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Secondary curve behaviour in Lenke Type 1C adolescent idiopathic scoliosis following thoracoscopic selective anterior thoracic fusion

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Structured Abstract

Study Design. Analysis of a case series of 24 Lenke 1C adolescent idiopathic scoliosis (AIS) patients receiving selective thoracoscopic anterior scoliosis correction.

Objective. To report the behaviour of the compensatory lumbar curve in a group of Lenke IC AIS patients following thoracoscopic anterior scoliosis correction, and to compare the results of this study with previously published data.

Summary of Background Data. Several prior studies have reported spontaneous lumbar curve correction for both anterior and posterior selective fusion in Lenke 1C/King-Moe II patients; however to our knowledge no previous studies have reported outcomes of thoracoscopic anterior correction for this curve type.

Methods. All AIS patients with a curve classification of Lenke 1C and a minimum of 24 months follow-up were retrieved from a consecutive series of 190 AIS patients who underwent thoracoscopic anterior instrumented fusion. Cobb angles of the major curve, instrumented levels, compensatory lumbar curve, and T5-T12 kyphosis were recorded, as well as coronal spinal balance, T1 tilt angle and shoulder balance. All radiographic parameters were measured before surgery and at 2, 6, 12 and 24 months after surgery.

Results. Twenty-four female patients with right thoracic curves had a mean thoracic Cobb angle of 53.0° before surgery, decreasing to 24.9° two years after surgery. The mean lumbar compensatory Cobb angle was 43.5° before surgery, spontaneously correcting to 25.4° two years after surgery, indicating balance between the thoracic and lumbar scoliotic curves. The lumbar correction achieved (41.8%) compares favourably to previous studies.

Conclusions. Selective thoracoscopic anterior fusion allows spontaneous lumbar curve correction and achieves coronal balance of main thoracic and compensatory lumbar curves, good cosmesis and patient satisfaction. Correction and balance are maintained 24 months after surgery.

Key points

- Several studies have reported on spontaneous lumbar curve correction for both anterior and posterior selective thoracic fusion in Lenke 1C patients, however no previous studies have reported outcomes of thoracoscopic anterior correction for this curve type.

- Two years after surgery, the mean Cobb angle of the major thoracic curve (24.9°) balanced the Cobb angle of the lumbar compensatory curve (25.4°) for a group of twenty four Lenke 1C patients who underwent thoracoscopic anterior fusion for AIS.

- The lumbar correction achieved (41.8%) compares favourably to previous studies.

- Single rod anterior scoliosis constructs are well suited to achieving the desired correction of the major thoracic curve, allowing spontaneous correction of the lumbar curve and a balanced spine.

Introduction

The goal of corrective surgery in Adolescent Idiopathic Scoliosis (AIS) is to achieve global spinal balance with optimal coronal and sagittal alignment and axial derotation, while sparing motion segments above and below the fusion construct. The selection of spinal levels to be instrumented, in particular the distal fusion level is a key issue in the treatment of primary thoracic scoliosis with a significant lumbar compensatory curve. Previous authors have focussed on the flexibility of the lumbar spine and the associated increased likelihood of back pain and degenerative changes with a more distal fusion into the mid and lower lumbar spine.[1-3]

In Lenke Type 1C[4,5] curves (equivalent to a Type II in the King-Moe classification[6,7]), the patient presents with a primary structural thoracic curve and a significant compensatory lumbar curve (Figure 1). Several previous studies have reported on spontaneous correction of the unfused compensatory lumbar curve in Lenke 1C/King-Moe II patients following posterior selective fusion (PSF) of the thoracic spine, and the potential for decompensation of these curves with time after surgery.[8-18] Unfused lumbar curve correction has also been reported for this curve type following open thoracic anterior approaches.[3,14,15,17,19,20] Potential advantages of the anterior approach in the thoracic spine are the ability to spare fusion levels and restore kyphosis,[3,21-23] with Betz *et al* [3] and Lowe *et al*[22] reporting savings of two or three distal fusion levels compared to an equivalent posterior fusion. However, open anterior approaches in the thoracic spine significantly disrupt the chest wall and permanently reduced pulmonary function has been reported.[24-26]

