Original Article

Is reduction or arthrodesis *in situ* the optimal choice for adolescent spondylolisthesis?—a systematic review and meta-analysis

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Background: Controversy remains about the choice of reduction or arthrodesis *in situ* for surgical management of adolescent spondylolisthesis, while no systematic review and meta-analysis were performed to determine which one is the optimal surgical choice. The study aims to compare outcomes of the two surgical strategies for adolescent spondylolisthesis.

Methods: A comprehensive search was performed through PubMed, Web of Science, Cochrane Library, Embase, OVID/MEDLINE, CBM, CNKI, and Wanfang with a cutoff date of May 21st, 2021. Search terms included "spondylolisthesis", "*in situ*" and "reduction". Included studies had following characteristics: (I) participants: adolescents with spondylolisthesis. (II) Intervention: reduction following arthrodesis. (III) Control: arthrodesis *in situ*. (IV) Outcomes: postoperative clinical and/or radiographic results. (V) Study design: randomized controlled trial (RCT), cohort or case-control study. Data were analyzed with Review Manager 5.4, and risk of bias assessment of studies was assessed via Newcastle-Ottawa quality assessment scale (NOS).

Results: Six cohort studies were included, with NOS scores of all ≥6. There were no significant differences regarding operative time [mean difference (MD) =152.62; 95% [confidence interval (CI)]: −54.02 to 359.26; I^2=96%; P=0.15], blood loss (MD =786.61; 95% CI: −646.82 to 2,220.04; I^2=90%; P=0.28), patient satisfaction (MD =1.98; 95% CI: 0.72 to 5.43; I^2=0%; P=0.18), neurological complications (MD =1.02; 95% CI: 0.25 to 4.18; I^2=0%; P=0.98), or total complications (MD =0.59; 95% CI: 0.29 to 1.19; I^2=0%; P=0.14). However, patients undergoing reduction achieved better radiographic results: fusion rate (MD =3.09; 95% CI: 1.22 to 7.84; I^2=40%; P=0.02), postoperative pseudarthrosis (MD =0.35; 95% CI: 0.15 to 0.79; I^2=24%; P=0.01), percentage of slippage (MD =−20.58; 95% CI: −26.32 to −14.84; I^2=0%; P<0.00001), and slipping angle (MD =−10.05; 95% CI: −14.55 to −5.54; I^2=0%; P<0.0001). And no overt publication bias was found in the studies.

Discussion: Both reduction and arthrodesis *in situ* in adolescent spondylolisthesis are safe and demonstrate good clinical outcomes. However, reduction showed better radiographic results and was associated with less pseudarthrosis, better relief of disability, and improvements in self-image. In conclusion, reduction may be the optimal choice compared with arthrodesis *in situ*, but further verification of these findings is recommended using RCTs.

Keywords: Lumbar spondylolisthesis; adolescent; arthrodesis; reduction; *in situ*

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Introduction

Spondylolisthesis is characterized as the anterior displacement of a vertebra on the subjacent one and has a prevalence rate of approximately 15% among patients with low back pain (1). Spondylolisthesis can be observed in different age groups, including adolescents, among which spondylolisthesis has proven to be the most common cause of low back pain. In the last decade, it has been associated with increased morbidity and a heavy economic burden (2-5). In the general population, adolescents and adults show a similar incidence of 6%, but athletes engaged in specific sporting activities show a much higher incidence (23–62%), and most of these are adolescents (6,7). Moreover, progression of spondylolisthesis increases with age as constant stresses are applied to the slipping vertebra—the condition progresses from an asymptomatic status to long-term pain in the lower back and extremities or an increased percentage of slippage, which can severely affect the individual's quality of life as an adult (8-11).

The management of spondylolisthesis involves conservative treatment and surgical interventions. Nonoperative management tends to be considered for minimally symptomatic or asymptomatic adolescents with low-grade spondylolisthesis (12). At the same time, surgical treatment provides a better outcome for those who are unresponsive to conservative therapy, such as individuals with high-grade spondylolisthesis, continual symptomatology, or neurological deficits (13-16). In terms of surgical management, arthrodesis has shown to be effective for lumbar spondylolisthesis (17), but consensus has yet to be reached on whether reduction or arthrodesis *in situ* is the more suitable technique for adolescent spondylolisthesis. The choice of surgical management for adolescents is especially important when different surgical approaches can affect prognosis. Issues such as intraoperative neurological injury, restoration of sagittal balance, and postoperative pseudarthrosis can significantly impact the adolescent's positive self-image and need for physical exercise (18). Previous studies vary greatly in their opinions. Several researchers have argued that superior postoperative results are obtained with arthrodesis *in situ* compared with the reduction due to reduced blood loss and a shorter operative time; that there is a higher risk of intraoperative neurologic deficits associated with reduction, and that no correlation was found between reduction and improved clinical outcomes (19-22). Opponents of these opinions have argued that arthrodesis *in situ* has a higher mean blood loss, a higher incidence of neurologic complications and that no statistical differences have been found in operative time or clinical outcomes between the two procedures (23,24). At the same time, other authors have reported that reduction facilitates the restoration of lumbar sagittal alignment, thus indirectly creating decompression and improving the fusion rate, and has the advantages of long-term stability and a reduced risk of pseudarthrosis (25,26). However, no obvious improvement in fusion rates has been reported in other studies (23,27). Furthermore, many of these studies either had no comparison group or no division in ages, indicating that the results may not be applicable or relevant for adolescent spondylolisthesis.

