a sensitivity analysis was done with the study excluded. The results were only minimally changed (weighted mean difference of 16.40 (95% CI: 15.39, 17.41) and therefore it was included in our main meta-analysis and reported separately here. This sensitivity analysis can be seen in figure 18. This did not show a significant difference between anterior, posterior or unspecified approaches.

Study or Subgroup	Pre-op Mean	Pre-op SD	Pre-op Total	Post-op Mean	Post-op SD	Post-op Total	Weight	Mean Difference IV, Random, 95% CI
2.14.1 Anterior group								
Dobbs 2004	40.5	7.4	56	24.8	7.1	56	6.3%	15.70 [13.01, 18.39]
Edwards 2004	44.1	7.04	15	27.4	9.15	15	2.6%	16.70 [10.86, 22.54]
Kamimura 1999	31.9	9.7	17	15.9	10.5	17	2.0%	16.00 [9.20, 22.80]
Lenke 1999	34	10.5	70	15	9.2	70	5.3%	19.00 [15.73, 22.27]
Liljenqvist 2013	47.7	4.8	28	30.5	6	28	6.0%	17.20 [14.35, 20.05]
Na 2010	35	0	28	13.6	0	28		Not estimable
Patel 2008	39	7	132	22	8	132	8.0%	17.00 [15.19, 18.81]
Potter 2005	37.6	6.44	14	23.5	10.03	14	2.3%	14.10 [7.86, 20.34]
Yong 2012	43.5	5.6	24	25.4	6.6	24	5.0%	18.10 [14.64, 21.56]
Subtotal (95% CI)			**356**			**356**	**37.6%**	**17.02 [15.92, 18.13]**
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 3.66$, df = 7 (P = 0.82); $I^2 = 0\%$								
Test for overall effect: Z = 30.21 (P < 0.00001)								
2.14.2 Posterior group								
Behensky 2007 Compensated	42	10	26	28	11	26	2.7%	14.00 [8.29, 19.71]
Behensky 2007 decompensated	47	5	10	36	9	10	2.3%	11.00 [4.62, 17.38]
Dobbs 2004	40.3	8	44	25.1	8.6	44	5.0%	15.20 [11.73, 18.67]
Dobbs 2006 Hook group	49.48	51.5284	32	37.5	17.2388	32	0.3%	11.98 [-6.85, 30.81]
Dobbs 2006 Pedicle Group	44.6	53.1142	34	27.6	17.7694	34	0.3%	17.00 [-1.83, 35.83]
Edwards 2004	48.2	9.45	26	32.4	9	26	3.2%	15.80 [10.78, 20.82]
Frez 2000	40.7	6.6	24	32.2	9.7748	24	3.5%	8.50 [3.78, 13.22]
Goshi 2004	36.17	5.04	6	12.5	4.3	6	3.0%	23.67 [18.37, 28.97]
Gotfryd 2013 Group 1	36.7	8	23	17.5	9.9	23	3.1%	19.20 [14.00, 24.40]
Gotfryd 2013 Group 2	31.9	9.1	23	13.5	8.5	23	3.2%	18.40 [13.31, 23.49]
Lenke 1999	38	12.8	53	24	11.6	53	3.6%	14.00 [9.35, 18.65]
Liu 2014 Hybrid group	31	8.1	21	11.749	24.5867	21	0.9%	19.25 [8.18, 30.32]
Liu 2014 Pedicle Screw	32.1	4.6	21	12.4548	24.5867	21	0.9%	19.65 [8.95, 30.34]
McCance 1998 Compensated	44	0	47	31	0	47		Not estimable
McCance 1998 Decompensated group	45	0	20	32	0	20		Not estimable
Morr 2015 CON Group	26.3	11.2395	20	11.8	5.1156	20	2.9%	14.50 [9.09, 19.91]
Morr 2015 SKP Group	29.3	11.2395	20	13.4	5.1156	20	2.9%	15.90 [10.49, 21.31]
Patel 2008	40	8	44	21	9	44	4.9%	19.00 [15.44, 22.56]
Potter 2005	29.82	10.76	11	14.27	6.99	11	1.7%	15.55 [7.97, 23.13]
Schulz 2004	41	7	106	25	8	106	7.6%	16.00 [13.98, 18.02]
Studer 2015	41.7	7.33	16	18.3	5.47	16	3.7%	23.40 [18.92, 27.88]
Van Rhijn 2002	32.9	6.33	23	21	7.06	23	4.5%	11.90 [8.02, 15.78]
Wang 2012 No trunk shift group	41	5.7	30	22.9	19.2542	30	1.9%	18.10 [10.91, 25.29]
Wang 2012 Trunk shift	43.1	7.6	14	27.1	28.1852	14	0.5%	16.00 [0.71, 31.29]
Subtotal (95% CI)			**627**			**627**	**62.4%**	**16.24 [14.59, 17.89]**
Heterogeneity: $Tau^2 = 6.66$; $Chi^2 = 42.81$, df = 21 (P = 0.003); $I^2 = 51\%$								
Test for overall effect: Z = 19.32 (P < 0.00001)								
Total (95% CI)			**983**			**983**	**100.0%**	**16.51 [15.42, 17.59]**
Heterogeneity: $Tau^2 = 2.98$; $Chi^2 = 47.72$, df = 29 (P = 0.02); $I^2 = 39\%$								
Test for overall effect: Z = 29.81 (P < 0.00001)								
Test for subgroup differences: $Chi^2 = 0.60$, df = 1 (P = 0.44), $I^2 = 0\%$								

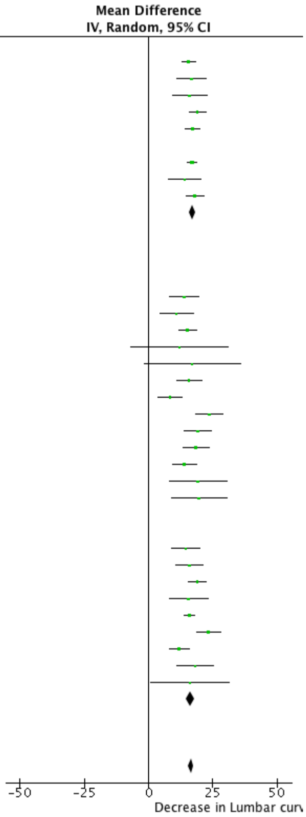


Figure 19: Effect of selective thoracic fusion on the compensatory lumbar curve magnitude (º). Sensitivity analysis excluding those treated with unspecified approach.

A sensitivity analysis was done with the unspecified approach groups excluded. The results can be seen in figure 19. This showed that the mean weighted difference was 16.51 degrees (95% CI: 15.42, 17.59). There was no significant change (p=0.44) between the anterior or posterior approaches which supports the results found in our anterior versus posterior approach meta-analysis.

Those studies not eligible for meta-analysis

Engsberg et al.[75], Graham et al.[84], Haber et al.[33], Kim et al.[91], Lonner et al.[28], Newton et al.[73], Maldenov et al.[9], Tao et al.[87] and Wong et al.[37] were not eligible for inclusion in meta-analysis or descriptive analysis as they did not report any pre-operative or post-operative lumbar curve magnitude. Na et al.[93] reported compensatory lumbar curve magnitude from 35 degrees pre-operatively to 13.6 degrees post-operatively with a correction of 21.4 degrees. However, no range, P value or standard deviation was reported for inclusion in meta-analysis. McCance et al. [56] reported compensatory lumbar curve magnitude from 44 degrees pre-operatively to 31 degrees post-operatively with a correction of 13 degrees in their compensated group and values of 45 degrees reduced to 32 degrees with a change of 13 degrees in their decompensated group. However, no range, P value or standard deviation was reported for inclusion in meta-analysis. Ilgenfritz et al.[89] reported correction of the lumbar curve as 39% (+/-19), however did not report absolute values and therefore could not be included for meta-analysis. Takahashi et al.[47] reported the correction of the compensatory lumbar curve as 46% (+/- 20) in the SBE group, 42% (+/- 21) in the SAE group and 42% (+/-

14) in the EBS group however did not report the post-operative value or standard deviation and therefore was not eligible for inclusion in the meta-analysis

Coronal Balance

Study or Subgroup	Pre-op Mean	Pre-op SD	Pre-op Total	Post-op Mean	Post-op SD	Post-op Total	Weight	Mean Difference IV, Random, 95% CI
2.3.1 Anterior approach								
Edwards 2004	19.6	10.97	15	16.3	12.42	15	4.1%	3.30 [-5.09, 11.69]
Liljenqvist 2013	18	12	28	14	12	28	5.5%	4.00 [-2.29, 10.29]
Lonner 2006	12.9	10.3	28	7.7	6.1	28	7.1%	5.20 [0.77, 9.63]
Na 2010	4.3	0	28	6.6	0	28		Not estimable
Patel 2008	7	16	132	8	14	132	7.9%	-1.00 [-4.63, 2.63]
Subtotal (95% CI)			**203**			**203**	**24.7%**	**2.45 [-0.98, 5.87]**
Heterogeneity: $Tau^2 = 4.95$; $Chi^2 = 5.11$, df = 3 (P = 0.16); $I^2 = 41\%$								
Test for overall effect: Z = 1.40 (P = 0.16)								
2.3.2 Posterior approach								
Behensky 2007 Compensated	8	9	26	12	9	26	0.0%	-4.00 [-8.89, 0.89]
Behensky 2007 decompensated	7	6	10	27	8	10	0.0%	-20.00 [-26.20, -13.80]
Dobbs 2006 Hook group	18	12.0376	32	21	10.4771	32	6.2%	-3.00 [-8.53, 2.53]
Dobbs 2006 Pedicle Group	17	12.408	34	17.3	10.4771	34	6.2%	-0.30 [-5.76, 5.16]
Edwards 2004	18.2	13.9	26	19.3	15.61	26	4.3%	-1.10 [-9.13, 6.93]
Goshi 2004	10.3	11.59	6	13.17	9.04	6	2.6%	-2.87 [-14.63, 8.89]
McCance 1998 Compensated	9.2	0	47	8.7	0	47		Not estimable
McCance 1998 Decompensated group	13	0	20	27.2	0	20		Not estimable
Mladenov 2011 DVD group	17	11	17	8.2	6.4	17	5.7%	8.80 [2.75, 14.85]
Mladenov 2011 SRR group	11.2	5.5	13	13	6.1	13	7.1%	-1.80 [-6.26, 2.66]
Patel 2008	9	17	44	9	11	44	5.8%	0.00 [-5.98, 5.98]
Studer 2015	5.8	13.55	16	10.9	11.92	16	3.8%	-5.10 [-13.94, 3.74]
Tao 2011	14	8.2	36	5.1	7.9	36	7.8%	8.90 [5.18, 12.62]
Subtotal (95% CI)			**224**			**224**	**49.5%**	**0.91 [-2.89, 4.71]**
Heterogeneity: $Tau^2 = 22.87$; $Chi^2 = 28.81$, df = 8 (P = 0.0003); $I^2 = 72\%$								
Test for overall effect: Z = 0.47 (P = 0.64)								
2.3.3 Unspecified approach								
Chang 2010	14.5	14.3	32	17.7	13.6	32	5.1%	-3.20 [-10.04, 3.64]
Ilgenfritz 2013	19	19	24	12	16	24	3.3%	7.00 [-2.94, 16.94]
Takahashi 2011 EBS	21	20	93	14	15	93	6.6%	7.00 [1.92, 12.08]
Takahashi 2011 SAE	15	12	66	11	12	66	7.5%	4.00 [-0.09, 8.09]
Takahashi 2011 SBE	5	14	13	9	11	13	3.4%	-4.00 [-13.68, 5.68]
Subtotal (95% CI)			**228**			**228**	**25.8%**	**2.69 [-1.52, 6.90]**
Heterogeneity: $Tau^2 = 11.32$; $Chi^2 = 8.34$, df = 4 (P = 0.08); $I^2 = 52\%$								
Test for overall effect: Z = 1.25 (P = 0.21)								
Total (95% CI)			**655**			**655**	**100.0%**	**1.89 [-0.31, 4.09]**
Heterogeneity: $Tau^2 = 12.48$; $Chi^2 = 42.93$, df = 17 (P = 0.0005); $I^2 = 60\%$								
Test for overall effect: Z = 1.68 (P = 0.09)								
Test for subgroup differences: $Chi^2 = 0.49$, df = 2 (P = 0.78), $I^2 = 0\%$								

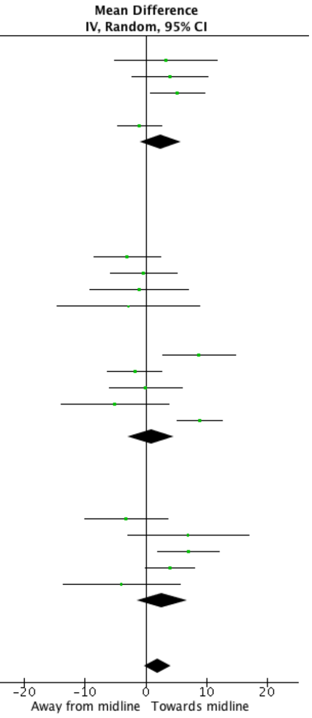


Figure 20: Effect of selective thoracic fusion on the coronal balance. All values are millimetres from midline.

Figure 20 outlines the effectiveness of selective thoracic fusion on the coronal balance. For all studies, the mean pre-operative values and post-operative values are listed in millimetres (mm) from midline. Those studies which were unable to be included for meta-analysis due to missing data are listed here but not included in patient numbers or calculated in weighted mean difference. Normally the coronal balance is listed as negative when it is to the left, and positive when shifted to the right. As the coronal balance changes with the surgery towards midline the change can either be positive (from left to right) or negative (right to left) however both can signify improvement. In view of changing the data to millimetres from midline, a positive change is indicating a shift towards midline, with a negative change indicating a shift away from midline. Studies which had compensated and decompensated groups were described here but were not included for meta-analysis as to not skew results.

Of those using the anterior approach, 5 studies with 231 patients included coronal balance data. Included for meta-analysis using the anterior approach was 4 studies involving 203 patients. There was no statistically significant change between the pre-operative and post-operative values (P=0.16), with the weighted mean difference of change of 2.45 millimetres closer to midline (95 CI: -0.98mm, 5.87mm). There was no significant heterogeneity between studies (P=0.16) with an I^2 of 41% signifying moderate study variance.

Nine studies involving 327 patients described the effect of selective thoracic fusion on coronal balance. Of those using the posterior approach were 9 treatment arms across 7 studies involving 224 patients. There was no statistically significant change (P=0.64) in the coronal balance following selective thoracic fusion with an improvement of 0.91mm towards the midline (95% CI: -2.90, 4.71). There was statistically significant heterogeneity (P<0.0003) and a I^2 of 72% indicates considerable study variance.

Dobbs et al.[79] did not provide standard deviations of the pre-operative or post-operative coronal balance but instead gave a P value. The standard deviation for the table was calculated using the P value and the formula given from the Cochrane Handbook for Systematic Reviews of Interventions.[97]

There were 3 studies (with 5 treatment arms) with 228 patients that did not specify what approach was used or did not isolate the approach groups that were eligible for inclusion in meta-analysis. The weighted mean difference was 2.69 millimetres towards the midline (95 CI:-1.52, 6.90) which was not statistically significant (p=0.21). There was no significant heterogeneity (P=0.08) with I^2 of 52% signifying substantial study variance.

Overall selective thoracic fusion was not statistically effective in changing the coronal balance of the patients. 12 studies and 18 treatment arms and 655 patients were included for meta-analysis which did not reach statistical significance (p=0.09). The weighted mean difference pre-operatively and post-operatively was 1.89mm towards the midline (95% CI: -0.31, 4.09). Across all studies there was significant heterogeneity (p<0.0005) and I^2 was 60% signifying considerable study variance.

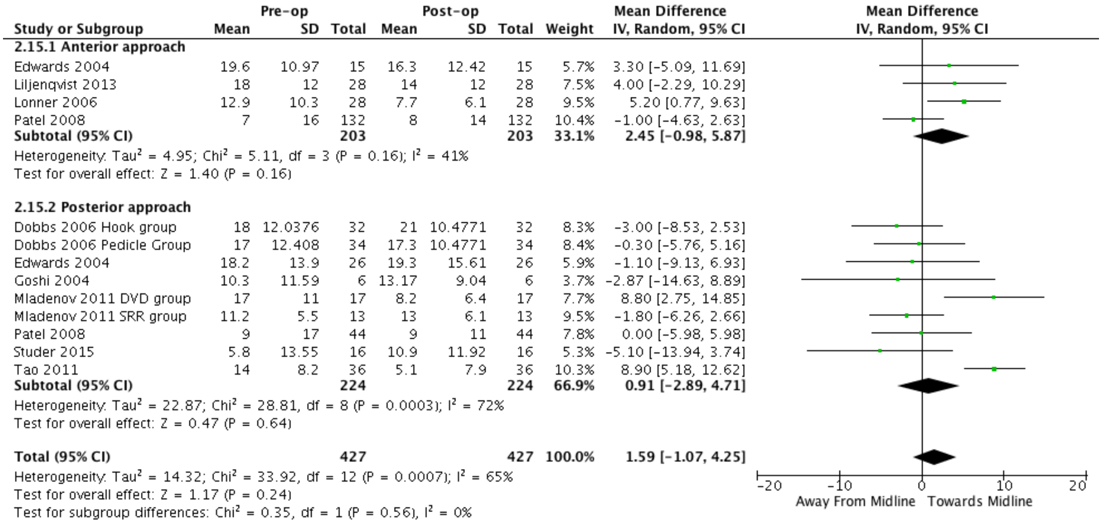


Figure 21: Effect of selective thoracic fusion on the coronal balance. All values are millimetres from midline. Sensitivity analysis excluding those treated with unspecified approach.

A sensitivity analysis was done with the unspecified approach groups excluded. The results can be seen in figure 21. This showed that the mean weighted difference was 1.59

millimetres closer to midline (95% CI: -1.07, 4.25) which was still not statistically significant. There was no significant change (p=0.56) between the anterior or posterior approaches which supports the results found in our anterior versus posterior approach meta-analysis.

Those studies not eligible for meta-analysis

Dobbs et al.[49], Engsberg et al.[75], Graham et al.[84], Haber et al.[33], Kamimura et al.[90], Kim et al.[91], Lenke et al.[76], Newton et al.[73], Potter et al.[34], Wong et al.[37], Yong et al.[85], Gotfryd et al.[80], Liu et al.[81], Morr et al.[82], Schulz et al.[94], Van Rhijn et al.[95], and Wang et al.[78], were not eligible for inclusion in meta-analysis or descriptive analysis as they did not report any pre-operative or post-operative coronal balance values. Frez et al.[88] and Demura et al.[83] reported the mean pre-operative coronal however no post-operative values were given and therefore it was unable to be included for meta-analysis.

Na et al.[93] reported coronal balance from 4.3mm to the left pre-operatively to 6.6mm to the right post-operatively with a change of 2.3mm to the left. However, no range, P value or standard deviation was reported for inclusion in meta-analysis.

Behensky et al.[48] and McCance et al.[56] were excluded due to coronal balance reported only in the compensated and decompensated subgroups. As the compensated group would have had significantly higher correction and the decompensated group would have had significantly worsening deformity it was excluded as to not create bias. They are described earlier in the compensated versus decompensated comparison.

