Review Article

Surgical treatment of severe adolescent idiopathic scoliosis through one-stage posterior-only approach: A systematic review and meta-analysis

ABSTRACT

The aim of this meta-analysis was to analyze the results of one-stage all-posterior spinal fusion for severe adolescent idiopathic scoliosis (AIS). A systematic search of articles about one-stage posterior spinal fusion for severe AIS was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. Data about population, pre-and postoperative radiographical data, surgical procedure details, and complications were extracted. Meta-analyses were performed when possible. Fourteen studies (640 patients) were included. The mean Cobb angle of the major curve varied from 80.0 ± 7.3 to 110.8 ± 12.1. The meta analysis showed a comprehensive coronal correction rate of the major curve of 58.6%, a comprehensive operative time of 274.5 min, and a comprehensive estimated intraoperative blood loss of 866.5 mL (95% confidence interval: 659.3–1073.6, $I^2 \approx 0\%$). A total of 48 complications (5.4%) were reported. Overall, the meta-analysis showed a major complication rate of 4%. In seven cases, revision surgery was needed. Posterior-only approach is effective enough to correct severe curves and can spare the patient possible adverse events due to anterior approach. However, when choosing this approach for severe AIS, screw density needs to be high and posterior column osteotomies may need to be planned to mobilize the spine and maximize correction.

Keywords: Adolescent idiopathic scoliosis, pedicle screw, Ponte osteotomy, posterior spinal fusion, severe scoliosis

INTRODUCTION

Severe adolescent idiopathic scoliosis (AIS) is a complex, stiff, three-dimensional spinal deformity whose treatment remains controversial. In fact, the management of scoliotic patients with severe curves may lead to significant complications related to extended exposure and blood loss, cord injury, and pulmonary compromise.[1] The goal of operative treatment is to obtain an acceptable correction of the deformity, to improve the patient's quality of life and cardiopulmonary status, and to prevent painful degeneration and curve progression.[2]

Historically, severe AIS has often been treated with combined anterior release, followed by posterior correction and instrumentation,[3-8] resulting in good three-dimensional curve correction, but with high risk of pulmonary complications.[9,10] Some authors have also used preoperative traction or internal distraction as a part of a staged correction, in order to achieve better correction and shorter fusion.[11-17] However, preoperative traction implies an increased risk of perioperative complications such as pin loosening, pin tract infection, and cranial nerve palsies.[11-17] Combined anterior and posterior or all-posterior vertebral column resection has also been used to treat severe and rigid scoliosis, but this demanding procedure is affected by a considerably

Matteo Traversari, Alberto Ruffilli, Francesca Barile, Giovanni Viroli, Marco Manzetti, Fabio Vita, Cesare Faldini

IRCCS Istituto Ortopedico Rizzoli, 1st Orthopaedics and Traumatology Clinic, University of Bologna, Bologna, Italy

Address for correspondence: Dr. Matteo Traversari, IRCCS Istituto Ortopedico Rizzoli, 1st Orthopaedics and Traumatology Clinic, University of Bologna, Bologna, Italy.
E-mail: matteo.traversari@ior.it

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high rate of perioperative complications.[18-20] Then, the introduction of all pedicle screws constructs allowed the all-posterior procedures to gradually gain popularity due to the high reliability of three-columnar fixation systems.[21] In fact, powerful corrective forces were exerted and spine mobilization through anterior release was not necessarily needed.

The aim of this meta-analysis was to systematically review the literature and analyze the results of one-stage all-posterior fusion for severe AIS.

METHODS

A systematic review of the literature regarding surgical treatment of severe AIS was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (PRISMA guidelines).[22]

Eligibility criteria

Only peer-reviewed publications were considered for inclusion. Studies were included if they involved patients affected by severe AIS who underwent surgical correction through one-stage posterior-only approach and if they described perioperative outcomes including correction rate and complications. Only articles in English who met the population, intervention, comparison, and outcomes criteria on systematic reviews were included.

Randomized controlled trials, prospective and retrospective cohort studies, and case series (CS) were considered for inclusion.

Search strategy

Studies eligible for this systematic review have been identified through an electronic systematic search of PubMed and Cochrane Central Registry of Controlled Trials until May, 1 2022.

The search strings utilized were:

- PubMed: "Severe scoliosis AND (surgery OR treatment OR surgical)"; "(Spine deformity OR Spinal deformity) AND coronal AND (surgery OR treatment OR surgical)"; "Severe scoliosis AND fusion;" "Scoliosis AND (VCR OR Vertebral column resection)"
- Cochrane: "Severe scoliosis AND surgery."

