



# Comparison of long fusion terminating at L5 versus the sacrum in treating adult spinal deformity: a meta-analysis

Fei Jia<sup>1,2</sup> · Guodong Wang<sup>1</sup> · Xiaoyang Liu<sup>1</sup> · Tao Li<sup>1</sup> · Jianmin Sun<sup>1</sup>

Received: 12 December 2018 / Revised: 31 August 2019 / Accepted: 15 September 2019  
© The Author(s) 2019

## Abstract

**Purpose** Choosing an optimal distal fusion level for adult spinal deformity (ASD) is still controversial. To compare the radiographic and clinical outcomes of distal fusion to L5 versus the sacrum in ASD, we conducted a meta-analysis.

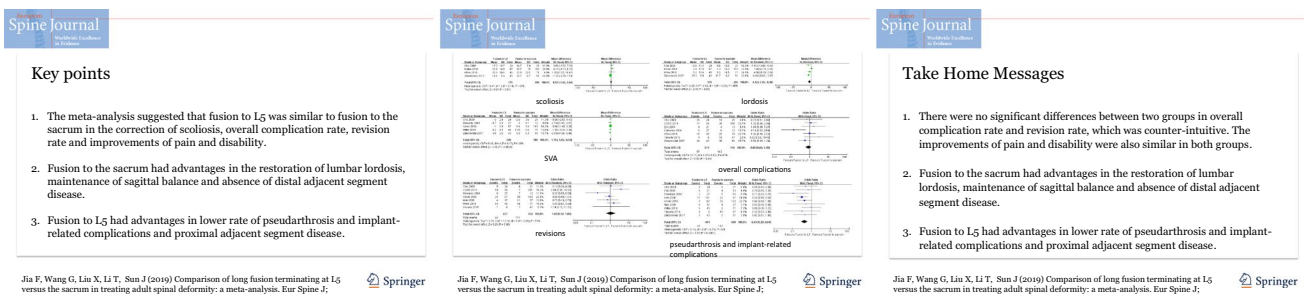
**Methods** Relevant studies on long fusion terminating at L5 or the sacrum in ASD were retrieved from the PubMed, Embase, Cochrane, and Google Scholar databases. Then, studies were manually selected for inclusion based on predefined criteria. The meta-analysis was performed by RevMan 5.3.

**Results** Eleven retrospective studies with 1211 patients were included in meta-analysis. No significant difference was found in overall complication rate (95% CI 0.60 to 1.30) and revision rate (95% CI 0.59 to 1.99) between fusion to L5 group (L group) and fusion to the sacrum group (S group). Significant lower rate of pseudarthrosis and implant-related complications (95% CI 0.29 to 0.64) as well as proximal adjacent segment disease (95% CI 0.35 to 0.92) was found in L group. Patients in S group obtained a better correction of lumbar lordosis (95% CI -7.85 to -0.38) and less loss of sagittal balance (95% CI -1.80 to -0.50).

**Conclusion** Our meta-analysis suggested that long fusion terminating at L5 or the sacrum was similar in scoliosis correction, overall complication rate, revision rate, and improvement in pain and disability. However, fusion to L5 had advantages in lower rate of pseudarthrosis, implant-related complications, and proximal adjacent segment disease, while fusion to the sacrum had advantages in the restoration of lumbar lordosis, maintenance of sagittal balance, and absence of distal adjacent segment disease.

## Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.



**Keywords** Adult spinal deformity · Spinal fusion · Distal fusion level · L5-S1 disc · Meta-analysis

**Electronic supplementary material** The online version of this article (<https://doi.org/10.1007/s00586-019-06187-8>) contains supplementary material, which is available to authorized users.

✉ Jianmin Sun  
spine2000@msn.cn

Extended author information available on the last page of the article

## Introduction

Adult spinal deformity is a common disease with a reported incidence ranging from 29 to 68% [1, 2]. Adult patients with spinal deformity can present with back pain, symptoms of nerve compression, and impaired quality of life [3–6]. Surgical management offers better radiographic and clinical

outcomes than non-surgical treatment, with many patients experiencing relief of pain and improvement in disability after surgery [7, 8]. The goal of surgery is to achieve neural decompression, correct the deformity, and restore the balance of spine in both coronal and sagittal planes. Achieving these goals can be challenging and cause various complications such as wound infection, neurological impairment, pseudarthrosis, and adjacent segment disease [9–13]. Unlike scoliosis in adolescents, ASD is often accompanied by lateral listhesis, osteoporosis, and degenerative lumbar disorders such as spinal stenosis [10, 14]. Therefore, surgery for adult deformity is often more complicated and technically difficult. Additionally, patients are older and may have some medical comorbidities [15]. These factors contribute to the high incidence of complications.

A long thoracolumbar fusion extending to the lower lumbar or sacral spine is usually necessary in the treatment of adult spinal deformity. It is generally accepted that if the L5-S1 level is involved in the disease process such as advanced disc degeneration, spinal stenosis, L5 spondylolisthesis, and fixed lumbosacral obliquity, multi-level fusion to the sacrum should be indicated [16–18]. But for patients with healthy or minimal degenerated L5-S1 discs, whether to preserve this motion segment or fuse to the sacrum is still debated [19, 20]. L5 and the sacrum each have advantages and limitations as a choice for the level of distal fusion [16, 18–25]. End at L5 offers preservation of lumbosacral motion and less invasion. On the other hand, it may bring about subsequent degeneration of the L5-S1 disc. Subsequent disc degeneration is often related to axial pain, neurological compression, and loss of sagittal balance. In addition, the functional significance of preserving a single open segment below a long fusion is poorly defined and theoretical convenience on daily activities has rarely been shown [26, 27].

Therefore, choosing which vertebra to terminate a long fusion remains a controversial topic. Although several studies had compared the outcomes of distal fusion to L5 versus the sacrum, there were no prospective randomized controlled trials (RCTs) existed to illuminate the issue directly. Aiming to compare the radiographic and clinical outcomes of fusion stopping at L5 with extension to the sacrum in ASD, we performed a meta-analysis focusing on curvature correction, complications, and symptom improvement. It is hoped that the article could provide some guidance value to current operation choice for patients with ASD.

## Materials and methods

### Inclusion/exclusion criteria

Studies were included according to the following inclusion criteria: (1) patients were diagnosed with adult spinal

deformity (adult idiopathic/degenerative scoliosis, etc.); (2) patients with at least 18 years of age at the time of surgery; (3) fusion of four or more segments; (4) patients with healthy or minimal degenerated L5-S1 discs (Grade 0 to 1); (5) availability of comparative data of distal fusion level between L5 and the sacrum; and (6) a minimum 1-year follow-up.

Studies were excluded according to the following exclusion criteria: (1) patients were diagnosed with neuromuscular scoliosis; (2) child or adolescent patients; (3) patients were treated by short fusion or non-fusion procedure; (4) pooled results were reported without distinguishing endpoint L5 from the sacrum; (5) the article was a case/case series report; and (6) biomechanical study or studies of corpses.

### Study search strategies

We searched on electronic databases of PubMed, Embase, Cochrane, and Google Scholar using the following keywords: “lumbar”, “L5”, “sacrum”, “S1”, “pelvis”, “adult”, “scoliosis”, “spinal deformity”, “fusion”, “arthrodesis”, “distal”, “caudal”, and “instrumented” with Boolean operators “AND”, “OR”, and “NOT”. We retrieved all clinical studies on distal fusion levels without restriction of language and year of publication. Full texts of the published articles were manually obtained, and references of relevant studies were reviewed to ensure that no relevant researches were omitted. The PRISMA checklist is given in Online Resource 1.