Thoracoscopic anterior instrumented fusion is an accepted alternative to open approaches in the correction of major thoracic curve[27-30] with pulmonary function recovering to and/or exceeding preoperative levels by 12 to 24 months after surgery.[31,32] The thoracoscopic approach also allows smaller skin incisions, less blood loss and soft tissue dissection than open anterior or posterior procedures.[30,33,34] To our knowledge, the behaviour of the unfused lumbar curve in exclusively Lenke 1C patients following thoracoscopic anterior scoliosis correction has not been reported to date.

The purpose of this study is to report the behaviour of the compensatory lumbar curve in a group of Lenke IC AIS patients following thoracoscopic anterior scoliosis correction, and to compare the results of this study with previously published data. Our hypothesis is that thoracoscopic anterior scoliosis correction in Lenke 1C curves consistently achieves spontaneous correction of the uninstrumented lumbar spine with comparable outcomes to previously reported studies, and with no lumbar decompensation over time.

Methods

Patient selection

All patients with a curve classification of Lenke 1C were retrieved from a consecutive series of 190 AIS patients who underwent thoracoscopic anterior instrumented fusion by the two senior authors (GNA and RDL) at the Mater Children's Hospital, Brisbane, Australia between September 2000 and June 2011. All patients shared the following characteristics; female, the diagnosis of primary thoracic AIS, Lenke type 1C curves with the apex of the major thoracic curve convex to the right with compensatory lumbar curve to the left, with a minimum of 24 months follow-up.

Surgical technique

The procedures were performed by the two senior authors and the surgical technique has been reported previously.[32, 35] The anterior instrumentation system used was either Legacy (n=12) or Eclipse (n=12) systems (Medtronic Sofamor Danek, Memphis, TN) utilising a single 4.5 mm (n=8) or 5.5 mm (n=16) titanium rod. The bone graft material used was mulched autograft (rib heads for 4 cases, iliac crest for 1 case) or mulched femoral head allograft (19 cases) which is now the standard practice.

Radiographic evaluation

Posteroanterior (PA), lateral (Lat) and bending radiographs of the spine were obtained before surgery. Bending radiographs included a fulcrum bending radiograph[36,40] to assess correctibility of the thoracic curve and an active side bending radiograph to assess correctibility of the compensatory curve (Figure 2). Standard full length PA and Lat radiographs were also performed at 2, 6, 12, and 24 months after surgery. Pre-operative radiographs were used to classify the type of scoliosis according to the Lenke classification system.[4] Skeletal maturity was assessed using the Risser method.[37]

Radiographic parameters were measured using the Cobb method[38] by independant experienced spinal orthopaedic surgeons, according to the Spinal Deformity Study Group's *Radiographic Measurement Manual.*[39] The following radiographic parameters were investigated; Cobb angle of the major curve, Cobb angle of the instrumented levels, Cobb angle of the compensatory lumbar curve, Cobb angle of the T5-T12 kyphosis, coronal spinal balance, T1 tilt angle and shoulder balance. All radiographic parameters were measured prior to surgery and at 2, 6, 12 and 24 months after surgery.

After surgery, we distinguished between the major Cobb angle and the instrumented Cobb angle.[30, 32, 35, 40, 41] The instrumented Cobb angle is measured only for the instrumented vertebral levels, and therefore does not always encapsulate the full extent of the postoperative major curve (Figure 1). The major Cobb angle and compensatory lumbar Cobb angles are a true measure according to the definition of Cobb, that is, between the most inclined endplates at the proximal and distal ends of the postoperative curves, regardless of what level the instrumentation starts and finishes. As a result, either of these Cobb angles may include levels that are instrumented or uninstrumented, and are bound by selecting the most inclined endplates at the extremes of the curves.

Quality of life questionnaire

Clinical outcomes were measured using the SRS-24 questionnaire at the 24 month review.