Study selection

Articles considered relevant by electronic search were retrieved in full-text, and a hand search of their bibliography was performed to find further related articles. Reviews and meta-analyses were also analyzed to identify potentially missed eligible papers. Duplicates were removed. The study selection process was carried out in accordance with the PRISMA flowchart [Figure 1].

Included studies were categorized by type, according with the Oxford Centre for Evidence-Based Medicine. Quality of the included studies was evaluated using the National Institutes of Health tool [Figure 2].

Data collection process

All the included studies were analyzed, and the data related to the following outcomes of interest were extracted and summarized [Table 1]: study design, number of patients (total and severe AIS), mean age, cutoff parameters of severe AIS, curve types according to Lenke classification, mean follow-up, gender, surgical technique, mean pre and postoperative Cobb angle, correction rate, flexibility of the curves, surgical time, estimated intraoperative blood loss (EBL), length of stay, average number of fused levels, and perioperative complications.

When studies involved both patients with severe and nonsevere AIS, data about severe scoliosis patients group were pooled: if this was not possible, the study was excluded.

Heterogeneity between studies was assessed using the inconsistency statistic ($I^2 > 75\%$ was considered as highly heterogeneity). Publication bias was assessed with Egger's test and represented with forest plots. Correction rate, EBL, and surgical time were used as measure of effect size. A random-effects model was applied. All statistical analyses were conducted with Jamovi version 2.2 (The Jamovi Project, Sydney, Australia) software.

RESULTS

Baseline studies' characteristics and quality assessment

A total of 1337 studies were found through electronic search; after screening, 14 studies (1 prospective cohort study,[23] 3 retrospective comparative studies,[24-26] 1 retrospective cohort study,[27] 6 retrospective studies,[28-33] 1 prospective CS,[34] and 2 retrospective CS[1,21]) were included.[1,21,23-28,30,31,33,34] The quality of the papers was good in 13 cases[1,21,23-28,30,31,33] and fair in 1 case.[34]

The included studies chose different criteria for the definition of severe scoliosis: Seven authors used a major curve Cobb >90° as a cutoff[24,27,28,30-33] (1 of them[30] used major curve Cobb >90° and flexibility index <30%), 4 used a major curve Cobb >80°[1,21,25,34] (2 of them[1,34] used major curve Cobb >80° and flexibility index <25%), 3 used a major curve Cobb >70°[23,26,35] [Table 1].

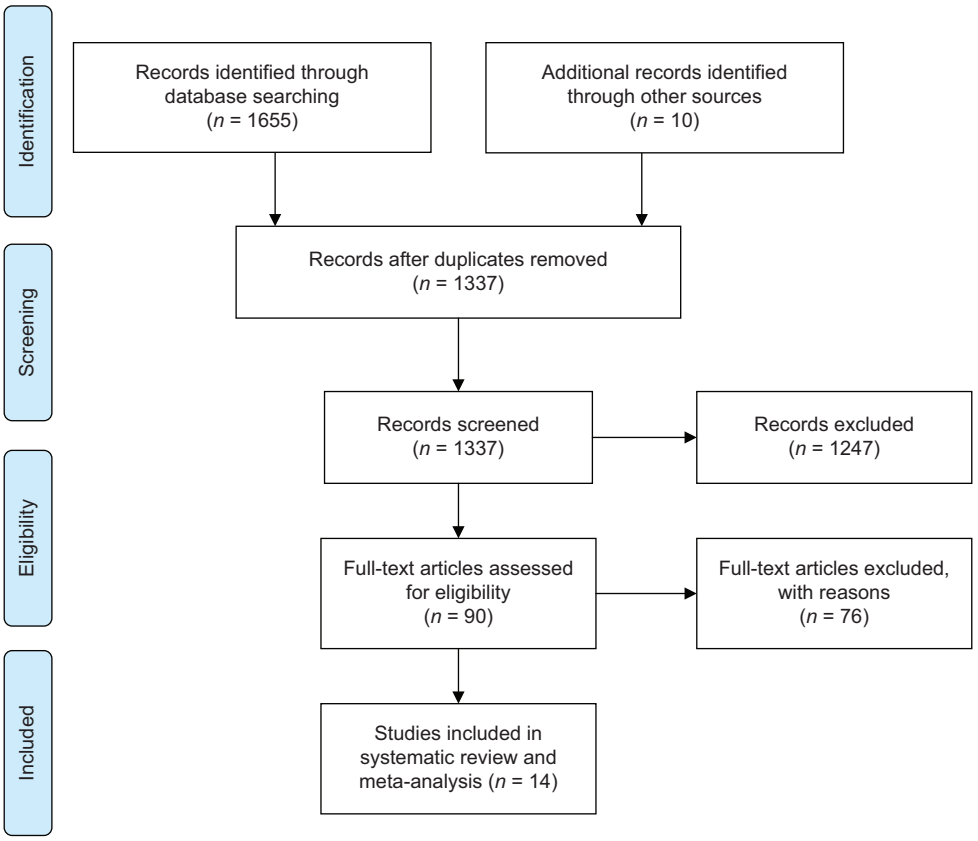

Figure 1: PRISMA flow diagram and the selection of studies. PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

