Systematic Review

Risk factors for proximal junctional kyphosis in adult spinal deformity after correction surgery: A systematic review and meta-analysis

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ABSTRACT

Objective: This study aimed to conduct a systematic review and meta-analysis to assess the risk factors for proximal junctional kyphosis after the correction surgery of adult spinal deformity.

Methods: Relevant studies were systematically retrieved from databases including Cochrane Library, PubMed, and Embase. Based on inclusion and exclusion criteria, literature screening, quality evaluation, and data extraction were conducted. Analysis was performed with Revman 5.3 software.

Results: Sixteen studies with 2388 patients, covering 905 cases with proximal junctional kyphosis and 1483 cases without proximal junctional kyphosis, were included in the study. The high-risk factors for the development of proximal junctional kyphosis were found to be high body mass index, osteoporosis, severe fatty infiltration of paravertebral muscles, small functional area of paravertebral muscles, lumbar lordosis over-correction, lack of ligament reinforcement device at the proximal vertebrae and upper instrumented vertebra at the thoracolumbar segment, and pelvic fixation. The results were statistically significant.

Conclusion: Evidence from this study has revealed that the independent risk factors for proximal junctional kyphosis complications after correction surgery of adult spinal deformity are high body mass index, osteoporosis, severe degeneration of paravertebral muscles, lumbar lordosis over-correction, fixed fusion to the pelvis, and lack of ligament reinforcement device at the proximal vertebrae and upper instrumented vertebra at the thoracolumbar segment.

Level of Evidence: Level IV, Therapeutic Study

Introduction

Adult spinal deformity (ASD) is a common disease that causes low back pain and lower limb pain and seriously affects people’s quality of life. With an increasing proportion of elderly individuals in the population, spinal surgeons have focused on ASD and aimed to improve the health-related quality of life of patients with ASD.1 Surgical treatment is an effective method for patients with ASD. However, surgical treatment may be associated with the risk of intraoperative and postoperative complications, which make it challenging. Proximal junctional kyphosis (PJK) is a common complication in patients with ASD and has an incidence rate of 20-40%.2 Proximal junctional kyphosis is a final proximal junctional sagittal Cobb angle between the lower endplate of the uppermost instrumented vertebra and the upper endplate of 2 supra-adjacent vertebrae >10° and at least 10° greater than the preoperative measurement.3 Proximal junctional kyphosis may lead to damage to sagittal balance, vertebral collapse, and nerve lesions. In some cases, revision surgery is even needed, which seriously affects the postoperative efficacy in patients with ASD.4

Studies of the risk factors for PJK are necessary to help surgeons implement effective measures to reduce the incidence of PJK and improve the clinical efficacy after correction surgery. Risk factors related to PJK are general patient factors, surgical factors, and imaging sequences of the spine and pelvis.5 However, most of these factors related to PJK remain controversial. A previous meta-analysis6 showed that age greater than 55 years at operation, osteoporosis, fusion to S1, Thoracic kyphosis (TK) >40°, and Sagittal vertebral axis (SVA) correction >5 cm are risk factors for PJK. However, this study has defects leading to a decrease in its evidence-based significance. For example, in the meta-analysis of risk factors, the results of multivariate regression were not extracted as the effect size, and other eligible studies were omitted. Therefore, we retrieved relevant studies on risk factors for PJK in patients with ASD after surgery and conducted a high-quality meta-analysis to provide guidance for the surgical treatment of ASD.

Materials and Methods

Retrieval strategy

The meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and the Guidelines for Meta-Analysis.7 We retrieved studies on risk factors for PJK after ASD correction surgery from PubMed, Embase, and the Cochrane Library. Keywords for retrieval included “Adult Spinal Deformity” or “ASD” and “Proximal Junctional Kyphosis” or “PJK.” Studies published in English were retrieved, and no time limit for publication was
All relevant studies released before March 2021 were covered. Two researchers screened individual studies according to the inclusion and exclusion criteria and collected odds ratios (ORs) and 95% CIs of risk factors. Secondary retrieval was conducted based on the list of references in the selected studies.