Therefore, the purpose of this review is to compare the outcomes of the two different surgical strategies for adolescent spondylolisthesis and provide a better option for young patients. We present the following article following the PRISMA reporting checklist (available at https://dx.doi.org/10.21037/apm-21-569).

Methods

Literature search strategy

Systematic retrieval was performed by searching PubMed [1981–2021], WOS [1981–2021], Cochrane Library [2006–2021], Embase [1979–2021], OVID/MEDLINE [1981–2021], CBM [2002–2021], CNKI [1995–2021], and Wanfang [2009–2021] via the keywords "spondylolisthesis" in combination with "in situ" and "reduction", with a cutoff date of May 21st, 2021. More specifically, the search terms in the various databases are listed as follows: ((((reset) OR (reduction)) OR (reductive)) AND (((in-situ[Title/Abstract]) OR (in situ[Title/Abstract])) OR (original[Title/Abstract]))) AND (("Spondylolysis"[Mesh]) OR "Spondylolisthesis"[Mesh]) in PubMed; TS = (spondylos?s or sponylolys?s or spondylolisthes?s or spondylisthes?s)

Table 1 Characteristics of included studies

Study	Year	Study design	Sampled size		Gender: M/F		Age span (year)	Etiology	Grade	Slippage site	Surgical procedure	Outcome	Mean follow up period (month)
			R	I	R	I							
Burkus *et al.* (29)	1992	Cohort study	24	18	12/12	11/7	7.9–17.11	IS and DS	I–IV	L3–4, L4–5, L5–S1	PLIF	e, g, h, I	…
Martiniani *et al.* (30)	2012	Cohort study	10	6	…	…	15.8–27.9	DCS	IV	L5–S1	PLIF	a, b, e, h	24
Molinari *et al.* (31)	1999	Cohort study	26	11	9/17	5/6	9–20	DS	III–IV	L4–5, L5–S1	PLIF	d, e, f, g, i	37.2
Muschik *et al.* (32)	1997	Cohort study	30	29	13/17	11/18	9–19	IS and DS	III–IV	L5–S1	ALIF	c, e, f, g, h, i	95.5
Poussa *et al.* (33)	2006	Cohort study	11	11	3/8	3/8	10.7–18.5	IS	III–IV	L4–5, L5–S1	PLIF	d, e, f, g, h	177.6
Poussa *et al.* (34)	1993	Cohort study	11	11	4/7	2/9	11–17	IS	III–IV	L4–5, L5–S1	PLIF	a, b, c, d, e, f, g, h	57.8

R, reduction; I: *in situ*; …, the form of data not conforming to the corresponding format rather than missing, and the follow-up period (month) ranging from 48 to 331. a, operative time; b, blood loss; c, patients satisfaction; d, neurological complications rate; e, total complications rate; f, fusion rate; g, postoperative pseudarthrosis; h, percentage of slippage; i, slipping angle. IS, isthmic spondylolisthesis; DS, degenerative spondylolisthesis; DCS, dysplastic spondylolisthesis; PLIF, posterior lumbar interbody fusions.

AND TS=(in situ, or in-situ, or original) AND TS=(reduction, or reductive, or reset) in Web of Science; TKA=('spondylolisthesis') AND TKA=('arthrodesis in situ' + 'reduction') in CNKI. Moreover, we checked the references of all original relevant trials and reviews for other supplementary articles.

Study eligibility criteria

Studies were included based on the following criteria: (I) subjects with a preoperative diagnosis of lumbar spondylolisthesis; (II) the surgical treatment was a comparison of fusion *in situ* with reduction; (III) the study design was either randomized controlled trials (RCTs), cohort, or case-control; (IV) the study included adolescent patients aged 10–24 years (28); (V) all included patients were followed up for at least 24 months postoperatively.

The exclusion criteria were as follows: (I) reviews, case reports, letters to the editors, conference abstracts, and editorials; (II) articles not specifically reporting outcomes, and data overlapping with previous publications.

All the processes were performed independently by two reviewers. When faced with disagreement, the reviewers reached a consensus by group discussion.

Data extraction

Relevant data were extracted independently by the two reviewers, who e-mailed the authors when necessary for specific information not included in their articles. Moreover, disagreements between the two reviewers were resolved by group discussion. The information collected fell into two categories: basic information concerning the trials and patients, and clinical and radiological outcomes. More specifically, the surname of the primary author, year of publication, study design, the number and age span of participants, gender, etiology, grade of spondylolisthesis, site of slippage, type of surgery, and mean follow up period can be found in *Table 1*. Clinical and radiographic results concerning operative time, blood loss, patient satisfaction, neurological complications, total complications, fusion rate, postoperative pseudarthrosis, percentage of slippage, and slipping angle can also be found in *Table 1*.