### Data extraction

Data extraction was performed independently by two investigators with disagreement resolved by discussion. The following parameters were extracted: (1) study’s author and publication year; (2) study type; (3) patient demographic information; (4) number of fusion segments; (5) follow-up time; (6) surgical technique and approach; (7) radiographic outcomes (final changes in scoliosis angle, lordosis, angle and sagittal vertical axis (SVA)); (8) number and rate of complications, type of complications; (9) revision rate; and (10) clinical outcomes (final changes in Oswestry Disability Index (ODI) and visual analogue scale (VAS) scores).

### Quality assessment and publication bias assessment

Quality assessment was performed independently by two investigators using the Newcastle–Ottawa scale (NOS). The NOS is recommended by Cochrane Handbooks version 5.2.0

to evaluate the qualities of non-randomized studies and is widely used nowadays. Since the study types of our included studies were all retrospective studies, we used NOS to assess the risk of bias. Disagreements were resolved through consensus. Publication bias was evaluated by a funnel plot analysis.

### Data analysis

Continuous variables were presented as mean difference (MD) and 95% confidence interval (95% CI), whereas dichotomous variables were reported as odds ratios (OR) and 95% CI. The rate of distal adjacent segment disease was an exception because it was 0% when fusion ended at the sacrum. Hence, ratio difference (RD) and 95% CI were used instead. To get the change values and its standard deviation (SD) from pre-operation to the last follow-up that we needed, we conducted a statistical transformation from the data in some articles with the formula from the Cochrane Handbooks version 5.2.0. Heterogeneity was tested using a Chi-square test, for which  $P < 0.1$  was considered to be statistically significant. The  $I^2$  index was used to quantify heterogeneity. In the case of extensive heterogeneity ( $I^2 > 50\%$ ), the random effects model was used; otherwise, the fixed effects model was used. Sensitivity analysis was conducted to explain the source of heterogeneity. All statistical tests were performed using Review Manager, version 5.3 (Cochrane Collaboration, Copenhagen, Denmark).

## Result

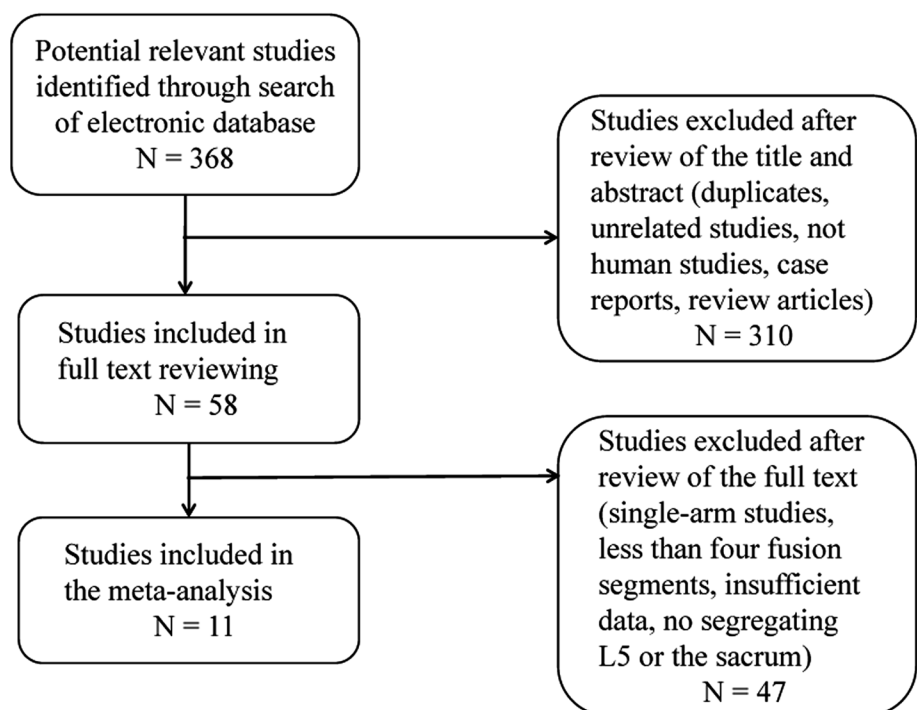
### Search results

368 studies were extracted from the PubMed, Embase, Cochrane, and Google Scholar databases initially. After review of the abstract and title, 310 studies were excluded for the following reasons: duplicates; unrelated studies; studies of corpses or animals; case reports; and review articles. Then, the full texts of the remaining 58 studies were reviewed. A further 47 studies were excluded for the following reasons: single-arm studies ( $n = 13$ ); less than four segments fused ( $n = 3$ ); insufficient data ( $n = 20$ ); and pooled results without segregating termination site L5 or the sacrum ( $n = 11$ ). Hence, a total of 11 studies were finally selected into the meta-analysis [10, 14–18, 23, 28–31]. The flow diagram is shown in Fig. 1.

### Study characteristics

All of the 11 studies were non-randomized retrospective studies. The basic characteristics of included studies are shown in Table 1. There were no significant differences on age, gender, diagnosis, and follow-up between the two groups. Because the preoperative scoliosis angles, lordosis angles, SVA, ODI, and VAS scores were significantly different in some studies [14, 16, 17, 29], the change values from pre-operation to the last follow-up were used for analysis to eliminate the influence of different preoperative values.

**Fig. 1** Flow diagram of study selection



**Table 1** Basic characteristics of included studies in this meta-analysis

References	Type	Group	Sample size	Age (years)	Gender (M/F)	Preoperative curve (°)	Number of complications	Number of revisions	Follow-up (months)
Kim et al. [10]	Retrospective	L	151	40.8 (18.1–77.3) (P)	40/192 (P)	NR	NR	NR	60 (24–201.6) (P)
Koller et al. [14]	Retrospective	S	81			NR	NR	NR	
		L	67	58.5 ± 10	NR	47.9 ± 20	NR	24/67	36
Mok et al. [15]	Retrospective	S	153	61 ± 10	NR	43.2 ± 19.3	NR	59/153	40
		L	17	48.5 ± 15.5 (P)	18/71 (P)	NR	NR	4/17	45.2 (24–82.8) (P)
Cho et al. [16]	Retrospective	S	37			NR	NR	11/37	
		L	24	63.6 ± 6.3	6/39 (P)	24.7 ± 11.6	21/24	5/24	42 ± 20.4 (P)
Witiw et al. [17]	Retrospective	S	21	65.6 ± 6.8		22.8 ± 7.5	19/21	4/21	
		L	45	60.9 ± 12.9	11/34	39.8 ± 14.1	16/45	14/45	33.0 ± 9.8
Edwards et al. [18]	Retrospective	S	71	59.5 ± 12.7	14/57	40.8 ± 18.3	25/71	16/71	35.0 ± 10.5
		L	27	44 (20–61)	3/36 (P)	NR	6/27	6/27	57.6 (24–171.6) (P)
Eck et al. [23]	Retrospective	S	12	44 (27–77)		NR	9/12	7/12	
		L	21	45.8 ± 8.2	3/56 (P)	NR	9/21	NR	60 (24–153) (P)
Yasuda et al. [28]	Retrospective	S	13	44.7 ± 9.6		NR	4/13	NR	
		L	6	68.3 (40–83) (P)	8/45 (P)	NR	4/6	1/6	> 24
Zaborovskii et al. [29]	Retrospective	S	47			NR	18/47	7/47	> 24
		L	43	68.7 ± 5.9	9/34	28.7 ± 12.1	24/43	NR	> 36
Complex Spine Study Group et al. [30]	Retrospective	S	51	67.3 ± 5.6	12/39	32.9 ± 10.4	35/51	NR	> 36
		L	45	53 (P)	31/115 (P)	NR	17/45	10/45	> 60
Decker et al. [31]	Retrospective	S	101			NR	34/101	7/101	> 60
		L	89	54.1 ± 15.4	20/69	NR	NR	NR	12
		S	89	54.4 ± 14.0	21/68	NR	NR	NR	12

