Adolescent Idiopathic Scoliosis: Is the Feasible Option of Minimally Invasive Surgery using Posterior Approach?

Hong Jin Kim¹, Lawrence G. Lenke², Javier Pizones³, René Castelein⁴, Per D. Trobsch⁵, Mitsuru Yagi⁶, Michael P. Kelly⁷, Dong-Gune Chang¹

¹Department of Orthopedic Surgery, Inje University Sanggye Paik Hospital, College of Medicine, Inje University, Seoul, Korea
²Department of Orthopedic Surgery, The Daniel and Jane Och Spine Hospital, Columbia University, New York, NY, USA
³Department of Orthopedic Surgery, Hospital Universitario La Paz, Madrid, Spain
⁴Department of Orthopedic Surgery, University Medical Centre Utrecht, Utrecht, The Netherlands
⁵Department of Spine Surgery, Eifelklinik St. Brigida, Simmerath, Germany
⁶Department of Orthopedic Surgery, International University of Health and Welfare, School of Medicine, Nara, Japan
⁷Department of Orthopedic Surgery, Rady Children’s Hospital, University of California, San Diego, CA, USA

Study Design: Systematic review and meta-analysis.

Purpose: To perform a systematic review and meta-analysis of previous studies on minimally invasive scoliosis surgery (MISS) in adolescent idiopathic scoliosis (AIS).

Overview of Literature: There is some conflicting data on MISS in AIS compared to conventional open scoliosis surgery (COSS).

Methods: A systematic literature search was conducted in Medline, Embase, and Cochran library, including studies reporting outcomes for MISS in AIS. The meta-analysis compared the operative, radiological, and clinical outcomes and complications between MISS and COSS in AIS.

Results: Of the 208 records identified, 15 nonrandomized studies with 1,369 patients (reviews and case reports are excluded) are finally included in this systematic review and meta-analysis. The mean scale was 6.1, and 8 of the included studies showed satisfactory quality using the Newcastle–Ottawa scale. For operative outcomes, MISS had significant benefits in terms of estimated blood loss (standard mean difference [SMD]: −1.87; 95% CI: −2.94 to −0.91) and hospitalization days (SMD −2.99; 95% CI: −4.45 to −1.53) compared to COSS. However, COSS showed significant favorable outcomes for operative times (SMD 1.71; 95% CI: 0.92 to 2.51). No significant differences existed for radiological outcomes, including Cobb’s angle of the main curve and thoracic kyphosis. For clinical outcomes, MISS showed significant benefits on VAS (SMD −0.91; 95% CI: −1.36 to −0.47). Overall complication rates of MISS were similar to that of COSS (SMD 0.96; 95% CI: 0.61 to 1.52).

Conclusions: The MISS using posterior approach provides equivalent radiological and clinical outcomes, and complication rates compared to COSS. Considering the lower estimated blood loss, shorter hospitalization days, but longer operative times in MISS, COSS is still the mainstay of surgical treatment in AIS but MISS using posterior approach is also one of surgical options as surgeon’s choice in the case of moderate AIS.

Keywords: Adolescent idiopathic scoliosis; Minimally invasive scoliosis surgery; Conventional open scoliosis surgery; Systematic reviews; Meta-analysis
Introduction

Minimally invasive surgery (MIS) in the spine field has become a widely employed practice in degenerative spine disorders, with approaches ranging from discectomy and fusion to deformity correction [1,2]. The advantages of MIS compared to conventional open surgery include smaller incisions, less blood loss, and musculo-ligamentous sparing, which contribute to lower complication rates [3]. Owing to its distinct characteristics, MIS has been explored in the treatment of various diseases, including the surgical treatment of adolescent idiopathic scoliosis (AIS) [3,4].

With respect to its biomechanics, AIS has been generally recognized as a three-dimensional deformity [5]. Thus, the surgical goal of AIS is to correct the scoliotic deformity (i.e., coronal deformity) as well as the sagittal deformity. To restore the coronal and sagittal balance, pedicle screw instrumentation (PSI) with rod derotation (RD) using the posterior approach is a standard surgical treatment in AIS [6]. Despite the rapid evolution of MIS, attempts of conducting MIS in AIS have been challenging because it requires correction of a much larger curve, longer instrumentation, and specific surgical techniques, such as RD, and direct vertebral rotation (DVR) [7].