Thoracic Kyphosis

Study or Subgroup	Pre-op Mean	Pre-op SD	Pre-op Total	Post-op Mean	Post-op SD	Post-op Total	Weight	Mean Difference IV, Random, 95% CI
2.4.1 Anterior approach								
Graham 2000	22	15	51	29	13	51	4.4%	-7.00 [-12.45, -1.55]
Kamimura 1999	15.7	8.7	17	20.8	11.2	17	3.7%	-5.10 [-11.84, 1.64]
Kim 2007	18.2	7.7	42	22.4	7.2	42	5.5%	-4.20 [-7.39, -1.01]
Liljenqvist 2013	28.5	13.2	28	32.3	8.4	28	4.2%	-3.80 [-9.60, 2.00]
Lonner 2006	25.8	8.4	28	31.1	6.84	28	5.1%	-5.30 [-9.31, -1.29]
Newton 2010	19.9	11.2	168	27.76	9.9	168	5.9%	-7.86 [-10.12, -5.60]
Wong 2004	17.3	12.37	10	22.2	4.66	10	3.1%	-4.90 [-13.09, 3.29]
Yong 2012	17.6	5.6	24	29.3	5.1	24	5.6%	-11.70 [-14.73, -8.67]
Subtotal (95% CI)			**368**			**368**	**37.6%**	**-6.74 [-8.91, -4.57]**
Heterogeneity: Tau² = 4.68; Chi² = 15.06, df = 7 (P = 0.04); I² = 54%								
Test for overall effect: Z = 6.09 (P < 0.00001)								
2.4.2 Posterior approach								
Behensky 2007 Compensated	27	11	26	25	6	26	4.7%	2.00 [-2.82, 6.82]
Behensky 2007 decompensated	36	16	10	31	8	10	2.2%	5.00 [-6.09, 16.09]
Gotfryd 2013 Group 1	23.5	11.8	23	26.1	8	23	4.2%	-2.60 [-8.43, 3.23]
Gotfryd 2013 Group 2	19.1	8.1	23	27.2	7.6	23	4.8%	-8.10 [-12.64, -3.56]
Liu 2014 Hybrid group	19.4	10.2	21	22.1	7.2	21	4.4%	-2.70 [-8.04, 2.64]
Liu 2014 Pedicle Screw	15.6	8.9	21	17.3	5.9	21	4.8%	-1.70 [-6.27, 2.87]
McCance 1998 Compensated	24	0	47	28	0	47		Not estimable
McCance 1998 Decompensated group	24	0	20	20	0	20		Not estimable
Mladenov 2011 DVD group	23.4	9	17	15.2	6.9	17	4.4%	8.20 [2.81, 13.59]
Mladenov 2011 SRR group	13.9	9.7	13	16.7	8.3	13	3.7%	-2.80 [-9.74, 4.14]
Morr 2015 CON Group	19.9	30.3107	20	16.9	12.3235	20	1.5%	3.00 [-11.34, 17.34]
Morr 2015 SKP Group	23	30.3107	20	19.4	12.3235	20	1.5%	3.60 [-10.74, 17.94]
Newton 2010	23	12	83	20.2	8.4	83	5.5%	2.80 [-0.35, 5.95]
Studer 2015	18.5	11.25	16	23.1	5.58	16	4.0%	-4.60 [-10.75, 1.55]
Tao 2011	20.53	4.83	36	23.42	5.08	36	5.9%	-2.89 [-5.18, -0.60]
Van Rhijn 2002	16.8	15.96	23	23.04	15.48	23	2.8%	-6.24 [-15.33, 2.85]
Wong 2004	15.875	8.97	8	21.25	8.03	8	3.1%	-5.38 [-13.72, 2.97]
Subtotal (95% CI)			**360**			**360**	**57.6%**	**-1.20 [-3.54, 1.15]**
Heterogeneity: Tau² = 11.12; Chi² = 36.56, df = 14 (P = 0.0009); I² = 62%								
Test for overall effect: Z = 1.00 (P = 0.32)								
2.4.3 Unspecified approach								
Ilgenfritz 2013	18	6	24	27	10	24	4.8%	-9.00 [-13.67, -4.33]
Subtotal (95% CI)			**24**			**24**	**4.8%**	**-9.00 [-13.67, -4.33]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 3.78 (P = 0.0002)								
Total (95% CI)			**752**			**752**	**100.0%**	**-3.54 [-5.57, -1.52]**
Heterogeneity: Tau² = 16.74; Chi² = 95.71, df = 23 (P < 0.00001); I² = 76%								
Test for overall effect: Z = 3.42 (P = 0.0006)								
Test for subgroup differences: Chi² = 15.23, df = 2 (P = 0.0005), I² = 86.9%								

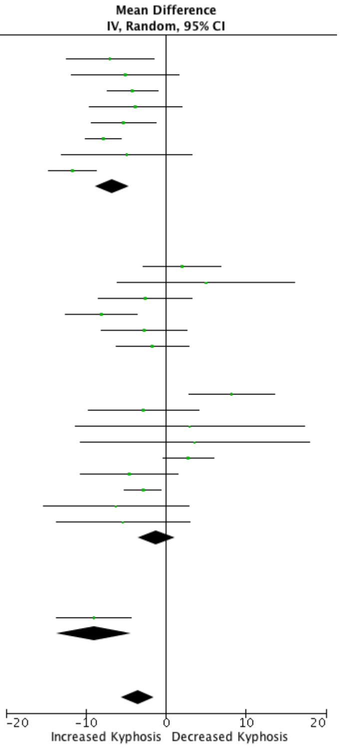


Figure 22: Effect of selective thoracic fusion on the thoracic kyphosis (º).

Figure 22 shows the effect of selective thoracic fusion on the thoracic kyphosis curve. For each study, the mean pre-operative value in degrees and the mean post-operative value in degrees are listed. Those studies which were unable to be included for meta-analysis due to missing data are listed here but not included in patient numbers or calculated in weighted mean difference.

Using the anterior approach there were 8 studies involving 368 patients. Overall there was a statistically significant effect of selective thoracic fusion using the anterior approach ($p<0.00001$) with the mean weighted difference was 6.74 degrees increase in kyphosis (95% CI: 4.57, 8.91). There was significant heterogeneity ($p=0.04$) with I^2 of 54% signifying substantial study variance.

A total of 11 studies using the posterior approach involving 427 patients reported outcomes of thoracic kyphosis with selective thoracic fusion. Of these studies, there were 15 treatment arms across 10 studies involving 360 patients. Overall there was no statistically significant effect ($p=0.32$) with mean weighted difference of 1.20 degrees increase in kyphosis (95% CI: -1.15, 3.54). There was significant heterogeneity ($p=0.0009$) and I^2 of 62% signifying substantial study variance. Morr et al.[82] did not provide standard deviations of the pre-operative and post-operative main thoracic curve but instead gave a P value. The standard deviation for the table was calculated using the P value and the formula given from the Cochrane Handbook for Systematic Reviews of Interventions.[97]

There was only 1 study (with 1 treatment arm) with 24 patients that did not specify what approach was used or did not isolate the approach groups that were eligible for inclusion in meta-analysis. The weighted mean difference was 9.00 degrees increase in kyphosis (95 CI:4.33, 13.67) which was statistically significant (p=0.0002). As there was only study in this subgroup, heterogeneity was unable to be commented on.

Overall selective thoracic fusion was statistically effective in changing the thoracic kyphosis in the patients. 17 studies and 24 treatment arms and 752 patients were included for meta-analysis which did reach statistical significance (p<0.0006). The weighted mean difference between pre-operatively and post-operatively was an increase in thoracic kyphosis of 3.54 degrees (95% CI: 1.52, 5.57). Across all studies there was significant heterogeneity (p<0.00001) and I^2 was 76% signifying considerable study variance.

Study or Subgroup	Pre-op Mean	Pre-op SD	Pre-op Total	Post-op Mean	Post-op SD	Post-op Total	Weight	Mean Difference IV, Random, 95% CI
2.16.1 Anterior approach								
Graham 2000	22	15	51	29	13	51	4.5%	-7.00 [-12.45, -1.55]
Kamimura 1999	15.7	8.7	17	20.8	11.2	17	3.9%	-5.10 [-11.84, 1.64]
Kim 2007	18.2	7.7	42	22.4	7.2	42	5.7%	-4.20 [-7.39, -1.01]
Liljenqvist 2013	28.5	13.2	28	32.3	8.4	28	4.3%	-3.80 [-9.60, 2.00]
Lonner 2006	25.8	8.4	28	31.1	6.84	28	5.3%	-5.30 [-9.31, -1.29]
Newton 2010	19.9	11.2	168	27.76	9.9	168	6.1%	-7.86 [-10.12, -5.60]
Wong 2004	17.3	12.37	10	22.2	4.66	10	3.2%	-4.90 [-13.09, 3.29]
Yong 2012	17.6	5.6	24	29.3	5.1	24	5.8%	-11.70 [-14.73, -8.67]
Subtotal (95% CI)			**368**			**368**	**38.8%**	**-6.74 [-8.91, -4.57]**
Heterogeneity: $Tau^2 = 4.68$; $Chi^2 = 15.06$, df = 7 (P = 0.04); $I^2 = 54\%$								
Test for overall effect: Z = 6.09 (P < 0.00001)								
2.16.2 Posterior approach								
Behensky 2007 Compensated	27	11	26	25	6	26	4.8%	2.00 [-2.82, 6.82]
Behensky 2007 decompensated	36	16	10	31	8	10	2.3%	5.00 [-6.09, 16.09]
Gotfryd 2013 Group 1	23.5	11.8	23	26.1	8	23	4.3%	-2.60 [-8.43, 3.23]
Gotfryd 2013 Group 2	19.1	8.1	23	27.2	7.6	23	5.0%	-8.10 [-12.64, -3.56]
Liu 2014 Hybrid group	19.4	10.2	21	22.1	7.2	21	4.6%	-2.70 [-8.04, 2.64]
Liu 2014 Pedicle Screw	15.6	8.9	21	17.3	5.9	21	5.0%	-1.70 [-6.27, 2.87]
Mladenov 2011 DVD group	23.4	9	17	15.2	6.9	17	4.5%	8.20 [2.81, 13.59]
Mladenov 2011 SRR group	13.9	9.7	13	16.7	8.3	13	3.8%	-2.80 [-9.74, 4.14]
Newton 2010	23	12	83	20.2	8.4	83	5.7%	2.80 [-0.35, 5.95]
Studer 2015	18.5	11.25	16	23.1	5.58	16	4.2%	-4.60 [-10.75, 1.55]
Tao 2011	20.53	4.83	36	23.42	5.08	36	6.1%	-2.89 [-5.18, -0.60]
Van Rhijn 2002	16.8	15.96	23	23.04	15.48	23	2.9%	-6.24 [-15.33, 2.85]
Wong 2004	15.875	8.97	8	21.25	8.03	8	3.2%	-5.38 [-13.72, 2.97]
Subtotal (95% CI)			**320**			**320**	**56.3%**	**-1.41 [-3.86, 1.04]**
Heterogeneity: $Tau^2 = 11.96$; $Chi^2 = 35.76$, df = 12 (P = 0.0004); $I^2 = 66\%$								
Test for overall effect: Z = 1.13 (P = 0.26)								
2.16.3 Unspecified approach								
Ilgenfritz 2013	18	6	24	27	10	24	4.9%	-9.00 [-13.67, -4.33]
Subtotal (95% CI)			**24**			**24**	**4.9%**	**-9.00 [-13.67, -4.33]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 3.78 (P = 0.0002)								
Total (95% CI)			**712**			**712**	**100.0%**	**-3.76 [-5.82, -1.69]**
Heterogeneity: $Tau^2 = 16.86$; $Chi^2 = 93.53$, df = 21 (P < 0.00001); $I^2 = 78\%$								
Test for overall effect: Z = 3.57 (P = 0.0004)								
Test for subgroup differences: $Chi^2 = 13.50$, df = 2 (P = 0.001), $I^2 = 85.2\%$								

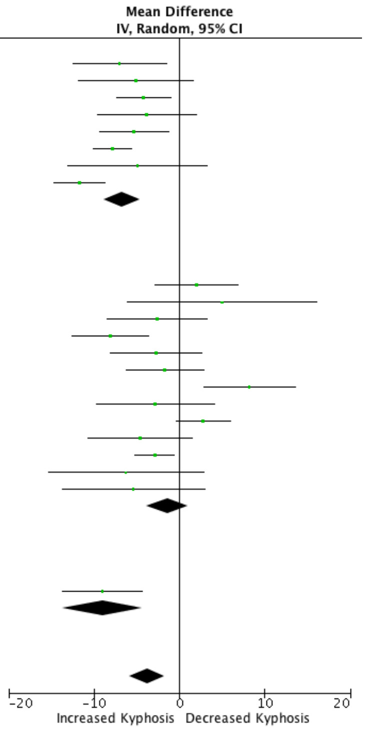


Figure 23: Effect of selective thoracic fusion on the thoracic kyphosis (°). Sensitivity analysis excluding Morr et al.[82]

Due to the large standard deviation calculated for the data from Morr et al.[82] a sensitivity analysis was done with the study excluded. The results were only minimally changed (weighted mean difference of 3.76 degree increase in kyphosis (95% CI: 1.69, 5.82) but still showed a statistically significant result (p=0.0004) and therefore it was included in our main meta-analysis and reported separately here. This sensitivity analysis can be seen in figure 23. This did show a significant difference between approaches with the posterior approach showing a lesser increase in thoracic kyphosis than either the anterior approach or unspecified approach.

Study or Subgroup	Pre-op Mean	Pre-op SD	Pre-op Total	Post-op Mean	Post-op SD	Post-op Total	Weight	Mean Difference IV, Random, 95% CI
2.17.1 Anterior approach								
Graham 2000	22	15	51	29	13	51	4.6%	-7.00 [-12.45, -1.55]
Kamimura 1999	15.7	8.7	17	20.8	11.2	17	3.9%	-5.10 [-11.84, 1.64]
Kim 2007	18.2	7.7	42	22.4	7.2	42	5.8%	-4.20 [-7.39, -1.01]
Liljenqvist 2013	28.5	13.2	28	32.3	8.4	28	4.4%	-3.80 [-9.60, 2.00]
Lonner 2006	25.8	8.4	28	31.1	6.84	28	5.4%	-5.30 [-9.31, -1.29]
Newton 2010	19.9	11.2	168	27.76	9.9	168	6.2%	-7.86 [-10.12, -5.60]
Wong 2004	17.3	12.37	10	22.2	4.66	10	3.3%	-4.90 [-13.09, 3.29]
Yong 2012	17.6	5.6	24	29.3	5.1	24	5.9%	-11.70 [-14.73, -8.67]
Subtotal (95% CI)			**368**			**368**	**39.5%**	**-6.74 [-8.91, -4.57]**
Heterogeneity: Tau² = 4.68; Chi² = 15.06, df = 7 (P = 0.04); I² = 54%								
Test for overall effect: Z = 6.09 (P < 0.00001)								
2.17.2 Posterior approach								
Behensky 2007 Compensated	27	11	26	25	6	26	4.9%	2.00 [-2.82, 6.82]
Behensky 2007 decompensated	36	16	10	31	8	10	2.3%	5.00 [-6.09, 16.09]
Gotfryd 2013 Group 1	23.5	11.8	23	26.1	8	23	4.4%	-2.60 [-8.43, 3.23]
Gotfryd 2013 Group 2	19.1	8.1	23	27.2	7.6	23	5.1%	-8.10 [-12.64, -3.56]
Liu 2014 Hybrid group	19.4	10.2	21	22.1	7.2	21	4.7%	-2.70 [-8.04, 2.64]
Liu 2014 Pedicle Screw	15.6	8.9	21	17.3	5.9	21	5.1%	-1.70 [-6.27, 2.87]
Mladenov 2011 DVD group	23.4	9	17	15.2	6.9	17	4.6%	8.20 [2.81, 13.59]
Mladenov 2011 SRR group	13.9	9.7	13	16.7	8.3	13	3.8%	-2.80 [-9.74, 4.14]
Morr 2015 CON Group	19.9	30.3107	20	16.9	12.3235	20	1.6%	3.00 [-11.34, 17.34]
Morr 2015 SKP Group	23	30.3107	20	19.4	12.3235	20	1.6%	3.60 [-10.74, 17.94]
Newton 2010	23	12	83	20.2	8.4	83	5.8%	2.80 [-0.35, 5.95]
Studer 2015	18.5	11.25	16	23.1	5.58	16	4.2%	-4.60 [-10.75, 1.55]
Tao 2011	20.53	4.83	36	23.42	5.08	36	6.2%	-2.89 [-5.18, -0.60]
Van Rhijn 2002	16.8	15.96	23	23.04	15.48	23	2.9%	-6.24 [-15.33, 2.85]
Wong 2004	15.875	8.97	8	21.25	8.03	8	3.2%	-5.38 [-13.72, 2.97]
Subtotal (95% CI)			**360**			**360**	**60.5%**	**-1.20 [-3.54, 1.15]**
Heterogeneity: Tau² = 11.12; Chi² = 36.56, df = 14 (P = 0.0009); I² = 62%								
Test for overall effect: Z = 1.00 (P = 0.32)								
Total (95% CI)			**728**			**728**	**100.0%**	**-3.27 [-5.35, -1.19]**
Heterogeneity: Tau² = 16.76; Chi² = 91.67, df = 22 (P < 0.00001); I² = 76%								
Test for overall effect: Z = 3.08 (P = 0.002)								
Test for subgroup differences: Chi² = 11.57, df = 1 (P = 0.0007), I² = 91.4%								

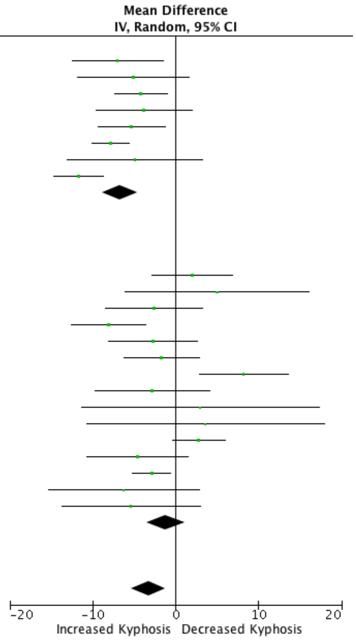


Figure 24: Effect of selective thoracic fusion on the thoracic kyphosis (º). Sensitivity analysis excluding those treated with an unspecified approach.

Further sensitivity analysis was done with the unspecified approach groups excluded. The results can be seen in figure 24. This showed that the significant (p=0.02) mean weighted difference was 3.27 degree increase in kyphosis (95% CI: 1.19, 5.35). This did show a significant difference between approaches with the posterior approach showing no statistically significant change in thoracic kyphosis (p=0.32) compared to a significant change in kyphosis with the anterior approach (p<0.0001). This is different to our anterior versus posterior approach meta-analysis but does contain more studies, and so is likely to be a significant result.

Those studies not eligible for meta-analysis

Both papers by Dobbs et al.[49,79], Demura et al.[83], Edwards et al.[22], Engsberg et al.[75], Goshi et al.[19], Haber et al.[33], Lenke et al.[76], Na et al.[93], Patel et al.[77], Potter et al.[34], Schulz et al.[94], Takahashi et al.[47] and Wang et al.[78], were not eligible for inclusion in meta-analysis or descriptive analysis as they did not report any pre-operative or post-operative thoracic kyphosis values.