Assessment of methodological quality

The Newcastle-Ottawa quality assessment scale (NOS) (35) was adopted for the six cohort studies. As described above,

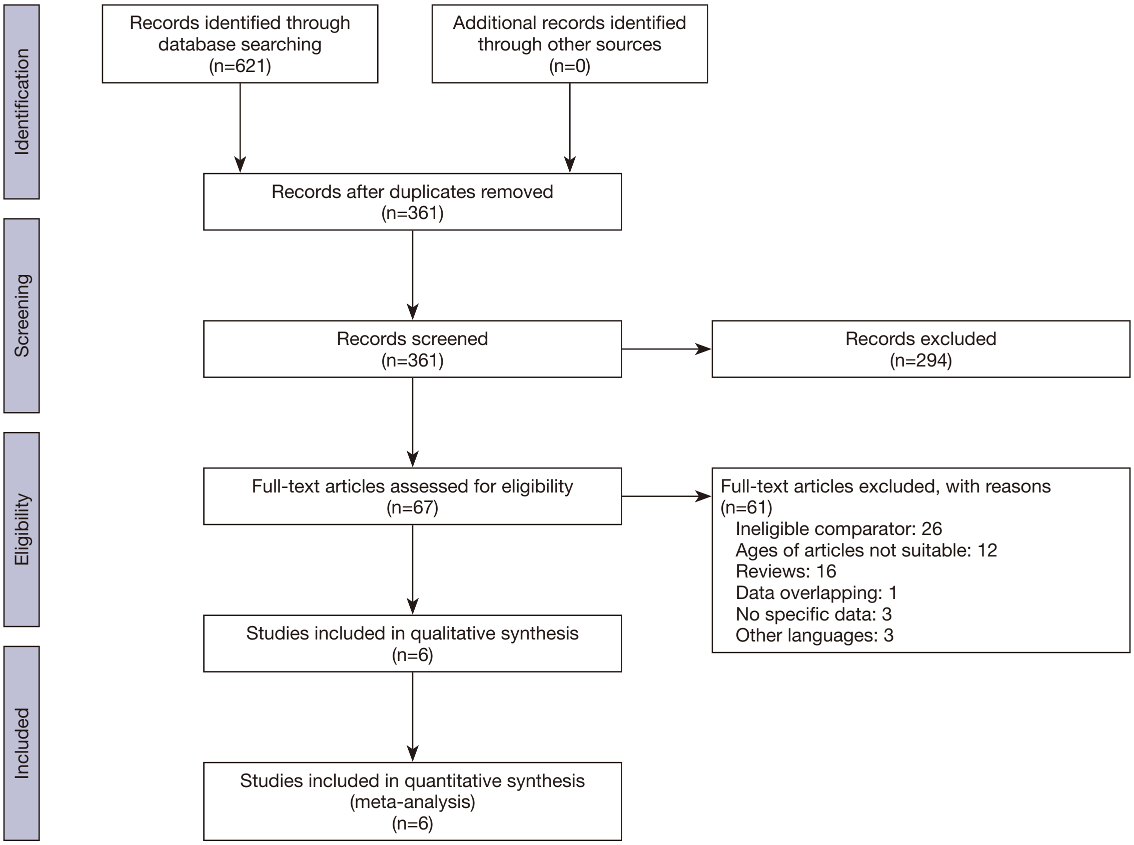

Figure 1 The screening flow diagram of the included studies.

two reviewers performed the assessment independently, and any disagreement was resolved by group discussion.

Statistical analysis

Data were analyzed with Review Manager 5.4. Continuous variables in each treatment group are reported as the mean, standard deviation (SD), and a total number of patients to obtain the pooled mean difference (MD) and the 95% confidence interval (CI). Dichotomous outcomes are presented as odds ratio (OR) with 95% CI by the number of events and the total patients in each treatment arm. Heterogeneity among studies was analyzed with Cochrane's Q test and the I^2 statistic. Heterogeneity was taken into account if P≤0.1 and/or I^2>50% were observed. Namely, a random-effects model was adopted in the case of P≤0.1 and/or I^2>50%, otherwise a fixed-effects model was used. A funnel plot was used for the main and most frequently reported outcome to screen for potential publication bias, and all studies were symmetrically distributed and within 95% CI, which indicate no publication bias.

Results

Search results

As shown in *Figure 1*, a total of 621 records were found by the database searches. After removing 260 studies for duplication and excluding 294 others based on titles and abstracts, the remaining 67 records were examined, and a further 61 studies were excluded for the following reasons: twenty-six articles did not contain comparisons of reduction and in-situ procedures, 12 articles did not include the required age ranges, 16 were reviews, one had overlapping data, three were lacking specific data, and three were in languages other than English or Chinese. Finally, six English language studies (29-34) with a total of 198 patients were included in the qualitative and quantitative analyses.