Data analysis

The curve correction or correction rate is defined as the difference in Cobb angle after surgery divided by the Cobb angle before surgery and is expressed as a percentage. Coronal spinal balance is defined as the offset distance in centimetres of the C7 plumb line from the CSVL. Shoulder balance is defined as the vertical distance between left and right shoulders. T1 tilt is defined as the T1 cephalad vertebral endplate angle. For the analysis of deformity correction behaviour over time, patients were analysed according to their coronal spinal balance, shoulder balance, T1 tilt and thoracic kyphosis before surgery. In analysing the shoulder balance, left shoulder elevation was assigned a positive value, right elevation a negative value and zero denoting level shoulders. Similarly for the T1 tilt angle, when the left edge of the vertebral body is higher, the tilt angle is defined as positive, and vice versa, with a horizontal endplate denoting zero tilt. For coronal balance, a negative value denotes deviation of the C7 plumb line to the left of the CSVL, zero coronal balance implies alignment, and a positive coronal balance is deviation of C7 to the right of the CSVL. After grouping according to the criteria defined above, each radiographic parameter was expressed at each time point in terms of means and standard deviations, and paired t-tests were performed to compare the value before surgery with the 2, 6, 12 and 24 month post-operative time points.

Lumbar spine decompensation was defined as the lumbar compensatory Cobb angle having increased by 10° or more on the 24 month radiograph relative to the immediate postoperative value. Coronal imbalance was deemed to have occurred when the C7 plumb line had deviated more than 2cm from the CSVL, and shoulder imbalance was defined as a difference in shoulder heights of more than 2cm.

Results

Twenty-four female patients with Lenke 1C curves met the inclusion criteria for the study. All major thoracic curves were convex to the right. The mean age at surgery was 14.8 ± 2.1 years (range, 10.8-22.4). With respect to skeletal maturity, four of the patients in the group were Risser 0; two were Risser 1; two were Risser 2; three were Risser 3; ten were Risser 4; and three were Risser 5. The mean major thoracic Cobb angle for the group before surgery was 53.0° ± 8.4 (range 40-75) and decreased to mean 21.5°± 7.9 (range 10-38) on the fulcrum bending radiographs. The mean secondary lumbar Cobb angle before surgery measured 43.5° ± 5.6 (range 34-55) and decreased to mean 11.5° ± 7.4 (range 0-25) on active side bending radiographs. At surgery, the mean number of levels instrumented was 6.8 ± 0.6 (range 6-8). Four patients were instrumented to T10, eleven to T11, and nine were instrumented to T12.

At the 24 months follow-up after surgery, the mean major thoracic Cobb angle measured 24.9° ± 5.9 (range 14-41) representing a 52.5% correction. The mean Cobb angle of the instrumented vertebral levels was 21.6° ± 6.2 (range 14-37), a correction rate of 58.9%. The mean compensatory lumbar Cobb angle was 25.4°± 6.6 (range 14-37) which represented a spontaneous correction of 41.8%. Figure 3 shows the change in mean major Cobb angle and mean compensatory Cobb angles measured before surgery and at each successive review appointment. Compensatory curves remained mostly stable during the follow-up period with one patient decreasing as much as 7° in contrast to one patient who increased 7° to reach a final Cobb angle of 30° which remained stable thereafter. No patients in the study group required any revision procedures despite four cases being found to have an asymptomatic rod fracture on the 24 month radiograph. These patients were followed up, with the most recent now five years after surgery and all curves have remained stable.

Changes in the mean T5-12 kyphosis Cobb angle before surgery and at each review appointment are displayed in Table 1. The values shown are for all study patients combined, as well as separate rows for the skeletally immature (Risser 0) patients, and all other patients (Risser 1-5) on the radiographs taken just prior to surgery.

With respect to shoulder balance, one of the 24 patients had an elevated left shoulder before surgery, seven patients had level shoulders, and 16 patients had an elevated right shoulder. Figure 4 shows the changes in shoulder balance during successive review appointments for these three subgroups (elevated left, level, and elevated right shoulders). At the 6 month radiograph, all patients with initial imbalance had achieved shoulder balance within ±0.5cm which remained stable through to the 24-month follow-up. Patients with level shoulders before surgery maintained shoulder balance throughout the follow-up period. Similarly for the T1 tilt angle, Figure 5 shows that the trend for each subgroup of patients closely follows the behaviour of the shoulder balance after surgery.