L fusion to L5 group, S fusion to the sacrum group, M/F male/female, P pooled, NR not reported

**Table 2** Quality assessment according to the Newcastle–Ottawa scale

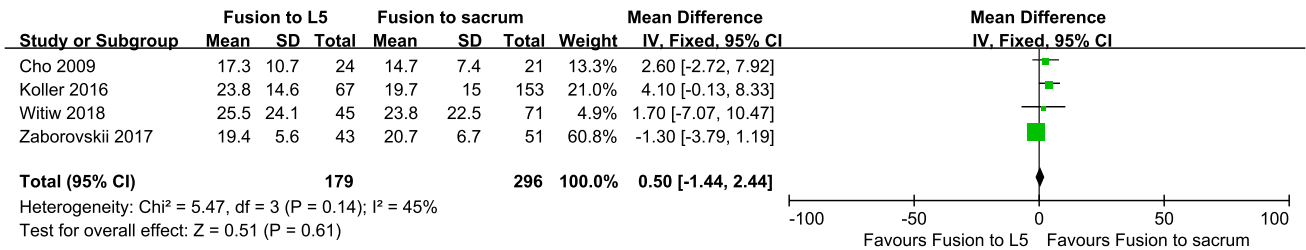
References	Selection	Compa-rability	Exposure	Total
Kim et al. [10]	3	2	2	7
Koller et al. [14]	3	2	2	7
Mok et al. [15]	3	2	3	8
Cho et al. [16]	3	2	2	7
Witiw et al. [17]	3	2	2	7
Edwards et al. [18]	3	2	3	8
Eck et al. [23]	3	2	2	7
Yasuda et al. [28]	3	2	2	7
Zaborovskii et al. [29]	3	2	3	8
Complex Spine Study Group et al. [30]	3	2	2	7
Decker et al. [31]	3	2	3	8

**Quality assessment and publication bias assessment**

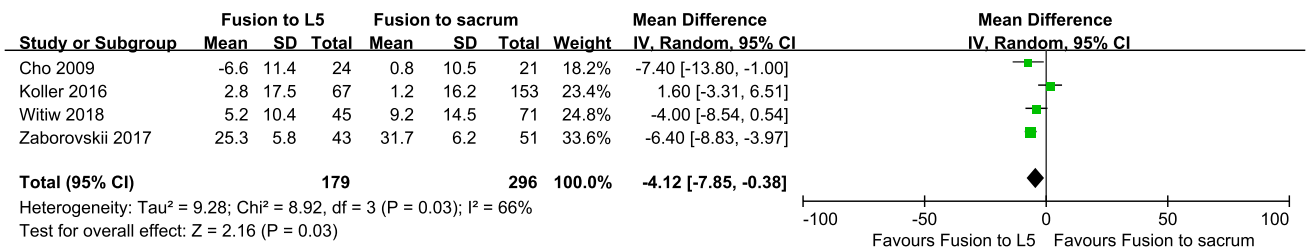
Two investigators assessed the quality of studies independently. All of the 11 included studies scored more than 7 points; hence, the studies were of relatively high quality. The quality assessment is summarized in Table 2. Evidence of publication bias was not indicated in the symmetrical funnel plot on visual inspection (Online Resource 2).

**Final correction of scoliosis**

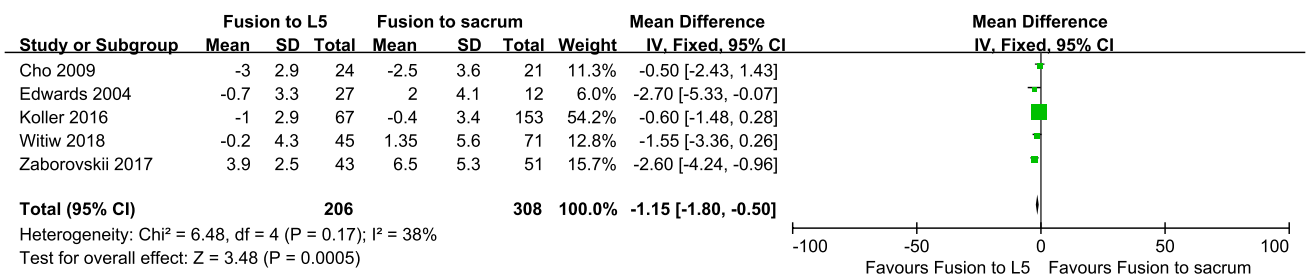
We used the change values from pre-operation to the last follow-up for analysis. The data of main scoliosis angles were extracted from four articles [14, 16, 17, 29] (Fig. 2). There was no significant difference between L group and S group in analysis (MD 0.50; 95% CI – 1.44 to 2.44,  $P=0.61$ ) with moderate heterogeneity ( $P=0.14$ ,  $I^2=45%$ ).



**Fig. 2** Forest plot for change values of main scoliosis angle from pre-operation to the last follow-up between fusion to L5 group and fusion to the sacrum group



**Fig. 3** Forest plot for change values of lordosis angle from pre-operation to the last follow-up between fusion to L5 group and fusion to the sacrum group



**Fig. 4** Forest plot for change values of SVA from pre-operation to the last follow-up between fusion to L5 group and fusion to the sacrum group

### Final correction of lordosis

Data on the preoperative and final lordosis were available from four studies [14, 16, 17, 29] (Fig. 3). There was a significant difference between L group and S group in analysis (MD -4.12; 95% CI -7.85 to -0.38,  $P=0.03$ ) with significant heterogeneity ( $P=0.03$ ,  $I^2=66\%$ ). Hence, the random effects model was used. Sensitivity analysis was conducted to explain the source of heterogeneity. When omitting the study Koller 2016 [14], the  $I^2$  index fell to 0%. The reason might lie in their adequate correction and little loss of lumbar lordosis with the use of appropriate surgical approach in L group.

### Final correction of SVA

The SVA was calculated as the distance from the C7 plumb line to the posterior endplate corner of S1. Data on the preoperative and final SVA were available from five studies [14, 16–18, 29] (Fig. 4). There was a significant difference between L group and S group in analysis (MD -1.15; 95% CI -1.80 to -0.50,  $P=0.0005$ ) with moderate heterogeneity ( $P=0.17$ ,  $I^2=38\%$ ).

### Overall complication rate and revision rate

The records of complications were different in forms—some studies listed all complications, whereas some provided the overall complication rate. Data on overall postoperative complications were retrieved from seven studies totalling 527 patients [16–18, 23, 28–30] (Fig. 5). There was no significant difference between L group and S group in analysis (OR, 0.89; 95% CI 0.60 to 1.30,  $P=0.54$ ) with moderate heterogeneity ( $P=0.12$ ,  $I^2=41\%$ ). As for revision rate, data of revisions were available from seven studies totalling 673 patients [14–18, 28, 30] (Fig. 6). There was also no significant difference between two groups (OR, 1.08; 95% CI 0.59 to 1.99,  $P=0.80$ ) with significant heterogeneity ( $P=0.06$ ,  $I^2=51\%$ ). When omitting the study Complex Spine Study Group (CSSG) 2011 [30], the  $I^2$  index dropped to 14%. The relatively low incidence of pseudoarthrosis and revision rate in this study’s S group might lead to the clinical heterogeneity.