**Inclusion and exclusion criteria**
The inclusion criteria for this meta-analysis included (1) patients diagnosed with ASD and undergoing correction surgery; (2) comparison of PJK and non-PJK groups and risk factors determined by a regression analysis; and (3) extraction or transformation of OR and 95% CI data. The exclusion criteria included (1) adolescent idiopathic scoliosis, congenital scoliosis, and other types of spinal deformities; (2) failure to analyze risk factors for PJK; (3) lack of data that could be extracted; (4) repeated release of data or studies; and (5) meeting abstracts, case reports, or summaries.

**Data extraction and quality evaluation**
Two researchers extracted each item of data from the included studies. Disputes over data were resolved by reaching an agreement through discussion. The following general information of the studies was obtained: first author, year of publication, country, numbers of patients with and without PJK, follow-up time, and study type. The risk factors for PJK after multivariate regression analysis were collected and analyzed, including patient factors, surgical factors, and imaging parameters. The quality of each study was evaluated using the Newcastle Ottawa Quality Assessment Scale.

**Statistical analysis**
Review Manager 5.3 software was used for the statistical analysis. \( P < .05 \) indicated statistical significance. The OR value and 95% CI were used to represent the risk factors for PJK. The heterogeneity of the included studies was tested using Q statistics and quantified using the \( I^2 \) metric. If \( I^2 > 50\% \) or \( P < 0.1 \), then the random effect model was used to merge ORs; otherwise, the fixed-effect model was used. A sensitivity analysis was conducted to evaluate the effects of 2 models on the meta-analysis result when the heterogeneity was not significant; when the heterogeneity was significant, a sensitivity analysis was conducted to identify sources of heterogeneity.

**Results**

HIGHLIGHTS

- Proximal junctional kyphosis (PJK) is a common complication in patients with adult spinal deformity. This study aimed to clarify the risk factors for PJK to help surgeons implement effective measures to reduce the incidence of PJK and improve the clinical effectiveness after correction surgery.
- High body mass index, osteoporosis, severe fatty infiltration of paravertebral muscles, small functional area of paravertebral muscles, lumbar lordosis over-correction, lack of ligament reinforcement device at the proximal vertebrae and upper instrumented vertebra at the thoracolumbar segment, and pelvic fixation were associated with the development of proximal junctional kyphosis.
- The results suggests that the BMI, bone mineral density, and the condition of paravertebral muscles should be evaluated before surgery, upper instrumented vertebra should be chosen at the upper thoracic spine, fixation to the pelvis should be avoided when the conditions are suitable, the posterior ligament complex should be it is important to strengthened, and lumbar lordosis over-correction should be avoided.

Screening and characteristics of studies
Based on the inclusion and exclusion criteria, 16 studies were included in our meta-analysis. The screening process is shown in Figure 1. The characteristics of the included studies are shown in Table 1.
Quality evaluation
As shown in Table 2, 7 and 9 studies scored 7 and 8 points, respectively, indicating the high quality of the included studies.

PJK risk factor evaluation
Many factors are associated with an increased risk of PJK. However, almost all studies are controversial. We collected statistical data from relevant studies for the meta-analysis of risk factors for PJK.

Demographic factors
Three studies reported the relationship between age and PJK, and high heterogeneity existed among them (P=0.0001; $I^2=89%$). The sensitivity analysis showed that the heterogeneity remained high based on retesting after deleting any study. Further analysis shows that age is a continuous variable in 1 study and a binary variable in 2 studies. The classification criteria are inconsistent. The heterogeneity was large, and the effect size could not be merged. Hence, this variable was deleted.