Table 2 Risk of bias assessment of cohort studies (NOS*)

Criteria	Burkus *et al.*, 1992	Martiniani *et al.*, 2012	Molinari *et al.*, 1999	Muschik *et al.*, 1997	Poussa *et al.*, 2006	Poussa *et al.*, 1993
Selection						
Representativeness of the exposed cohort	1	1	1	1	1	1
Selection of the non-exposed cohort	1	1	0	1	1	1
Ascertainment of exposure	1	1	1	1	0	1
Demonstration that outcome of interest was not present at start of study	1	1	1	1	1	1
Comparability						
Comparability of cohorts on the basis of the design or analysis	1	1	0	1	1	1
Outcome						
Assessment of outcome	1	1	1	1	1	1
Was follow-up long enough for outcomes to occur	1	1	1	1	1	1
Adequacy of follow up of cohorts	1	1	1	1	1	1
Total score	8	8	6	8	7	8

*, NOS, Newcastle-Ottawa quality assessment scale.

Description of included studies

As shown in *Table 1*, the included research papers were all cohort studies. Among the 198 patients, 112 had received reduction following arthrodesis, and the remaining 86 individuals underwent arthrodesis *in situ*. Except for five patients with 1 or 2 years younger or older than the age criterion, 193 patients ranged in age from 10 to 24 years. In terms of the etiology of spondylolisthesis, one study comprised dysplastic spondylolisthesis and the remainder comprised isthmic and degenerative spondylolisthesis. The grades of spondylolisthesis were either Grade IV or Grade III–IV, with five studies reporting on high grade spondylolisthesis, and one containing patients with mixed grades. Most of the surgical interventions were posterior lumbar interbody fusions (PLIF), with one study of anterior lumbar interbody fusion (ALIF). The mean follow-up period varied from 24 months to 177.6 months, with all patients followed up for at least 24 months postoperatively [the follow-up period of one study (29) ranged from 48 to 331 months]. The comparative items among studies are listed below the outcomes in *Table 1*.

The methodological quality of included studies

The methodological quality of the eligible studies was evaluated by the NOS (*Table 2*). Any disagreements between the two reviewers were settled by group discussion until consensus was reached.

Clinical results

Operative time

Operative time was reported in two studies, as shown in *Figure 2*. A random-effects model was used due to substantial heterogeneity in the pooled results (I^2=96%). Results demonstrated no significant difference between the reduction and *in situ* groups (MD =152.62; 95% CI: −54.02 to 359.26; P=0.15).

Blood loss

Two studies covered the comparison of blood loss between the reduction and *in situ* groups. As seen in *Figure 3*, a random-effects model was used due to obvious heterogeneity (I^2=90%). No significant difference between

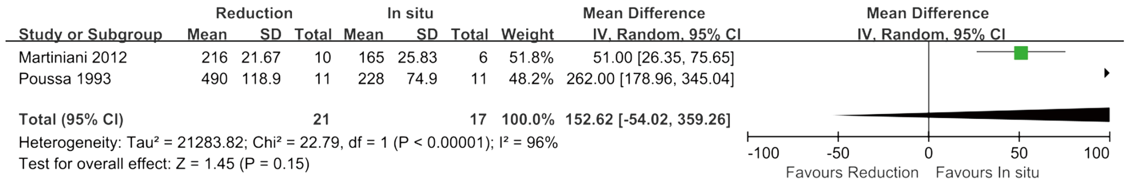

Figure 2 Analysis of operative time (min) between reduction and *in situ*.

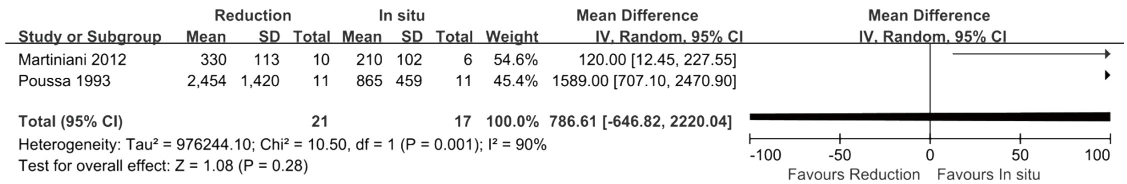

Figure 3 Analysis of blood loss (mL) between reduction and *in situ*.

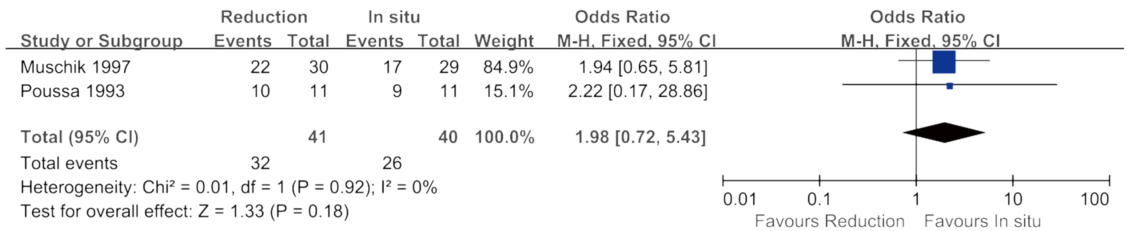

Figure 4 Analysis of satisfaction between reduction and *in situ*.