Results and complications

A total of 640 patients affected by severe AIS and treated with one-stage posterior-only approach were included. The mean age at surgery ranged from 14.4[27] to 19 years[28] and the mean follow-up ranged from 12 months[34] to 80.4 months.[25]

The included studies are heterogeneous in Lenke distribution of the curves, internal fixation devices, and use of Schwab >1 osteotomies[36] [Table 1]. Lenke type was reported on 549 patients: [1,21,34,24-27,30-33] 157 Lenke 1 (28.6%), 252 Lenke 2 (45.9%), 50 Lenke 3 (9.1%), 59 Lenke 4 (10.7%), 1 Lenke 5 (0.2%), and 30 Lenke 6 (5.4%). As for constructs, 11 authors used all pedicle screws constructs,[1,21,23-25,27,28,30-34] while 3 preferred hybrid constructs.[25,26,35] As for osteotomies, most of the authors only performed partial facetectomies, while Mirzashahi *et al*. and Dobbs *et al*.[1,24] chose periapical Ponte osteotomies and Di Silvestre *et al*.[25] performed pedicle subtraction osteotomies at the apex of scoliosis in curves with Cobb angle of more than 100°.

The mean Cobb angle of the major curve varied from 80.0 ± 7.3[23] to 110.8° ± 12.1,[30] with a flexibility index range between 21.4% ± 3.8%[1] and 38.6% ± 11.8%.[27] The meta-analysis showed a comprehensive coronal correction rate of the major curve of 58.6% (95% confidence interval [CI]: 53.0–64.1, $I^2 \approx 0\%$, Figures 3 and 4).

A total of 48 complications (5.4%) were reported; complication rate varied widely, from 0% [1,21,23,24,28,34] to 14.8%.[25] Overall, the meta-analysis showed a major complication rate of 4% [95% CI: 3–6, $I^2 \approx 0\%$, Figure 5]. In seven cases, revision surgery was needed: one hook replacement due to hook dislodgement, one partial implant removal due to screw pull-out, two revision procedures due to pseudoarthrosis causing loss of correction, one implant removal for late operative site pain, one hook removal due to hook dislodgement causing implant prominence, and one implant removal for late deep infection.

The meta-analysis showed a comprehensive operative time of 274.5 min (95% CI: 225.1–324.0, $I^2 = 74.4\%$) [Figure 6], and a comprehensive EBL of 866.5 mL (95% CI: 659.3–1073.6, $I^2 \approx 0\%$) [Figure 7].

Length of hospital stay was reported in a minority of the studies, ranging from a mean of 3.1 to 10 days.

DISCUSSION

The aim of the present study was to evaluate the efficacy and safety of one-stage posterior-only spinal fusion (PSF) in the treatment of severe AIS. This procedure resulted to be as effective as more invasive techniques (such as

Figure 2: Quality assessment of the included study in meta-analysis according to the National Institutes of Health tool

Studies	Was the study question or objective clearly stated?	Was the study population clearly and fully described, including a case definition?	Were the cases consecutive?	Were the subjects comparable?	Was the intervention clearly described?	Were the outcome measures clearly defined, valid, reliable, and implemented consistently across all study participants?	Was the length of follow-up adequate?	Was the statistical methods well-described?	Were the results well-described?	Quality summary
Chung 2022	↘	↘	↘	↘	↘	↘	✗	↘	↘	2
Chan 2021	↘	↘	↘	↘	↘	↘	✗	✗	↘	2
Mihara 2021	↘	↘	↘	↘	↘	↘	✗	↘	↘	2
Gatam 2020	↘	✗	↘	↘	↘	↘	✗	✗	✗	1
Mirzashi 2020	↘	↘	↘	↘	↘	↘	↘	↘	↘	2
Mihara 2020	↘	↘	↘	↘	↘	↘	✗	✗	↘	2
Chan 2020	↘	↘	↘	↘	↘	↘	✗	↘	↘	2
Cinnella 2019	↘	↘	✗	↘	↘	↘	↘	↘	↘	2
Tarrant 2016	↘	↘	↘	↘	↘	↘	↘	↘	↘	2
Crostelli 2013	↘	↘	↘	↘	↘	✗	↘	✗	↘	2
Di Silvestre 2008	↘	↘	↘	↘	↘	↘	↘	✗	↘	2
Dobbs 2006	↘	↘	↘	↘	↘	↘	↘	✗	↘	2
Burton 2005	↘	↘	↘	↘	↘	↘	↘	✗	↘	2
Kuklo 2005	↘	↘	↘	↘	↘	✗	✗	↘	↘	2