Three studies reported the relationship between osteoporosis and PJK, and high heterogeneity existed among them (P=0.09; $I^2=58%$). Based on the sensitivity analysis, the study by Yuan published in 2020 exerted a large effect on heterogeneity. After excluding this study, no heterogeneity was observed (P=0.78; $I^2=0$). Therefore, the

| Study or Subgroup | Odds Ratio IV, Fixed, 95% CI | Odds Ratio IV, Fixed, 95% CI | Odds Ratio IV, Fixed, 95% CI |
|-------------------|-----------------------------|-----------------------------|-----------------------------|
| Hyun 2016         | 2.73 [1.43, 5.20]           |                             |                             |
| Wang 2016         | 3.27 [1.08, 9.95]           |                             |                             |
| Yuan 2020         | Not estimable               |                             |                             |

Total (95% CI): 100.0% 2.86 [1.64, 4.99]

Heterogeneity: $\chi^2 = 0.08$, df = 1 (P = 0.78); $I^2 = 0$
Test for overall effect: Z = 3.69 (P = 0.0002)

Figure 2. The odds ratio estimate for osteoporosis.
fixed-effect model was used to merge the effect size. Osteoporosis was associated with a significant increase in the incidence of PJK (OR 2.86, 95% CI: 1.64-4.99; \( P = 0.0002 \)) (Figure 2).

Two studies reported the relationship between body mass index (BMI) and PJK, and no heterogeneity existed among them (\( P = 0.18; I^2 = 43\% \)). The fixed-effect model was used to merge the effect size. The results showed that BMI was associated with a significant increase in the incidence of PJK (OR 1.19, 95% CI: 1.04-1.36; \( P = 0.01 \)) (Figure 3).

Three studies reported the relationship between the functional area of the paravertebral muscles and PJK, and high heterogeneity existed among them (\( P = 0.01; I^2 = 77\% \)). Based on the sensitivity analysis, the study by Yuan published in 2020 exerted a large effect on the heterogeneity. After excluding this study, no heterogeneity existed (\( P = 0.88; I^2 = 0 \)). Therefore, the fixed-effect model was used to merge the effect size. The results showed that the functional area of the paravertebral muscles was associated with a significant increase in the incidence of PJK (OR 2.17, 95% CI: 1.47-3.20; \( P < 0.0001 \)) (Figure 4).

Two studies reported the relationship between fatty infiltration of paraspinal muscles and PJK, and high heterogeneity was observed (\( P = 0.06; I^2 = 73\% \)). The fixed-effect model was used to merge the effect size. Fatty infiltration of the paraspinal muscles was associated with a significant increase in the incidence of PJK (OR 6.29, 95% CI: 1.34-29.43; \( P = 0.02 \)) (Figure 5).

Surgical variables
Four studies reported the relationship between the lack of a ligament reinforcement device at the proximal vertebrae and PJK. Moderate heterogeneity existed among the studies (\( P = 0.04; I^2 = 64\% \)). Based on the sensitivity analysis, the study by Buell published in 2018 (1) had a substantial effect on the heterogeneity. After excluding this study, no heterogeneity existed (\( P = 0.23; I^2 = 33\% \)). Therefore, the fixed-effect model was used to merge the effect size. The lack of a ligament reinforcement device at the proximal end of the uppermost instrumented vertebrae was associated with a significant increase in the incidence of PJK (OR 9.34, 95% CI: 3.11-28.07; \( P < 0.0001 \)) (Figure 6).
Four studies reported the relationship between the upper instrumented vertebra (UIV) at the thoracolumbar segment and PJK, and no heterogeneity existed ($P=0.21; I^2=34\%$). The fixed-effect model was used to merge the effect size. Upper instrumented vertebra at the thoracolumbar segment was associated with a significant increase in the incidence of PJK (OR 2.72, 95% CI: 1.66-4.44; $P<0.0001$) (Figure 7).

Two studies reported the relationship between pelvic fixation and PJK, and no heterogeneity existed ($P=0.33; I^2=0$). The fixed-effect model was used to merge the effect size. The results showed that pelvic fixation was associated with a significant increase in the incidence of PJK (OR 5.53, 95% CI: 3.10-9.86; $P<0.00001$) (Figure 8).