Chang et al.[86] and Frez and colleagues[88] reported a pre-operative thoracic kyphosis however did not give any post-operative values and therefore was unable to be included for meta-analysis.

McCance et al.[56] reported thoracic kyphosis values of 24 degrees pre-operatively to 28 degrees post-operatively with an kyphotic increase of 4 degrees in their compensated group and values of 24 degrees reduced to 20 degrees with a decrease of kyphosis by 4 degrees in their decompensated group. However, no range, P value or standard deviation was reported for inclusion in meta-analysis.

Lumbar Lordosis

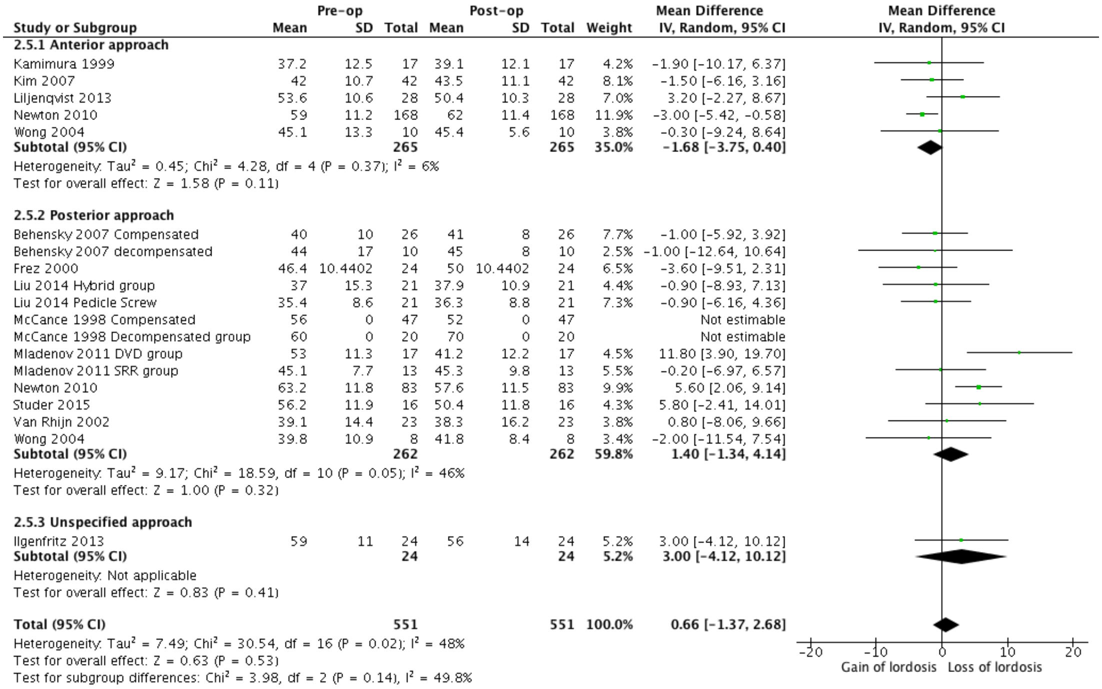


Figure 25: Effect of selective thoracic fusion on the lumbar lordosis (°).

Figure 25 shows the effect of selective thoracic fusion on the thoracic kyphosis curve. For each study, the mean pre-operative value in degrees and the mean post-operative value in degrees are listed. Those studies which were unable to be included for meta-analysis due to missing data are listed here but are not included in patient numbers or calculated in weighted mean difference.

Using the anterior approach there were 6 treatment arms across 6 studies involving 280 patients, of which 5 studies and 265 patients were eligible for inclusion for meta-analysis. Overall there was no statistically significant effect of selective thoracic fusion using the anterior approach (p=0.11) with the mean weighted difference was -1.68 degrees decrease in lordosis (1.68 degree increase) (95% CI: -3.75, 0.41). There was no significant heterogeneity (P=0.37) with I^2 of 6% signifying non-important study variance.

Of the studies using the posterior approach there was 14 treatment arms across 10 studies involving 355 patients, of which 8 studies, 11 treatment arms and 262 patients were eligible for inclusion for meta-analysis. Overall there was no statistically significant effect (p=0.32) with mean weighted difference of 1.40 degrees decrease in lordosis (95% CI: -1.34, 4.14). There was significant heterogeneity (p=0.05) and I^2 of 46% signifying moderate study variance. Frez et al.[88] did not provide standard deviations of the pre-operative and post-operative main thoracic curve but instead gave a P value. The standard deviation for the table was calculated using the P value and the formula given from the Cochrane Handbook for Systematic Reviews of Interventions.[97]

There was 1 study (with 1 treatment arm) with 24 patients that did not specify what approach was used or did not isolate the approach groups that were eligible for inclusion in meta-analysis. The weighted mean difference was 3.00 degrees decrease in lordosis (95 CI: -4.12, 10.12) which was not statistically significant (p=0.41). As there was only study in this subgroup, heterogeneity was unable to be commented on.

Overall selective thoracic fusion was statistically effective in maintaining the lumbar lordosis in the patients. 12 studies and 17 treatment arms and 551 patients were included for meta-analysis which did not reach statistical significance (p=0.53). The weighted mean difference between pre-operatively and post-operatively was a decrease in lumbar lordosis of 0.66 degrees (95% CI: -1.37, 2.68). Across all studies there was significant heterogeneity (p=0.02) and I^2 was 48% signifying moderate study variance.

	Pre-op			Post-op				Mean Difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**
2.18.1 Anterior approach								
Kamimura 1999	37.2	12.5	17	39.1	12.1	17	4.5%	-1.90 [-10.17, 6.37]
Kim 2007	42	10.7	42	43.5	11.1	42	8.5%	-1.50 [-6.16, 3.16]
Liljenqvist 2013	53.6	10.6	28	50.4	10.3	28	7.4%	3.20 [-2.27, 8.67]
Newton 2010	59	11.2	168	62	11.4	168	12.2%	-3.00 [-5.42, -0.58]
Wong 2004	45.1	13.3	10	45.4	5.6	10	4.0%	-0.30 [-9.24, 8.64]
Subtotal (95% CI)			**265**			**265**	**36.7%**	**-1.68 [-3.75, 0.40]**
Heterogeneity: $Tau^2 = 0.45$; $Chi^2 = 4.28$, df = 4 (P = 0.37); $I^2 = 6\%$								
Test for overall effect: Z = 1.58 (P = 0.11)								
2.18.2 Posterior approach								
Behensky 2007 Compensated	40	10	26	41	8	26	8.1%	-1.00 [-5.92, 3.92]
Behensky 2007 decompensated	44	17	10	45	8	10	2.7%	-1.00 [-12.64, 10.64]
Frez 2000	46.4	10.4402	24	50	10.4402	24	6.8%	-3.60 [-9.51, 2.31]
Liu 2014 Hybrid group	37	15.3	21	37.9	10.9	21	4.7%	-0.90 [-8.93, 7.13]
Liu 2014 Pedicle Screw	35.4	8.6	21	36.3	8.8	21	7.7%	-0.90 [-6.16, 4.36]
Mladenov 2011 DVD group	53	11.3	17	41.2	12.2	17	4.8%	11.80 [3.90, 19.70]
Mladenov 2011 SRR group	45.1	7.7	13	45.3	9.8	13	5.8%	-0.20 [-6.97, 6.57]
Newton 2010	63.2	11.8	83	57.6	11.5	83	10.3%	5.60 [2.06, 9.14]
Studer 2015	56.2	11.9	16	50.4	11.8	16	4.6%	5.80 [-2.41, 14.01]
Van Rhijn 2002	39.1	14.4	23	38.3	16.2	23	4.1%	0.80 [-8.06, 9.66]
Wong 2004	39.8	10.9	8	41.8	8.4	8	3.7%	-2.00 [-11.54, 7.54]
Subtotal (95% CI)			**262**			**262**	**63.3%**	**1.40 [-1.34, 4.14]**
Heterogeneity: $Tau^2 = 9.17$; $Chi^2 = 18.59$, df = 10 (P = 0.05); $I^2 = 46\%$								
Test for overall effect: Z = 1.00 (P = 0.32)								
Total (95% CI)			**527**			**527**	**100.0%**	**0.54 [-1.58, 2.65]**
Heterogeneity: $Tau^2 = 8.01$; $Chi^2 = 29.88$, df = 15 (P = 0.01); $I^2 = 50\%$								
Test for overall effect: Z = 0.50 (P = 0.62)								
Test for subgroup differences: $Chi^2 = 3.07$, df = 1 (P = 0.08), $I^2 = 67.4\%$								

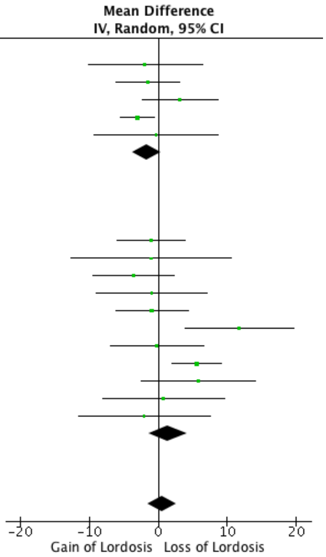


Figure 26: Effect of selective thoracic fusion on the lumbar lordosis (º). Sensitivity analysis excluding those treated with an unspecified approach.

Further analysis was done between those with unspecified approach excluded to see the effect of the anterior vs posterior approach. Overall there was a non-significant change in lumbar lordosis with surgery (p=0.62) and a non-significant difference between approaches (0.08). The weighted mean difference was only minimally changes with a mean difference of 0.54 degree loss of lordosis (95% CI: -1.58, 2.65).

Those studies not eligible for meta-analysis

Dobbs et al.[49,79], Demura et al.[83], , Engsberg et al.[75], Goshi et al.[19], Gotfryd et al.[80], Graham et al.[84], Haber et al.[33], Lenke et al.[76], Lonner et al.[28], Morr et al.[82], Na et al.[93], Patel et al.[77], Potter et al.[34], Schulz et al.[94], Tao et al.[87] ,Takahashi et al.[47], Wang et al.[78] and Yong et al.[85] were not eligible for inclusion in meta-analysis or descriptive analysis as they did not report any pre-operative or post-operative lumbar lordosis values.

Chang et al.[86] reported a pre-operative lumbar lordosis of 64.5 (+/-13.9) degrees however did not give any post-operative values and therefore was unable to be included for meta-analysis. Edwards et al.[22] reported a change in lordosis of 7 degrees in their anterior group (from 57 to 64 degrees) and change of 2 degrees in the posterior group (from 64 to 66 degrees). However, no range, P value, or standard deviation was reported for inclusion in meta-analysis. McCance et al.[56] reported lumbar lordosis values of 56 degrees pre-operatively to 52 degrees post-operatively with a lordotic decrease of 4 degrees in their compensated group and values of 60 degrees increased to 70 degrees with an increase of lordosis by 10 degrees in their decompensated group. However, no range, P value or standard deviation was reported for inclusion in meta-analysis.

Sagittal Balance

Study or Subgroup	Pre-op Mean	Pre-op SD	Pre-op Total	Post-op Mean	Post-op SD	Post-op Total	Weight	Mean Difference IV, Random, 95% CI
2.6.1 Anterior approach								
Kim 2007	13.9	7.7	42	9.9	23.8	42	12.9%	4.00 [-3.57, 11.57]
Subtotal (95% CI)			**42**			**42**	**12.9%**	**4.00 [-3.57, 11.57]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 1.04 (P = 0.30)								
2.6.2 Posterior approach								
Behensky 2007 Compensated	5	7.1867	26	12	11.7633	26	14.4%	-7.00 [-12.30, -1.70]
Behensky 2007 decompensated	7	4.457	10	16	6.1997	10	14.8%	-9.00 [-13.73, -4.27]
Liu 2014 Hybrid group	14.6	15	21	15	14.4	21	12.0%	-0.40 [-9.29, 8.49]
Liu 2014 Pedicle Screw	19.1	22.6	21	19.2	13.2	21	10.3%	-0.10 [-11.29, 11.09]
McCance 1998 Compensated	26	0	47	28	0	47		Not estimable
McCance 1998 Decompensated group	19	0	20	41	0	20		Not estimable
Mladenov 2011 DVD group	30.5	20.4	17	11.8	8.4	17	10.8%	18.70 [8.21, 29.19]
Mladenov 2011 SRR group	24.5	16.9	13	16.3	10.8	13	10.5%	8.20 [-2.70, 19.10]
Studer 2015	26.85	25.9	16	26.6	32.03	16	5.7%	0.25 [-19.93, 20.43]
Subtotal (95% CI)			**124**			**124**	**78.5%**	**0.77 [-6.40, 7.93]**
Heterogeneity: $Tau^2 = 67.33$; $Chi^2 = 29.46$, df = 6 ($P < 0.0001$); $I^2 = 80\%$								
Test for overall effect: Z = 0.21 (P = 0.83)								
2.6.3 Unspecified approach								
Chang 2010	12.2	29	32	20.1	28.2	32	8.6%	-7.90 [-21.92, 6.12]
Subtotal (95% CI)			**32**			**32**	**8.6%**	**-7.90 [-21.92, 6.12]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 1.10 (P = 0.27)								
Total (95% CI)			**198**			**198**	**100.0%**	**0.35 [-5.62, 6.31]**
Heterogeneity: $Tau^2 = 56.84$; $Chi^2 = 33.26$, df = 8 ($P < 0.0001$); $I^2 = 76\%$								
Test for overall effect: Z = 0.11 (P = 0.91)								
Test for subgroup differences: $Chi^2 = 2.16$, df = 2 (P = 0.34), $I^2 = 7.3\%$								

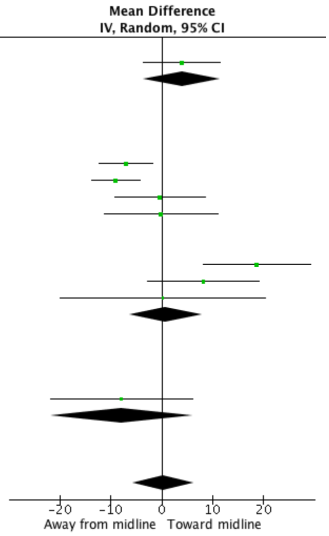


Figure 27: Effect of selective thoracic fusion on the sagittal balance. All values are millimetres from midline.

Figure 27 outlines the effectiveness of selective thoracic fusion on the sagittal balance. For all studies, the mean pre-operative values and post-operative values are listed in millimetres (mm) from midline. Those studies which were unable to be included for meta-analysis due to missing data are listed here but not included in patient numbers or calculated in weighted mean difference. Normally the sagittal balance is listed as negative when it is to the posterior of the midline, and positive when shifted anteriorly. As the sagittal balance changes with the surgery towards midline the change can either be positive (from posterior to anterior) or negative (anterior to posterior) however both can signify improvement. In view of changing the data to millimetres from midline, a positive change is indicating a shift towards midline, with a negative change indicating a shift away from midline.

Included for meta-analysis using the anterior approach was 1 study involving 42 patients. There was no statistically significant change between the pre-operative and post-operative values (P=0.30), with the weighted mean difference of change of 4mm towards midline (95 CI: -3.57, 11.57). As there was only one study in this subgroup, heterogeneity was unable to be commented on.

Of those using the posterior approach were 5 studies and 191 patients that reported sagittal balance data however only 7 treatment arms across 4 studies involving 124 patients were eligible for inclusion for meta-analysis. There was a no statistically significant change (P=0.83) in the sagittal balance following selective thoracic fusion with weighted mean difference of 0.77mm towards midline (95% CI: -6.40, 7.93). There was statistically significant heterogeneity (P<0.0001) and an I^2 of 80% indicates considerable study variance. Behensky et al.[48] did not provide standard deviations of the pre-operative and post-operative main thoracic curve but instead gave a P value. The standard deviation for the table was calculated using the P value and the formula given from the Cochrane Handbook for Systematic Reviews of Interventions.[97]

There was 1 study[86] (with 1 treatment arm) with 32 patients that did not specify what approach was used or did not isolate the approach groups that were eligible for inclusion in meta-analysis. The weighted mean difference of the sagittal balance was -7.90mm towards midline (7.9mm away from midline) (95 CI: -21.92, 6.12) which was not statistically significant (p=0.27). As there was only study in this subgroup, heterogeneity was unable to be commented on.

Overall selective thoracic fusion was not statistically effective in changing the sagittal balance of the patients. 6 studies and 9 treatment arms and 198 patients were included for meta-analysis which did not reach statistical significance (p=0.91). The weighted mean difference between pre-operatively and post-operatively was 0.35mm towards midline (95% CI: -5.62, 6.31). Across all studies there was significant heterogeneity (p<0.0001) and I^2 was 76% signifying considerable study variance.

Study or Subgroup	Pre-op Mean	Pre-op SD	Pre-op Total	Post-op Mean	Post-op SD	Post-op Total	Weight	Mean Difference IV, Random, 95% CI
2.19.1 Anterior approach								
Kim 2007	13.9	7.7	42	9.9	23.8	42	14.1%	4.00 [-3.57, 11.57]
Subtotal (95% CI)			**42**			**42**	**14.1%**	**4.00 [-3.57, 11.57]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 1.04 (P = 0.30)								
2.19.2 Posterior approach								
Behensky 2007 Compensated	5	7.1867	26	12	11.7633	26	15.6%	-7.00 [-12.30, -1.70]
Behensky 2007 decompensated	7	4.457	10	16	6.1997	10	16.0%	-9.00 [-13.73, -4.27]
Liu 2014 Hybrid group	14.6	15	21	15	14.4	21	13.1%	-0.40 [-9.29, 8.49]
Liu 2014 Pedicle Screw	19.1	22.6	21	19.2	13.2	21	11.4%	-0.10 [-11.29, 11.09]
Mladenov 2011 DVD group	30.5	20.4	17	11.8	8.4	17	11.9%	18.70 [8.21, 29.19]
Mladenov 2011 SRR group	24.5	16.9	13	16.3	10.8	13	11.6%	8.20 [-2.70, 19.10]
Studer 2015	26.85	25.9	16	26.6	32.03	16	6.4%	0.25 [-19.93, 20.43]
Subtotal (95% CI)			**124**			**124**	**85.9%**	**0.77 [-6.40, 7.93]**
Heterogeneity: Tau² = 67.33; Chi² = 29.46, df = 6 (P < 0.0001); I² = 80%								
Test for overall effect: Z = 0.21 (P = 0.83)								
Total (95% CI)			**166**			**166**	**100.0%**	**1.16 [-5.24, 7.56]**
Heterogeneity: Tau² = 60.98; Chi² = 32.71, df = 7 (P < 0.0001); I² = 79%								
Test for overall effect: Z = 0.36 (P = 0.72)								
Test for subgroup differences: Chi² = 0.37, df = 1 (P = 0.54), I² = 0%								

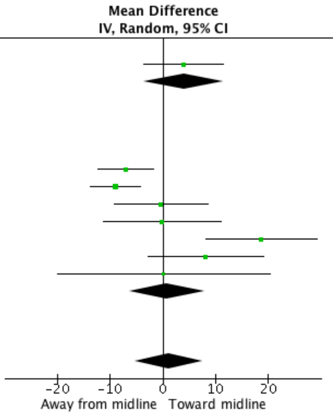


Figure 28: Effect of selective thoracic fusion on the coronal balance. All values are millimetres from midline. Sensitivity analysis excluding those treated with unspecified approach.

