

A systematic review of pseudarthrosis and reoperation rates in minimally invasive adult spinal deformity correction

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ARTICLE INFO

Keywords:

Pseudarthrosis
Minimally invasive surgery
Adult spinal deformity

ABSTRACT

Background/objective: The recent development of minimally invasive surgical techniques (MIS) has made possible the correction of adult spinal deformity (ASD) with less blood loss and shorter hospital stays. However, minimally invasive placement of pedicle screws at the proximal level of the construct can increase pseudarthrosis risk, leading to implant failure, kyphosis, and reoperations. We aggregate existing literature to describe pseudarthrosis rates at the proximal thoracic or thoracolumbar junction in MIS and subsequent reoperation rates.

Methods: After a three-tiered search strategy in PubMed, we identified 9 articles for study inclusion, describing outcomes from MIS correction of ASD, pseudarthrosis as complication, and surgery on 4+ levels. Baseline patient characteristics and combined rates of pseudarthrosis and reoperation were calculated.

Results: A total of 482 patients were studied with an average [range] age of 65.5 [60.4,72], 6.3 [4.4,11] levels fused per patient, follow-up time of 28.3 [12,39] months, and 64.8% females. Pseudarthrosis was reported in 28 of 482 pooled patients (5.8%) of which 15 of 374 pooled patients (4.0%) ultimately underwent a reoperation for pseudarthrosis. Post-operative characteristics included an estimated blood loss (EBL) of 527.1 [241,1466] mL, operating time of 297.9 [183,475] minutes, and length of stay of 7.7 [5,10] days. Among the papers comparing MIS to open surgery, all reported a significantly lower EBL in patients treated with MIS.

Conclusion: This analysis demonstrate a measurable pseudarthrosis risk when using MIS to treat ASD, overwhelming requiring reoperation. The benefits of MIS must be considered against the drawbacks of pseudarthrosis when determining ASD management.

1. Introduction

Adult spinal deformity (ASD) is a broad diagnosis describing an estimated 27.5 million adults in the United States with scoliosis, kyphosis, spondylolisthesis, and sagittal imbalance.^{1,2} Surgical management for ASD aims to correct segmental and global balance to achieve spinal decompression and realignment.³ Historically, ASD has been corrected with open fusion techniques, which are associated with complications such as soft tissue and vascular injury, excessive blood loss, neurologic injury, and significant postoperative pain.⁴

Recent advances have made spinal correction possible via minimally invasive surgery (MIS). MIS approaches have been associated with less blood loss, shorter hospital stays, decreased opioid use, and faster post-

operative ambulation.⁵ Several MIS approaches have been described, including minimally invasive or lateral anterior lumbar interbody fusion (ALIF), transforaminal lumbar interbody fusion (TLIF), and lateral approaches inclusive of lateral lumbar interbody fusion (LLIF) and oblique lumbar interbody fusion (OLIF).⁵ Whether these techniques are able to deliver equal deformity correction for ASD patients is currently debated as MIS techniques can decrease the odds of mature bony fusion, leading to pseudarthrosis, a complication when solid fusion is not achieved. This systematic review aggregates existing literature to assess rates of pseudarthrosis and subsequent reoperation in MIS for ASD.

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<https://doi.org/10.1016/j.wnsx.2024.100282>

Received 21 October 2022; Accepted 20 February 2024

Available online 25 February 2024

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2. Methods

A comprehensive, staged PubMed search was performed. In stage one, abstracts and article titles discussing the minimally invasive correction of ASD were reviewed. For stage two, this article list was refined to include only those mentioning symptomatic or asymptomatic pseudarthrosis as a complication. For stage three, these articles were separately read by two independent reviewers to ascertain that articles included four or more fused levels and had a mean follow up time of at least one year. Articles that met all of the above criteria were included. Studies that only discussed MIS-open (hybrid) procedures were excluded as they would not allow us to determine the pseudarthrosis risk from MIS alone. Case reports, conference abstracts, and non-English studies were also excluded. There were no restrictions on date, country of origin, or patient population for this study.