Quality was rated as 0 for poor (0-3 out of 9 questions), 1 for fair (4-6 out of 9 questions), or 2 for good (7-9 out of 9 questions)

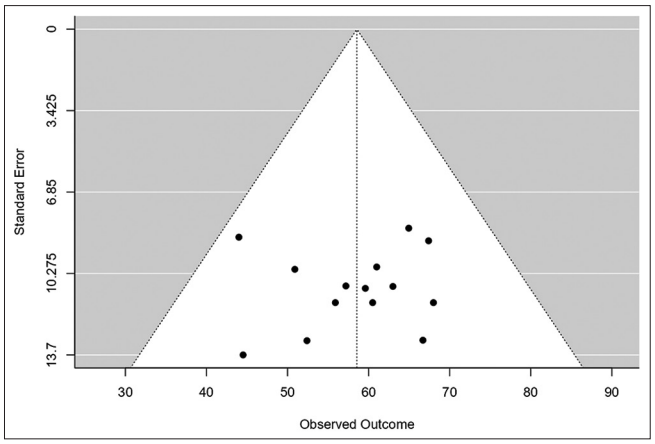

Figure 3: Funnel plot of observed outcomes for publication bias of the included study in meta-analysis

anterior/posterior combined techniques or preoperative Halo traction), with a lower complications rate [Figure 8].

As for efficacy, the meta-analysis showed a comprehensive coronal correction rate of the major curve of 58.6%. The highest correction rate was reported by Kuklo *et al*. in 2005, who described the first series of severe AIS patients (mean preoperative major curve Cobb angle 100.2 ± 10.8°, mean flexibility index of 29%) treated with one-stage PSF obtaining a coronal correction rate of 68%.[28] After that, several other studies reported very good results (around 55%–60% of major curve correction rate) with one-stage PSF.[1,21,35,23,24,26,27,30-33] This is in line with the current literature. In fact, most of the studies on the surgical treatment of severe AIS show contained correction rate values, often lower than 60% regardless of the technique used:[2-10] in these cases, the aim was not to maximize correction but to obtain an acceptable balance of the spine and save levels of fusion. When comparing one-stage PSF to combined anterior/posterior techniques, studies conducted by Dobbs *et al*.[24] and Shi *et al*.[37] both demonstrated no statistically significant difference in terms of curve correction between the two techniques. Finally, Burton *et al*.[35] also showed that curves between 70° and 90° curves do not need anterior release to achieve good results.

However, it is important to highlight that, when choosing a posterior-only approach for severe AIS, a suitable implant density needs to be selected: when thoracic Cobb angle is >70°–80° and an anterior stage is not planned, screw density needs to be at least 60% in order to obtain an acceptable correction and to avoid screws pull-out and pedicles breakage.[25,37,38]

Another major issue of severe AIS treatment is safety. Perioperative complications are reported to be much higher than in nonsevere AIS;[27] the most frequent are respiratory

Table 1: Characteristics of patients, surgical treatments, and perioperative complications of the studies analyzed in this review

Article	Study	Level of evidence	Patients N° (M/F)	Mean patients age (years)	Cut-off and parameters for severe AIS	Lenke types	Internal fixation system	Schwab >1 vertebral osteotomies	Mean pre-operative major Cobb angle (°)	Mean flexibility index of major curve (%)	Mean post-operative major Cobb angle (°)	Mean correction rate (%)	Mean surgical time (min)	Mean intraoperative blood loss (mL)	Perioperative major complication N°	Complication rate (%)	Complications
Chung *et al.* 2022[27]	Retrospective cohort study	III	35 (3/32)	14.4±2.8	Cobb angle ≥90°	I: 12 II: 23	Pedicle screws and rods	No	105.7±15.3	38.6±11.8	42.5±15.5	60.5±11.5	155.9±41.4	1349.2±1019.0	4	11.4	lung collapse, superior mesenteric artery syndrome, massive blood loss, deep infection
Chan *et al.* 2021[33]	Retrospective study	IV	105 (12/93)	15.7±5.0	Cobb angle ≥90°	I: 26 II: 59 III: 1 IV: 10 V: 0 VI: 6	Pedicle screws and rods	No	104.5±12.3	37.8±12.9	42.5±13.5	59.6±10.9	193.3±47.9	1612.2±873.5	6	5.7	somatosensory-evoked potential signal loss intraoperatively, intraoperative massive blood loss, generalized tonic-clonic seizure intraoperatively, lung collapse, 2 superficial wound breakdowns
Mihara *et al.* 2021[32]	Retrospective study	IV	128 (16/112)	15.5±4.5	Cobb angle ≥90°	I: 32 II: 71 III: 3 IV: 10 V: 0 VI: 12	Pedicle screws and rods	No	102.8±12.3	37.5±13.7	44.4±13.5	57.2±10.8	185.1±49.8	n.s.	7	5.5.	somatosensory-evoked potential signal loss intraoperatively, intraoperative massive blood loss, generalized tonic-clonic seizure intraoperatively, lung collapse, superior mesenteric artery syndrome, 2 superficial wound infections
Gatam *et al.* 2020[34]	Prospective case series	IV	8 (1/7)	16.4±1.9	Cobb angle >80° and curve flexibility <25%	I: 1 II: 2 III: 3 IV: 2	Pedicle screws and rods	No	103.6±11.0	n.s.	34.4±12.0	67.4±8.9	n.s.	n.s.	0	0.0	/