Conventional open scoliosis surgery (COSS) by the posterior approach in AIS has been proven effective in achieving powerful fixation using PSI and three-dimensional deformity correction using RD and DVR. However, COSS has the drawback of a significantly long surgical incision, which leads to postoperative dissatisfaction among adolescents [5,7,8]. Consequently, the demand for MIS using posterior approaches has increased. In 2008 Sarwahi et al. first introduced the MIS technique for moderate AIS patients with three skin incisions of approximately 2 inch [7]. MISS in AIS has been performed by many skilled surgeons [9-23]. In particular, the coin-hole technique, reported by Yang et al., has been introduced to overcome wound-related problems from MISS using posterior approach [14]. However, there are conflicting outcomes for surgical treatment of AIS using posterior approach between COSS and MISS [9-23]. Given the paucity and conflicting data, this systematic review and meta-analysis assess on operative, radiological, and clinical outcomes, including the complication rates, between MISS and COSS using posterior approach in moderate AIS.

Materials and Methods

The protocol for this systematic review and meta-analysis was registered in advance with the International Prospective Register of Systematic Reviews (PROSPERO; CRD42023430522). The systematic review and meta-analysis were performed and reported according to the Meta-analysis Of Observational Studies in Epidemiology (MOOSE) and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklists. A published protocol does not exist for this review [24,25].

1. Search strategy and selection criteria

We used various databases, including PubMed/Medline, Embase, and Cochrane Library on 27 May 2023 for MISS studies comparing COSS in AIS. The search syntax was ("idiopathic"[All Fields] OR "idiopathically"[All Fields] OR "idiopathics"[All Fields]) AND ("scoliosis"[MeSH Terms] OR "scoliosis"[All Fields] OR "scolioses"[All Fields]) AND ("minimal*"[All Fields] AND "invasibility"[All Fields] OR "invasible"[All Fields] OR "invasion"[All Fields] OR "invasions"[All Fields] OR "invasive"[All Fields] OR "invasively"[All Fields] OR "invasiveness"[All Fields] OR "invasives"[All Fields] OR "invasivity"[All Fields])) in Pubmed/Medline, "idiopathic AND ('scoliosis'/exp OR scoliosis) AND minimal* AND invasive" in Embase, and (idiopathic scoliosis) AND (minimal* invasive) in Cochrane Library using terms Medical Subject Headings (MeSH) to identify studies published in English.

After removing the duplicate articles in Endnote, two reviewers independently screened for eligibility of extracted studies based on the titles and abstracts using Covidence. After title and abstract screening, the same two reviewers independently reviewed full-text articles; any disagreements on the eligibility of full-text articles were resolved by consensus or by discussion with a third reviewer. Inclusion criteria in this review were studies that reported MISS in moderate AIS, which included randomized controlled trials, cross-sectional studies, and cohort studies (retrospective or prospective studies). The moderate AIS was defined as the major curve's Cobb angle < 70° or 80°, and flexibility > 50% on side-bending films in patients with AIS. The exclusion criteria in this review were case reports, reviews, a language other than English, no availability of full-text articles, non-fusion surgery, MISS...
using anterior approaches, and revision surgery of MISS. The outcomes of interest of MISS compared to those of COSS were operative (estimated blood loss, operative time, and hospitalization days), radiological (Cobb’s angle of main curve, and thoracic kyphosis), and clinical (Scoliosis Research Society [SRS]-22r score, and VAS for surgical site pain), as well as complications (overall, surgical site infection, implant failure, and pedicle screw misplacement).

2. Data extraction

The same four reviewers, working in pairs, independently extracted the data using a predefined data extraction file. Two of the reviewers independently performed the risk of bias assessment and extracted the study data. The following baseline characteristics were extracted from the included studies: first author, year of publication, study design, period, country in which the study was performed, setting, number of included patients, mean ages, sex, mean follow-up duration, MIS indication for AIS patients, and MIS techniques.

3. Quality assessment

The same two reviewers in pairs independently assessed the quality of the non-randomized studies using the Newcastle–Ottawa Scale in meta-analysis [26]. Any discrepancy was resolved by two authors after discussion. The publication bias was assessed using funnel plots.