The following variables were reviewed: publication year; journal; total number of patients; number of patients to be included our analysis specifically; patient characteristics, including age and gender; peri- and post-operative characteristics, including surgical approach, number of levels operated on, operating time, estimated blood loss, length of stay in the hospital, and follow up time; and incidence of pseudarthrosis after surgery and reoperation due to pseudarthrosis.

Data analysis consisted of the averaging of patient demographic and peri- and post-operative characteristics across all articles. The combined rates of pseudarthrosis and subsequent revision surgery were calculated by comparing the pooled incidence of pseudarthrosis and revision surgery to the total number of patients studied across all papers.

3. Results

The Stage 1 screen yielded 799 articles, culled to 28 at stage 2, and 9

final articles at Stage 3 (Fig. 1). Among the final 9 articles, 7 were retrospective studies and 2 were prospective studies (Table 1). Five studies discussed MIS only, two compared results from MIS and hybrid surgery, one study compared MIS and open surgery, and one compared MIS, open, and hybrid surgery.

The average age of MIS patients ranged from 60.4 to 72 years and the majority of patients were female (64.4%) (Table 2). The average number of levels for each study ranged from 4.4 to 11. Operative variables included an average estimated blood loss (EBL) of 527.1 mL, a mean operating time of 297.9 min, average length of stay (LOS) of 7.7 days, and a mean follow-up duration of 28.3 months. Among the papers comparing MIS to open and/or hybrid surgery, all reported a statistically significant lower EBL in patients treated with MIS. Mean length of stay mean follow up time, and LOS were inconsistently reported as lower or equal between MIS and open and/or MIS-open hybrid surgery.

Among the pooled 482 patients who underwent MIS, 28 patients (5.8%) had pseudarthrosis as a post-operative complication. Specifically, Eastlack et al⁶ reports a 5.9% incidence of pseudarthrosis in their cohort of 68 patients, and Hamilton et al⁷ reports a pseudarthrosis rate of 7.9% in their cohort of 63 patients. Anand et al (2013),⁵ Anand (2014),⁸ and Chan et al⁹ report similar pseudarthrosis rates of 12.9% 10.8%, and 9.26% in their cohorts of 31, 46, and 108 patients, respectively. The nature of such pseudarthroses were described by only a few papers in this analysis; Anand et al (2014) describe four pseudarthroses in their MIS patient cohort, two due to late-onset infection and two with sacral pedicle screw loosening. Anand et al (2013) also report that out of the four observed pseudarthroses cases, two occurred at L5-S1 and two occurred due to DLIF alone, and Eastlack et al report a pseudarthrosis at L5-S1. A 0% incidence of pseudarthrosis was reported by Leveque et al,¹⁰ Wang et al,¹¹ Anand et al (2019),¹² and Anand et al (2010)¹³ in their cohorts of 13, 25, 60, and 28 patients, respectively.