With respect to coronal spinal balance, the C7 vertebral body was deviated to the left of the CSVL before surgery in 13 of the 24 patients, aligned in 10 patients, and deviated to the right in one patient. Figure 6 shows the changes in coronal spinal balance during successive review appointments for these three subgroups (C7 left, aligned, and right of CSVL). Regardless of the coronal balance before surgery, all subgroups were deviated to the left of the CSVL immediately after surgery with a trend over time toward alignment with the CSVL. At the 24 month follow-up all patients had achieved coronal balance according to the previous stated definition.

SRS-24 questionnaire clinical outcome data was available for 22 of 24 (91.7%) patients at minimum 24 months after surgery (Table 2). For all patients surveyed, there was no individual question that scored below 3 points. In the satisfaction domain (3 questions) 86.4% of patients scored 12 or higher (out of possible 15). For the overall score (out of a possible 120), 70% of patients scored 100 or higher.

A detailed comparison of the results of this study with previous studies that report corrections of Lenke Type IC or King-Moe Type II patient groups at minimum 24 months after surgery is shown in Table 3. Cobb angles of the major thoracic curve as well as the compensatory lumbar curves are included, as well as the incidence of coronal and lumbar decompensation after surgery, where it has been reported. Figure 7 compares the balance achieved between the main and compensatory curves after surgery in the current study with previous studies of this curve type.

Discussion

From a patient cosmesis perspective, the balance achieved and therefore the appearance of the trunk is more important than the degrees of correction or the often reported correction rate. This concept is especially relevant for the patient with a significant lumbar compensatory curve or lumbar spine modifier ‘C’, with the optimal distal level of fusion chosen, debated by physicians since the 1940’s.[43] In this study we examined 24 patients with Lenke 1C curves who underwent selective thoracoscopic anterior thoracic fusion at a single centre with the hypothesis that spontaneous correction of the uninstrumented lumbar curve could be consistently achieved and trunk balance preserved with the single rod thoracoscopic technique.

The results presented show that selective thoracic fusion allows for spontaneous correction of the compensatory curve and restored coronal balance after surgery. Twenty-four months after surgery, the mean secondary curve Cobb angle (25.4°) was almost identical to the major thoracic Cobb angle (24.9º), indicating balance between the thoracic and lumbar scoliotic curves. The spontaneous lumbar curve correction of 41.8% compares favourably to previous studies (Table 3). Coronal balance, T1 tilt and shoulder balance continued to improve during the follow-up period without any significant imbalance found which indicates that overcorrection of the structural deformity was avoided. Patient satisfaction was high as evidenced by SRS questionnaire results (Table 2) which are comparable to those previously reported after this type of procedure[28,34,41,42].

Fusion extending into the lumbar spine can flatten lumbar lordosis, leading to an increased incidence of pain and degeneration.[1] However, selective thoracic fusion can only be considered successful if the unfused lumbar curve mirrors the correction achieved in the fused thoracic curve thus maintaining trunkal alignment in the coronal plane in combination with balanced shoulders. Therefore, as stated in 1948 by Von Lackum and Miller[43], it is desirable to achieve a correction of the primary thoracic curve that is not beyond the ability of the compensatory lumbar curve to balance the patient. This necessitates a thoracic correction based on the information gained before surgery from the bending radiographs. Note that the mean correction of the thoracic curve in this study to 24.9º (instrumented levels to 21.6 º) is a clinically equivalent measure to that predicted by the fulcrum bending radiograph (21.5º) before surgery.[40]