4. Statistical analysis

Continuous variables were extracted as the mean±standard deviation by converting the values for extracted data using the methods described in the Cochrane Handbook for Systematic Reviews of Interventions, if sufficient information was available [27]. They were presented as standardized mean differences (SMDs) with a 95% confidence interval (CI) by using the inverse variance weighting method. Dichotomous variables were extracted as absolute numbers and/or percentages, pooled using the Mantel–Haenszel method, and presented as odd ratios (ORs) with a 95% CI. The random effects model was used for all analyses, and the statistical heterogeneity between studies was evaluated by visual inspection of forest plots and by $I^2$ and $\chi^2$ statistics for heterogeneity. For the subgroup assessment, the difference in effect estimates between the two subgroups was assessed as described in the Cochrane Handbook for Systematic Reviews of Interventions [27]. The significance level across subgroups was determined by testing for subgroup differences. We also assessed potential publication bias by the visual inspection of funnel plots of the risk ratios and standard errors. The statistical analyses were performed using Revman Web (Cochrane Library) or the Meta package in R (version 4.3.0; R Foundation for Statistical Computing, Vienna, Austria).

Results

1. Search

After the screening of 208 articles from the title and abstracts, a total of 26 articles were identified in reports for eligibility. After reviewing the full-text articles, 11 articles were excluded as follows: review articles (n=6), other article types such as case reports and letters (n=3), and studies including non-relevant outcomes of MISS and COSS (n=2). Finally, 15 non-randomized studies were included in this systematic review and meta-analysis (Fig. 1).

Fig. 1. A flow chart of this systematic review and meta-analysis.
2. Baseline study characteristics

A total of 15 nonrandomized studies with 1,369 patients—of whom 805 were treated with MISS and 564 were treated with COSS—were used. Five studies of the included studies only assessed the outcome of MISS and included the COSS information. The baseline study characteristics of these included studies are summarized in Table 1.

3. Quality assessment

All of the 15 included studies were non-randomized; thus, we assessed the risk of bias using the Newcastle–Ottawa scale. The mean scale was 6.1 (range 5–7) and 8 of the 15 included studies showed satisfactory quality. Details of the quality assessment in this study are presented in Table 2.

4. Operative outcome measures

We measured the estimated blood loss in eight studies, the operative time in eight studies, and the number of hospitalization days in seven studies as operative outcomes. All of the measured operative parameters exhibited heterogeneity ($I^2=96\%$ in estimated blood loss, $I^2=94\%$ in operative time, $I^2=96\%$ in hospitalization days). For estimated blood loss, the overall pooled effect showed that MISS was associated with a significant reduction in estimated blood loss compared to COSS (SMD=$−1.87$, 95% CI: $−2.94$ to $−0.91$, $p<0.001$) (Fig. 2A). For operative time, the overall pooled effects showed that MISS had significantly longer operative time than COSS (SMD=$1.71$, 95% CI: 0.92 to 2.51, $p<0.001$) (Fig. 2B). For hospitalization days, the overall pooled effect showed that MISS was associated with a significant reduction in hospitalization days compared to COSS (SMD=$−2.99$, 95% CI: $−4.45$ to $−1.53$, $p<0.001$) (Fig. 2C).

To evaluate the radiological outcomes, we measured Cobb’s angle of the main curve in ten studies and thoracic kyphosis in eight studies. We observed heterogeneity as $I^2=86\%$ in Cobb’s angle of the main curve and $I^2=79\%$ in thoracic kyphosis. For Cobb’s angle of the main curve, the overall pooled effect showed that MISS did not show significant differences in Cobb’s angle of the main curve compared to COSS (SMD=$−0.3$, 95% CI: $−0.70$ to 0.10, $p=0.15$) (Fig. 3A). For thoracic kyphosis, no significant differences were shown between MISS and COSS (SMD=$−0.20$, 95% CI: $−0.59$ to 0.19, $p=0.31$) (Fig. 3B). Cobb’s angle of the main curve was measured from more than ten studies. The presented funnel plots were relatively symmetrical, indicating no evidence of publication bias (Fig. 3C).