Contd...

Table 1: Contd...

Article	Study	Level of evidence	Patients N° (M/F)	Mean patients age (years)	Cut-off and parameters for severe AIS	Lenke types	Internal fixation system	Schwab >1 vertebral osteotomies	Mean pre-operative major Cobb angle (°)	Mean flexibility index of major curve (%)	Mean post-operative major Cobb angle (°)	Mean correction rate (%)	Mean surgical time (min)	Mean intraoperative blood loss (mL)	Perioperative major complication N°	Complication rate (%)	Complications
Mirzashahi *et al*. 202[01]	Retrospective case series	IV	23 (8/15)	16.2±1.9	Cobb angle >80° and curve flexibility <25%	I: 9 II: 1 III: 7 IV: 2 V: 1 VI: 3	Pedicle screws and rods	Multiple asymmetrical Ponte osteotomies	97.5±14.8	21.4±3.75	34.8±12.1	65.0±8.4	246.7±30.0	660.0±212.5	0	0.0	/
Mihara *et al*. 2020[31]	Retrospective study	IV	71 (6/65)	16.1±5.8	Cobb angle ≥90°	I: 19 II: 39 III: 1 IV: 5 V: 0 VI: 7	Pedicle screws and rods	No	104.4±11.7	35.2±12.9	46.4±14.2	55.9±11.5	180.5±43.2	1574.5±929.3	4	5.6	Somato-sensory evoked potentials loss, massive blood loss, 2 superficial wound infections
Chan *et al*. 2020[30]	Retrospective study	IV	41 (3/38)	16.9±5.6	Cobb angle ≥90° and curve flexibility ≤30%	I: 9 II: 22 III: 1 IV: 7 V: 0 VI: 2	Pedicle screws and rods	No	110.8±12.1	23.1±6.3	54.4±12.8	50.9±10.1	215.5±45.2	1752.6±830.5	4	9.8	Somato-sensory evoked potentials loss, superior mesenteric artery syndrome, superficial wound infection and lung collapse
Cinnella *et al* 2019 (PSF-Hybrid group)[26]	Retrospective comparative study	III	12 (4/8)	16.6±2.6	Cobb angle >70°	I: 17 II: 2 III: 8	Pedicle screws, sublaminar bands and rods	No	87.9±14.1	26.8	40.2±6.5	/	405.0±49.1	/	0	0	/
Cinnella *et al* 2019 (PSF-Screws group)[26]			15 (5/10)	16.0±1.5			Pedicle screws and rods		80.1±5.5	20.5	33.4±7.6		386.0±56.0		1	6.7	One deep infection after 3 years that required hardware removal and surgical debridement
Tarrant *et al*. 2016[23]	Prospective cohort study	III	21	14.5±1.5	Cobb angle >70°	n.s.	Pedicle screws and rods	No	80.0±7.3	n.s.	25.0±9.6	66.7±13.1	390.0±75.6	1250.0±747.4	0	0.0	/

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Table 1: Contd...