A sensitivity analysis was done with the unspecified approach groups excluded. The results can be seen in figure 28. This showed that the mean weighted difference was 1.16 millimetres closer to midline (95% CI: -5.24, 7.56) which was still not statistically significant. There was no significant change (p=0.54) between the anterior or posterior approaches which supports the results found in our anterior versus posterior approach meta-analysis.

Those studies not eligible for meta-analysis

Demura et al.[83], Dobbs et al.[49,79], Edwards et al.[22], Engsberg et al.[75], Frez et al.[88], Goshi et al.[19], Gotfryd et al.[80], Graham et al.[84], Haber et al.[33], Ilgenfritz et al.[89], Kamimura et al.[90], Lenke et al.[76], Liljenqvist et al.[92], Lonner et al.[28], Morr et al.[82], Na et al.[93], Newton et al.[73], Patel et al.[77], Potter et al.[34], Schulz et al.[94], Takahashi et al.[47], Tao et al.[87], Van Rhijn et al.[95], Wang et al.[78], Wong et al.[37], Yong et al.[85] were not eligible for inclusion in meta-analysis or descriptive analysis as they did not report any pre-operative or post-operative sagittal balance values.

McCance et al.[56] reported sagittal balance values of 26mm posterior pre-operatively to 28mm posterior post-operatively with a sagittal balance shift of 2mm posteriorly in their compensated group and values of 19mm posterior increased to 41mm posterior with an increase of sagittal imbalance by 21mm posteriorly in their decompensated group. However, no range, P value or standard deviation was reported for inclusion in meta-analysis

Thoracic apical vertebral rotation

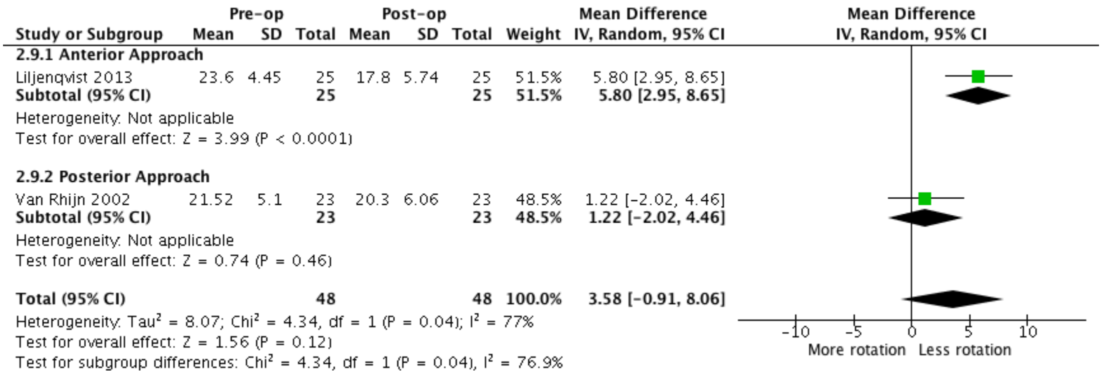


Figure 29: Effect of selective thoracic fusion on the thoracic apical vertebral rotation measured by the Perdriolle method (°).

Thoracic apical vertebral rotation (AVR-T) is reported in 3 studies involving 64 patients. Of these three, one study[74] measured AVR-T via the Nash-Moe method and the other two report values using the Perdriolle method. Meta-analysis was performed on the two studies using the Perdriolle method in 48 patients. Overall there was a mean weighted difference of 3.58 degrees (95% CI: -0.91, 8.06) between pre-operative and post-operative values. This did not reach statistical significance (p=0.12). There was significant heterogeneity (p=0.04) and I^2 was 77% which signifies substantial study variance. Interestingly the only study[92] using the anterior approach found a statistically significant change in rotation, where as the only study[95] using the posterior approach found a non-statistically significant change in rotation following surgery. This was noted to be statistically significant between approaches (p=0.04) however with the low level of evidence available the clinical significance is not truly known.

Those studies not eligible for meta-analysis

Studer et al.[74] reported a mean AVR-T score pre-operatively of 2.13 (+/-0.34) which reduced to 1.19 (+/- 0.75) post-operatively. This represents a correction of 0.9 (+/-0.68). However, no other studies used the Nash-Moe method of measuring rotation and therefore this study was unable to be included for meta-analysis.

Kamimura et al.[90] reported the pre-operative AVR-T however did not report any post-operative values and therefore was not eligible for inclusion.

Behensky et al.[48], Chang et al.[86], Demura et al.[83], Dobbs et al.[49,79], Edwards et al.[22], Engsberg et al.[75], Frez et al.[88], Goshi et al.[19], Gotfryd et al.[80], Graham et al.[84], Haber et al.[33], Ilgenfritz et al.[89], Kim et al.[91], Lenke et al.[76], Liu et al.[81], Lonner et al.[28], McCance et al.[56], Mladenov et al.[9], Morr et al.[82], Na et al.[93], Newton et al.[73], Patel et al.[77], Potter et al.[34], Schulz et al.[94], Takahashi et al.[47], Tao et al.[87], Wang et al.[78], Wong et al.[37], Yong et al.[85] were not eligible for inclusion in meta-analysis or descriptive analysis as they did not report any pre-operative or post-operative thoracic apical vertebral rotation values.

Lumbar apical vertebral rotation

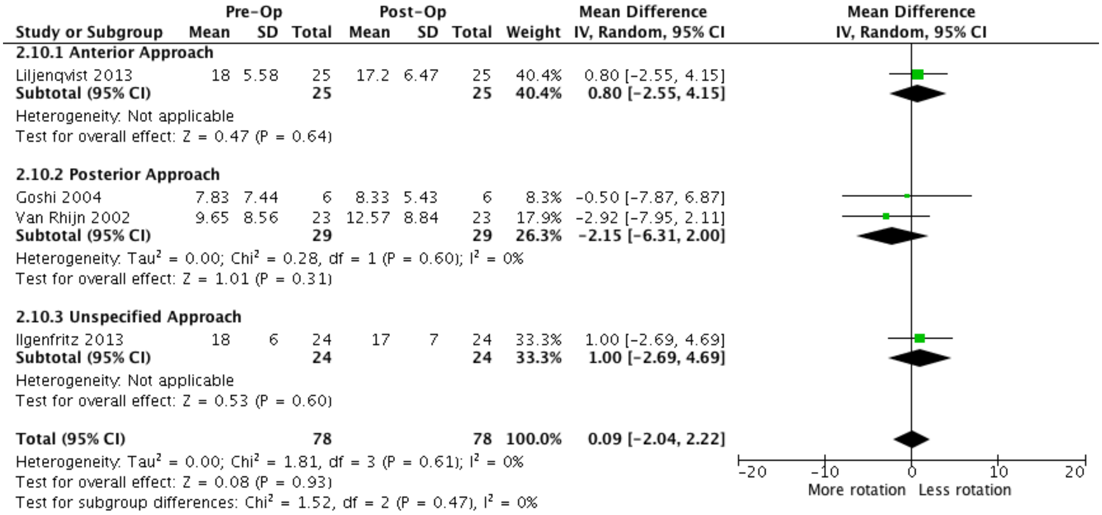


Figure 30: Effect of selective thoracic fusion on the lumbar apical vertebral rotation measured by the Perdriolle method (°).

Lumbar apical vertebral rotation (AVR-L) is reported in 5 studies involving 94 patients. Of these five, one study[74] measured AVR-L via the Nash-Moe method and the other four report values using the Perdriolle method. Meta-analysis was performed on the four studies using the Perdriolle method in 78 patients. Overall there was a mean weighted difference of 0.09 degrees (95% CI: -2.04, 2.22) between pre-operative and post-operative values. This did not reach statistical significance (p=0.93). There was no significant heterogeneity (p=0.61) and I^2 was 0% which signifies no important study variance. None of the approaches in isolation produced a statistically significant change in lumbar apical vertebral rotation. A sensitivity analysis done excluding any studies done with unspecified approach showed no statistically significant difference between the anterior and posterior approaches (p=0.28) and can be seen in figure 31.

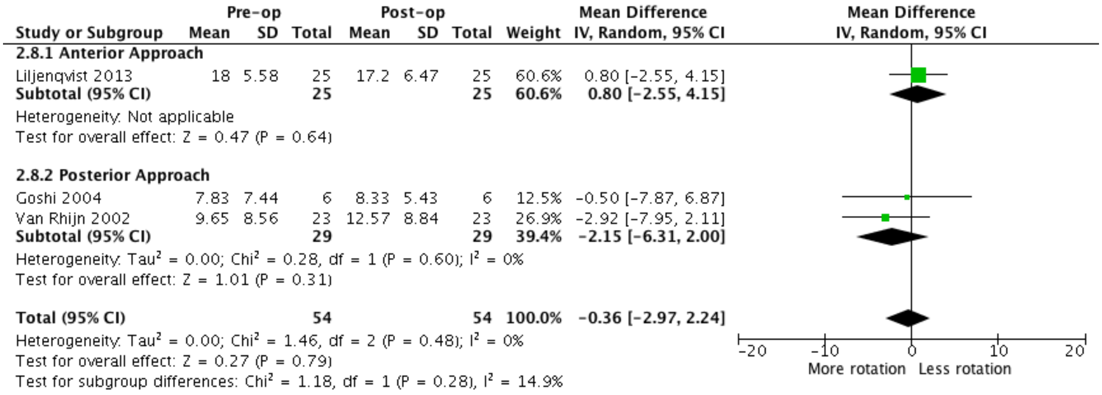


Figure 31: Effect of selective thoracic fusion on the lumbar apical vertebral rotation measured by the Perdriolle method (º). Sensitivity analysis excluding those treated with unspecified approach.

Those studies not eligible for meta-analysis

Studer et al.[74] reported a mean AVR-L pre-operatively of 1.38 (+/- 0.5) which reduced to 1.31 (+/-0.48) post-operatively. This represents a correction of only 0.1 (+/- 0.57). However, no other studies used the Nash-Moe method of measuring rotation and therefore this study was unable to be included for meta-analysis.

Chang et al.[86] reported the pre-operative AVR-L however did not report any post-operative values and therefore was not eligible for inclusion.

Behensky et al.[48], Demura et al.[83], Dobbs et al.[49,79], Edwards et al.[22], Engsberg et al.[75], Frez et al.[88], Goshi et al.[19], Gotfryd et al.[80], Graham et al.[84], Haber et al.[33], Ilgenfritz et al.[89], Kamimura et al.[90], Kim et al.[91], Lenke et al.[76], Liu et al.[81], Lonner et al.[28], McCance et al.[56], Mladenov et al.[9], Morr et al.[82], Na et al.[93], Newton et al.[73], Patel et al.[77], Potter et al.[34], Schulz et al.[94], Takahashi et al.[47], Tao et al.[87], Wang et al.[78], Wong et al.[37], Yong et al.[85] were not eligible for inclusion in meta-analysis or descriptive analysis as they did not report any pre-operative or post-operative lumbar apical vertebral rotation values.

Quality of life

Six studies reported outcomes of quality of life surveys for their patients. There was heterogeneity of the surveys used however all used different variations of the Scoliosis Research Society Questionnaires, therefore involving very similar questions. 2 studies[28,82] (3 treatment arms) used the SRS-22, 2 studies[22,85] (3 treatment arms) used the SRS-24 and 2 studies[33,86] used the SRS-30. The SRS-30 includes both the questions of the SRS-22 and the SRS-24. Between the SRS-22 and SRS-24 there are 16 questions that were the same. Individual question results were not reported, therefore where possible categories were reported and analysed.

Of the 4 studies reporting SRS-22 and SRS-24 results, all 6 treatment arms reported on all 6 modalities of the SRS-22 in 68 patients and 5 modalities of the SRS-24 in 65 patients. The two studies reporting SRS-30 results, only one study reported all modalities with Haber et al.[33] only reporting the total score of their 6 patients who returned questionnaire results. The mean scores of all the studies can be seen in table 4.

Survey	Study	Patients	Function	Pain	Self-Image	Mental Health	Satisfaction	Total Score
SRS-22	Lonner 2006[28]	28	4.8	5	5	5	5	4.9
	Morr 2005[82] (Con grp)	20	4	4.3	4.2	4.9	4.5	4.4
	Morr 2005[82] (Skp grp)	20	4.1	4.2	4.2	4.7	4.4	4.5
SRS-24	Edwards 2004[22] (Anterior group)	15	4.0	4.1	4.6	-	4	4.0
	Edwards 2004[22] (Posterior group)	26	4.0	4.0	4.4	-	4.3	3.9
	Yong 2012[85]	24	3.8	4.1	3.4	-	4.1	3.8
SRS-30	Haber 2012[33]	6	-	-	-	-	-	3.7
	Chang 2010[86]	23	4.0	3.7	3.8	3.6	4.2	3.9

Table 4: Quality of Life Survey's Results of Selective Thoracic Fusion

Pulmonary Function

Only two studies both utilizing the anterior approach included pulmonary function tests as outcomes. Lonner and colleagues[28] described a transient decrease in both FVC and FEV_1 following selective thoracic fusion. This was described as a statistically significant decrease ($p<0.001$). Both values returned to baseline at final follow-up (mean of 31 months). Graham et al.[84] in their prospective study described a similar decrease in their spirometry values 3 months post-operatively. FVC dropped from 3.06 (+/- 0.6) pre-operatively to 2.46 (+/- 0.5) at 3 months. FEV_1 dropped from 2.61 (+/-0.5) pre-operatively to 2.22 (+/-0.4) at 3 months. TLC dropped from 4.02 (+/-0.8) pre-operatively to 3.50 (+/-0.5) at 3 months. At 2 years the values of the FVC, FEV1 and TLC have all returned to baseline (supported by their non-significant p values). The decrease in values in the early post-operative period can be seen in table 5.

Study	FVC	FEV_1	TLC	
Graham 2000[84]	19%	15%	13%	$p<0.05$
Lonner 2006[28]	28%	17%	-	$p<0.01$

Table 5: Early post-operative decrease in pulmonary function

Complications

15 studies reported on complications in selective thoracic fusion.

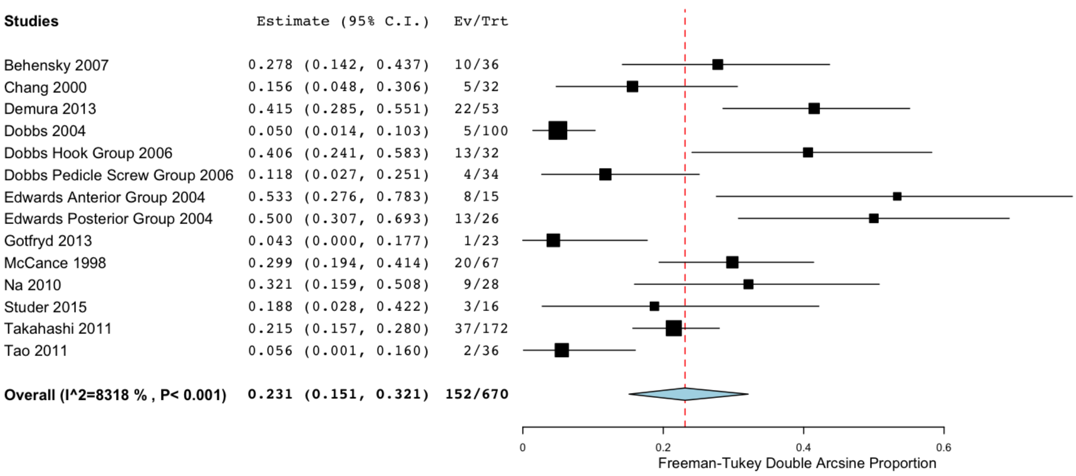


Figure 32: Incidence of coronal decompensation with selective thoracic fusion.

The most common reported complication was coronal decompensation which was reported in 12 studies.[22,47-49,56,74,79,80,83,86,87,93] A binary random effects model was used for single arm statistical meta-analysis. The weighted incidence of coronal decompensation in the studies was 23.1% (95% CI: 15.1, 32.1%). There was however significant heterogeneity found ($p<0.001$), with I^2 of 83% signifying substantial variance between studies. The reported rates of coronal decompensation reported in the studies can be view in figure 32.

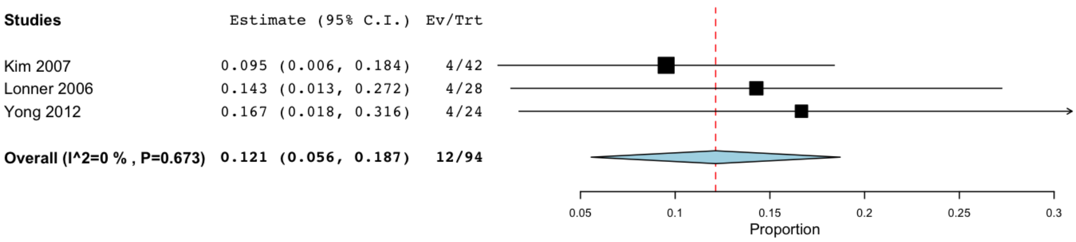


Figure 33: Incidence of implant failure with selective thoracic fusion.

Implant failures was reported in 3 studies. Kim et al.[91] reported 4 failures in 42 patients (2 broken screws, 1 rod failure and 1 proximal screw pull-out), Lonner et al.[28] reported 3 incidents of implant failure from their 28 patients (1 screw pull-out, and 2 broken rods) and Yong et al.[85] described 4 rod breaks in their study of 24 patients. Single arm meta-analysis was conducted (see figure 33) which showed a weighted mean incidence of 12.1% (95% CI: 5.6, 18.7). There was no significant heterogeneity ($p=0.673$) and I^2 was 0% which signifies no substantial study variance.

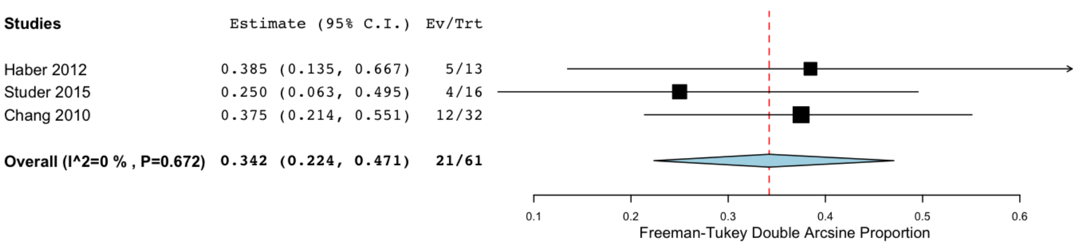


Figure 34: Incidence of progression of deformity and adding-on with selective thoracic fusion.

Progression of curves was described in 3 studies. Studer et al.[74] reported 4 cases of adding-on phenomenon in their study of 16 patients. Haber et al.[33] reported 5 failures (out of 13 patients), mainly due to adding-on. Chang[86] described 12 patients (out of 32) who had complications related to worsening deformity. Worsening lumbar AVT was seen in 4, worsening lumbar AVR was seen in 1, 2 patients had increases of their compensatory lumbar curve cobb angle, and 5 had an increase in thoracolumbar kyphosis. These complications were combined as deformity progression to perform single arm meta-analysis. The results are shown in figure 34 which showed a weighted mean incidence of 34.1% (95% CI: 22.4, 47.1). There was no significant heterogeneity (p=0.672) and I^2 was 0% which signifies no substantial study variance.