For the clinical outcomes, we measured the postoperative Visual Analog Scale (VAS) in two studies and SRS-22r score in four studies. Heterogeneity was observed in the SRS-22r score ($I^2=83\%$); however, it was not observed in VAS ($I^2=56\%$). For VAS, the overall pooled effect showed that MISS was associated with a significant reduction in postoperative VAS compared to COSS (SMD=$−0.91$, 95% CI: $−1.36$ to $−0.47$, $p<0.001$) (Fig. 4A). For the SRS-22r score, the overall pooled effect of the SRS-22r score showed no significant difference between MISS and COSS (SMD=$0.31$, 95% CI: $−0.29$ to 0.91, $p=0.31$) (Fig. 4B).

Overall complication, surgical site infection, implant failure, and pedicle screw misplacement were evaluated for comparison of the complication rate between MISS and COSS. None of the data regarding the complication-related parameters had heterogeneity as an overall complication ($I^2=0\%$), surgical site infection ($I^2=5\%$), implant failure ($I^2=0\%$), or pedicle screw misplacement ($I^2=0\%$). The overall pooled effect of overall complication (OR=0.96, 95% CI: 0.61 to 1.52, $p=0.87$), surgical site infection (OR=1.63, 95% CI: 0.82 to 3.22, $p=0.16$), implant failure (OR=1.36, 95% CI: 0.47 to 3.93, $p=0.57$), and pedicle screw misplacement (OR=1.18, 95% CI: 0.94 to 1.48, $p=0.15$) showed no significant difference between MISS and COSS (Fig. 5).

Discussion

In the era of MIS in the field of spine surgery, the demand for MIS in AIS has increased to overcome the disadvantages of COSS [14]. Since Sarwahi et al. initially suggested the MIS technique in AIS, many studies on the surgical outcomes of MISS in AIS have been published in the literature [7,9-23]. In numerous studies, conflicting results have been observed, such as those for complications; however, the causes of the discrepancies have been explained from various perspectives. Considering the pooled effect estimate in outcome measures, this meta-analysis provided the advantages of MISS in moderate curves of AIS: less blood loss, fewer hospitalization days, and lower postoperative pain score with equivalent radiological correction compared to COSS in the surgical treatment of AIS using posterior approaches. Meanwhile, COSS is favorable.
Table 1. Baseline characteristics of studies included in systematic reviews and meta-analysis