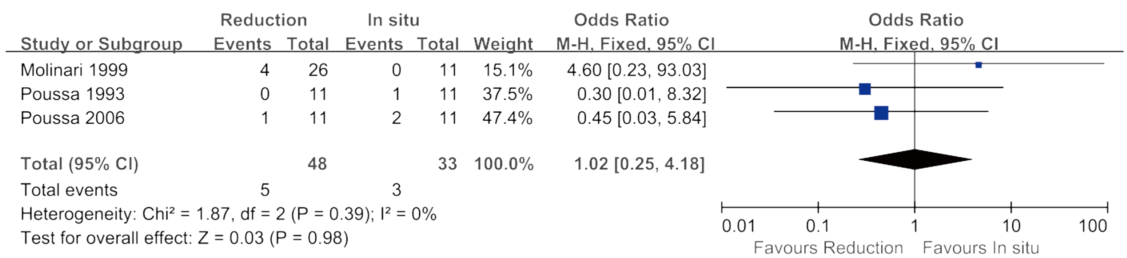

Figure 5 Analysis of neurological complications between reduction and *in situ*.

the reduction and *in situ* groups was observed (MD =786.61; 95% CI: –646.82 to 2,220.04; P=0.28).

Patient satisfaction

As shown in *Figure 4*, two studies compared patient satisfaction in the reduction and *in situ* groups, and a fixed-effects model was applied because of nil heterogeneity (I^2=0%). No significant difference between the reduction and *in situ* groups was observed (MD =1.98; 95% CI: 0.72 to 5.43; P=0.18).

Neurological complications

As shown in *Figure 5*, three studies compared neurological complications in the reduction and *in situ* groups. A fixed-effects model was adopted because of low heterogeneity (I^2=0%). No significant difference between the reduction and *in situ* groups was observed (MD =1.02; 95% CI: 0.25 to 4.18; P=0.98).

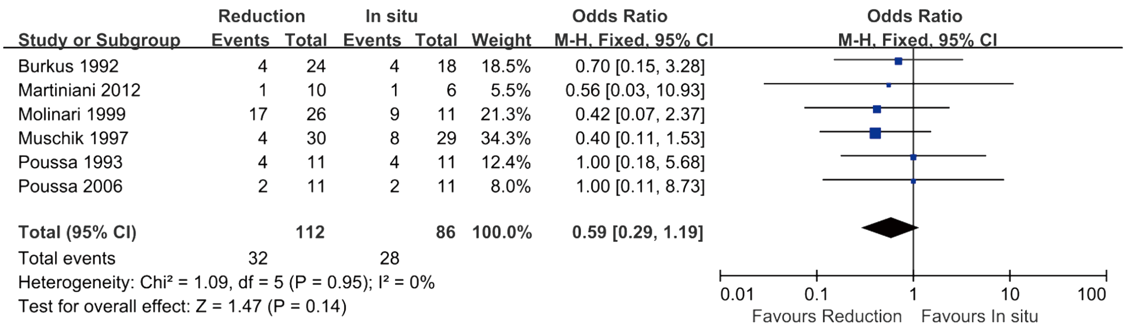

Figure 6 Analysis of total complications between reduction and *in situ*.

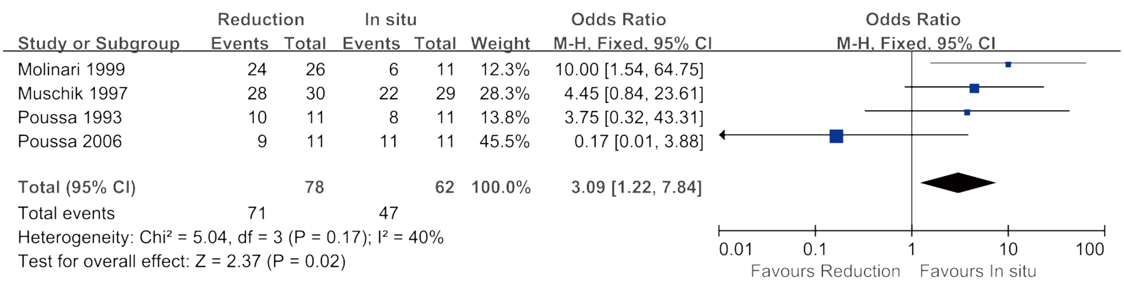

Figure 7 Analysis of fusion rate between reduction and *in situ*.

Total complications

Data concerning total complications were extracted from all six studies (*Figure 6*). A fixed-effects model was used owing to the low heterogeneity of the merged results (=0%). No significant difference between the reduction and *in situ* groups was observed (MD =0.59; 95% CI: 0.29 to 1.19; P=0.14).