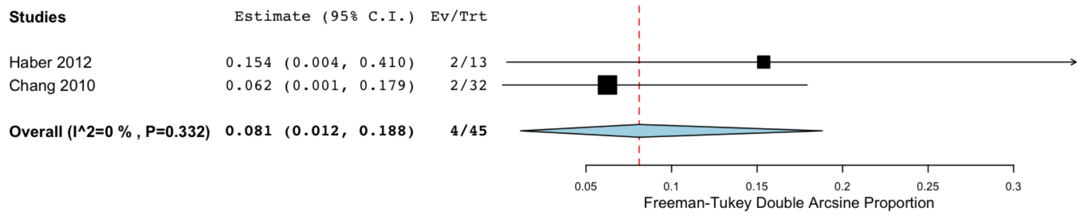


Figure 35: Incidence of revision surgery with selective thoracic fusion.

Two studies mentioned revision surgery which occurred in 2 patients in Haber's study[33] (secondary to adding on), and 2 patients in Chang's series[86] (one due to adding on, and the other due to coronal decompensation). Figure 35 shows the single arm meta-analysis for revision surgery. The weighted mean incidence was 8.1% (95% CI: 1.2, 18.8). There was no significant study heterogeneity (p=0.332) and I^2 was 0% which signifies no substantial study variance.

Only one study by Haber et al.[33] reported complications of proximal thoracic kyphosis and only in a mild case that required no treatment.

Two other studies described non-surgical complications with 1 patient developing a pneumothorax, 1 patient developing a mucous plug[28] and 1 patient developing a non-infected seroma.[80]

GRADE Summary of Findings Table

Anterior approach against posterior approach selective thoracic fusion for adolescent idiopathic scoliosis

Patient or population: Adolescent Idiopathic Scoliosis
Intervention: Anterior approach selective thoracic fusion
Comparison: Posterior approach selective thoracic fusion
Follow-Up: Minimum of 24 months

Outcomes	**No of participants (studies)**	**Quality of the evidence (GRADE)**	**Weighted means difference (95% CI)**
Post-operative main thoracic curve	499 (7 studies)	⊕⊖⊖⊖ very low[1]	Patients in the anterior approach had a curve 3.53 degrees less than the posterior approach group (95% CI: -8.21, 1.14)
Main thoracic curve correction	499 (7 studies)	⊕⊕⊖⊖ low	Patients in the anterior approach group had 2.44% more correction than the posterior approach group (95% CI: -2.76, 7.64)
Post-operative compensatory lumbar curve	465 (5 studies)	⊕⊖⊖⊖ very low[2]	Patients in the anterior approach had a curve 1.10 degrees less than the posterior approach group (95% CI: -6.08, 3.87)
Compensatory lumbar curve correction	465 (5 studies)	⊕⊕⊖⊖ low	Patients in the anterior approach group had 0.34% more correction than the posterior approach group (95% CI: -6.50, 7.17)
Coronal balance	217 (2 studies)	⊕⊕⊖⊖ low	Patients in the anterior group had a coronal balance -1.35mm closer to the midline than the posterior group (95% CI: -5.01, 2.30)

Anterior approach against posterior approach selective thoracic fusion for adolescent idiopathic scoliosis			
Patient or population: Adolescent Idiopathic Scoliosis **Intervention:** Anterior approach selective thoracic fusion **Comparison:** Posterior approach selective thoracic fusion **Follow-Up:** Minimum of 24 months			
Outcomes	**No of participants (studies)**	**Quality of the evidence (GRADE)**	**Weighted means difference (95% CI)**
Post-operative thoracic kyphosis	269 (2 studies)	⊕⊖⊖⊖ very low[3]	Patients in the anterior approach had a kyphosis 4.92 degrees more than the posterior approach group (95% CI: -1.42, 11.27)
Thoracic kyphosis change	269 (2 studies)	⊕⊖⊖⊖ very low[4]	Patients in the anterior approach group had 6.05 degrees more kyphosis change than the posterior approach group (95% CI: -4.69, 16.8)
Post-operative lumbar lordosis	269 (2 studies)	⊕⊕⊖⊖ low	Patients in the anterior approach had a lordosis 4.29 degrees more than the posterior approach group (95% CI: 1.50, 7.05)*
Lumbar lordosis change	269 (2 studies)	⊕⊖⊖⊖ very low[5]	Patients in the anterior approach group had 4.55 degrees more lordosis change than the posterior approach group (95% CI: -5.34, 14.43)
CI: Confidence interval; **OR:** Odds ratio;			
GRADE Working Group grades of evidence **High quality:** Further research is very unlikely to change our confidence in the estimate of effect. **Moderate quality:** Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate. **Low quality:** Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate. **Very low quality:** We are very uncertain about the estimate.			
[1]Decision made to downgrade for significant heterogeneity despite wide range of pre-operative curve magnitudes [2]Decision made to downgrade for significant heterogeneity despite wide range of pre-operative curve magnitudes [3]Decision made to downgrade for significant heterogeneity despite wide range of pre-operative curve			

magnitudes, and due to small overall weighted mean effect [4]Decision made to downgrade 1 point for significant heterogeneity and wide confidence interval [5]Decision made to downgrade 1 point for significant heterogeneity and wide confidence interval *Findings were significant

Table 6: Summary of findings for Anterior approach against posterior approach selective thoracic fusion for adolescent idiopathic scoliosis

Selective thoracic fusion for adolescent idiopathic scoliosis comparing Lenke B curves against Lenke C curves			
Patient or population: Adolescent Idiopathic Scoliosis **Intervention:** Selective thoracic fusion in Lenke B Curves **Comparison:** Selective thoracic fusion in Lenke C Curves **Follow-Up:** Minimum of 24 months			
Outcomes	No of participants (studies)	Quality of the evidence (GRADE)	Weighted means difference (95% CI)
Post-operative main thoracic curve	165 (2 studies)	⊕⊕⊝⊝ low	Patients with Lenke B curves had curves 4.27 degrees less than those with Lenke C curves (95% CI: -10.00, 1.46)
Post-operative compensatory lumbar curve	165 (2 studies)	⊕⊕⊝⊝ low	Patients with Lenke B curves had curves 5.80 degrees less than those with Lenke C curves (95% CI: -10.15, 1.45)
CI: Confidence interval; **OR:** Odds ratio;			
GRADE Working Group grades of evidence **High quality:** Further research is very unlikely to change our confidence in the estimate of effect. **Moderate quality:** Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate. **Low quality:** Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate. **Very low quality:** We are very uncertain about the estimate.			

Table 7: Summary of findings for selective thoracic fusion in adolescent idiopathic scoliosis Lenke B curves against Lenke C curves.

Effectiveness of selective thoracic fusion comparing pre-operative and post-operative values			
Patient or population: Adolescent Idiopathic Scoliosis **Intervention:** Selective thoracic fusion **Follow-Up:** Minimum of 24 months			
Outcomes	**No of participants (studies)**	**Quality of the evidence (GRADE)**	**Weighted means difference (95% CI)**
Main thoracic curve correction	1302 (29 studies, 43 treatment arms)	⊕⊕⊕⊝ moderate[1]	Selective thoracic fusion caused the main thoracic curve to decrease by 29.79 degrees (95% CI: 28.10, 31.45)*
Compensatory lumbar curve correction	1068 (21 studies, 30 treatment arms)	⊕⊕⊕⊝ moderate[2]	Selective thoracic fusion caused the compensatory lumbar curve to decrease by 16.39 degrees (95% CI: 15.41, 17.38)*
Coronal balance	655 (12 studies, 18 treatment arms)	⊕⊝⊝⊝ very low[3]	Selective thoracic fusion caused the coronal balance to move 1.89mm towards midline (-0.31, 4.09)
Thoracic kyphosis	752 (17 studies, 24 treatment arms)	⊕⊝⊝⊝ very low[4]	Selective thoracic fusion caused the thoracic kyphosis to increase by 3.54 degrees (95% CI: 1.52, 5.57)*
Lumbar lordosis	551 (12 studies, 17 treatment arms)	⊕⊝⊝⊝ very low[5]	Selective thoracic fusion caused the lumbar lordosis to decrease by 0.66 degrees (95% CI: -1.37, 2.68)
Sagittal balance	198 (6 studies, 9 treatment arms)	⊕⊝⊝⊝ very low[6]	Selective thoracic fusion caused the sagittal balance to move 0.35mm towards midline (-5.62, 6.31)

Effectiveness of selective thoracic fusion comparing pre-operative and post-operative values			
Patient or population: Adolescent Idiopathic Scoliosis **Intervention:** Selective thoracic fusion **Follow-Up:** Minimum of 24 months			
Outcomes	**No of participants (studies)**	**Quality of the evidence (GRADE)**	**Weighted means difference (95% CI)**
Thoracic apical vertebral rotation	48 (2 studies)	⊕⊝⊝⊝ very low[7]	Selective thoracic fusion caused the thoracic apical vertebral rotation to improve by 3.58 degrees (95% CI: -0.91, 8.06)
Lumbar apical vertebral rotation	78 (4 studies)	⊕⊝⊝⊝ very low[8]	Selective thoracic fusion caused the lumbar apical vertebral rotation to improve by 0.09 degrees (95% CI: -2.04, 2.22)
CI: Confidence interval; **OR:** Odds ratio;			
GRADE Working Group grades of evidence **High quality:** Further research is very unlikely to change our confidence in the estimate of effect. **Moderate quality:** Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate. **Low quality:** Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate. **Very low quality:** We are very uncertain about the estimate.			
[1]Decision made not to downgrade for significant heterogeneity in view of wide range of pre-operative curve magnitudes and the presence of a large number of studies. Decision made to upgrade by 1 point for increased magnitude of effects with narrow confidence interval [2]Decision made not to downgrade for significant heterogeneity in view of wide range of pre-operative curve magnitudes and the presence of a large number of studies. Decision made to upgrade by 1 point for increased magnitude of effects with narrow confidence interval [3]Decision made to downgrade by 1 point for significant heterogeneity, and inconsistency, with a very small inconclusive magnitude of change [4]Decision made to downgrade for significant heterogeneity and inconsistency with some studies suggesting anterior was superior and some suggesting posterior was superior [5]Decision made to downgrade for significant heterogeneity and inconsistency with some studies suggesting anterior was superior and some suggesting posterior was superior [6]Decision made to downgrade for significant heterogeneity and inconsistency with some studies suggesting anterior was superior and some suggesting posterior was superior. Final results were a small inconclusive magnitude of change			

[7]Decision made to downgrade for significant heterogeneity in a small number of patients [7]Decision made to downgrade for significant heterogeneity in a small number of patients *Findings were significant

Table 8: Summary of findings for effectiveness of selective thoracic fusion in adolescent idiopathic scoliosis.

CHAPTER FOUR - DISCUSSION

Thoracic curve correction

The main thoracic curve is the structural curve of patients in those with thoracic adolescent idiopathic scoliosis. This radiographic factor is the usual indication for surgical management of scoliosis, and the main outcome described as whether treatment has been successful.

Overall 29 studies, with 43 treatment arms and 1302 patients were included in the meta-analysis for effectiveness. There was a statistically difference in main thoracic curve following selective thoracic fusion therefore making the surgery effective ($p<0.00001$). The average change in the main thoracic curve was 29.79 degrees (95% CI: 28.10, 31.47) which can be considered clinically significant. Although there was heterogeneity present, all studies showed that there *was* positive correction of the main thoracic curve which would indicate that there is a clinical significant change with surgery.

Seven studies[22,34,37,49,73,75-77] were included in meta-analysis in this review comparing the effectiveness of the anterior approach against the posterior approach in selective thoracic fusion. The meta-analysis showed that there was no statically significant difference between the two approaches regarding main thoracic curve correction. Moderate heterogeneity between studies was found (I^2 of 54%) however it is likely that it is attributed to no clear consensus between studies that anterior or posterior approach results in a better main thoracic curve correction.

Two studies[46,52] were included for descriptive analysis between coronally compensated and coronally unbalanced curves. The mean correction ranged from 37.5-51.8% or 21-29 degrees in the compensated group compared to 40.3-43.9%% or 25 degrees in the coronally unbalanced group. This is likely to not represent a clinically significantly change as both groups have values with overlapping ranges.

One study with two treatment arms were included for descriptive analysis comparing the effectiveness of selective thoracic fusion in Lenke B vs Lenke C curves. The descriptive analysis showed that there was likely no statistically significant difference in main thoracic curve correction between the two curve types with both groups having values with overlapping ranges.

Compensatory lumbar curve correction

The lumbar curve is usually non-structural and is compensatory in patients with thoracic adolescent idiopathic scoliosis. The compensatory component is left unfused in selective thoracic fusion.

Overall 21 studies, with 30 treatment arms, and 1068 patients were included in the meta-analysis for effectiveness. There was a statistically difference in compensatory lumbar curve following selective thoracic fusion therefore making the surgery effective (P<0.00001). The average change in compensatory lumbar curve was 16.39 degrees (95% CI: 15.41, 17.38) which can be considered clinically significant. Interestingly the change in lumbar curve was only 54.8% of that of the main thoracic curve, which is much different to the equal change that is reported by some authors.[18-21] There was significant heterogeneity between the studies which is likely due to the wide range of correction between all studies. All studies however showed that there *was* positive correction of the compensatory lumbar curve which would indicate that there is a clinical significant change with surgery.

Five studies[22,34,49,76,77] were included in meta-analysis in this review comparing the effectiveness of the anterior approach against the posterior approach in selective thoracic fusion. The meta-analysis showed that there was no statistically significant difference between the two approaches in compensatory lumbar curve correction. Moderate heterogeneity between studies was found (I^2 of 58%) however it is likely that it is attributed to no clear consensus between studies about whether selective thoracic fusion via an anterior or posterior approach results in a better compensatory lumbar curve correction.

Two studies[46,52] were included for descriptive analysis between coronally compensated and coronally unbalanced curves. The mean correction ranged between 29.5 and 33.3% in the compensated group compared to 23.4-28.9% in the coronally unbalanced group. Unfortunately, the comparison was not able to undergo meta-analysis, but it is likely that there may be a clinical effect as the ranges of the two groups do not cross over. This potential clinically significant difference is complicated by the fact that the change in the curve magnitude in degrees between the two groups are similar (13-14 degrees and 11-13 degrees respectively). Further studies into comparing patients who show coronal decompensation against those who have a good coronal result need to occur in order for this potentially clinically significant difference to be proved.

Two studies (four treatment arms) was included for descriptive analysis comparing the effectiveness of selective thoracic fusion in Lenke B vs Lenke C curves on compensatory lumbar curve correction. The descriptive analysis showed that there was no likely statistically significant difference in compensatory lumbar curve correction between the two curve types due to overlapping values and ranges. Interestingly the anterior approach treatment arms had less correction in Lenke B curves, but the posterior approach treatment arms had more correction in the Lenke B curves. Therefore it is unlikely that there is a statistical or clinical significant change in compensatory lumbar curve correction between Lenke B or Lenke C groups.

Coronal balance and Coronal Decompensation

Coronal balance is a measure of distance between a vertical line dropped down from the middle of the C7 vertebral body and the central sacral vertical line. Decompensation or coronal imbalance can be described as one of the most common complications of selective thoracic fusion and is described when the C7 plumb line is 20mm from the central sacral vertical line. One of the desired outcomes of spinal surgery is to have a balanced straight spine. This means both coronal balance and sagittal balance. Clinically, patients which are unbalanced in the coronal plane present with shoulder asymmetry. However the clinical importance of coronal decompensation is not entirely clear as the level of decompensation at which patients become aware and report related symptoms has never been defined.[56] Coronal decompensation which may progress from immediately post-operative to at last follow-up, can lead to pain, increasing deformity and the further need for revision surgery.[99]

The effectiveness of selective thoracic fusion is hard to quantify in terms of the coronal balance. If a patient is imbalanced towards the left pre-operatively then a successful surgery will make them more balanced towards the central line (as shown by a decrease in the negative value or positive coronal balance change), however if a patient is coronally balanced pre-operatively then a successful surgery will keep them balanced at their post-operative follow-ups and therefore have a minimal coronal balance change. If a patient is coronally imbalanced to the right then a successful surgery will cause them to be balanced towards the left (as shown by a decrease in the positive value or negative coronal balance change). It is therefore difficult, when assessing for change in coronal balance, to evaluate the effectiveness of selective thoracic fusion. For example, a positive coronal balance change and a negative coronal balance change may be acceptable outcomes depending on the pre-operative status of the patient. It is for this reason that we decided to convert coronal balance (usually reported as negative for balance to the left, and positive to the right) into coronal balance from midline. This meant that a positive change in balance with surgery was associated with a return to midline or a more balanced spine.

18 treatment arms, 12 studies and 655 patients were eligible for meta-analysis. Studies involving coronally balanced and decompensated groups were excluded as to not bias results. Selective thoracic fusion was not statistically significant in changing the coronal balance of the patients. Patients had a weighted mean change of 1.89mm towards the midline. Across all studies there was significant heterogeneity ($p<0.0005$) and I^2 was 60% signifying considerable study variance. A random effects model was chosen as there was significant heterogeneity between the studies which was likely due to wide range of coronal balance between all studies.

There was only one treatment arm[79] with mean post-operative coronal balance unacceptable at greater than 20mm. This study aimed to compare the results of selective thoracic fusion using hooks or pedicle screws. The hook group which contained 32 patients had similar coronal balance with the pedicle screw group pre-operatively and immediately post-operatively however at the last follow-up had a significantly greater coronal balance than the pedicle screw group, and finishes with a mean post-operative coronal balance of 21mm. Interestingly, the change in coronal balance was very minimal with the groups have pre-operative values of 18mm and 17mm respectively.

Two studies[22,77] were included in meta-analysis in this review comparing the effectiveness of the anterior approach against the posterior approach in selective thoracic fusion. The meta-analysis showed that there was no statistically significant difference between the two approaches in coronal balance change. There was no significant heterogeneity between studies (I^2 of 0%).

Two studies[46,52] were included for descriptive analysis between coronally compensated and coronally unbalanced curves. The mean correction was ranged between 0.5mm towards midline to 4mm away from midline in the compensated group compared to 14.2-20mm *away* from midline in the coronally unbalanced group. Unfortunately, the comparison was not able to undergo meta-analysis for significance, but this was the expected result when coronal decompensation is diagnosed solely on the coronal balance value. Despite the lack of ability to perform meta-analysis this is likely to be a clinically significant problem. Further studies into comparing patients who show coronal decompensation against those who have a good coronal result need to occur in order for this potentially clinically significant difference to be proved.

No studies were included in meta-analysis of Lenke B curves against Lenke C curves and therefore no comment can be made as to the effectiveness of selective thoracic fusion in these two curve subgroups. More studies are needed to further define any difference between coronal balance and curve types.

Clinically this can mean that coronally balanced children pre-operatively are likely to remain balanced with selective thoracic fusion, and it also means that children who are pre-operatively unbalanced coronally are not likely to return to a balanced state with selective thoracic fusion.

Thoracic Kyphosis

The thoracic kyphotic curve is important for normal upright posture and respiratory function as well as sagittal balance. A hyperkyphotic or hypokyphotic thoracic curve can lead to a restriction of respiratory function due to a change in shape and size of the thoracic cavity. While selective thoracic fusion has benefits of correcting the coronal plane curves, it may do it so at the detriment of the sagittal curves. Therefore, the ideal adolescent idiopathic scoliosis treatment involves correction of the coronal curves whilst maintaining or increasing thoracic kyphosis and lumbar lordosis. Thoracic kyphosis can be affected by rod-precontouring, surgical approach and correction of the lumbar lordosis.[81] Most studies looking at radiological outcomes in scoliosis surgery will include the thoracic kyphosis magnitude as a primary or secondary outcome.