Radiological Parameters

Three studies reported the relationship between lumbar lordosis (LL) correction and PJK, and high heterogeneity was observed among them ($P=0.003; F=82\%$). Based on the sensitivity analysis, the study by Buell published in 2018 (1) exerted a substantial effect on the heterogeneity. After excluding this study, heterogeneity was not observed ($P=0.68; F=0$). Therefore, the fixed-effect model was used to merge the effect size. Based on the results, LL overcorrection was associated with a significant increase in the incidence of PJK (OR 2.20, 95% CI: 1.41-3.42; $P=0.0005$) (Figure 9).

Two studies reported the relationship between thoracic kyphosis (TK) correction and PJK, and high heterogeneity existed ($P=0.0001; I^2=93\%$). The fixed-effect model was used to merge the effect size. The results showed that TK correction was not associated with a significant increase in the incidence of PJK (OR 1.87, 95% CI: 0.57-6.10; $P=0.30$) (Figure 10).

Two studies reported the relationship between postoperative TK and PJK, and high heterogeneity existed ($P=0.0006; F=91\%$). The
fixed-effect model was used to merge the effect size. Postoperative TK was associated with a significant increase in the incidence of PJK (OR 1.09, 95% CI: 0.97-1.23; $P = 0.14$) (Figure 11).

Two studies reported the relationship between postoperative pelvic tilt (PT) and PJK, and high heterogeneity existed ($P = 0.02; I^2 = 80\%$). The fixed-effect model was used to merge the effect size. Postoperative PT was not associated with a significant increase in the incidence of PJK (OR 1.79, 95% CI: 0.56-5.76; $P = 0.33$) (Figure 12).

Two studies reported the relationship between preoperative PT and PJK, and moderate heterogeneity was observed ($P = 0.11; I^2 = 61\%$). The fixed-effect model was used to merge the effect size. Preoperative PT was not associated with a significant increase in the incidence of PJK (OR 1.05, 95% CI: 0.99-1.11; $P = 0.12$) (Figure 13).

Sensitivity analysis and publication bias

The fixed- and random-effect models were used to estimate the merged OR value for the factors without significant heterogeneity. The results were very similar, indicating that our meta-analysis result was stable. The evaluation of publication bias using a funnel plot is difficult due to the lower number of included studies (<10) in each factor analysis.

Discussion

Some studies report risk factors for PJK after posterior correction surgery for spinal deformities in adults. However, the ranges of the OR value and its 95% CI of a single study are relatively scattered, making it difficult to reflect the nature of the problem. At present, the risk factors for PJK remain controversial. In the present study, a combined analysis was conducted on materials that independently studied PJK risk factors using a meta-analysis. The scope of the total OR value converged. The conclusion is more comprehensive, more reliable, and more suitable for the population. The risk factors for the incidence of PJK are a high BMI, osteoporosis, severe degeneration of paravertebral muscles, LL overcorrection, fixed fusion to pelvis, and lack of ligament reinforcement device at the proximal vertebrae and UIV at the thoracolumbar segment.

Demographic factors

This study shows an important relationship between osteoporosis and PJK. The bone mineral density of patients with osteoporosis decreases, resulting in decreases in the bonding strength between the screw and bone interface and the holding force of the screws. Therefore, the risk of screw loosening is increased. Moreover, patients with osteoporosis often have decreased strength of the paravertebral muscles of the thoraco-lumbar spine, causing local instability, rendering them more susceptible to postoperative PJK. Therefore, many recent studies have suggested that bone cement should be used to reinforce the vertebral body at the proximal-end junction during surgery, and osteoporosis is treated with teriparatide after surgery. These measures may reduce the incidence of PJK.4,25

Some studies suggest that an increase in BMI is an important risk factor for postoperative PJK.20,23,26 This meta-analysis also confirms this conclusion. The possible explanation is that the load on the spine and inside fixation of overweight patients is increased, causing increased stress in the proximal-end junction. Therefore, measures should be implemented to decrease the BMI of patients before surgery and subsequently reduce the incidence of postoperative PJK.