<table>
<thead>
<tr>
<th>First author, year of publication</th>
<th>Design</th>
<th>Period</th>
<th>Country</th>
<th>Settings</th>
<th>N (T)</th>
<th>N (I)</th>
<th>N (C)</th>
<th>Age (I) (years)</th>
<th>Age (C) (years)</th>
<th>Sex (I) M:F</th>
<th>Sex (C) M:F</th>
<th>F/U(I) (years)</th>
<th>F/U (C) (years)</th>
<th>Indications for AIS patients</th>
<th>MIS Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sarwahi et al., 2016*</td>
<td>R</td>
<td>2007-2009</td>
<td>United States</td>
<td>Single institute</td>
<td>23</td>
<td>7</td>
<td>15</td>
<td>15.5±2.6</td>
<td>15.4±1.9</td>
<td>1.0</td>
<td>2.0</td>
<td>2.0</td>
<td>1) Cobb angle &lt;70°&lt;br&gt;2) Flexibility &gt;50% on side bending films</td>
<td>MIS technique developed by Sarwahi et al.</td>
<td></td>
</tr>
<tr>
<td>Sarwahi et al., 2021*</td>
<td>P</td>
<td>2013-2018</td>
<td>United States</td>
<td>Single institute</td>
<td>485</td>
<td>192</td>
<td>293</td>
<td>15.1±1.9</td>
<td>15.0±2.4</td>
<td>25:167</td>
<td>66:227</td>
<td>2.6±0.2</td>
<td>2.3±0.2</td>
<td>1) Lenke 1-4 curve&lt;br&gt;2) Age 12-18 years&lt;br&gt;3) Cobb angle &lt;70°&lt;br&gt;4) Flexibility &gt;50% on side bending films</td>
<td>MIS technique developed by Sarwahi et al.</td>
</tr>
<tr>
<td>Si et al., 2021</td>
<td>R</td>
<td>2007-2015</td>
<td>China</td>
<td>Multi-center</td>
<td>112</td>
<td>64</td>
<td>48</td>
<td>13.2±1.7</td>
<td>14.6±1.9</td>
<td>20:44</td>
<td>14:34</td>
<td>2.6±0.4</td>
<td>2.7±0.5</td>
<td>1) Lenke 1-4 curve&lt;br&gt;2) Age 12-18 years&lt;br&gt;3) Cobb angle &lt;70°&lt;br&gt;4) Flexibility &gt;50% on side bending films</td>
<td>MIS technique developed by Sarwahi et al.</td>
</tr>
<tr>
<td>Bodman et al., 2017</td>
<td>P</td>
<td>2013-2016</td>
<td>Switzerland</td>
<td>Single center</td>
<td>70</td>
<td>70</td>
<td>N/A</td>
<td>15±4.5</td>
<td>N/A</td>
<td>8:62</td>
<td>N/A</td>
<td>2</td>
<td>N/A</td>
<td>Not specified</td>
<td>Posterior MIS technique (with three incision) using the slots of reduction tubes</td>
</tr>
<tr>
<td>Bodman et al., 2020</td>
<td>R</td>
<td>2013-2016</td>
<td>Switzerland</td>
<td>Two tertiary centers</td>
<td>93</td>
<td>93</td>
<td>N/A</td>
<td>15.2±2.2</td>
<td>N/A</td>
<td>11:82</td>
<td>N/A</td>
<td>4.4±1.0</td>
<td>N/A</td>
<td>1) Cobb angle &lt;70-80°&lt;br&gt;2) Flexibility &gt;50% on side bending films</td>
<td></td>
</tr>
<tr>
<td>Yang et al., 2020**</td>
<td>P</td>
<td>2015-2017</td>
<td>South Korea</td>
<td>Single institute</td>
<td>84</td>
<td>84</td>
<td>N/A</td>
<td>15.2±5.6</td>
<td>N/A</td>
<td>7.77</td>
<td>N/A</td>
<td>1</td>
<td>N/A</td>
<td>Not specified</td>
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</tr>
<tr>
<td>Yang et al., 2021**</td>
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<td>2014-2015</td>
<td>South Korea</td>
<td>Single institute</td>
<td>34</td>
<td>34</td>
<td>N/A</td>
<td>15.2±3.0</td>
<td>N/A</td>
<td>0.34</td>
<td>N/A</td>
<td>2</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yang et al., 2021 (2)</td>
<td>R</td>
<td>2015-2016</td>
<td>South Korea</td>
<td>Single institute</td>
<td>49</td>
<td>24</td>
<td>25</td>
<td>15.0±1.9</td>
<td>14.0±1.5</td>
<td>0.24</td>
<td>0.25</td>
<td>4.6±0.2</td>
<td>9.7</td>
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<tr>
<td>Yang et al., 2023</td>
<td>R</td>
<td>2014-2015</td>
<td>South Korea</td>
<td>Single institute</td>
<td>86</td>
<td>43</td>
<td>43</td>
<td>15.7±2.0</td>
<td>14.6±2.4</td>
<td>5.38</td>
<td>6.37</td>
<td>2.0</td>
<td>2.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yang et al., 2023 (2)</td>
<td>R</td>
<td>2015-2017</td>
<td>South Korea</td>
<td>Single institute</td>
<td>76</td>
<td>76</td>
<td>N/A</td>
<td>15.7±2.1</td>
<td>N/A</td>
<td>6.70</td>
<td>N/A</td>
<td>1.0</td>
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</tr>
<tr>
<td>Nam et al., 2023</td>
<td>R</td>
<td>2014-2020</td>
<td>South Korea</td>
<td>Single institute</td>
<td>76</td>
<td>28</td>
<td>48</td>
<td>17.7±4.7</td>
<td>17.6±5.5</td>
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<td>11.37</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>Miyazaki et al., 2015</td>
<td>P</td>
<td>2019-2012</td>
<td>Canada</td>
<td>Multi-center</td>
<td>46</td>
<td>23</td>
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<td>16.4±0.3</td>
<td>3.20</td>
<td>4.19</td>
<td>2.0</td>
<td>2.0</td>
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</tr>
<tr>
<td>Zhu et al., 2017</td>
<td>R</td>
<td>2012-2014</td>
<td>China</td>
<td>Single institute</td>
<td>45</td>
<td>15</td>
<td>30</td>
<td>16.5±1.6</td>
<td>15.1±1.7</td>
<td>2.13</td>
<td>3.27</td>
<td>2.3±0.3</td>
<td>2.7±0.3</td>
<td>1) Lenke 5C curve&lt;br&gt;2) Age 14-18 years&lt;br&gt;3) Cobb angle 30°-70°&lt;br&gt;4) Flexibility &gt;50% on side bending films</td>
<td></td>
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<tr>
<td>Urbanski et al., 2019</td>
<td>P</td>
<td>2016-2018</td>
<td>Poland</td>
<td>Single institute</td>
<td>8</td>
<td>4</td>
<td>4</td>
<td>15.5±2.1</td>
<td>21.3±10.0</td>
<td>0.4</td>
<td>1.3</td>
<td>N/A</td>
<td>N/A</td>
<td>Lenke 5C curve</td>
<td>1) A midline skin incision&lt;br&gt;2) Pedicle screw fixation under the guidance of Image-O-arm navigation</td>
</tr>
<tr>
<td>Syundyukov et al., 2023</td>
<td>R</td>
<td>2014-2020</td>
<td>Russia</td>
<td>Single center</td>
<td>82</td>
<td>47</td>
<td>35</td>
<td>16.1±2.2</td>
<td>15.7±1.5</td>
<td>3.44</td>
<td>4.31</td>
<td>8.4±0.5</td>
<td>3.9±1.1</td>
<td>1) Lenke type I curve&lt;br&gt;2) Cobb angle 30°-70°&lt;br&gt;3) A midline skin incision&lt;br&gt;4) Pedicle screw fixation under the guidance of Image-O-arm navigation</td>
<td></td>
</tr>
</tbody>
</table>