### Rate of proximal/distal adjacent segment disease

The evidence of adjacent segment disease is based on clinical symptoms instead of radiographic assessment, which included symptomatic junctional degeneration,

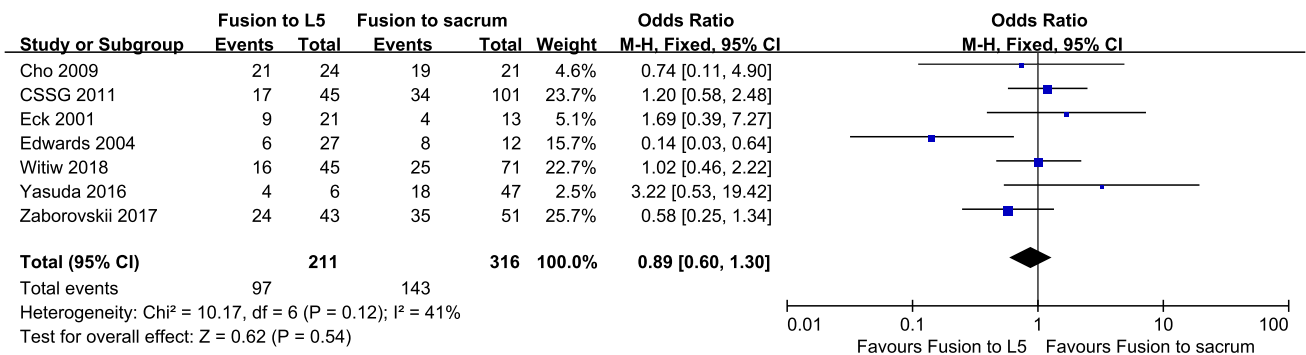


Fig. 5 Forest plot for overall complication rates between fusion to L5 group and fusion to the sacrum group

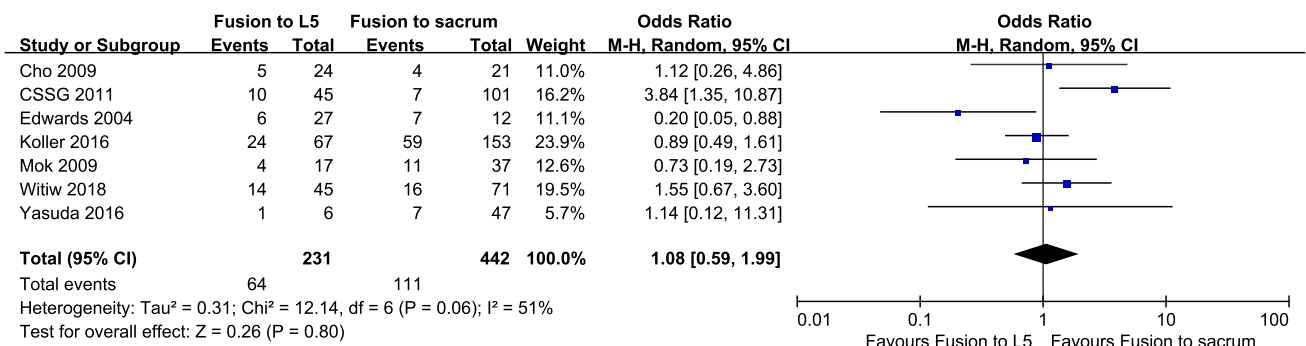


Fig. 6 Forest plot for revision rates between fusion to L5 group and fusion to the sacrum group

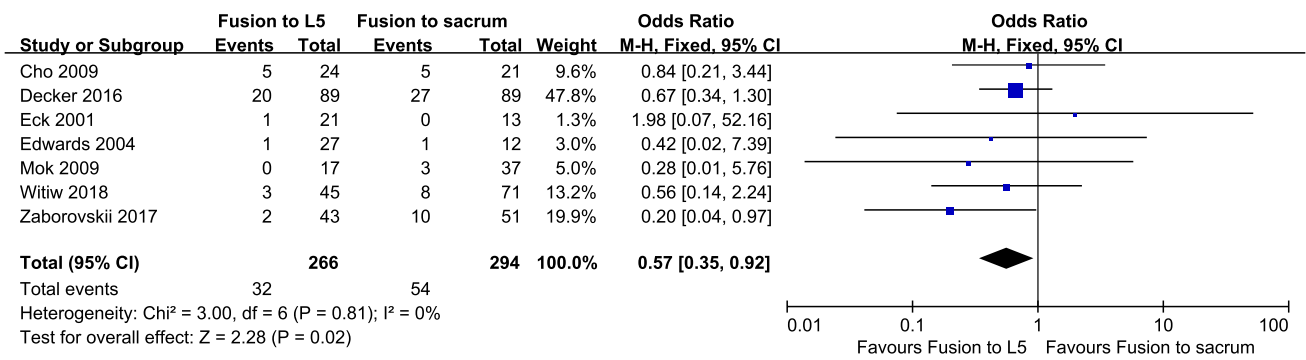


Fig. 7 Forest plot for rates of proximal adjacent segment disease between fusion to L5 group and fusion to the sacrum group

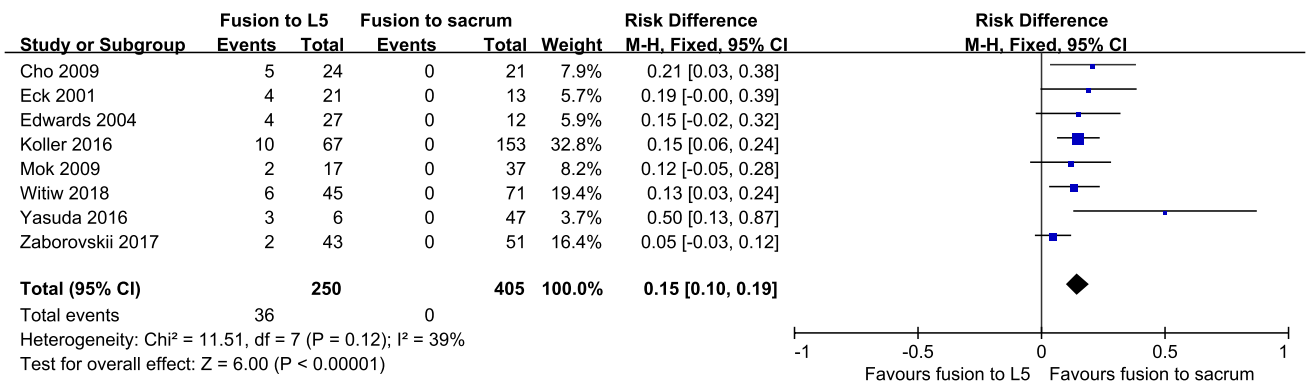


Fig. 8 Forest plot for rates of distal adjacent segment disease between fusion to L5 group and fusion to the sacrum group

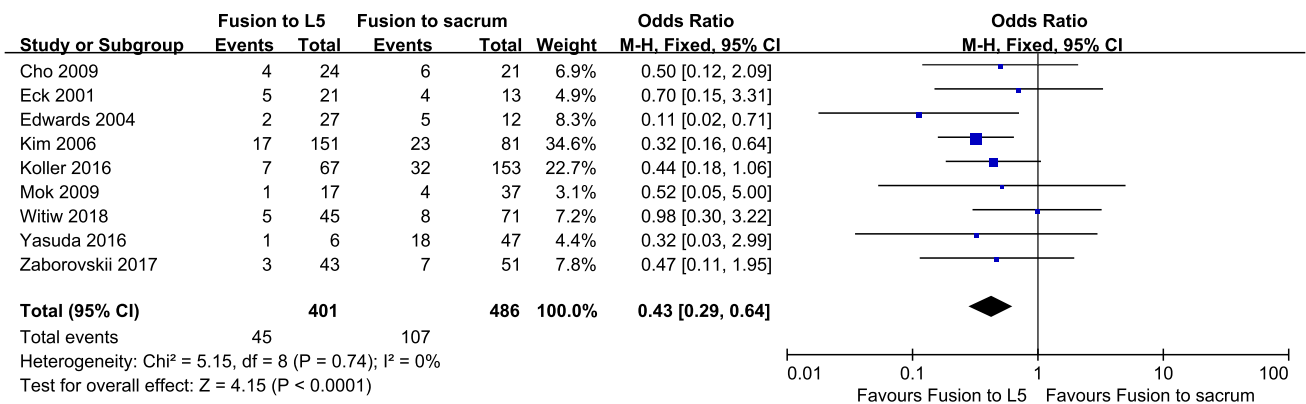
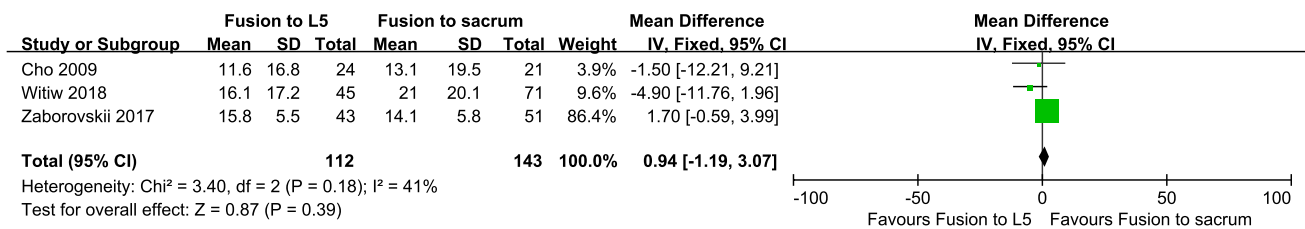