Radiographic results

Fusion rate

The fusion rate was reported in four studies, as shown in *Figure 7*. Because there was no obvious heterogeneity in the pooled results (I^2=40%), a fixed-effects model was used. The *in situ* group had significantly fewer fusions than the reduction group (MD =3.09; 95% CI: 1.22 to 7.84; P=0.02).

Postoperative pseudarthrosis

Five studies reported on differences in the incidence of postoperative pseudarthrosis between the reduction and *in situ* groups. A fixed-effects model was applied due to low heterogeneity (I^2=24%). As shown in *Figure 8*, the reduction was associated with significantly less postoperative pseudarthrosis compared with the *in situ* procedure (MD =0.35; 95% CI: 0.15 to 0.79; P=0.01).

Percentage of slippage

Five studies reported the percentage of slippage. *Figure 9* shows the results of a random-effects model conducted due to large heterogeneity (I^2=78%). The percentage of slippage in the reduction group demonstrated a significantly better outcome than that of the in situ group (MD =−26.31; 95% CI: −38.16 to −14.46; P<0.0001). *Figure 10* shows the result with low heterogeneity (I^2=0%) after performing sensitivity analysis and removing the study conducted by Martiniani *et al.* (30) (MD =−20.58; 95% CI: −26.32 to −14.84; P<0.00001).

Slipping angle

Data from three studies were used to compare the slipping angle at follow-up, as shown in *Figure 11*. A fixed-effects model was used due to low heterogeneity in the pooled results (I^2=0%). The results showed that the slipping angle in the reduction group was significantly less than that in the *in situ* group (MD =−10.05; 95% CI: −14.55 to −5.54; P<0.0001).

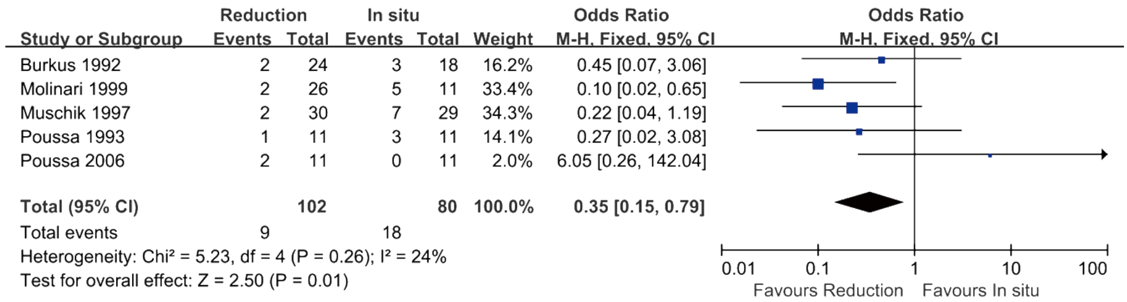

Figure 8 Analysis of postoperative pseudarthrosis between reduction and *in situ*.

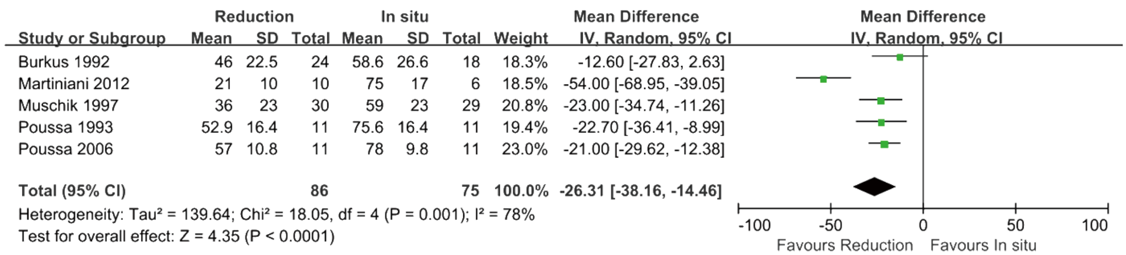

Figure 9 Analysis of percentage of slippage between reduction and *in situ*.

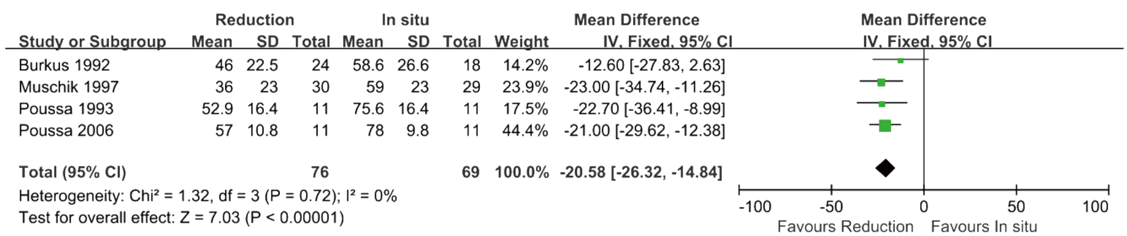

Figure 10 Analysis of percentage of slippage between reduction and *in situ* after removing Martiniani *et al.* 2012.