*Data and **Data were respectively expressed as median value (the 25th percentile value, the 75th percentile value) and mean value (minimum value, maximum value), which were converted to mean±standard deviation for the purpose of quantitative synthesis. All of the continuous values are expressed as mean±standard deviation. N=Number; T=Total; I=Intervention group; C=Control group; M=Male; F=Female; F/U=Follow-up; AIS=Adolescent idiopathic scoliosis; MIS=Minimally invasive surgery; R=Retrospective design; p=Prospective design.
## Table 2. Assessment of quality for included cohort studies in the systematic review and meta-analysis.

<table>
<thead>
<tr>
<th>Study</th>
<th>Selection</th>
<th>Comparability</th>
<th>Outcome</th>
<th>Total points</th>
<th>Quality</th>
</tr>
</thead>
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<tr>
<td></td>
<td>Representativeness of the exposed cohort</td>
<td>Selection of the non-exposed cohort</td>
<td>Ascertainment of exposure</td>
<td>Demonstration that outcome of interest was not present at start of study</td>
<td>Comparability of cohorts on the basis of the design or analysis controlled for confounders</td>
</tr>
<tr>
<td>Sarwahi et al., 2016</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>-</td>
</tr>
<tr>
<td>Sarwahi et al., 2021</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>-</td>
</tr>
<tr>
<td>Si et al., 2021</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>-</td>
<td>★</td>
</tr>
<tr>
<td>Bodman et al., 2017</td>
<td>★</td>
<td>-</td>
<td>★</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bodman et al., 2020</td>
<td>★</td>
<td>-</td>
<td>★</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Yang et al., 2020</td>
<td>★</td>
<td>-</td>
<td>★</td>
<td>-</td>
<td>★</td>
</tr>
<tr>
<td>Yang et al., 2021 (2)</td>
<td>★</td>
<td>-</td>
<td>★</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Yang et al., 2023 (2)</td>
<td>★</td>
<td>-</td>
<td>★</td>
<td>-</td>
<td>★</td>
</tr>
<tr>
<td>Nam et al., 2023</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>-</td>
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<tr>
<td>Miyanji et al., 2015</td>
<td>★</td>
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<td>★</td>
<td>-</td>
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<tr>
<td>Zhu et al., 2017</td>
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<td>Urbanski et al., 2019</td>
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<td>Syundyukov et al., 2023</td>
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for operative time. Furthermore, there were no differences in complications between MISS and COSS. However, radiation exposure in the management of AIS is one of the problems that needs to caution for adolescents, which was not considered in this study. Thus, future studies with long-term follow-up data need to be established.