When dealing with lumbar curves of a larger magnitude (King-Moe II, Lenke Type 1C), the posterior approach, being capable of achieving strong corrective forces of the thoracic curve, is at risk of correcting the thoracic scoliosis beyond the capability of the lumbar curve to compensate and balance the spine.[9, 10, 12, 14, 15, 20, 44, 45] For instance, a study of 15 Lenke IC cases by Puno et al[13], reported a 39.4% spontaneous correction of the lumbar curve following selective posterior instrumentation of the thoracic curve but also noted a 27% coronal decompensation rate. The single rod anterior approach is less capable of achieving the high corrective forces of posterior systems so is well suited to achieving the desired selective thoracic correction when dealing with this curve type, with the added advantage of an immediate and sustained increase in thoracic kyphosis.[30]

To our knowledge there are only four studies reporting on deformity correction after selective anterior thoracic fusion exclusively for this curve type. A multi-site study in 1999[19] reported on a small group of Lenke 1C patients with either open anterior (n=7) or posterior (n=10) selective fusion of the thoracic spine, and found that anterior procedures provided better coronal correction of both the main thoracic and lumbar curves with no lumbar decompensation. Edwards et al[14] reported on 36 Lenke 1C patients treated with either open anterior (n=14) or posterior (n=22) selective fusion and although the authors concluded that correction and coronal balance were satisfactory, high rates of coronal imbalance (>2cm) were reported at final follow-up; 57% for anterior and 59% for posterior from the published radiographic data table. The only other study found (Dobbs et al[15]), reported groups of Lenke 1C patients who had open anterior (n=16) or posterior (n=19) selective thoracic fusion. This paper recommended limiting correction of the thoracic curve to mimic the correction achieved on a push-prone radiograph before surgery. Results showed that for both anterior and posterior groups, mean lumbar Cobb angle continued to decrease from immediately after surgery (mean Cobb=30.9° anterior, 32.4° posterior) to two years after surgery (mean Cobb=26.8° anterior, 28.8° posterior). Four of the posterior group developed coronal decompensation (imbalance) and none of the anterior group. The Chang et al.[20] study of long term outcomes of selective thoracic fusion in a group of Lenke 1C and 2C curves (7 open anterior, 25 posterior) observed that decompensation of lumbar curves (22%) occurred as a consequence of overcorrection of the thoracic curve and suggested that despite this, clinical outcomes were excellent. This study did not report which surgical approach was used in the cases where lumbar decompensation occurred.

We have found that there is inconsistency in the literature as to the definition of the term decompensation. Terms such as global balance, spinal balance, coronal balance, trunk shift, decompensation, lumbar decompensation, and coronal decompensation are often used interchangeably without clear definition. Coronal decompensation used interchangeably with Coronal imbalance is the most reliably defined term; a greater than 2cm shift of the C7 plumb line from the CSVL.[7, 15, 16] However Lenke et al[19] and Chang et al[18] chose to analyse their CSVL against the apex of the lumbar compensatory curve, while Bridwell et al[9] reported the deviation of the lowest fused segment from the CSVL, which makes comparison between studies difficult. Lumbar decompensation has been defined both as progression of the lumbar compensatory curve beyond the Cobb angle measured before surgery, but also as progression of the lumbar compensatory curve greater than 10° on the 24 month radiograph relative to the immediate postoperative value. We suggest that an agreed quantitative definition for decompensation measures would benefit future studies in this area.

It has also been suggested that anterior fusion surgery may induce an undesirable progression of thoracic kyphosis in skeletally immature (Risser 0) patients.[3, 46] In the current study, the Risser 0 patient group did demonstrate some increase in kyphosis (mean 5.3°) between the immediate post surgery and 2 year radiographs, but this progression was nearly identical to the Risser 1-5 group (mean 5.6°), see Table 1. Of the four patients who were Risser 0 at surgery, one had achieved Risser 5 and the others Risser 4 at 24 months follow-up, indicating that there was little potential for further spinal growth.[47] We note that no patient in the current study fell outside the normal T5-T12 kyphosis range of 10° to 40° at final follow-up.

Finally, we suggest that when assessing balance, the magnitude of the Cobb angle after surgery is more important than the correction rate. This is demonstrated in Figure 1, where the thoracic and lumbar Cobb correction rates for the patient shown were 63% and 48% respectively, which is not as useful as knowing that the thoracic and lumbar Cobb angles both measured within a few degrees of 20° after surgery.