Article	Study	Level of evidence	Patients N° (M/F)	Mean patients age (years)	Cut-off and parameters for severe AIS	Lenke types	Internal fixation system	Schwab >1 vertebral osteotomies	Mean pre-operative major Cobb angle (°)	Mean flexibility index of major curve (%)	Mean post-operative major Cobb angle (°)	Mean correction rate (%)	Mean surgical time (min)	Mean intraoperative blood loss (mL)	Perioperative major complication N°	Complication rate (%)	Complications
Crostelli *et al*. 2013[21]	Retrospective case series	IV	25 (5/20)	16.5±3.8	Cobb angle ≥80°	I: 12 II: 8 III: 4 IV: 3	Pedicle screws and rods	No	95.0±12.5	n.s.	37.0±8.8	61.0±10.0	300.0±32.5	850.0±212.5	0	0.0	/
Di Silvestre *et al*. 2008 (PSF-Hybrid group)[25]	Retrospective comparative study	III	27 (4/23)	14.9±4.5	Cobb angle ≥80°	I: 11 II: 9 III: 3 IV: 4	Hybrid construct (proximal hooks and distal pedicle screws)	Pedicle subtraction osteotomy at apex of scoliosis when Cobb angle >100°	92.0±13.8	27.2±7.0	51.0±16.3	44.5±13.7	270.0±42.5	858.0±200.0	4	14.8	One hook replacement due to hook dislodgement, one revision procedure due to pseudoarthrosis, one implant removal for late operative site pain, one adding-on phenomenon
Di Silvestre *et al*. 2008 (PSF-Screws group)[25]			25 (9/16)	16.4±4.5		I: 9 II: 9 III: 3 IV: 4	Pedicle screws and rods		88.0±14.0	25.6±5.6	40.0±21.3	52.4±13.1	380.0±40.0	900.0±312.5	2	8.0	One surgical revision due to screw pull-out, one adding-on phenomenon
Dobbs *et al*. 2006[24]	Retrospective comparative study	III	34	13.4±1.2	Cobb angle ≥90°	I: 0 II: 7 III: 15 IV: 12	Pedicle screws and rods	No	94.3±5.3	34.0	51.1±8.3	44.0±8.8	n.s.	n.s.	0	0.0	/
Burton *et al*. 2005[35]	Retrospective study	IV	50	14.4±2.5	Cobb angle >70°	n.s.	Hybrid construct (anchors, wires, pedicle screws)	No	74.8±4.5	37.3±10.7	27.0±8.8	63.0±10.8	369.0±118.3	1100.0±550.0	3	6.0	One revision procedure due to pseudoarthrosis, one implant removal for prominence, one implant removal for late operative site pain
Kuklo *et al*. 2005[28]	Retrospective study	IV	20 (3/17)	19.0	Cobb angle ≥90°	n.s.	Pedicle screws and rods	No	100.2±10.8	29.0	32.3±16.0	68.0±11.5	n.s.	n.s.	0	0.0	/

PSF - Posterior-only spinal fusion, AIS - Adolescent idiopathic scoliosis, NS - Not significance

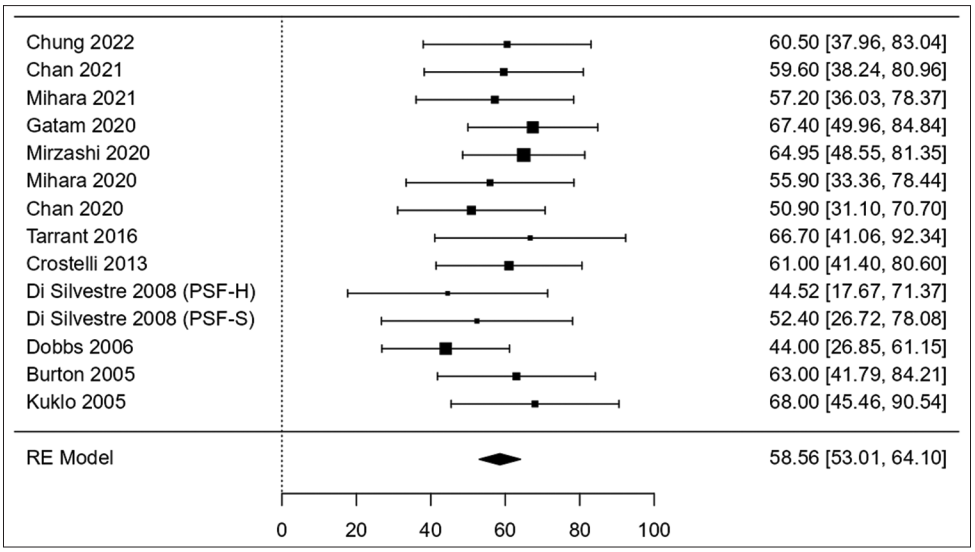

Figure 4: Forest plot of overall meta-analysis of the included studies with data about coronal correction rate of main scoliotic curve after one stage PSF. PSF: Posterior-only spinal fusion