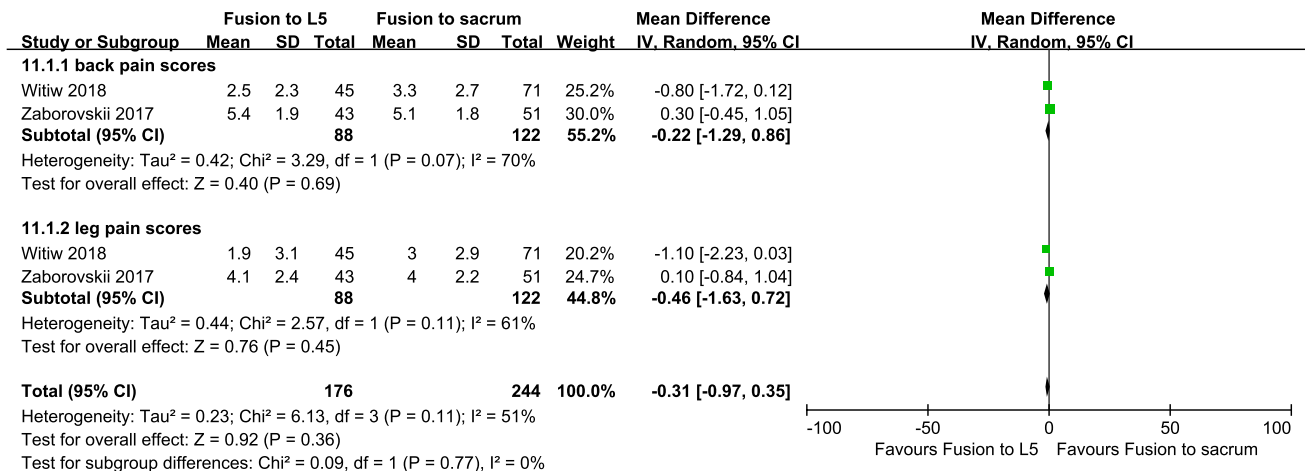
Fig. 9 Forest plot for rates of pseudarthrosis and implant-related complications between fusion to L5 group and fusion to the sacrum group

kyphosis, and failure. Data on proximal adjacent segment disease were available from seven studies [15–18, 23, 29, 31] (Fig. 7). There was a significant difference between L group and S group in analysis (OR, 0.57; 95% CI 0.35 to 0.92,  $P = 0.02$ ) without heterogeneity ( $P = 0.81$ ,  $I^2 = 0\%$ ). Data on distal adjacent segment disease were available from eight studies [14–18, 23, 28, 29] (Fig. 8). There was

a significant difference between L group and S group in analysis (RD, 0.15; 95% CI 0.10 to 0.19,  $P < 0.00001$ ) with moderate heterogeneity ( $P = 0.12$ ,  $I^2 = 39\%$ ). In other words, since no distal junctional disease would occur in S group, the incidence of advanced degeneration of L5-S1 disc with clinical sequelae in L group was 15% (10 to 19%).



**Fig. 10** Forest plot for change values of ODI from pre-operation to the last follow-up between fusion to L5 group and fusion to the sacrum group



**Fig. 11** Forest plot for change values of VAS scores from pre-operation to the last follow-up between fusion to L5 group and fusion to the sacrum group

## Rate of pseudarthrosis and implant-related complications

Data on pseudarthrosis and implant-related complications occurred during follow-up were available from nine studies totalling 887 patients [10, 14–18, 23, 28, 29] (Fig. 9). There was a significant difference between L group and S group in analysis (OR, 0.43; 95% CI 0.29 to 0.64,  $P < 0.0001$ ) without heterogeneity ( $P = 0.74$ ,  $I^2 = 0\%$ ).

## Final improvement of ODI and VAS scores

We used the change values from pre-operation to the last follow-up for analysis. Data on the preoperative and final ODI were available from three studies [16, 17, 29] (Fig. 10). There was no significant difference between L group and S group in analysis (MD 0.94; 95% CI -1.19 to 3.07,  $P = 0.39$ ) with moderate heterogeneity ( $P = 0.18$ ,  $I^2 = 41\%$ ). Data on the preoperative and final VAS scores were available from two studies [17, 29] (Fig. 11). We introduced two subgroups according to the painful place (back and leg). There was no significant difference between L group and S group in subgroup analysis, respectively (MD = -0.22, 95% CI -1.29 to 0.86,  $P = 0.69$ ; MD = -0.46, 95% CI -1.63

to 0.72,  $P = 0.45$ ). Heterogeneity existed within both subgroups ( $P = 0.07$ ,  $I^2 = 70\%$ ;  $P = 0.11$ ,  $I^2 = 61\%$ ); hence, the random effects model was conducted.

## Subgroup meta-analysis

Although we required that the fusion length must be greater than four in the inclusion criteria, the fusion segments were significantly different in some studies. We made the subgroup meta-analysis to eliminate the influence of different fusion lengths. There were two groups as subgroups,  $4 \leq \text{fusion segments} \leq 8$  group and fusion segments  $> 8$  group. Eight were chosen because fusion of so many segments could just cross the thoracolumbar junction to the thoracic spine.

For the final correction of SVA, there was significant difference in each subgroup (MD = -0.74, 95% CI -1.47 to -0.01,  $P = 0.05$ ; MD = -2.70, 95% CI -5.33 to -0.07,  $P = 0.04$ ), which was consistent with the previous meta-analysis. There was no significant difference between subgroups ( $P = 0.16$ ) (Online Resource 3).

For the overall complication rate, there was no significant difference in each subgroup (OR = 1.16, 95% CI 0.60 to 2.23,  $P = 0.67$ ; OR = 0.52, 95% CI 0.20 to 1.36,  $P = 0.19$ ),



which was also consistent with the previous meta-analysis. There was no significant difference between subgroups ( $P=0.18$ ) (Online Resource 4). For the revision rate, there was no significant difference in each subgroup (OR = 1.08, 95% CI 0.69 to 1.70,  $P=0.74$ ; OR = 0.40, 95% CI 0.12 to 1.39,  $P=0.15$ ), which identified with the previous meta-analysis. There was no significant difference between subgroups ( $P=0.14$ ) (Online Resource 5).

For the rate of proximal adjacent segment disease, there was no significant difference in each subgroup (OR = 0.68, 95% CI 0.26 to 1.81,  $P=0.44$ ; OR = 0.65, 95% CI 0.35 to 1.21,  $P=0.17$ ), which was still consistent with the previous meta-analysis. There was no significant difference between subgroups ( $P=0.94$ ) (Online Resource 6). Similarly, for the rate of distal adjacent segment disease, there was significant difference in each subgroup (RD = 0.17, 95% CI 0.11 to 0.24,  $P < 0.00001$ ; RD = 0.15, 95% CI 0.04 to 0.26,  $P=0.007$ ), which was consistent with the previous meta-analysis. There was no significant difference between subgroups ( $P=0.70$ ) (Online Resource 7).