### Study or Subgroup

| Study or Subgroup | log(Odds Ratio) | SE | Weight | Odds Ratio IV, Random, 95% CI |
|-------------------|----------------|----|--------|----------------------------|
| Thomas J 2018     | 0.15186235     | 0.03530768 | 46.3% | 1.16 [1.09, 1.24] |
| Fred 2017         | 0.03343478     | 0.009 | 53.7% | 1.03 [1.02, 1.05] |
| Total (95% CI)    | 100.0%         | 1.09 [0.97, 1.23] |

**Heterogeneity:** $\tau^2 = 0.01; Ch^2 = 11.65, df = 1 (P = 0.0006); I^2 = 91\%$

**Test for overall effect:** $Z = 1.49 (P = 0.14)$

Figure 11. The odds ratio estimate for postoperative TK. TK, thoracic kyphosis.

### Study or Subgroup

| Study or Subgroup | log(Odds Ratio) | SE | Weight | Odds Ratio IV, Random, 95% CI |
|-------------------|----------------|----|--------|----------------------------|
| Thomas J 2018     | 0.09440068     | 0.03825004 | 59.7% | 1.10 [1.02, 1.18] |
| Francisco 2020    | 1.30832822     | 0.53332901 | 40.3% | 1.79 [1.30, 10.57] |
| Total (95% CI)    | 100.0%         | 1.79 [0.56, 5.76] |

**Heterogeneity:** $\tau^2 = 0.59; \ Ch^2 = 5.12, df = 1 (P = 0.02); I^2 = 80\%$

**Test for overall effect:** $Z = 0.98 (P = 0.33)$

Figure 12. The odds ratio estimate for postoperative PT. PT, pelvic tilt.

### Study or Subgroup

| Study or Subgroup | log(Odds Ratio) | SE | Weight | Odds Ratio IV, Random, 95% CI |
|-------------------|----------------|----|--------|----------------------------|
| Young-Hoon 2020   | 0.08709471     | 0.03737597 | 33.6% | 1.09 [1.01, 1.17] |
| Fred 2017         | 0.02469261     | 0.011 | 66.4% | 1.03 [1.00, 1.05] |
| Total (95% CI)    | 100.0%         | 1.05 [0.99, 1.11] |

**Heterogeneity:** $\tau^2 = 0.00; \ Ch^2 = 2.57, df = 1 (P = 0.11); I^2 = 61\%$

**Test for overall effect:** $Z = 1.55 (P = 0.12)$

Figure 13. The odds ratio estimate for preoperative PT. PT, pelvic tilt.
An increasing number of studies have reported the relationship between the paravertebral muscles and sagittal balance of the spine. The degeneration of paravertebral muscles affects the sagittal sequence of the spine.12,13,14 According to our meta-analysis, increased fatty infiltration of paravertebral muscles and a small functional area of paravertebral muscles are risk factors for PJK after ASD correction surgery. The spine is a structure composed of multiple tissues, and its stability depends on the bone ligament structure and its associated muscle system. When dysfunction occurs in one part and causes spinal instability, the other part will compensate. Therefore, when the degeneration of the paravertebral muscles of patients with ASD is severe and the function of maintaining spinal stability is decreased, kyphosis may develop in the proximal junction area without fixation and fusion. For these patients, an magnetic resonance imaging evaluation is needed before surgery. A thoracolumbar brace can be used for external fixation after the operation to reduce the incidence of PJK.

Surgical variables
Our studies confirmed the definite correlation between some surgical factors and the incidence of PJK. These factors include fixed fusion to the pelvis, lack of a ligament reinforcement device at the proximal vertebrae and UIV at the thoracolumbar segment. Ligament reinforcement technology used near the uppermost instrumented vertebrae might effectively reduce the incidence of PJK. The posterior ligament complex is easily damaged when the UIV is exposed and the pedicle screws are embedded, leading to local instability of the proximal part and an increase in the incidence of PJK.15 Therefore, the application of ligament reinforcement technology according to the situation during the operation may enhance the posterior ligament complex,16 reduce the stress in the proximal junction, and decrease the incidence of PJK.