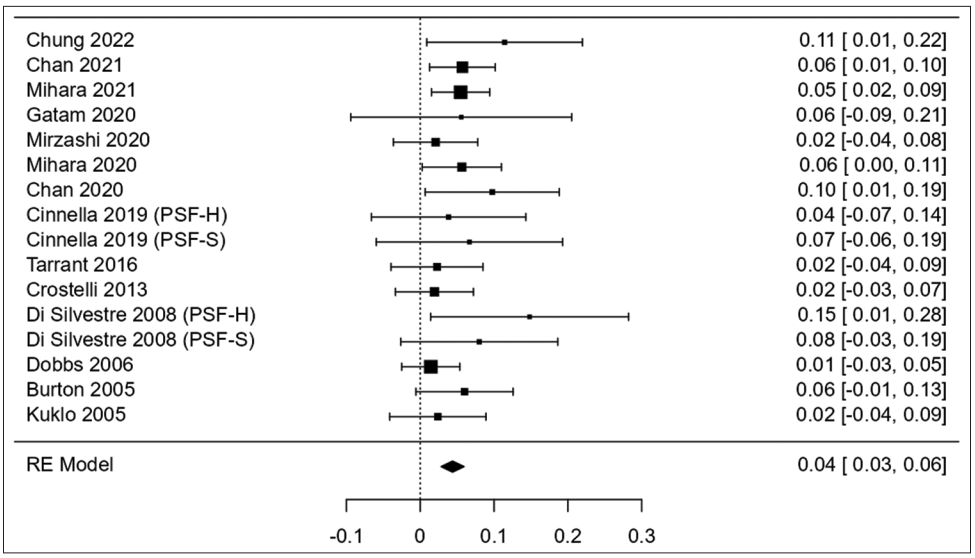

Figure 5: Forest plot of overall meta-analysis of the included studies with data about perioperative complications after one stage PSF. PSF: Posterior-only spinal fusion

complications, massive blood loss, neurological deficits, implant-related failures, and wound infections.[39,40] In one-stage PSF, our meta-analysis showed a major complication rate of 4%. This is inferior to combined techniques, such as anterior/posterior approaches and preoperative halo traction that are prone to the same complications as one-stage PSF, but also present some intrinsic issues. The main problem of the combined anterior/posterior procedure is the risk of pulmonary complications;[9,10] moreover, even if intraoperative complications do not occur, the anterior release has always a negative impact on pulmonary function when compared to posterior only approach, determining a significant decrease of forced expiratory volume and forced expiratory volume in 1 s values at 5 years postoperatively.[24] As for preoperative traction, it implies an increased risk of perioperative complications such as pin loosening, pin tract infection, and cranial nerve palsies.[8]

It is important to notice that performing osteotomies to increase spine flexibility and maximize correction may affect complication rate. In our results, two studies described the use of multilevel Ponte osteotomies,[1,24] with a complication rate of 1% and 10% and a coronal correction rate similar or higher than cohorts treated with single-stage PSF only. The use of pedicle subtraction osteotomies was described by Di Silvestre *et al.*,[25] obtaining acceptable results in terms of deformity correction at the price of the highest reported perioperative complication rate (14.8%). This study presented several limitations. First of all, there was no agreement in

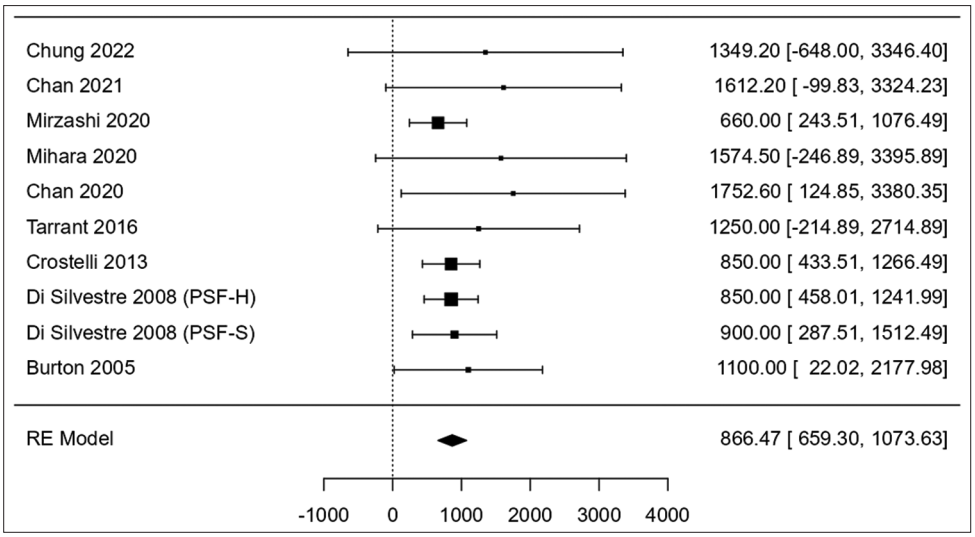

Figure 6: Forest plot of overall meta-analysis of the included studies with data about EBL after one stage PSF. PSF: Posterior-only spinal fusion, EBL: Estimated intraoperative blood loss