For the rate of pseudarthrosis and implant-related complications, there was significant difference in each subgroup (OR = 0.53, 95% CI 0.29 to 0.97,  $P=0.04$ ; OR = 0.33, 95% CI 0.19 to 0.60,  $P=0.0002$ ), which was still in line with the previous meta-analysis. There was no significant difference between subgroups ( $P=0.27$ ) (Online Resource 8). Other variables could not be divided into two subgroups.

## Discussion

ASD is a highly intricate clinical condition in which the main associated issues are pain and disability, which should be taken into account when making treatment decisions [6]. Despite a relatively high rate of complications, surgery is generally considered to be an effective and rational treatment option that has the capacity to significantly reduce pain in patients [7, 8]. In the treatment of patients with ASD, decompression is usually combined with fusion [32]. Decompressive surgery is used to release the neurological symptoms, while the purpose of spinal fusion is to stabilize the corrected alignment and prevent deterioration of the curve [33]. Long-segment fusion has been extensively used with better curve correction and long-term outcomes in ASD than short-segment fusion [34, 35].

An important aspect of long fusion surgery is the determination of fusion extent. Most studies presented unique advantages and disadvantages of L5 or the sacrum as the choice of distal endpoint, respectively. Edwards et al. [18] compared 27 patients with fusions to L5 to 12 patients with sacral fusions. Complication rates, including pseudarthrosis and medical morbidity, were higher in the sacral group at final follow-up. A systematic review of subsequent

progression of L5-S1 disc degeneration found the risk of developing new symptoms was approximately 18–20%, with most requiring re-operation [36]. Cho et al. [16] found a 58% rate of subsequently advanced L5-S1 disc degeneration in patients fused to L5 and 21% developed associated symptoms. Fusion to the sacrum was recommended by the author in patients with preoperative sagittal imbalance and lumbar hypolordosis. Kuhns et al. [21] reported 69% of patients with long fusions to L5 had evidence of advanced L5-S1 degeneration, and 23% required subsequent surgery to extend the construct to the sacrum, over a minimum 5-year follow-up.

Thus, the choice of distal fusion level remains equivocal today. To our knowledge, the study is the first meta-analysis comparing the results of long fusion stopping at L5 with extending to the sacrum in ASD. We collected data from 1211 patients with healthy or minimal degenerated L5-S1 discs in 11 articles. The quality of included studies was relatively high according to the Newcastle–Ottawa scale.

Scoliosis correction angle is an important parameter to judge the efficacy of ASD surgery. The results showed no statistically significant difference between the two groups, which means that stopping a long fusion at L5 may be effective enough to correct spinal deformity in coronal plane. The magnitude of curve improvement in ASD patients was not affected by an additional lumbosacral fusion.

For lumbar lordosis angle, the final change was significantly greater in the S group than in the L group. In other words, patients fused to the sacrum obtained better restoration of lumbar lordosis. It was mainly due to the greater lordotic angle at L5-S1 given by lumbosacral instrumented correction in S group and more loss of correction in L group, which might be related to the degeneration of L5-S1 disc [16, 18]. Loss of L5-S1 segmental lordosis contributes to loss of global lumbar lordosis.

Most of included studies revealed that global sagittal balance deteriorated after long fusion in both groups [14, 16, 17]. However, there was a significant difference in the final change in SVA between two groups. Patients with sacral fusion tended to maintain global sagittal balance better than their L5 counterparts. The inability to maintain sagittal balance with long fusion to L5 might be attributed to multiple factors, such as subsequent degeneration of L5-S1 disc and fixation failure [25]. Patients with subsequent L5-S1 disc degeneration were usually in a compensatory position with a greater forward shift of the sagittal C7 plumb than in patients without disc degeneration [37]. The forward shift in sagittal balance was not benign [18]. Loss of lumbar lordosis was also in part responsible for the sagittal imbalance. Moreover, because the L5 pedicles were short and cancellous and were subject to large cantilever force at the base of long fusions, there might be insufficient fixation with a strong tendency of L5 screws to pullout [19, 38]. Fixation failures would result in loss of balance in the sagittal plane. For the coronal plane,

the stiffness of the lumbosacral junction or main lumbosacral curve was usually the cause of fixation to the pelvis, whereas fixation to L5 or above was recommended for normal lumbosacral junction. Fixation to the pelvis might improve coronal balance and pelvic obliquity [39].

Overall complication rate was similar in two groups with no significant difference. The result was counter-intuitive and inconsistent with the results of some previous studies involving only perioperative medical complications [10, 15, 18]. There was also no significant difference in revision rate between both groups. The result was consistent with a previous systematic review of three studies on this topic [40]. In L group, extension of fusion to the sacrum was the most common revision procedure [15, 18]. It implied that complications related to disc degeneration at L5-S1 were the main cause of revisions in L group, and patients suffering might benefit from the extended fusion. Patients in S group were revised for various causes, such as pseudarthrosis, fixation failure, and proximal junctional kyphosis (PJK).

Specifically, the rate of proximal adjacent segment disease was significantly higher in S group in our meta-analysis. Longer fusion would create a greater lever arm that increased the stress concentration and predisposed adjacent segments to degeneration [41]. Considering the low revision rate of PJK patients, fusion to the sacrum still seemed beneficial for ASD patients to avoid advanced L5-S1 disc degeneration despite the correlation between PJK and fusion to the sacrum [42]. The rate of symptomatic distal adjacent segment disease was 15% (10 to 19%) in L group. The studies of cho et al. [16] and Brown et al. [36] presented similar results—21% and 19%. A higher incidence of subsequent degeneration of L5-S1 disc (38 to 61%) has been reported in the literature [18, 21, 43, 44]. Most cases remained asymptomatic over time, however.

Pseudarthrosis was strongly related to fixation loosening, and we combined them for analysis. The rate of pseudarthrosis and implant-related complications was significantly higher in S group than in L group. Likewise, arthrodesis to S1 with long fusion was considered one risk factor for pseudarthrosis in Kim and his colleagues' study [10]. The location of the pseudarthrosis varied, but they occurred mostly at L5-S1 due to the high mechanical demand and short pedicles at S1 [45]. Interbody fusion at L5-S1 level and sacropelvic fixation using iliac screws were frequently recommended to reduce the incidence of lumbosacral pseudarthrosis and screw loosening [17, 28].

Clinical outcomes of individuals with ASD were evaluated using validated tools. The degree of disability was quantified by ODI, and the degree of back and leg pain by VAS. Similar improvements in pain and disability based on patients' subjective evaluation were obtained in both groups. The result was similar to many previous findings. Bafus et al. [26] found a similar incidence of perineal care difficulties in

patients with fusion to L5 or the sacrum. Daniels et al. [27] showed the functional impacts of lumbar stiffness were not significantly different between patients with distal endpoints of L5 versus S1. Therefore, the functional significance of retaining an open segment below a long fusion may need to be further measured according to age stratification and specific daily activity in the future.

Subgroup meta-analysis showed that the fusion length did not affect the change in sagittal balance, overall complication rate, and incidence of various complications. Its effect on scoliosis and kyphosis correction was unclear. Furthermore, the use of different surgical techniques and approaches may lead to clinical heterogeneity. In reference to previous studies, interbody fusion at the lumbosacral junction was conducive to reinforce the fusion and reduce the risk of fixation failure [16, 45]. It is also well accepted that in case of long fusion ending at sacrum, iliac fixation could reduce the occurrences of pseudarthrosis and result in better radiological and clinical outcomes [46–48]. Many of the included studies did not clearly distinguish the iliac fixation group from the non-iliac fixation group, so subgroup meta-analysis was not conducted in our study.