Overall 17 studies, with 24 treatment arms and 752 patients were included in the meta-analysis for effectiveness. There was a statistically difference in thoracic kyphosis following selective thoracic fusion therefore making the surgery effective ($p<0.0006$) at increasing thoracic kyphosis. The weighted mean change in thoracic kyphosis was 3.52 degrees (95% CI: 1.52, 5.57) which can be considered clinically significant but minimal in the context of the thoracic kyphosis curve. A random effects model was chosen as there was significant heterogeneity between the studies which is likely due to a wide range of correction between all studies. In addition, not all studies showed that there was positive increase in the thoracic kyphosis which would indicate that there this is still some debate on the fate of the thoracic kyphosis value with selective thoracic fusion.

Two studies[37,73] were included in meta-analysis in this review comparing the effectiveness of the anterior approach against the posterior approach in selective thoracic fusion. The meta-analysis showed that there was no statistically significant difference between the two approaches regarding change in thoracic kyphosis or post-operative thoracic kyphosis. Moderate heterogeneity between studies was found in both post-operative values and change in thoracic kyphosis (I^2 of 73% and 79% respectively) however it is likely that it is attributed to a wide range of corrections. Anterior selective thoracic fusion has been described as causing an increase in thoracic kyphosis (beneficial) compared with posterior approach which has been shown to decrease thoracic kyphosis.[27,28,85] This was further supported by the post-operative thoracic kyphosis values which were both higher in the anterior group with the anterior group having a weighted mean average 4.92 degrees increased kyphosis than the posterior group, however this did not reach significance. This is complicated by the change in thoracic kyphosis being greater in the posterior group in one study and in the anterior group in one study.

However, when a sensitivity analysis was done comparing all studies using anterior approach against all studies using posterior approach there was a statistically significant result (see Figure 24). The anterior approach selective thoracic fusion resulted in a significant increase in thoracic kyphosis (mean 6.74, 95% CI: 4.57, 8.91) compared with a non-significant change in the posterior group (mean 1.20, 95% CI: -1.15, 3.54). This further supports the previous studies and proves that the anterior approach results in an increased thoracic kyphosis.

Both studies[48,56] comparing coronally compensated and decompensated patients were eligible for descriptive analysis of thoracic kyphosis change. The compensated group had change in kyphosis ranging from -2 to 4 degrees with selective thoracic fusion compared with the decompensated group which had a decrease range of 4 to 5 with surgery. This is likely to represent a clinically significant change in groups as the ranges do not cross over however more research is needed in the area before a correlation can be properly described. It is possible that with worsening of one plane of the deformity (coronal plane) there is a similar but not equal change in the other two components (sagittal plane and rotation).

No studies were included in meta-analysis of Lenke B curves against Lenke C curves and therefore no comment can be made as to the effectiveness of selective thoracic fusion in these two curve subgroups. More studies are needed to further define any difference between thoracic kyphosis and curve types.

All studies had mean pre-operative and post-operative values within the normal ranges of thoracic kyphosis (10-40 degrees). There were only four studies that presented a mean decrease in thoracic kyphosis but all others had an increase in mean post-operative thoracic kyphosis values. Therefore it is possible to conclude that while the main thoracic or compensatory lumbar curves dramatically and significantly changed there was minimal change in the thoracic kyphosis out of the normal range.

Lumbar lordosis

The lumbar lordosis curve is also involved in the sagittal profile of the scoliotic curve. A hyperlordotic or hypolordotic lumbar curve can lead to a variety of symptoms such as “flatback syndrome”, back pain and degenerative disk disease. It is thought that a loss in lumbar lordosis leads to pelvic retroversion to maintain balance which leads to pain and excess energy expenditure.[100] In addition, lumbar lordosis has been reported to have a relation to health-related quality of life.

As the thoracic kyphosis correction is usually coupled to the lumbar lordosis correction,[73] we would expect that the lumbar lordosis value would also not stray from normal range with selective thoracic fusion. In fact, the reason selective thoracic fusion was first investigated and used was that with issues described with Harrington rods and early instrumentation fusion techniques into the lumbar spine lead to a higher incidence of post-instrumentation back pain. Ideally then selective thoracic fusion should then keep the lumbar spine mobile to prevent back pain but also keep the lumbar lordosis within a normal range to promote good sagittal balance and prevent pelvic compensatory mechanisms and further pain.

As described above, while selective thoracic fusion corrects the coronal plane curves and keeps the thoracic kyphosis within normal values, the behaviour of the lumbar lordosis is undescribed. Most recent studies looking at radiological outcomes in scoliosis surgery will include sagittal parameters as a primary or secondary outcome however very little studies focus on the correction, behaviour and importance solely of the lumbar lordosis magnitude.

Overall 12 studies, with 17 treatment arms and 551 patients were included in the meta-analysis for effectiveness. There was no statistically significant difference in lumbar lordosis following selective thoracic fusion therefore making the surgery effective (p=0.53) at maintaining but not changing lumbar lordosis. The weighted mean change was a decrease in lumbar lordosis of 0.66 degree (95% CI: -1.37, 2.68) which can be considered clinically insignificant and minimal in the context of the lumbar lordosis kyphosis curve. A random effects model was chosen as there was significant heterogeneity between the studies which is likely due to wide range of correction between all studies. In addition, 12 studies showed that there was positive increase in the lumbar lordosis which would indicate that there this is still some debate on the fate of the lumbar lordosis value with selective thoracic fusion. It is interesting to note that while the results were not statistically significant, the anterior group favoured a decrease in lumbar lordosis (which nearly reached significance), while the posterior group favoured an increase in lumbar lordosis. This was further supported in our effectiveness sensitivity meta-analysis for lumbar lordosis (see Figure 26). It is possible that with more studies in this area, the results will reach significance.

Two studies[37,73] were included in meta-analysis in this review comparing the effectiveness of the anterior approach against the posterior approach in selective thoracic fusion. The meta-analysis showed that there was no statically significant difference between the two approaches regarding change in lumbar lordosis (p=0.37) however there was a significant difference in the post-operative lumbar lordosis between the anterior and posterior approach (p=0.002). Patients treated via the anterior posterior approach had a weighted mean average lumbar lordosis of 4.29 degrees higher than their posterior approach counterparts. There was statistically significant heterogeneity between the lumbar lordosis change groups however the post-operative lumbar lordosis value had no significant heterogeneity. It is likely that the post-operative lumbar lordosis value is clinically significant between the two groups however the change in values represent a minor change and is clinically insignificant as further supported in the studies not directly comparing anterior against the posterior approach. Anterior selective thoracic fusion has been described as causing an increase in lumbar lordosis compared to the posterior approach which is beneficial, however our analysis suggests that although the post-operative value is significantly different, the change in angle with surgery is not.

Both studies[48,56] comparing coronally compensated and decompensated patients were eligible for descriptive analysis of lumbar lordosis change. The compensated group had a change in the range of -1 to 4 degrees with selective thoracic fusion compared with the decompensated group which had a decrease of 1 to 10 degrees with surgery. This is likely to represent a clinically significant change in groups as the ranges do not cross over however more research is needed in the area before a correlation can be properly described. As previously described with thoracic kyphosis, It is possible that with increasing in coronal plane curve value there is an inverse relationship with the sagittal plane (on both lumbar lordosis and sagittal kyphosis).

All studies had mean pre-operative and post-operative values within the normal ranges of lumbar lordosis (31.5 - 62 degrees).[55,98,101] There were seven studies that presented a mean decrease in post-operative lumbar lordosis and seven others that had an increase in mean post-operative lumbar lordosis values. Therefore it is safe to conclude that while the main thoracic or compensatory lumbar curves dramatically and significantly changed there was minimal change in the lumbar lordosis out of the normal range.

Sagittal Balance

Sagittal balance is defined as a measure of distance between a vertical line dropped down from the middle of the C7 vertebral body and the posterior body of the S1 vertebra. The goals of scoliosis surgery in the sagittal plane are to bring the thoracic kyphosis and lumbar lordosis into the normal ranges, and to promote a harmonious sagittal contour with the patient in slightly negative or neutral sagittal balance.[91] The instrumentation on the thoracic curve in selective thoracic fusion can have detrimental effects on the thoracic kyphosis which affects the overall sagittal balance.[81] Unfortunately, up until recently, efforts were awarded to the resolution of the coronal deformity but left the sagittal component ignored. However, if the sagittal balance is not corrected, it leads to a loss of posture, early fatigue of extensor muscles of the back and hip which develops into lower back pain and early degeneration of the intervertebral discs.[91] Over positive sagittal balance can lead to flat back syndrome.[52] Recent research has now changed the thinking of scoliosis surgery to attempt and restore the harmonious sagittal curves however the difficulty lies in determining the normality of sagittal balance. As current research does not currently explain what level of decompensation is symptomatic it is hard to define a clinically relevant ideal range to guide clinicians. [56]

As with coronal balance, the effectiveness of selective thoracic fusion is hard to quantify in terms of the sagittal balance. If a patient is imbalanced towards the posterior aspect pre-operatively then a successful surgery will make them more balanced towards the central line (as shown by a decrease in the negative value or positive sagittal balance change), however if a patient is sagittally balanced pre-operatively then a successful surgery will keep them balanced at their post-operative follow-ups and therefore have a minimal sagittal balance change. If a patient is sagittally imbalanced to the anterior aspect then a successful surgery will cause them to shift to the central line posteriorly (as shown by a decrease in the positive value or negative sagittal balance change). It is therefore hard when looking purely at the change in sagittal balance to evaluate the effectiveness of selective thoracic fusion. For example; a positive sagittal balance change and a negative sagittal balance change may be acceptable outcomes depending on the pre-operative status of the patient. It is for this reason that we decided to convert sagittal balance (usually reported as negative for a C7 vertebral plumb line to the posterior of the S1 body, and positive if anterior to the S1 body) into sagittal balance from midline. This meant that a negative change in balance with surgery was associated with a return to equilibrium or a more balanced spine.

Unfortunately, decompensation of the sagittal curve is not well described in the literature. There were only 7 studies which reported data on sagittal balance which is much less than the 33 studies that reported on thoracic curve change. Overall 6 studies with 9 treatment arms were included in the meta-analysis for effectiveness of selective thoracic fusion. Overall there was no statistically significant change in sagittal balance with selective thoracic fusion, with the mean weighted movement of 0.35mm (95% CI: -5.62, 6.31) towards a centred spine. This may be clinically significant because selective thoracic fusion has not caused a shift away from the midline (or a more sagittally unbalanced spine). This effect however is minimal with 6 out of 9 treatment arms actually showing an increase in sagittal balance post-operatively. A random effects model was chosen as there was significant heterogeneity between the studies which is likely due to wide range of pre-operative values and correction between all studies.

Unfortunately, no studies were included in meta-analysis of anterior approach against posterior approach and therefore no comment can be made as to the effectiveness of selective thoracic fusion in these two approach subgroups. More studies are needed to further define any difference between sagittal and approach.

Both studies[48,56] reported post-operative sagittal balance data in compensated versus decompensated patients. Both compensated and decompensated groups saw a change in sagittal balance away from the midline (2-7mm in the compensated, 9-22mm in the decompensated) which is likely to be both clinically and statistically significant. This descriptive analysis suggests that coronal decompensation is also likely to be associated with sagittal balance decompensation.

No studies were available for a meta-analysis of Lenke B curves against Lenke C curves and therefore no comment can be made as to the effectiveness of selective thoracic fusion in these two curve subgroups. More studies are needed to further define any difference between sagittal balance and curve types.

Five treatment arms had pre-operative sagittal balance of unacceptable values (>20mm from midline), of these 3 remained unbalanced post-operatively, while 2 returned to a balanced state. One further treatment arm started balanced pre-operatively but then further deteriorated post-operatively just past the acceptable cut off (20.1mm).

Clinically this can mean that most sagittally balanced children pre-operatively are likely to remain balanced with selective thoracic fusion, however it also means that children who are pre-operatively unbalanced sagittally are not likely to return to a balanced state with selective thoracic fusion.

Thoracic apical vertebral rotation

Although the main goals of surgical treatment of the adolescent idiopathic are to correct the 3D deformity of scoliosis, it seems that many papers focus only on the coronal balance, and then sagittal balance before leaving the importance of rotation out of the question. Many techniques describe “de-rotating” the spine to correct coronal and sagittal balance much like a twisted rope, however very few papers measure thoracic and lumbar apical vertebral rotation. In addition an excess of thoracic axial rotation causes cosmetically concerning rib hump which may need the prominent section to be resected (thoracoplasty).[52] Unfortunately, there is no one globally used method for measuring rotation in the apical vertebra. All of the studies that reported on vertebral rotation used either the Perdriolle method[54] or the Nash-Moe method.[53] As the two methods are not easily integrated together, separate analysis had to be done utilizing each method.

In the meta-analysis for effectiveness of selective thoracic fusion, only three studies were eligible. However due to the method reported only the two studies using the Perdriolle method could be included. The results showed an overall weighted mean difference of 3.58 degrees (95% CI: -0.91, 8.06) which was not statistically significant and had significant heterogeneity between the two studies. Additionally, this result is likely to not have a significant impact clinically.

No studies were included in meta-analysis of Lenke B curves against Lenke C curves or the meta-analysis of anterior against posterior approach and therefore no comment can be made as to the effectiveness of selective thoracic fusion in these subgroups. More studies are needed to further define any difference between thoracic apical vertebral rotation and curve type or approach.

No data could be descriptively analysed in the compensated and decompensated comparisons and therefore no comment can be made as the effectiveness in these patient subgroups.

No further studies reporting pre-operative and post-operative thoracic apical vertebral rotation were available for descriptive analysis.

Lumbar apical vertebral rotation

As with thoracic apical vertebral rotation there was difficulties due to lack of reported data values across the studies and the use of both the Nash-Moe method and the Perdriolle method. The lack of reported rotational data was surprising especially considering the published classification and Lenke criteria published by Lenke et al.[15] for selective thoracic fusion contains thoracic and lumbar apical vertebral rotation.

Nevertheless, there were four studies which reported lumbar apical vertebral rotation using the Perdriolle method that were included in the meta-analysis for effectiveness of selective thoracic fusion. The mean weighted difference of 0.09 degrees (95% CI:-2.04, 2.22) decrease with selective thoracic fusion did not reach statistical significance and is unlikely to make any significant clinical difference.

No studies were included in meta-analysis of Lenke B curves against Lenke C curves or the meta-analysis of anterior against posterior approach and therefore no comment can be made as to the effectiveness of selective thoracic fusion in these subgroups. More studies are needed to further define any difference between lumbar apical vertebral rotation and curve type or approach.

No data could be descriptively analysed in the compensated and decompensated comparisons and therefore no comment can be made as the effectiveness in these patient subgroups.

Further research needs to aim at the resulting change in the rotational profile of the patient, as the current evidence is severely lacking and appears as though selective thoracic fusion does not significantly change the rotational profile of the patient.

Quality of life

Quality of life was overall under-reported across all the studies. Only six studies reported outcomes of quality of life surveys using the SRS-22[28,82], SRS-24[22,85], and SRS-30.[33,86] Overall the quality of life following selective thoracic fusion was 3.7-4.9. There is currently no accepted value that is the threshold for a good or excellent result, however we deem these results to be at least acceptable values. Unfortunately, a meta-analysis was unable to be performed due to questionnaire heterogeneity. There was no data reported to distinguish whether the quality of life is better from the anterior or posterior approach, in Lenke B or Lenke C curves, or in compensated or decompensated curves. Quality of life is discussed poorly in spinal surgical literature, mainly due to the complex nature of their spinal deformity on their quality of life. Spinal deformity may or may not impact the patient in their pain, self-image, function, mental health and satisfaction, however each attribute will affect different patients differently based on the patient's perceived values. Future studies will need to firstly include quality of life as a standard outcome, use one standardised quality of life survey across all studies and have accepted values as to what signifies a good quality of life.

Pulmonary function tests

A reduction in pulmonary function is a common cause for intervention in scoliosis deformity. It is thought that as the thoracic curve worsens in either the sagittal or coronal plane that pulmonary function would worsen. In addition, one would expect that an anterior approach that disrupts the respiratory mechanism (through either an open or thoracoscopic approach) would further add insult to the injury. Surprisingly there is little data in the way of how selective thoracic fusion alters pulmonary function. Only two studies[28,84] were available for descriptive analysis and both were using the anterior approach and both showed similar results. FEV1 showed a transient decrease of 15-17%, and FVC a 19-28% decrease at an early post-operative stage. Both values returned to pre-operative baseline at the 2 years post-operative. Interestingly while there was no significant decrease in pulmonary function in either study with anterior selective thoracic fusion there was also no improvement reported either.

There was no comparison to be made between the pulmonary function tests using the anterior versus posterior approach. There was also no data to analyse as to whether an open anterior approach caused more change in pulmonary function testing than a thoracoscopically assisted approach. This has been previous shown in other studies involving non-selective fusion[102,103] but could not be shown in selective thoracic fusion.

Overall, we can draw the likely conclusion that anterior selective thoracic fusion does reduce the pulmonary function temporarily, however this is resolved by 2 years post-operatively, leaving the patients with a similar pulmonary function as they were pre-operatively. While this decrease in pulmonary function will likely not be an issue for children with no respiratory compromise, this may affect children with pre-existing respiratory function such as asthma or cystic fibrosis. If there is a pre-operative respiratory compromise, it is likely that selective thoracic fusion will not improve this compromise.

Complications

Fifteen studies were eligible for descriptive analysis of the complications of selective thoracic fusion. The most common reported complication was coronal decompensation which was reported with a weighted mean incidence of 23.1% (95% CI: 15.1, 32.1). This is definitely a higher than desired incidence of complications and resources need to be directed to reducing this rate. Many factors have been cited as risk factors including overcorrection of the thoracic curve, inappropriate choice of fusion level, incorrect identification of curve pattern, lumbar magnitude and stiffness and apical vertebral relative translation and rotation.[48,49] Regardless, this is an alarming figure, with the true incidence of coronal decompensation likely lying somewhere within the confidence interval. Over time and with more research the true incidence will become clear.

Progression of curve deformity was described in 3 studies[33,74,86], mainly relating to the adding-on phenomenon. The adding-on phenomenon is described as a progression of the lumbar spine or disc angulation below the instrumentation.[18,104] Progression of deformity had a weighted mean incidence of 34.2% (95% CI: 22.4, 47.1) of patients. This is somewhat higher than the previously reported data of 1.8% to 8.4% in all curves utilizing non-selective fusion.[18,105] The process of curve progression may be somewhat connected to the level of fusion and the curve type, with reports of King III and IV curves presenting with much higher rates of adding-on (21%, 37% respectively).[18] Despite the lack of reported rates, this figure however is quite concerning, and adding-on should be explained to patients as a risk of surgery.

Implant failures were described in three studies[28,85,91] for a weighted mean incidence of 12.1% (95% CI: 5.6, 18.7). Implant failures included broken screws, broken rods, and screw pull-out. Unfortunately, all studies that reported implant failures used different implant products that were not able to be separately advertised. Interestingly all the failures were reported in the studies via the anterior approach. The posterior approach usually utilises thicker rods in their construct than the anterior approach however I think it is unwise to suggest that implant failures do not occur when done via the posterior approach from the data reported, rather that it was not reported. There was no data for meta-analysis comparing the anterior against the posterior approach and therefore more detailed reporting will need to occur with future studies looking at selective thoracic fusion.