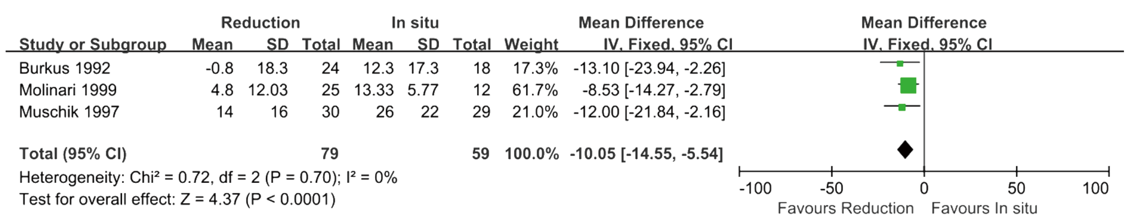

Figure 11 Analysis of slipping angle between reduction and *in situ*.

Publication bias

As shown in *Figure 12*, publication bias was assessed by a funnel plot, describing the total complications rates between the two groups. All six studies lay inside the 95% CI and the distribution was nearly symmetrical, indicating that there was no overt publication bias in the meta-analysis.

Discussion

Debate continues concerning whether reduction or

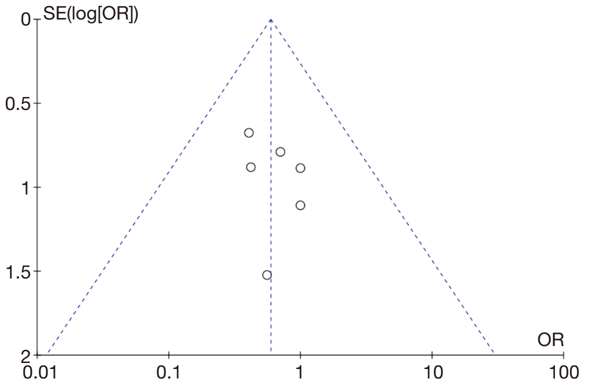

Figure 12 The assessment of publication bias through funnel plot illustrated by total complications rate.

arthrodesis *in situ* is the better surgical procedure for adolescent spondylolisthesis (29-34). Transfeldt and Mehbod (36) conducted a comparison of the two surgical interventions in high grade spondylolisthesis in a pediatric population, but their study did not include a quantitative analysis, difficult to draw an accurate conclusion. We conducted a meta-analysis, including a more recent study (30), to compare the outcomes between the two surgical procedures.

Six studies were taken into consideration in this review; however, they were cohort studies rather than RCTs. Concerning assessing the quality of the included studies, the research by Molinari *et al.* 1999 (31) received only 6 points because most patients in the reduction group had undergone prior surgery, unlike the control group, which implied a selection bias in participants. Despite this, the NOS scores of all studies were ≥6, indicating that they were generally of high quality. We also considered the heterogeneity of the included studies. Substantial heterogeneity was found in operative time and blood loss results, which can probably be attributed to the recent advancement in surgical techniques—arthrodesis surgery nowadays causes less blood loss and needs less operative time than in the past. A high degree of heterogeneity was also found in comparisons of the percentage of slippage, but low heterogeneity was obtained by removing the Martiniani *et al.* study (30) in the sensitivity analysis; the greater reduction in this percentage of slippage study may account for this phenomenon.

An evaluation of clinical safety was conducted by comparing clinical outcomes, except for patient satisfaction, of the reduction and arthrodesis *in situ* procedures. Previous studies have indicated that a longer operative time and greater blood loss are associated with a higher incidence of intraoperative and postoperative complications (37-40). However, thanks to the recent advances in surgical instrumentation and technology, acceptable safety limits for operative time and amount of blood loss have been achieved (23,41,42), which can also be seen in the decrease in the operative time and blood loss according to the results of Poussa 1993 and Martiniani 2012 in *Figures 1* and *2*. Moreover, in contrast to the previous opinions that longer operative times and greater blood loss occurred with reduction, we found no significant differences between reduction and *in situ* group in the case of operative time (P=0.15) and blood loss (P=0.28). It has also been reported that risk of neurological injury was higher in patients receiving reduction *vs.* arthrodesis *in situ* procedure (10.0% *vs.* 2.1%, P<0.05) (21). However, in our study, similar rates of neurological deficits was reported in both the reduction and in-situ group (10.4% *vs.* 9.1%, P=0.98), and also for total complications (28.6% *vs.* 32.6%, P=0.14).

Given that arthrodesis *in situ* for adolescent spondylolisthesis has been proven clinically safe in a previous study (24), and that no statistically significant differences in operative time, blood loss, or complications between the two groups were found in our results, we conclude that reduction for adolescent spondylolisthesis is also a clinically safe procedure. As for the effectiveness of the two treatments, several studies reported positive results of functional tests and significant improvement in pain relief in both groups, and both of these outcomes are essential for adolescents who have high requirements for spinal motor function (30,31,33,34). The high postoperative patient satisfaction demonstrated the effectiveness of the reduction and *in situ* group (78.0% *vs.* 65.0%, P=0.18). In general, the postoperative clinical outcomes in the reduction group were as high as those in the *in situ* group, indicating that the two approaches are both safe and effective in terms of clinical outcomes.