Conclusion

We conclude that selective thoracoscopic anterior instrumented fusion allows spontaneous lumbar curve correction and achieves excellent coronal balance of main thoracic and compensatory lumbar curves. As a result good cosmesis and patient satisfaction are also achieved. Correction and balance are maintained 24 months after surgery, with a slight increase in T5-T12 thoracic kyphosis. These results suggest that thoracoscopic anterior instrumented fusion is a safe and effective method for preservation of lumbar motion segments as well as for restoration and maintenance of coronal balance in patients with lumbar curves of a larger magnitude.

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Figure Legends

Figure 1. PA radiographs of Lenke 1C patient in current study, taken before surgery and at 24 months after sugery. The Coronal Balance and Shoulder Balance remain excellent with good balance between the Major and Compensatory curves. The Instrumented Cobb angle after surgery is more than 5º less than the major thoracic Cobb angle but is not a useful measure after selective fusion surgery.

Figure 2. Example set of radiographs taken before surgery of a patient in the current study. (**A**) Full length PA standing radiograph, (**B**) Fulcrum bending radiograph to assess correctibility of major thoracic curve, (**C**) Active side bending radiograph to assess correctibility of lumbar compensatory curve, (**D**) Full length Lat standing radiograph.

Figure 3. Mean major thoracic and secondary lumbar curve Cobb angles measured on PA radiograph before surgery and at 2, 6, 12 and 24 months after surgery for all patients. Error bars represent ± 1 standard deviation. * indicates statistically significant difference (P<0.05) between the pre-operative and post-operative values.

Figure 4. Trends of shoulder balance before surgery and at 2, 6, 12 and 24 months after surgery for patient subgroups based on PA radiograph before surgery. Subgroup 1; left shoulder elevated (n=1), subgroup 2; right shoulder elevated (n=16) and subgroup 3; level shoulders (n=7). Error bars represent ±1 standard deviation. Note no errors bars or statistically significant differences are shown on the data series containing a single patient (left shoulder elevated before surgery). * indicates statistically significant difference (P<0.05) between the pre-operative and post-operative values.

Figure 5. Trends of T1 tilt angle before surgery and at 2, 6, 12 and 24 months after surgery for patient subgroups based on PA radiograph before surgery. Subgroup 1; left edge of endplate higher (n=4), subgroup 2; right edge higher (n=15), and subgroup 3; endplate horizontal (n=5). Note no errors bars are shown on several of the points in the data series because all patients in the data series had the same T1 tilt angle recorded at these time points. * indicates statistically significant difference (P<0.05) between the pre-operative and post-operative values.

Figure 6. Trends of coronal balance before surgery and at 2, 6, 12 and 24 months after surgery for patient subgroups based on PA radiograph before surgery. Subgroup 1; C7 deviated to left of CSVL (n=13), subgroup 2; C7 deviated to right of CSVL (n=1) and subgroup 3; C7 aligned with CSVL (n=10). Note no errors bars or statistically significant differences are shown on the data series containing a single patient (C7 deviated right of the CSVL before surgery). * indicates statistically significant difference (P<0.05) between the pre-operative and post-operative values.

Figure 7. The balance achieved between the main thoracic and lumbar compensatory curves 24 months after surgery comparing the present study with previous studies involving selective thoracic fusion surgery for Lenke 1C/King-Moe II patient groups.

Table 1. Changes in mean (±SD) T5-12 kyphosis Cobb angle (°) over time following surgical correction (before surgery, 2, 6, 12 and 24 months) for all patients in the current study, and the effect of skeletal maturity before surgery on thoracic kyphosis over time (Risser 0 vs Risser 1-5). * indicates statistically significant changes (paired t-test, P<0.05) relative to the pre-operative value.