MISS using posterior approach involves distinctive procedures compared to COSS. Firstly, two or three shorter incisions are made during MISS compared to the long longitudinal single incisions in COSS [10]. Small scar length is considered one of the factors in functional outcomes in the perioperative period [14,16]. Secondly, MISS for facetal fusion involved less extensive soft tissue dissection and decreased area of subperiosteal exposure, whereas COSS was performed with posterior fusion with wide bone and soft tissue exposure [9,17]. Third, Yang et al. utilized a tubular retractor as a coin-hole technique to protect the surrounding soft tissue area of the operation field [15]. These distinctive characteristics of MISS have resulted in less estimated blood loss and fewer hospitalization days [10,16]. However, MISS is still in its early stages; therefore, the operative time did not reflect the learning
curve of MISS [3,18,28]. Yang et al. suggested that MISS has a mild learning curve with 46 cases of experience [18]. Furthermore, in our meta-analysis, Sarwahi et al. in 2021 showed 0.15 of SMD and −0.03 to 0.33 of a 95% CI, which are the results from proficient and skilled experience. Thus, the current data are mostly the results of MISS using posterior approach performed by proficient surgeons for moderate AIS curves requiring careful interpretation.

Fig. 3. Comparison of radiological outcome measures in this meta-analysis. (A) Cobb’s angle of the main curve. (B) Thoracic kyphosis. (C) Funnel plot for Cobb’s angle of the main curve to assess the publication bias.
of our meta-analysis.

The radiological outcomes of MISS showed consistently equivalent or similar results compared to those of COSS. Our focused radiological outcome measures were Cobb’s angle of the main curve in the coronal alignment and thoracic kyphosis in the sagittal alignment. Guo et al. noted that anterior column overgrowth leads to detrimental effects of thoracic kyphosis, which potentially contributes to cervical alignment [29]. Thus, thoracic hypokyphosis in sagittal alignment is a critical issue in the treatment of AIS [30-32]. Additionally, Schlösser et al. suggested the RD-only technique can lead to improper correction of thoracic kyphosis instead of proper correction of the main curves, or vice versa [33]. Therefore, MISS provided the equivalent radiological outcomes in Cobb’s angle of the main curve and thoracic kyphosis compared to COSS in our meta-analysis. However, MISS using posterior approach has a limitation for three-dimensional correction in larger and stiffer curves [14-16].

In terms of clinical outcomes between MISS and COSS, VAS was only measured in Sarwahi et al.’s studies [9,10]. Sarwahi et al. in 2016 showed no significant differences in VAS between MISS and COSS; however, small-sized sample data were measured with an early stage of MISS.9 After five years, Sarwahi et al. in 2021 showed the advantages of postoperative VAS in MISS with large-sized sample data. The benefit of postoperative VAS affected the management of the perioperative period; thus, it may have been associated with shorter hospital stays in MISS.10 Contrary to the VAS findings, the SRS-22r score was not significantly different between MISS and COSS. SRS-22r was measured based on function, pain, self-image, mental health, and satisfaction. The cosmesis in SRS-22r was only part of the factor; thus, a future trial may be needed to evaluate the cosmesis itself as a new measurement tool, such as scar cosmesis assessment and a rating scale from short-term to long-term follow-up between MISS and COSS [34].