Pelvic fixation also plays an important role in the incidence of postoperative PJK. Similarly, Yoshinao17 and Renaud18 reported that pelvic fixation is beneficial for patients with sagittal imbalance and distal degeneration; however, fixation to the pelvis will lead to the lack of a free gap in the distal end, resulting in proximal stress concentration and an increased risk of proximal degeneration. Therefore, we should not ignore the effect of fixation to the pelvis among patients with ASD. A careful assessment should be performed before surgery. Excessive distal fixation should be avoided in patients without indications for pelvic fixation.

The position of the UIV exerts a substantial effect on the incidence of PJK.3 Our study shows that UIV at the thoracolumbar segment is associated with a significantly increased risk of PJK. The thoracolumbar segment is the transitional zone between TK and LL. When the lower spine is firmly fixed, it leads to stress concentration. The facet joints and surrounding ligaments degenerate in adult patients with spinal deformities, and a floating rib appears in the thoracolumbar segment. Proximal junctional kyphosis may easily occur due to the lack of thoracic protection and poor stability. Therefore, when developing surgery plans, UIV should be chosen at the upper thoracic spine to reduce the incidence of PJK.

Radiological Parameters
In our meta-analysis, preoperative PT, postoperative PT, postoperative TK, and TK correction had no significant statistical correlation with the incidence of PJK. However, LL overcorrection is an important risk factor for the incidence of PJK. Duboussset’s19 concept of the economic cone explains the role of sagittal balance in maintaining the stability of posture and body. Sagittal overcorrection will destroy the balance between the sagittal-vertical axis and gravity vertical line, and the new optimal position is only achieved by adjusting the remaining nonfusion segments. Lumbar lordosis overcorrection will easily cause Pelvic incidence (PI)-LL mismatching. A negative spinal balance occurs. The increased kyphosis on the proximal side of the inside fixation under the spinal balance compensation mechanism leads to the incidence of PJK.20 Therefore, reconstruction of the sagittal plane and the matching scheme of spine and pelvis parameters should be planned before the operation.

We conducted a meta-analysis on the risk factors for the incidence of PJK after ASD surgery. This study has some limitations. First, effectively merging the studies and obtaining unified results are impossible because of the limited number of relevant studies on some possible risk factors, and thus they were excluded. Second, different studies had different follow-up times. Thus, the results of our study may be affected. Finally, the Newcastle Ottawa Quality Assessment Scale was adopted to evaluate the quality. However, the included studies were retrospective. Compared with randomized controlled trials, retrospective studies have some limitations, such as observation bias, which may affect the results. Therefore, we must conduct a meta-analysis of randomized controlled trials with a large sample size in the future.

Patients with ASD presenting a high BMI, osteoporosis, and severe fatty infiltration of paravertebral muscles potentially easily develop postoperative PJK. Fixation to the pelvis, lack of a ligament reinforcement device at the proximal vertebrae and UIV at the thoracolumbar segment, and LL overcorrection in the operation for ASD may increase the risk of PJK. Recommendations to reduce the incidence of PJK after surgery are as follows: (1) The BMI, bone density, and paravertebral muscle degeneration of patients with ASD should be evaluated before surgery. When patients have a high BMI, osteoporosis, and severe paravertebral muscle degeneration, corresponding measures should be implemented to reduce the incidence of PJK. (2) Upper instrumented vertebra should be chosen at the upper thoracic spine, and fixation to the pelvis should be avoided when the diseased condition permits. (3) The ligament reinforcement device should be used in the proximal end of the UIV to strengthen the posterior ligament complex. (4) Lumbar lordosis overcorrection should be avoided.

Author Contributions: Concept - J.R.; Design – J.R.; Supervision – J.R.; Funding – J.R.; Materials – X.X.H.; Data Collection and/or Processing – X.X.H.; Analysis and/or Interpretation – X.X.H.; Literature Review – X.X.H., J.R.; Writing – X.X.H., J.R.; Critical Review – X.X.H., J.R.

Declaration of Interests: The authors have no conflicts of interest to declare.

Funding: The authors declared that this study has received no financial support.

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