Several limitations of the meta-analysis should be mentioned. Firstly, all of the included studies were non-randomized controlled studies and had relatively low quality. Further randomized controlled trials should be performed to obtain more convincing conclusions. Secondly, relatively small numbers of studies and patients are analysed. It will be significant to carry out multicentre studies with large samples in the future. Thirdly, the patients with ASD included several different pathological types that presented differently and required different surgical procedures. In addition, disease severities of included patients were also different. These factors might lead to clinical heterogeneity. Finally, some of our data were statistically transformed data and it might influence the quality of our conclusion.

## Conclusion

According to our meta-analysis, we found that long fusion terminating at L5 or the sacrum was similar in scoliosis correction, overall complication rate, and revision rate. In addition, patients fused to the sacrum improved in pain and disability to a similar extent as patients fused to L5. However, long fusion to L5 had advantages in lower rate of pseudarthrosis, implant-related complications, and proximal adjacent segment disease, while long fusion to the sacrum had advantages in the restoration of lumbar lordosis, maintenance of sagittal balance, and absence of distal adjacent segment disease. Surgical strategy should be taken into comprehensive consideration weighing all aspects of each patient.

**Funding** None.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Open Access** This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

## References

- Schwab F, Dubey A, Gamez L et al (2005) Adult scoliosis: prevalence, SF-36, and nutritional parameters in an elderly volunteer population. *Spine (Phila Pa 1976)* 30(9):1082–1085. <https://doi.org/10.1097/01.brs.0000160842.43482.cd>
- Jimbo S, Kobayashi T, Aono K et al (2012) Epidemiology of degenerative lumbar scoliosis. *Spine (Phila Pa 1976)* 37(20):1763–1770. <https://doi.org/10.1097/brs.0b013e3182575ea>
- Schwab F, Blondel B, Bess S et al (2013) Radiographical spinopelvic parameters and disability in the setting adult spinal deformity. *Spine (Phila Pa 1976)* 38(13):803–812. <https://doi.org/10.1097/BRS.0b013e318292b7b9>
- Glassman SD, Berven S, Bridwell K et al (2005) Correlation of radiographic parameters and clinical symptoms in adult scoliosis. *Spine (Phila Pa 1976)* 30(6):682–688. <https://doi.org/10.1097/01.brs.0000155425.04536.f7>
- Yoshida G, Boissiere L, Larrieu D et al (2017) Advantages and disadvantages of adult spinal deformity surgery and its impact on health-related quality of life. *Spine (Phila Pa 1976)* 42(6):411–419. <https://doi.org/10.1097/BRS.0000000000001770>
- Aebi M (2005) The adult scoliosis. *Eur Spine J* 14(10):925–948. <https://doi.org/10.1007/s00586-005-1053-9>
- Li G, Passias P, Kozanek M et al (2009) Adult scoliosis in patients over sixty-five years of age: outcomes of operative versus nonoperative treatment at a minimum two-year follow-up. *Spine (Phila Pa 1976)* 34(20):2165–2170. <https://doi.org/10.1097/BRS.0b013e3181b3ff0c>
- Fu KMG, Bess S, Shaffrey CI et al (2014) Patients with adult spinal deformity treated operatively report greater baseline pain and disability than patients treated nonoperatively; however, deformities differ between age groups. *Spine (Phila Pa 1976)* 39(17):1401–1407. <https://doi.org/10.1097/brs.0000000000000414>
- Lapp MA, Bridwell KH, Lenke LG et al (2001) Long-term complications in adult spinal deformity patients having combined surgery a comparison of primary to revision patients. *Spine (Phila Pa 1976)* 26(8):973–983. <https://doi.org/10.1097/00007632-200104150-00025>
- Kim YJ, Bridwell KH, Lenke LG et al (2006) Pseudarthrosis in adult spinal deformity following multisegmental instrumentation and arthrodesis. *J Bone Joint Surg Am* 88(4):721–728. <https://doi.org/10.2106/JBJS.E.00550>
- Kim YJ, Bridwell KH, Lenke LG et al (2006) Pseudarthrosis in long adult spinal deformity instrumentation and fusion to the sacrum: prevalence and risk factor analysis of 144 cases. *Spine (Phila Pa 1976)* 31(20):2329–2336. <https://doi.org/10.1097/01.brs.0000238968.82799.d9>
- Ha Keeyong, Son JongMin, Im JinHyung, InSoo Oh (2013) Risk factors for adjacent segment degeneration after surgical correction of degenerative lumbar scoliosis. *Indian J Orthop* 47(4):346–351. <https://doi.org/10.4103/0019-5413.114912>
- Mackenzie WGS, Matsumoto H, Williams BA et al (2013) Surgical site infection following spinal instrumentation for scoliosis: a multicenter analysis of rates, risk factors, and pathogens. *J Bone Joint Surg Am* 95(9):800–806. <https://doi.org/10.2106/JBJS.L.00010>
- Koller H, Pfanz C, Meier O et al (2016) Factors influencing radiographic and clinical outcomes in adult scoliosis surgery: a study of 448 European patients. *Eur Spine J* 25(2):532–548. <https://doi.org/10.1007/s00586-015-3898-x>
- Mok JM, Cloyd JM, Bradford DS et al (2009) Reoperation after primary fusion for adult spinal deformity. *Spine (Phila Pa 1976)* 34(8):832–839. <https://doi.org/10.1097/BRS.0b013e31819f2080>
- Cho KJ, Suk S II, Park SR et al (2009) Arthrodesis to L5 versus S1 in long instrumentation and fusion for degenerative lumbar scoliosis. *Eur Spine J* 18(4):531–537. <https://doi.org/10.1007/s00586-009-0883-2>
- Witiw CD, Fessler RG, Nguyen S et al (2018) Re-operation after long-segment fusions for adult spinal deformity: the impact of extending the construct below the lumbar spine. *Neurosurgery* 82(2):211–219. <https://doi.org/10.1093/neuros/nyx163>
- Edwards CC II, Bridwell KH, Patel A et al (2004) Long adult deformity fusions to L5 and the sacrum. A matched cohort analysis. *Spine (Phila Pa 1976)* 29(18):1996–2005. <https://doi.org/10.1097/01.brs.0000138272.54896.33>
- Bridwell KH, Edwards CC II, Lenke LG (2003) The pros and cons to saving the L5-S1 motion segment in a long scoliosis fusion construct. *Spine (Phila Pa 1976)* 28(20):S234–S242. <https://doi.org/10.1097/01.BRS.0000092462.45111.27>
- Gao X, Wang L, Zhang J et al (2018) Long fusion arthrodesis stopping at L5 for adult scoliosis: fate of L5-S1 disk and risk factors for subsequent disk degeneration. *Clin Spine Surg* 31(3):E171–E177. <https://doi.org/10.1097/BSD.0000000000000624>
- Kuhns CA, Bridwell KH, Lenke LG et al (2007) Thoracolumbar deformity arthrodesis stopping at L5: fate of the L5-S1 disc, minimum 5-year follow-up. *Spine (Phila Pa 1976)* 32(24):2771–2776. <https://doi.org/10.1097/BRS.0b013e31815a7ece>
- Weistroffer JK, Perra JH, Lonstein JE et al (2008) Complications in long fusions to the sacrum for adult scoliosis: minimum five-year analysis of fifty patients. *Spine (Phila Pa 1976)* 33(13):1478–1483. <https://doi.org/10.1097/BRS.0b013e3181753c53>
- Eck KR, Bridwell KH, Ungacta FF et al (2001) Complications and results of long deformity fusions down to L4, L5 and the sacrum. *Spine (Phila Pa 1976)* 26(9):E182–E192. <https://doi.org/10.1097/00007632-200105010-00012>
- Kuklo TR, Bridwell KH, Lenke LG et al (2001) Minimum 2-year analysis of sacropelvic fixation and L5-S1 fusion using S1 and iliac screws. *Spine (Phila Pa 1976)* 26(18):1976–1983. <https://doi.org/10.1097/00007632-200109150-00007>
- Swamy G, Berven SH, Bradford DS (2007) The selection of L5 versus S1 in long fusions for adult idiopathic scoliosis. *Neurosurg Clin N Am* 18(2):281–288. <https://doi.org/10.1016/j.nec.2007.01.010>
- Bafus T, Shea M, Hart R (2005) Impairment of perineal care functions after long fusions of the lumbar spine. *Clin Orthop Relat Res* 433:111–114