Only two studies[33,86] reported revision surgery with weighted mean incidence of 8.1% (95% CI: 1.2, 18.8). While this figure may be minimal, the true incidence of revision is likely to be higher than this due to reporter bias. Revision surgery can also be biased because the patient or the patient's parents need to make a serious decision about whether to undergo revision surgery. Some children may have deformity but choose not to have revision surgery due to the additional risks, scale of intervention and increased stiffness.

The lack of reported complications can be secondary to publication bias, with a Journal not publishing negative results.[106] For this reason we recommend that when the complications are quoted to patients for informed consent, that the true incidence of that particular complication is reported (from this analysis) as an "at least" basis, using the upper end of the reported range. For example, selective thoracic fusion is complicated by the need for revision surgery in at least 1.2% and up to in 18.8% of cases. However, this can be overcome if specific institutional data on the same complication has already been reported.

Limitations of the Review

Our review does have some limitations. Most studies included involved small sample sizes and they were mostly observational studies, rather than the preferred randomised controlled trials. This can sometimes imply that the data was from studies of moderate methodological soundness, however this is the best available evidence on the subject. Either way this needs to be taken into account when interpreting the results of this meta-analysis.

Further limitations can be seen in the study selection stage. Only articles published in English were included. Although scoliosis is treated worldwide in a similar fashion, those studies publishing results in a language other than English were excluded.

Studies that did not specifically report that selective thoracic fusion was involved or that fusion was no lower than L1 were excluded early on. This may have meant that although the study may have used a similar intervention, there was no way of verifying that it indeed did fulfil all the study inclusion criteria. The authors of the studies identified as possible inclusions for review were contacted however only one author replied and was unable to release the raw data for their study. Studies that did include individual patient results were included if the new mean values could be extracted from the eligible patients that met all the inclusion criteria, however this meant that study conclusions and some reported mean values of the population could not be used in this review. As there were some studies that did not list the lowest instrumented vertebrae of the patients and therefore were excluded, there is a chance that some patients included in that study who were treated with selective thoracic fusion were not able to be included in this review.

There were multiple studies[10,17,18,27,37,39-41,87,95,107-134] that did state that selective thoracic fusion was utilised however were not able to be included because of the use of a lowest instrumented vertebrae lower than L1.

The results of this meta-analysis could also overestimate the true treatment effect because of publication bias. Although a thorough systematic search was conducted across multiple databases targeting both published and unpublished literature, it is possible that some articles may have been missed. In addition, a low number of studies reported complications. This could be due to positive publication bias which has been reported previously in Orthopaedic surgery.[106] Hasenboehler et al.[106] reported that there is a strong tendency to publish positive results rather than negative results and even worse discrepancy between significant findings and neutral studies with no significant findings.

Studies may have been conducted after the search and therefore, have not been included. This may mean that as further studies are published in this area, an update of this review will be required.

There was significant heterogeneity calculated in multiple of our meta-analyses, despite strict inclusion criteria and critical appraisal. In Orthopaedic literature involving surgery there is always small differences in several factors. The population can be subtly different including the patient’s views and values on deformity and on surgery. The pathology can be different with a large range of deformity possible in thoracic scoliosis. The surgery can be subtly different depending on the surgical implants used, the minor variations in approach, and the surgeon and surgical team themselves. Therefore, it is hard to find non-heterogeneous studies of high methodological quality for comparison in meta-analysis. However, evidence based practice is using the best available evidence, and at the time this is the best available evidence on selective thoracic fusion.

A listed conflict of interest should be my authorship on one of the included studies.[74] This study was included in the meta-analysis for effectiveness of selective thoracic fusion. To reduce any bias the same critical appraisal tool and regimen was used as the other papers and included a 3rd party independent critical appraisal undertaken involving no authors on that study.

Implications for practice

Using the meta-analyses involved in this review, many radiological factors can now be predicted by surgeons to plan the use of selective thoracic fusion. Main thoracic and compensatory lumbar curve correction can now be estimated for each patient with thoracic scoliosis undergoing selective thoracic fusion. Spinal fusion aims to correct the three-dimensional deformity of scoliosis however selective thoracic fusion did not show correction in all three dimensions when used for adolescent idiopathic scoliosis. Selective thoracic fusion showed significant correction in main thoracic and compensatory lumbar curve and thoracic kyphosis, however there was no significant change in lumbar lordosis, coronal and sagittal balance, and apical rotation. The non-significant change in thoracic kyphosis and lumbar lordosis is likely warranted and an acceptable outcome as the patient's usually have normal pre-operative values. The non-significant change in the coronal or sagittal balance however means that if children are balanced pre-operatively then they are unlikely to move to an unbalanced state, however children who are unbalanced pre-operatively are unlikely to return to a balanced state following selective thoracic fusion. The non-significant change in apical vertebral rotation in both the thoracic and lumbar curves may show that selective thoracic fusion is not the best treatment modality for those with a great rotational deformity.

Implications for research

There is a low number of high level prospective trials in the fields of spinal surgery and Orthopaedics as it is not always possible to apply the principles of randomisation to surgery. Therefore, reviews are important to pool data and provide evidence, however the output quality of the review will always be harboured by the low-level quality input of research. Our knowledge of selective thoracic fusion will grow as more prospective and hopefully randomised trials become published. In addition, further publishing of retrospective series will lead to a greater population available for further meta-analysis and reviews.

This review did not go into the patient characteristic of spinal flexibility. Flexibility is how the primary and secondary curves respond to bending usually described as a percentage of the non-bending curve. One would expect that the more flexible the curve is (especially the lumbar curve) the more correction the curve will receive with selective thoracic fusion, and is included in the criteria for using selective thoracic fusion for a select patient.[15] This was deemed beyond the scope of the review as it is not an outcome of selective thoracic fusion but rather a factor that may change outcome. Future research could be done into evaluating the effectiveness of selective thoracic fusion in patients with a flexible thoracic curve against those with inflexible curves.

There was a lack of uniformity of how to measure and report radiological outcomes across the studies investigated. Multiple methods of measuring lumbar lordosis, thoracic kyphosis and rotation were utilised across studies extracted. For the standard of Orthopaedic and spinal surgical literature to improve, there needs to be clear guidelines for the measurement of common radiological criteria including normal values that are reproducible and accurate, especially when those common radiological criteria are used to guide management and evidence based practice. In addition, the type of outcomes reported by studies was variable. For example, while there were 29 studies that reported thoracic curve correction, thoracic apical vertebral rotation was only reported in 3 of those studies. As scoliosis is a deformity in coronal, sagittal and axial planes, it seems that future accepted studies in peer-reviewed journals report outcomes of all three planes.

There is a general lack of data on how rotation is affected with selective thoracic fusion and a standardised way of measurement. Further studies can look at this in depth, comparing previously validated methods (such as the Nash-Moe or Perdriolle method) with newer methods such as CT or MRI measurement.

There was a general lack of data on how quality of life is effected following selective thoracic fusion. As there has been no definable level of radiological outcome which leads to a worsened quality of life, it is crucial that with surgery we are improving the quality of life of patients, more importantly than radiological outcomes. While quality of life surveys gathered post-operatively are important, there are no definable values to suggest what is good against what is average or acceptable. In view of this, the change in quality of life (using any validated survey) is more important for inclusion in future studies to see selective thoracic fusion's overall effectiveness.

It is through this and through further uniform prospective and randomised trials, that evidence based medicine on selective thoracic fusion will improve and flourish.

CHAPTER FIVE - CONCLUSION

Selectively fusing the thoracic curve is an effective surgical method of correcting the three-dimensional deformity of adolescent idiopathic scoliosis. This systematic review shows that there is significant change in the main thoracic curve, compensatory lumbar curve, while maintaining a harmonious sagittal contour including thoracic kyphosis and lumbar lordosis. The rotational aspect of deformity is poorly described with this analysis showing minimal change in the thoracic and lumbar apical vertebral rotation. Overall quality of life following surgery is good for patients, while respiratory function is likely to decrease following fusion via the anterior approach, the values return to baseline at 2 years post-operatively. Complications are uncommonly reported but appear to be uncommon except for coronal decompensation. Coronal decompensation has been reported to occur in 23.1% of patients however the clinical implication of this is not yet widely known and resulting revision surgery is uncommon.

CHAPTER SIX - REFERENCES

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CHAPTER SEVEN – APPENDICES
APPENDIX I: SEARCH STRATEGY

Search strategy for Pubmed run on 03/06/2015

No	Search	Results
1	"scoliosis"[MeSH Terms] OR "scoliosis"[All Fields]	19,029
2	"scoliosis"[MeSH Terms] OR "scoliosis"[All Fields] OR "scolioses"[All Fields]	19,058
3	#1 OR #2	19,058
4	"Nucl Eng Des/Fusion"[Journal] OR "fusion"[All Fields] OR "FUSION"[Journal] OR "fusion"[All Fields]	233,824
5	"spinal fusion"[MeSH Terms] OR ("spinal"[All Fields] AND "fusion"[All Fields]) OR "spinal fusion"[All Fields]	24,142
6	"spinal fusion"[MeSH Terms] OR ("spinal"[All Fields] AND "fusion"[All Fields]) OR "spinal fusion"[All Fields] OR ("fusions"[All Fields] AND "spinal"[All Fields])	24,298
7	("spine"[MeSH Terms] OR "spine"[All Fields]) AND ("Nucl Eng Des/Fusion"[Journal] OR "fusion"[All Fields] OR "FUSION"[Journal] OR "fusion"[All Fields])	21,769
8	("spine"[MeSH Terms] OR "spine"[All Fields]) AND fusions[All Fields]	1,856
9	("spine"[MeSH Terms] OR "spine"[All Fields]) AND ("surgery"[Subheading] OR "surgery"[All Fields] OR "surgical procedures, operative"[MeSH Terms] OR ("surgical"[All Fields] AND "procedures"[All Fields] AND "operative"[All Fields]) OR "operative surgical procedures"[All Fields] OR "surgery"[All Fields] OR "general surgery"[MeSH Terms] OR ("general"[All Fields] AND "surgery"[All Fields]) OR "general surgery"[All Fields])	74,299
10	Spinal[All Fields] AND ("surgery"[Subheading] OR "surgery"[All Fields] OR "surgical procedures, operative"[MeSH Terms] OR ("surgical"[All Fields] AND "procedures"[All Fields] AND "operative"[All Fields]) OR "operative surgical procedures"[All Fields] OR "surgery"[All Fields] OR	108,228

	"general surgery"[MeSH Terms] OR ("general"[All Fields] AND "surgery"[All Fields]) OR "general surgery"[All Fields])	
11	"spinal fusion"[MeSH Terms] OR ("spinal"[All Fields] AND "fusion"[All Fields]) OR "spinal fusion"[All Fields] OR "spondylodesis"[All Fields]	24,324
12	"spinal fusion"[MeSH Terms] OR ("spinal"[All Fields] AND "fusion"[All Fields]) OR "spinal fusion"[All Fields] OR "spondylodeses"[All Fields]	24,146
13	"spinal fusion"[MeSH Terms] OR ("spinal"[All Fields] AND "fusion"[All Fields]) OR "spinal fusion"[All Fields] OR "spondylosyndesis"[All Fields]	24,145
14	"spinal fusion"[MeSH Terms] OR ("spinal"[All Fields] AND "fusion"[All Fields]) OR "spinal fusion"[All Fields]	24,142
15	"arthrodesis"[MeSH Terms] OR "arthrodesis"[All Fields]	28,465
16	("surgical procedures, operative"[MeSH Terms] OR ("surgical"[All Fields] AND "procedures"[All Fields] AND "operative"[All Fields]) OR "operative surgical procedures"[All Fields] OR "surgical"[All Fields]) AND approach[All Fields]	165,589
17	("spine"[MeSH Terms] OR "spine"[All Fields]) AND ("Nucl Eng Des/Fusion"[Journal] OR "fusion"[All Fields] OR "FUSION"[Journal] OR "fusion"[All Fields]) AND implant[All Fields]	1,457
18	("spinal fusion"[MeSH Terms] OR ("spinal"[All Fields] AND "fusion"[All Fields]) OR "spinal fusion"[All Fields]) AND implant[All Fields]	1,472
19	(#4 OR #5 OR #6 OR #7 OR #8 OR #9 OR #10 OR #11 OR #12 OR #13 OR #14 OR #15 OR #16 OR #17 OR #18)	505,988
20	"thorax"[MeSH Terms] OR "thorax"[All Fields] OR "thoracic"[All Fields]	281,829
21	("thorax"[MeSH Terms] OR "thorax"[All Fields] OR "thoracic"[All Fields]) AND ("spine"[MeSH Terms] OR "spine"[All Fields])	25,939
22	"thorax"[MeSH Terms] OR "thorax"[All Fields]	71,624
23	thoracic vertebra[All Fields] OR thoracic vertebrae[All Fields] OR thoracic vertebral[All Fields] OR thoracic vertebras[All Fields] OR	17,495

	thoracic vertebrate[All Fields]	
24	#20 OR #21 OR #22 OR #23	281,829
25	#3 AND #19 AND #24	2,926

Search strategy for EMBASE run on 03/06/2015

No	Search	Results
1	‘scoliosis’/exp OR scoliosis	26,776
2	scolioses	586
3	#1 OR #2	26,827
4	fusion	193,049
5	spinal AND fusion	18,393
6	spinal AND fusions	1,713
7	spine AND fusion	27,714
8	spine AND fusions	2,494
9	spine AND surgery	91,984
10	spinal AND surgery	97,831
11	spondylodesis	1,798
12	spondylodeses	27
13	Spondylosyndesis	13
14	Spondylosyndeses	0
15	Arthrodesis	15,780
16	Surgical AND approach	177,867
17	Spine AND fusion AND implant	2,462
18	Spinal AND fusion AND implant	1,676

19	(#4 OR #5 OR #6 OR #7 OR #8 OR #9 OR #10 OR #11 OR #12 OR #13 OR #14 OR #15 OR #16 OR #17 OR #18)	487,447
20	Thoracic	352,785
21	Thoracic AND spine	21,203
22	Thorax	304,700
23	Thoracic AND vertebra*	13,577
24	#20 OR #21 OR #22 OR #23	589,359
25	#3 AND #19 AND #24	3,301

Search strategy for CINAHL run on 03/06/2015

No	Search	Results
1	TX scoliosis	4,327
2	TX scolioses	26
3	#1 OR #2	4,351
4	TX fusion	15,071
5	TX spinal fusion	5,212
6	TX spinal fusions	627
7	TX spine fusion	4,117
8	TX spine fusions	527
9	TX spine surgery	14,912
10	TX spinal surgery	20,169
11	TX spondylodesis	34
12	TX spondylodeses	0
13	TX Spondylosyndesis	0

14	TX Spondylosyndeses	0
15	TX arthrodesis	2,531
16	TX surgical approach	43,391
17	TX spine fusion implant	473
18	TX spinal fusion implant	504
19	#4 OR #5 OR #6 OR #7 OR #8 OR #9 OR #10 OR #11 OR #12 OR #13 OR #14 OR #15 OR #16 OR #17 OR #18	73,726
20	TX thoracic	29,283
21	TX thoracic spine	5,481
22	TX thorax	6,968
23	TX thoracic vertebra*	4,760
24	#20 OR #21 OR #22 OR #23	33,712
25	#3 AND #19 AND #24	973

Search strategy for CENTRAL run on 03/06/2015

No	Search	Results
1	scoliosis	688
2	scolioses	2
3	#1 OR #2	688
4	fusion	3,900
5	spinal fusion (word variations have been searched)	1407
6	spinal fusions (word variations have been searched)	1407
7	spine fusion (word variations have been searched)	1,250
8	spine fusions (word variations have been searched)	1,250

9	spine surgery (word variations have been searched)	2,803
10	spinal surgery (word variations have been searched)	5,701
11	spondylodesis (word variations have been searched)	32
12	spondylodeses (word variations have been searched)	3
13	Spondylosyndesis (word variations have been searched)	0
14	Spondylosyndeses (word variations have been searched)	0
15	Arthrodesis (word variations have been searched)	266
16	Surgical approach [(word variations have been searched)	6,937
17	Spine fusion implant (word variations have been searched)	188
18	Spinal fusion implant	192
19	(#4 OR #5 OR #6 OR #7 OR #8 OR #9 OR #10 OR #11 OR #12 OR #13 OR #14 OR #15 OR #16 OR #17 OR #18)	15,842
20	Thoracic (word variations have been searched)	15,882
21	Thoracic spine (word variations have been searched)	603
22	Thorax (word variations have been searched)	4,631
23	Thoracic AND vertebra*	627
24	#20 OR #21 OR #22 OR #23	19,370
25	#3 AND #19 AND #24	86

Search strategy for SCOPUS run on 03/06/2015

No	Search	Results
1	ALL(“scoliosis”)	39,668
2	ALL(“scolioses”)	39,668
3	#1 OR #2	39,668

4	ALL(“Fusion”)	1,012,711
5	ALL(“spinal fusion”)	30,918
6	ALL(“spinal fusions”)	30,918
7	ALL(“spine fusion)	23,990
8	ALL(“spine fusions)	23,990
9	ALL(“spine surgery”)	30,371
10	ALL(“spinal surgery”)	17,567
11	ALL(“spondylodesis”)	2,729
12	ALL(“spondylodeses”)	40
13	ALL(“Spondylosyndesis”)	30
14	ALL(“Spondylosyndeses”)	0
15	ALL(“Arthrodesis”)	30,743
16	ALL(“Surgical approach”)	120,169
17	ALL(“Spine fusion implant”)	50
18	ALL(“Spinal fusion implant”)	40
19	#4 OR #5 OR #6 OR #7 OR #8 OR #9 OR #10 OR #11	10,748
20	#12 OR #13 OR #14 OR #15 OR #16 OR #17 OR #18	148,274
21	#19 OR #20	155,395
22	ALL(“thoracic”)	775,519
23	ALL(“thoracic spine”)	16,576
24	ALL(“thorax”)	436,911
25	ALL(“thoracic vertebra*)	19,841
26	#22 OR #23 OR #24 OR #25	1,039,299
27	# 3 AND #21 AND #26	4,049

Search strategy for Web of Knowledge run on 03/06/2015

No	Search	Results
1	TS=(scoliosis)	57,599
2	TS=(scolioses)	57,599
3	#1 OR #2	57,599
4	TS=(fusion)	1,216,034
5	TS=(spinal fusion)	56,938
6	TS=(spinal fusions)	56,938
7	TS=(spine fusion)	43,747
8	TS=(spine fusions)	43,747
9	TS=(spine surgery)	88,174
10	TS=(spinal surgery)	178,098
11	TS=(spondylodesis)	859
12	TS=(spondylodeses)	28
13	TS=(Spondylosyndesis)	20
14	TS=(Spondylosyndeses)	0
15	TS=(arthrodesis)	32,206
16	TS=(surgical approach)	313,362
17	TS=(spine fusion implant)	6,526
18	TS=(spinal fusion implant)	8,116
19	#4 OR #5 OR #6 OR #7 OR #8 OR #9 OR #10 OR #11 OR #12 OR #13 OR #14 OR #15 OR #16 OR #17 OR #18	1,695,591
20	TS=(thoracic)	506,229

21	TS=(thoracic spine)	39,079
22	TS=(thorax)	177,404
23	TS=(thoracic vertebra*)	154,823
24	#20 OR #21 OR #22 OR #23	639,964
25	#3 AND #19 AND #24	3,046