In the background of the coin-hole technique by Yang et al., the initial study of the MIS technique by Sarwahi et al. reported a higher complication rate in MISS than that of COSS in terms of wound problems such as late-onset wound problems (from 1 month after the MISS to 3-year follow-up) and hypertrophied scars [9,10]. By employing the 20- to 24-mm diameter tubular retractor system, adequate exposure of the surgical field has been established as a form of coin-hole, which reduced skin–muscle damage during the free-hand pedicle screw insertion.15 Although the overall pooled effect of surgical site infection showed no significant difference, the OR of surgical site infection was higher in the MISS technique by Sarwahi et al. (OR=2.15 from the random effect model) than in the method of Yang et al. (OR=1.26 from the random effect model) between MISS and COSS in AIS. However, all of
the results in this meta-analysis were not fully considered as a learning curve, which is an important factor in assessing complication rates. Therefore, conducting an updated meta-analysis considering the learning curve is essential in the future [5,18,28]. Regarding the intra-operative pedicle screw misplacement rate, it was relatively higher in MISS than in COSS (OR=1.18, 95% CI: 0.94 to 1.48, \( p=0.15 \)). MISS with limited surgical vision had obstacles to the process of free-hand pedicle screw insertion.19

Limited surgical vision in coin-hole and angled lesion to insert the pedicle screw may intraoperatively lead to pedicle screw misplacement [10,19,35]. However, these results showed no significant differences, indicating the acceptable range of pedicle screw placement in MISS compared to COSS despite limited surgical vision.

Although MISS using the posterior approach is a feasible option based on our analysis, we believe that special attention is needed to judge based on these results. MISS
provide equivalent outcomes in the view of radiological, and clinical outcomes, and complication rates. Meanwhile, in operative parameters, COSS required more bleeding loss (about just 187 mL) and longer hospitalization days (about just 3 days) compared to MISS. However, COSS is favorable for operative time (about 1.71 hours) compared to MISS in our meta-analysis. The requirement of a longer operative time can be a factor in the surgeons’ hesitation to choose MISS. Although COSS is still a mainstay of surgical treatment of moderate AIS using posterior approach, this meta-analysis provides the need for future research on the preferences of the surgeon’s choices.

The several possible limitations in this systematic review and meta-analysis must be considered. Firstly, the missing article regarding MISS actually existed, which could have influenced the results of the meta-analysis. Although some missing articles may have existed in other databases, we collected the articles from a relatively sound evidence-based database using a highly sensitive search strategy. Secondly, our study contained very small-sample-sized data. Although MIS in AIS has been sufficiently developed, MIS research remains in early stages; thus, these data were also included, and consistent results were observed in this meta-analysis. After more evidence is presented in the literature, the efficacy and safety should be re-evaluated with an updated meta-analysis in the future. Thirdly, heterogeneity was observed in almost all of our meta-analysis results. This may have been caused by several factors, including the differences in the MISS technique between each surgeon, not considering the learning curve in the current meta-analysis, and some poor methodology quality from non-randomized studies. Fourthly, the definition of parameters in this review was slightly different, such as thoracic kyphosis from T1 to T3, or T4 to T12, which also influenced the results. Lastly, the data conversion process may have also affected the results by unifying the continuous data into mean±standard deviations. In this systematic review and meta-analysis, the studies from Sarwahi et al. had a large influence; however, they expressed the data as a median and interquartile range. Based on this meta-analysis, some concerns existed regarding heterogeneity and poor evidence data from non-randomized studies [24]. Therefore, in the research of MISS in AIS, large-sample-sized randomized controlled trials with the same standard of MISS technique are needed to support our meta-analysis results. Despite these limitations, it is evident that MISS offers significant advantages: our included studies consistently demonstrated its superior estimated blood loss and lower hospitalization days, with radiological outcomes in AIS comparable to those of COSS.

**Conclusions**

This systematic review and meta-analysis provide comparable evidence for the efficacy and safety of MISS using posterior approach in AIS. The MISS using posterior approach provides equivalent radiological and clinical outcomes, and complication rates compared to COSS. Considering the lower estimated blood loss, shorter hospitalization days, but longer operative times in MISS, COSS is still the mainstay of surgical treatment in AIS but MISS using posterior approach is also one of surgical options as surgeon’s choice in the case of moderate AIS.

**Conflict of Interest**

No potential conflict of interest relevant to this article was reported.
Author Contributions

HJK, and D-GC conceptualized the study. HJK, and HJK designed the study. HJK, and D-GC analyzed and interpreted the data. HJK acquired the data. HJK drafted the manuscript. LGL, JP, RC, PDT, MY, and MPK critically reviewed the work. LGL, JP, RC, PDT, MY, and MPK verified the data in the study. All authors had full access to all the data and had final responsibility for the decision to submit for publication.

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