Significant differences were found in the radiographic results. Overall, better outcomes were observed in the reduction than *in situ* group—a higher fusion rate (91.0% *vs.*75.8%, P<0.05), less postoperative pseudarthrosis (8.8% *vs.* 22.5%, P<0.05), less percentage of slippage (P<0.05), and less slipping angle (P<0.05). A higher fusion rate brought about by reducing slipping vertebra is associated with less shear force on the implants across the disc space and more contact area between the implants and the endplates, therefore avoiding future instability and complications (43,44). A previous study has shown that increased shear stress at the disc is correlated with an increased percentage of slippage, and shear stress combined with other stresses, especially in the lumbosacral junction, aggravated the slippage of the L5 vertebra by inducing the formation of a sacral dome (45). Though immediate stability can be achieved by instrumentation in arthrodesis *in situ*, achieving long-term stability is more challenging in this technique—the internal fixation materials may break down or become damaged after continual stress and fatigue. Long-term stability would therefore depend on subsequent fusion (46,47). There are significant implications for adolescents following a low fusion rate, one of which is postoperative pseudarthrosis. Pseudarthrosis, as one of the most common complications of lumbar spinal surgery, usually leads to recurrent postoperative pain and disability and even to revision lumbar surgery (48,49). The prognosis after a revision surgery is not as favorable as after the first operation: one study reported that although non-union was corrected, 10% of patients reported no change in their overall well-being, 26% stated that they were worse, and the overall well-being status after the revision was generally worse than before (49). Sometimes, pseudarthrosis can be adjusted by revision surgery; nevertheless, the mental health symptoms secondary to pseudarthrosis-associated back pain may be more refractory (50). For adolescents at a critical stage of mental development, the negative emotions they experience may become a danger to their future healthy functioning. Equally important are the percentage of slippage and the slipping angle. A large percentage of slippage has been associated with a high slipping angle with the resultant appearance of significant lumbosacral kyphosis, thus leading to an anomalous spinal alignment and disturbance of the sagittal spinopelvic balance (51-53).

In turn, sagittal spinopelvic imbalance might influence the pathogenesis of spondylolisthesis (53). Meanwhile, anomalous spinal alignment and an unbalanced sagittal spinopelvic system remain problematic for patients who have received arthrodesis *in situ*, leaving them with abnormal spinal mechanics and a diminished self-image. Large lumbosacral kyphosis creates maximal hyperextension of the thoracolumbar region for the sake of sagittal balance, causing muscle fatigue, disc degeneration, and changes of facet. Previous studies have also shown that some moderate, but recurring, low back and thigh pain after arthrodesis *in situ* results from terminal degeneration (54,55). A new classification of spondylolisthesis based on spinopelvic posture suggests that reduction should be applied in cases of high-grade spondylolisthesis with a retroverted pelvis (56) because further slippage or progression of lumbosacral deformity after arthrodesis *in situ* could occur in patients with high-grade spondylolisthesis with a balanced spine, which may result in a retroverted pelvis, unbalanced spine, and residual pain in the future (57). Because high-grade spondylolisthesis is very common among adolescent isthmic spondylolisthesis, progression of slippage and the resultant sagittal imbalance would not be a good outcome for these patients after arthrodesis *in situ* (18).

In contrast, adolescents in the reduction group showed less evidence of late progression of lumbosacral deformity (29). Self-image is vitally important for adolescents, especially for those with abnormal physical presentations (58). For these patients, full reduction of spondylolisthesis deformity meant correcting the abnormal waddling gait, restoration of trunk height, and disappearance of protruding ribs and flattened buttocks (59). Sometimes, the only reason for the reduction was that they hoped to improve their appearance (60).

The major shortcoming of this meta-analysis is that a total of five patients were 1 or 2 years younger or older than the criterion for adolescent age, which may weaken the accuracy of the findings. In addition, the lack of RCTs for adolescent spondylolisthesis and the small sample size should be taken into account. Another limitation is the few comparative items both in clinical and radiographic parameters due to the difficulty in obtaining the raw data. Furthermore, only Chinese and English databases were checked, so articles published in other languages may have been missed. Finally, we failed to analyze lumbar spondylolisthesis by subgroups based on etiology due to the small number of included studies.

In conclusion, both reduction and arthrodesis *in situ* of adolescent spondylolisthesis are safe and have good clinical outcomes. Reduction demonstrated better results concerning radiographic outcomes and was associated with less chance of pseudarthrosis, better relief of disability, and improvement of self-image. In conclusion, reduction may be the optimal choice compared with arthrodesis *in situ* for the surgical management of adolescent spondylolisthesis, but further verification of these findings is recommended using RCTs.

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Footnote

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