	Before surgery	2 months	6 months	12 months	24 months
All patients (n=24)	17.6 ± 5.6	24.4 ± 5.5*	26.9± 6.3*	28.1 ± 5.9*	29.3 ± 5.1*
Risser 0 (n=4)	14.8 ± 3.2	21.0 ± 4.5*	26.5 ± 7.0*	24.3 ± 6.7*	26.8 ± 5.0*
Risser 1-5 (n=20)	18.2 ± 5.9	25.1 ± 5.5*	26.9 ± 6.3*	28.9 ± 5.6*	29.9 ± 5.2*

Table 2. SRS-24 mean total score and mean (±SD) scores for each domain at 24 months after surgical correction for all patients (n=24)

SRS-24 Questionnaire	Mean Score at 24 months (out of 5)
All 24 questions	3.8 ± 1.2
Pain	4.1 ± 1.3
General self image	3.6 ± 1.3
General function	3.9 ± 1.2
Activity level	4.2 ± 1.4
Postoperative self image	3.1 ± 1.1
Postoperative function	3.1 ± 1.2
Satisfaction	4.1 ± 1.4

Table 3. A comparison of the results of the present study with previous studies that report selective thoracic fusion of Lenke Type IC or King-Moe Type II patient groups. Mean Cobb angles (degrees) and correction rates (%) of the major thoracic curve as well as the compensatory lumbar curves at minimum 24 months after selective thoracic fusion surgery are included, as well as the incidence of coronal and lumbar decompensation and shoulder imbalance, if reported, in these studies. Note that studies are listed in chronological order of publication, and that studies containing anterior patients are highlighted in grey. Abbreviations: TSF (Thoracoscopic selective fusion), PSF (Posterior selective fusion), OASF (Open anterior selective fusion). * Note that the definition of coronal imbalance used in the 2010 Chang et al, study (>3cm) is different to those of all other studies in the table. See next page.

	1C or KM II	Major Cobb angle (degrees)	Major curve correction rate (%)	Compensatory Cobb angle (degrees)	Compensatory curve correction rate (%)	Lumbar spine decompensation (≥10°)	Coronal imbalance (>2cm)
Present study, TSF n=24	**1C**	**24.9**	**52.5**	**25.4**	**41.8**	**n = 0**	**n = 0**
1990 Kalen et al,[8] PSF n=46	KM II	39	25	22	31	Not reported	Not reported
1992 Bridwell et al,[9] PSF n=31	KM II	26.3	50.5	24.5	35.7	n = 6 (19.4%)	n = 7 (22.6%)
1992 Richards,[10] PSF n=24	KM II	24	61	29	41	n = 0	n = 0
1992 Roye et al,[12] PSF n=19	KM II	29	50	26.7	38	n = 1 (5.3%)	n = 6 (31.6%)
1999 Lenke et al,[19] OASF n=7	1C	27	59	21	50	n = 0	n = 0
1999 Lenke et al,[19] PSF n=10	1C	49	27	37	30	n = 0	n = 0
2003 Puno et al,[13] PSF n=15	1C	20.3	62.7	24.5	39.4	Not reported	4 (26.7%)
2004 Edwards et al,[14] OASF n=14	1C	32.5	42.6	29.4	33.9	n = 0	8 (57.1%)
2004 Edwards et al,[14] PSF n=22	1C	41.5	33.6	32.7	32.2	n = 0	11 (59.1%)
2004 Dobbs et al,[15] OASF n=16	1C	33.2	46.6	26.8	40.2	Not reported	n = 0
2004 Dobbs et al,[15] PSF n=19	1C	37.5	39.7	28.8	35.1	Not reported	4 (21.1%)
2005 Suk et al,[16] PSF n=122	KM II	16	69	12	62	Not reported	7 (5.7%)
2006 Schulte et al,[17] PSF n=9	IC	26.3	58.3	23.1	52.9	n = 0	Not reported
2007 Chang et al,[18] PSF n=37	1C, 2C	11	82.6	9	80.9	n = 0	Not reported
2010 Chang et al,[20] PSF n=25/OASF n=7	1C, 2C	39.8	36	33.2	25.3	2 (6.3%)	5 (22%)*