27. Daniels AH, Koller H, Hiratzka SL et al (2017) Selecting caudal fusion levels: 2 year functional and stiffness outcomes with matched pairs analysis in multilevel fusion to L5 versus S1. *Eur Spine J* 26(6):1645–1651. <https://doi.org/10.1007/s00586-016-4790-z>
28. Yasuda T, Hasegawa T, Yamato Y et al (2016) Lumbosacral junctional failures after long spinal fusion for adult spinal deformity— which vertebra is the preferred distal instrumented vertebra? *Spine Deform* 4(5):378–384. <https://doi.org/10.1016/j.jspd.2016.03.001>
29. Zaborovskii N, Ptashnikov D, Mikhaylov D et al (2017) Spinal deformity in elderly patients: comparison of two distal termination sites of lumbar curve fusion. *Eur J Orthop Surg Traumatol* 27(1):73–78. <https://doi.org/10.1007/s00590-016-1858-8>
30. Complex Spine Study Group, Caridi J, Ross T et al (2011) Complications and revision rates for long fusions terminating at L5 versus the sacrum in adult spine deformity. *Spine J* 11:172S. <https://doi.org/10.1016/j.spinee.2011.08.411>
31. Decker S, Lafage R, Krettek C et al (2016) Sacral extension is not an overall risk factor for the development of proximal junctional kyphosis (PJK) in adult spinal deformity (ASD) surgery. *Eur Spine J* 25:3782. <https://doi.org/10.1007/s00586-016-4801-0>
32. Transfeldt EE, Topp R, Mehdob AA, Winter RB (2010) Surgical outcomes of decompression, decompression with limited fusion, and decompression with full curve fusion for degenerative scoliosis with radiculopathy. *Spine (Phila Pa 1976)* 35(20):1872–1875. <https://doi.org/10.1097/BRS.0b013e3181ce63a2>
33. Di Silvestre M, Lolli F, Bakaloudis G (2014) Degenerative lumbar scoliosis in elderly patients: dynamic stabilization without fusion versus posterior instrumented fusion. *Spine J* 14(1):1–10. <https://doi.org/10.1016/j.spinee.2012.10.023>
34. Cho KJ, Suk SI, Park SR (2008) Short fusion versus long fusion for degenerative lumbar scoliosis. *Eur Spine J* 17(5):650–656. <https://doi.org/10.1007/s00586-008-0615-z>
35. Kleinstueck FS, Fekete TF, Jeszenszky D, Haschtmann D, Mannion AF (2016) Adult degenerative scoliosis: comparison of patient-rated outcome after three different surgical treatments. *Eur Spine J* 25(8):2649–2656. <https://doi.org/10.1007/s00586-014-3484-7>
36. Kasliwal MK, Shaffrey CI, Lenke LG (2012) Frequency, risk factors, and treatment of distal adjacent segment pathology after long thoracolumbar fusion: a systematic review. *Spine (Phila Pa 1976)* 37(22 Suppl):S165–S179. <https://doi.org/10.1097/BRS.0b013e31826d62c9>
37. Liang C, Sun J, Cui X et al (2016) Spinal sagittal imbalance in patients with lumbar disc herniation: its spinopelvic characteristics, strength changes of the spinal musculature and natural history after lumbar discectomy. *BMC Musculoskelet Disord* 17:305. <https://doi.org/10.1186/s12891-016-1164-y>
38. Kwon BK, Elgafy H, Keynan O et al (2006) Progressive junctional kyphosis at the caudal end of lumbar instrumented fusion: etiology, predictors, and treatment. *Spine (Phila Pa 1976)* 31(17):1943–1951. <https://doi.org/10.1097/01.brs.0000229258.83071.db>
39. Obeid I, Berjano P, Lamartina C et al (2019) Classification of coronal imbalance in adult scoliosis and spine deformity: a treatment-oriented guideline. *Eur Spine J* 28(1):94–113. <https://doi.org/10.1007/s00586-018-5826-3>
40. Sardar ZM, Ouellet JA, Fischer DJ, Skelly AC (2013) Outcomes in adult scoliosis patients who undergo spinal fusion stopping at L5 compared with extension to the sacrum. *Evid Based Spine Care J* 4(2):96–104. <https://doi.org/10.1055/s-0033-1357360>
41. Etebar S, Cahill DW (1999) Risk factors for adjacent-segment failure following lumbar fixation with rigid instrumentation for degenerative instability. *J Neurosurg* 90(2 Suppl):163–169
42. Yagi M, Akilah KB, Boachie-Adjei O (2011) Incidence, risk factors and classification of proximal junctional kyphosis: surgical outcomes review of adult idiopathic scoliosis. *Spine (Phila Pa 1976)* 36(1):E60–E68. <https://doi.org/10.1097/BRS.0b013e3181eeae2>
43. Emami A, Deviren V, Berven S et al (2002) Outcome and complications of long fusions to the sacrum in adult spine deformity. Luque–Galveston, combined iliac and sacral screws, and sacral fixation. *Spine (Phila Pa 1976)* 27(7):776–786. <https://doi.org/10.1097/00007632-200204010-00017>
44. Horton WC, Holt RT, Muldowny DS (1996) Controversy fusion of L5–S1 in adult scoliosis. *Spine (Phila Pa 1976)* 21(21):2520–2522. <https://doi.org/10.1097/00007632-199611010-00024>
45. Pateder DB, Park YS, Kebaish KM (2006) Spinal fusion after revision surgery for pseudarthrosis in adult scoliosis. *Spine (Phila Pa 1976)* 31(11):E314–E319. <https://doi.org/10.1097/01.brs.0000217619.57333.96>
46. Kebaish KM (2010) Sacropelvic fixation: techniques and complications. *Spine (Phila Pa 1976)* 35(25):2245–2251. <https://doi.org/10.1097/BRS.0b013e3181f5cfaf>
47. Tsuchiya K, Bridwell KH, Kuklo TR, Lenke LG, Baldus C (2006) Minimum 5-year analysis of L5–S1 fusion using sacropelvic fixation (Bilateral S1 and Iliac Screws) for spinal deformity. *Spine (Phila Pa 1976)* 31(3):303–308. <https://doi.org/10.1097/01.brs.0000197193.81296.f1>
48. Hyun SJ, Rhim SC, Kim YJ, Kim YB (2010) A mid-term follow-up result of spinopelvic fixation using iliac screws for lumbosacral fusion. *J Korean Neurosurg Soc* 48(4):347–353. <https://doi.org/10.3340/jkns.2010.48.4.347>

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

## Affiliations

Fei Jia<sup>1,2</sup> · Guodong Wang<sup>1</sup> · Xiaoyang Liu<sup>1</sup> · Tao Li<sup>1</sup> · Jianmin Sun<sup>1</sup>

<sup>1</sup> Department of Spine, Shandong Provincial Hospital Affiliated to Shandong University, No. 9677, Jingshi Road, Jinan, Shandong Province, China

<sup>2</sup> Department of Orthopaedics, Peking University Third Hospital, North Garden Street No. 49, Haidian District, Beijing, China