Search strategy for Mednar run on 03/06/2015

No	Search	Results
1	“Adolescent idiopathic scoliosis” AND fusion	71

Search strategy for ProQuest theses run on 03/06/2015

No	Search	Results
1	“idiopathic scoliosis” AND fusion	316

Search strategy for Grey Source/Open Grey run on 03/06/2015

No	Search	Results
1	Scoliosis	48

Search strategy for Index to Theses run on 03/06/2015

No	Search	Results
1	Scoliosis	69

Search strategy for Libraries Australia run on 03/06/2015

No	Search	Results
1	“adolescent idiopathic scoliosis” – 49 results, 0 included	49

APPENDIX II: APPRAISAL INSTRUMENTS

JBI Critical Appraisal Checklist for Randomised Control / Pseudo-randomised Trial

Reviewer _ Date _

Author _ Year _ _ _ _ _ _ _ Record Number _ _ _ _ _ _ _

	Yes	No	Unclear	Not Applicable
1. Was the assignment to treatment groups truly random?	☐	☐	☐	☐
2. Were participants blinded to treatment allocation?	☐	☐	☐	☐
3. Was allocation to treatment groups concealed from the allocator?	☐	☐	☐	☐
4. Were the outcomes of people who withdrew described and included in the analysis?	☐	☐	☐	☐
5. Were those assessing outcomes blind to the treatment allocation?	☐	☐	☐	☐
6. Were the control and treatment groups comparable at entry?	☐	☐	☐	☐
7. Were groups treated identically other than for the named interventions	☐	☐	☐	☐
8. Were outcomes measured in the same way for all groups?	☐	☐	☐	☐
9. Were outcomes measured in a reliable way?	☐	☐	☐	☐
10. Was appropriate statistical analysis used?	☐	☐	☐	☐
	☐	☐	☐	☐

Overall appraisal: Include ☐ Exclude ☐ Seek further info. ☐

Comments (Including reason for exclusion)

Figure 36: JBI-MAStARI critical appraisal checklist for randomised control or pseudo-randomised trial

JBI Critical Appraisal Checklist for Descriptive / Case Series

Reviewer ______________________ Date ______________________

Author ________________________ Year ______ Record Number ______

	Yes	No	Unclear	Not Applicable
1. Was study based on a random or pseudo-random sample?	☐	☐	☐	☐
2. Were the criteria for inclusion in the sample clearly defined?	☐	☐	☐	☐
3. Were confounding factors identified and strategies to deal with them stated?	☐	☐	☐	☐
4. Were outcomes assessed using objective criteria?	☐	☐	☐	☐
5. If comparisons are being made, was there sufficient descriptions of the groups?	☐	☐	☐	☐
6. Was follow up carried out over a sufficient time period?	☐	☐	☐	☐
7. Were the outcomes of people who withdrew described and included in the analysis?	☐	☐	☐	☐
8. Were outcomes measured in a reliable way?	☐	☐	☐	☐
9. Was appropriate statistical analysis used?	☐	☐	☐	☐

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

Comments (Including reason for exclusion)

Figure 37: JBI-MAStARI critical appraisal checklist for descriptive or case series

JBI Critical Appraisal Checklist for Comparable Cohort/ Case Control

Reviewer _ Date _

Author _ Year _ _ _ _ _ _ Record Number _ _ _ _ _ _

	Yes	No	Unclear	Not Applicable
1. Is sample representative of patients in the population as a whole?	☐	☐	☐	☐
2. Are the patients at a similar point in the course of their condition/illness?	☐	☐	☐	☐
3. Has bias been minimised in relation to selection of cases and of controls?	☐	☐	☐	☐
4. Are confounding factors identified and strategies to deal with them stated?	☐	☐	☐	☐
5. Are outcomes assessed using objective criteria?	☐	☐	☐	☐
6. Was follow up carried out over a sufficient time period?	☐	☐	☐	☐
7. Were the outcomes of people who withdrew described and included in the analysis?	☐	☐	☐	☐
8. Were outcomes measured in a reliable way?	☐	☐	☐	☐
9. Was appropriate statistical analysis used?	☐	☐	☐	☐

Overall appraisal: Include ☐ Exclude ☐ Seek further info. ☐

Comments (Including reason for exclusion)

Figure 38: JBI-MASTARI critical appraisal checklist for comparable cohort or case control studies

APPENDIX III: DATA EXTRACTION INSTRUMENTS

JBI Data Extraction Form for
Experimental / Observational Studies

Reviewer ________________________ Date ________________________

Author ________________________ Year ________________________

Journal ________________________ Record Number ________________

Study Method

RCT	☐	Quasi-RCT	☐	Longitudinal	☐
Retrospective	☐	Observational	☐	Other	☐

Participants

Setting ________________________

Population ________________________

Sample size

Group A ________________ Group B ________________

Interventions

Intervention A ________________________

Intervention B ________________________

Authors Conclusions:

Reviewers Conclusions:

Study results

Dichotomous data

Outcome	Intervention ( ) number / total number	Intervention ( ) number / total number

Continuous data

Outcome	Intervention ( ) number / total number	Intervention ( ) number / total number

Figure 39: JBI-MAStARI data extraction form for experimental and observational studies

APPENDIX IV: TABLE OF INCLUDED STUDIES

Study and Year	Location	Design	Population	Included patient number	Curve type(s)	Mean Follow-up (range)	Approach	Treatment Arms or Comparators	Outcomes measured
Behensky 2007	Austria/UK	Retrospective observational	Radiographic review of 36 patients with AIS treated with selective thoracic fusion	36	Lenke 3C curves	38 months (25-82)	Posterior	Compensated (10) Vs Decompensated (26)	MT Curve, CL Curve, CB, TK, LL, SB, Complications
Chang 2010	USA	Retrospective observational	Long term evaluation of 32 patients with AIS treated with selective thoracic fusion	32	Lenke 1C and Lenke 2C curves	81.6 months (50.4-284.4)	Undetermined		MT curve, CL curve, CB, SB Complications, Quality of Life
Demura 2013	USA/Japan	Retrospective Observational	Review of coronal decompensation in 71 patients with AIS treated with selective thoracic fusion and non-selective spinal fusion	53	Lenke 1C curves	Minimum 2 year follow-up	Undetermined	Selective thoracic fusion Vs Non-selective spinal fusion	MT curve, CL curve Complications
Dobbs 2004	USA	Retrospective observational	Radiographic review 100 patients with AIS treated with anterior or posterior selective thoracic fusion	100	Lenke lumbar modifier B and C curves	Minimum 2 year follow-up	Anterior (56), Posterior (44)	Anterior Vs Posterior	MT curve, CL curve

Dobbs 2006	USA	Retrospective observational	Review of 66 patients with AIS treated with selective thoracic fusion	66	Lenke lumbar modifier C curves	48 months in hook group (24-120), 36 months in pedicle screw group (24-60)	Posterior	Hook group Vs Pedicle screw group	MT curve, CL curve, CB Complications
Edwards 2004	USA	Retrospective observational	Outcomes of 44 patients with AIS treated with selective thoracic fusion	41	Lenke lumbar modifier C	32.4 months in the anterior group (24-56.4), 67 months in the posterior group (24-181.2)	Anterior (15), Posterior (26) Both (3) – excluded	Anterior Vs Posterior	MT curve, CL curve, CB Complications, Quality of Life
Engsberg 2003	USA	Prospective Case Series	Evaluation of gait and spinal motion in 31 patients with AIS treated with selective thoracic fusion	16	Lenke lumbar modifier B and C curves	Minimum 2 year follow-up	Anterior (10), Posterior (6) 15 patients excluded due to fusion level	Anterior Vs Posterior	MT curve
Frez 2000	Hong Kong	Retrospective Observational	Review of 24 patients with AIS treated with selective thoracic fusion	24	King type II curves	46 months (36-96)	Posterior		MT curve, CL curve, TK, LL
Goshi 2004	USA	Retrospective Observational	Review of 22 patients with idiopathic scoliosis who underwent translational	6	Lenke 1 curves with lumbar	63 months (49-75)	Posterior		MT curve, CL curve, CB, AVR-Lumbar

			corrective techniques. 8 patients excluded for adult idiopathic scoliosis 8 patients excluded for Lenke lumbar modifier A.		modifier B or C				
Gotfryd 2013	Brazil	Randomised clinical trial	To analyse the impact of different pedicle screw density on clinical, functional and radiographic outcomes for patients with AIS	46	Lenke 1A and 1B curves	Minimum 2 year follow-up	Posterior	Strategically determined pedicle screws Vs segmental instrumentation	MT curve, CL curve, TK Complications
Graham 2000	USA	Prospective case series	Evaluation of pulmonary function tests following selective thoracic fusion in 51 patients with AIS	51		Minimum 2 year follow-up	Anterior	Single thoracotomy Vs double thoracotomy	MT curve, TK, Pulmonary function
Haber 2012	USA	Retrospective Observational	Analysis of long term results of Kaneda Anterior Scoliosis System for thoracic AIS in 16 patients. 2 patients excluded due to age, 1 due to short follow-up.	13	Lenke 1 and 2 curves	52.4 months (24-74.4)	Anterior		MT curve Complications, Quality of Life

Ilgenfritz 2013	USA	Prospective	Review of 24 patients with AIS treated with selective thoracic fusion	24	Lenke 1C curves	Minimum 5 years follow-up	Anterior (17), Posterior (7)		MT curve, CL curve, CB, TK, LL, AVR-lumbar
Kamimura 1999	Japan	Retrospective Observational	Analysis of results of Zielke instrumentation for selective thoracic fusion in 17 patients with AIS	17	King type II, III, IV, V curves	45.6 months (36-72)	Anterior		MT curve, CL curve, TK, LL
Kim 2007[91]	Korea	Retrospective Observational	Analysis of the effects of anterior selective thoracic fusion in 42 patients with AIS	42	Lenke 1 curves	35 months (24-48)	Anterior		MT curve, TK, LL, SB Complications
Lenke 1999	USA	Retrospective Observational	Review of selective thoracic fusion in 123 patients with AIS	123	Lenke 1 curves	Minimum 2 year follow-up	Anterior (70), Posterior (53)	Anterior Vs Posterior	MT curve, CL curve
Liljenqvist 2013	Germany	Prospective case series	Review of anterior selective thoracic fusion in 28 patients with AIS on the lumbar curve	28	Lenke 1C and 2C curves	47 months (24-84)	Anterior		MT curve, CL curve, CB, TK, LL, AVR thoracic, AVR lumbar
Liu 2014	China	Retrospective Observational	Comparison of sagittal profiles of selective posterior thoracic fusion in 42 patients with AIS	42	Lenke 1 curves	Minimum 2 year follow-up	Posterior	Pedicle screws Vs Hybrid Hooks/Screws	MT curve, CL curve, TK, LL, SB
Lonner	USA	Retrospective	Comparison of anterior versus posterior approach	28	Lenke 1	31 months	Anterior		MT curve, CB, TK Complications, Quality of

2006		Observational	scoliosis surgery for 51 patients with AIS. Anterior approach using the selective thoracic fusion. Posterior approach group excluded due to use of non-selective spinal fusion		curves	(24-43)			Life, Pulmonary function
McCance 1998	USA	Retrospective Observational	Review of 67 patients King type II AIS curves treated with selective thoracic fusion	67	King type II curves	66 months (24-288)	Posterior	Compensated (47) Vs Decompensated (20)	MT curve, CL curve, CB, TK, LL, SB Complications
Mladenov 2011	Germany	Retrospective Observational	Evaluate the effect of direct vertebral derotation on 30 patients with AIS treated with selective thoracic fusion	30	Lenke type 1 curves	Minimum 2 year follow-up	Posterior	Direct vertebral de-rotation (17) Vs Simple rod rotation(13)	MT curve, CB, TK, LL, SB
Morr 2015	USA	Retrospective Observational	Review of 40 patients with AIS treated with selective thoracic fusion	40	Lenke type 1 curves	28 months in the CON group (24-34), and 29 months in the SKP group (24-36)	Posterior	Pedicle screws bilaterally at every level (CON group) (20), Vs Skipped level on the convex side (SKP group) (20)	MT curve, CL curve, TK, Quality of Life
Na 2010	Germany	Retrospective	Review of 28 patients with AIS treated with selective	28		50.1 months	Anterior		MT curve, CL curve, CB

		Observational	thoracic fusion			(25-116)			Complications
Newton 2010	USA	Retrospective Observational	Review of 251 patients with AIS treated with selective thoracic fusion	251	Lenke type 1 curves	Minimum 2 year follow-up	Anterior (168), Posterior (83)	Anterior Vs Posterior	MT curve, TK, LL
Patel 2008	USA	Retrospective Observational	Review of 176 patients with AIS treated with selective thoracic fusion to evaluate the spontaneous lumbar curve correction	176	Lenke lumbar modifier B and C curves	Minimum 2 year follow-up	Anterior (132), Posterior (44)	Anterior Vs Posterior	MT curve, CL curve, CB
Potter 2005	USA	Retrospective Observational	To compare correction in 25 patients with AIS treated with anterior selective thoracic fusion against posterior thoracic fusion	25	Lenke 1B and 1C curves	44.1 months in the anterior group (24-80), and 55.1 months in the posterior group (25-83)	Anterior (14), Posterior (11)	Anterior Vs Posterior	MT curve, CL curve
Schulz 2004	USA	Retrospective Observational	Review of 106 patients with AIS treated with selective thoracic fusion	106	Lenke lumbar modifier C curves	Minimum 2 year follow-up	Posterior		MT curve, CL curve
Studer 2015	Australia	Retrospective Observational	Review of 16 patients with AIS treated with selective thoracic fusion	16	Lenke lumbar modifier B and C curves	Minimum 2 year follow-up	Posterior		MT curve, CL curve, CB, TK, LL, SB, AVR-thoracic, AVR-lumbar Complications

Takahashi 2011	USA/Japan	Retrospective Observational	To determine how selection of the LIV affects 172 patients with AIS treated with selective thoracic fusion	172	Lenke lumbar modifier B and C curves	Minimum 2 year follow-up	Undetermined	Stable vertebra below end vertebra (93), stable vertebra at end vertebra (66), stable vertebra below end vertebra (13)	MT curve, CL curve, CB Complications
Tao 2011	China	Randomised prospective study	72 patients were fused using either apical vertebra or the neutral vertebra to determine their LIV. The group using the neutral vertebra were excluded from our current group for not using selective thoracic fusion.	36	Lenke type 1 curves	36 months (25-55)	Posterior	Apical vertebral group (selective thoracic fusion) Vs Neutral vertebral group (non-selective spinal fusion)	MT curve, CB, TK Complications
Van Rhijn 2002	Netherlands	Retrospective Observational	Review of 27 patients with AIS treated with selective thoracic fusion. 2 patients were excluded due to age, and 2 patients were excluded for LIV lower than L2	23	King type II curves	72 months (24-100)	Posterior		MT curve, CL curve, TK, LL, AVR-thoracic, AVR-lumbar
Wang 2012	Denmark	Retrospective Observational	Review of trunk shift in 44 patients with AIS treated with selective thoracic	44	Lenke 1C curves	Minimum 2 year follow-up	Posterior	Trunk shift group (14) Vs No-trunk shift group (30)	MT curve, CL curve

			fusion						
Wong 2004	Singapore	Retrospective Observational	Review of 31 patients with AIS treated with anterior selective thoracic fusion compared with posterior selective thoracic fusion. 13 patients were excluded due to LIV lower than L2	18		44 months (25-97)	Anterior (10), Posterior (8)	Anterior approach Vs Posterior approach	MT curve, CL curve
Yong 2012	Australia	Retrospective Observational	Review of 24 patients with AIS treated with selective thoracic fusion	24	Lenke 1C curve	Minimum 2 year follow-up	Anterior		MT curve, CL curve, TK Complications, Quality of Life

Table 9: Table of included studies.

Legend: AIS: adolescent idiopathic scoliosis. MT: main thoracic. CL: compensatory lumbar. CB: coronal balance. TK: thoracic kyphosis. LL: lumbar lordosis. SB: sagittal balance, LIV: lowest instrumented vertebra.

APPENDIX V: LIST OF EXCLUDED STUDIES

Conference Abstract (45)

1. Akbar M, Carsten's C and Wiedenhofer B. Evaluation of the sagittal profile of surgically treated adolescent idiopathic scoliosis (AIS) patients. Eur Spine J 2010;19(11):2041
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4. Bakaloudis G and Lolli F. Sagittal plane alignment after posterior fusion in adolescent idiopathic scoliosis: Pedicle screw-only vs. hybrid constructs m di silvestre. Eur Spine J 2011; 20(4):S428-S429
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7. Blondel B, Jouve JL, Jacopin S, Lafage V and Bollini G. Reciprocal changes in sagittal balance following posterior fusion in the management of adolescent idiopathic scoliosis. Eur Spine J 2011;20(7):1202
8. Blondel B, Jouve JL, Lafage V, Jacopin S and Bollini G. Idiopathic adolescent scoliosis: Which form of correction should be preferred? Eur Spine J 2011;20(7):1203
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10. Carlos BP, Jesus BF, Gabriel PV, Jose Ignacio MP, Pedro DF, Jaime SR, et al. Cervical sagittal plane decompensation after surgical correction of idiopathic scoliosis and its relationship with postoperative thoracic kyphosis. Eur Spine J 2013; 22(1): 231-232.
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12. Di Silvestre M, Balsano M, Lolli F, Greggi T, Bakaloudis G, Vommaro F, et al.

Vertebral rotation correction and posterior fusion for thoracic adolescent idiopathic scoliosis: Direct derotation vs simple concave rod procedure. Eur Spine J 2012; 21: S317.

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15. Elmalky M, Arealis G and Grevitt M. Determinants of lumbar curve behaviour in Lenke type I A&B thoracic adolescent idiopathic scoliosis treated by posterior spinal fusion. Eur Spine J 2014; 23: S493-S494.
16. Fernandez Varela T, Mhaidli Hamdan H, Montesdeoca Ara A and Lorenzo Rivero JA. The structural proximal thoracic curve and shoulder balance in adolescent idiopathic scoliosis treated with posterior instrumentation. Eur Spine J 2014; 23(1): 273.
17. Finocchiaro FM, Costantini S, Nena U, Lo Scalzo V, Bernabei A and Fabris Monterumici DA. Adolescent idiopathic scoliosis. comparison of different methods of intraoperative correction. Eur Spine J 2013; 22(4): 916.
18. Harshavardhana NS, Sedra F, Mahmood B, Altaf F and Noordeen MHH. Surgical results of posterior spinal fusion in adolescent idiopathic scoliosis: Correlation of clinico-radiological results with implant density. Eur Spine J 2012; 21: S242-S243.
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and clinical results 13 years after ASF. Eur Spine J 2014; 23(11): 2488.
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31. Mladenov K, Vaterlein C and Stucker R. Sagittal Profile after direct vertebral derotation and selective posterior spinal fusion in Lenke Type 1 adolescent idiopathic scoliosis. Eur Spine J 2011; 20(11): 1984.
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33. Ozturk C, Alanay A, Enercan M, Karadeniz E, Baliolu M and Hamzaoglu A. Kyphosis restoration or maintenance in patients with Lenke type I scoliosis treated by pedicle screw construct: Is it really impossible by using 5.5 mm titanium rod. Eur Spine J 2011; 20(4): S428.
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