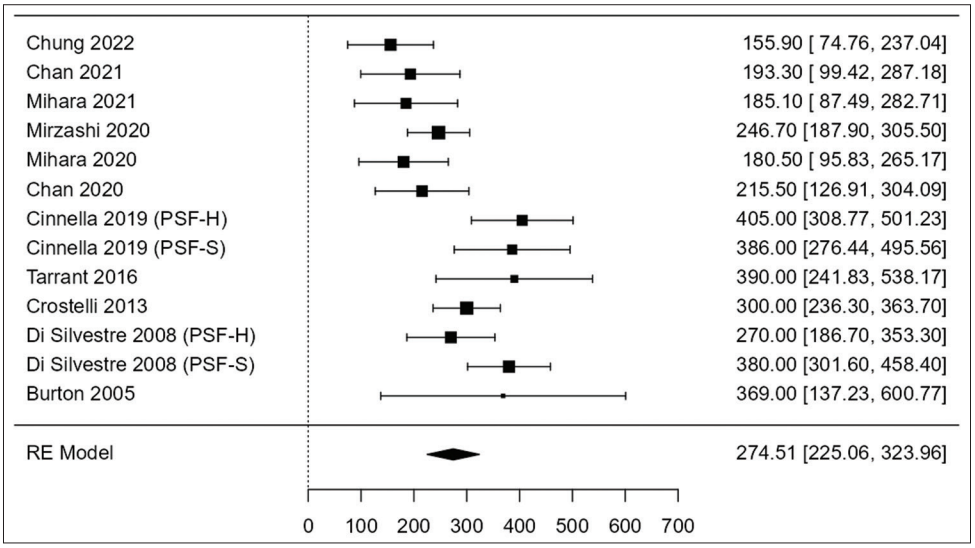

Figure 7: Forest plot of overall meta-analysis of the included studies with data about surgical time of one stage PSF. PSF: Posterior-only spinal fusion

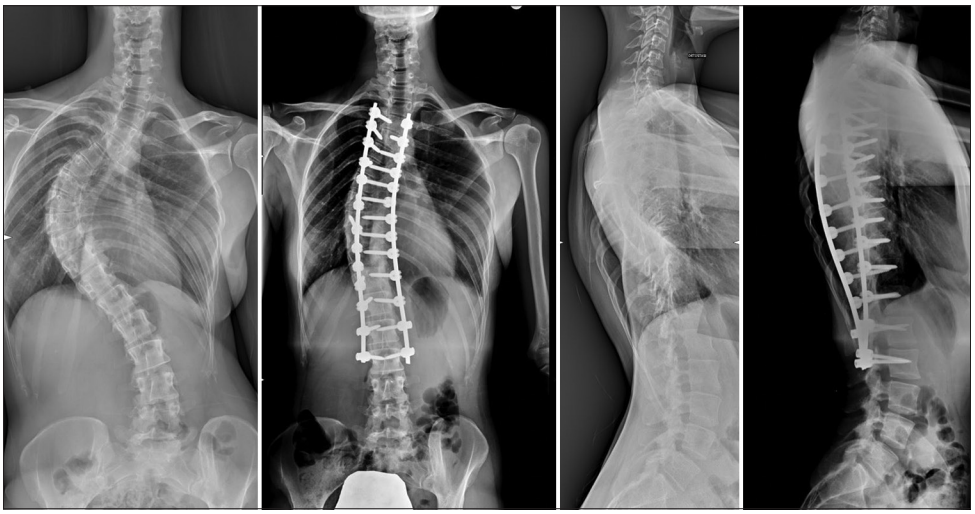

Figure 8: Female, 18 years old present with severe adolescent idiopathic scoliosis with pre-operative Cobb angle of main curve of 94°, underwent one-stage PSF with multiple periapical asymmetrical Ponte osteotomies. Postoperative Cobb angle was 38° with a coronal correction rate of 59.6%. PSF: Posterior-only spinal fusion

the definition of severe scoliosis: this represented a major bias in comparing the results of the included studies. Then, only a few studies are comparative, while the vast majority are CS where only one technique is used.

CONCLUSION

Our results suggest that posterior-only approach is effective enough to correct both moderate and severe curves and can spare the patient possible adverse events due to anterior approach. However, when choosing this approach for severe AIS, screw density needs to be high and posterior column osteotomies may need to be planned to mobilize the spine and maximize correction.

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Nil.

Conflicts of interest
There are no conflicts of interest.

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