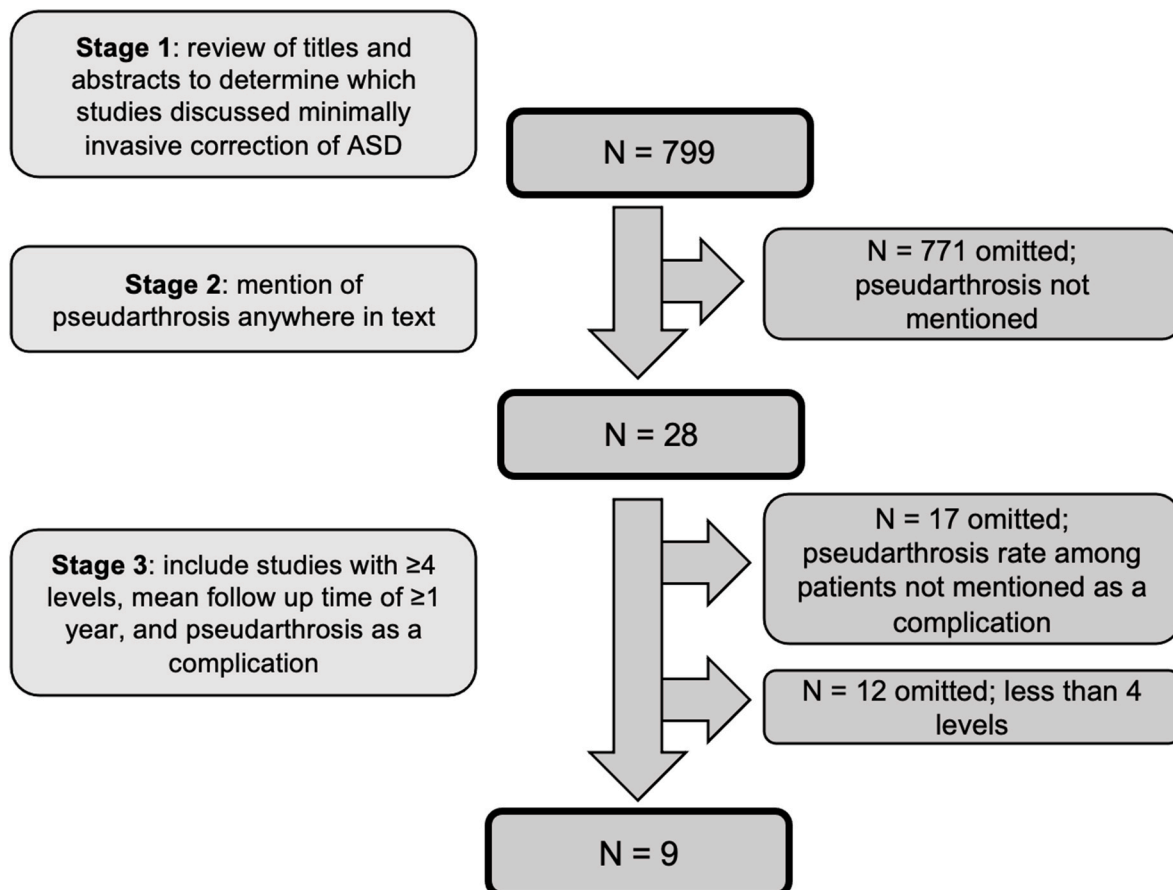


Fig. 1. Three stages of final article selection.

Table 1
Baseline characteristics of nine selected articles.

Lead Author	Year	Article Title	Study type	Techniques discussed	Type of MIS
Anand, N	2019	Analysis of Spino-Pelvic Parameters and Segmental Lordosis with L5-S1 Oblique Lateral Interbody Fusion at the Bottom of a Long Construct in Circumferential Minimally Invasive Surgical Correction of Adult Spinal Deformity	prospective	MIS	OLIF 5-1
Leveque, JC	2017	Correction of severe spinopelvic mismatch: decreased blood loss with lateral hyper-lordotic interbody grafts as compared with pedicle subtraction osteotomy	retrospective	MIS vs. open	LLIF-ACR
Anand, N	2014	Does minimally invasive trans-sacral fixation provide anterior column support in adult scoliosis?	retrospective	MIS	Trans-sacral discectomy, fusion, and fixation
Eastlack, R	2019	Early and Late Reoperation Rates With Various MIS Techniques for Adult Spinal Deformity Correction	retrospective	MIS vs. hybrid	ALIF or LLIF with posterior instrumentation placed percutaneously
Wang, M	2013	Improvement of sagittal balance and lumbar lordosis following less invasive adult spinal deformity surgery with expandable cages and percutaneous instrumentation	prospective	MIS	TLIF
Anand, N	2013	Long-term 2- to 5-year clinical and functional outcomes of minimally invasive surgery for adult scoliosis	retrospective	MIS	combination of 3 MIS techniques: (1) DLIF; (2) axial LIF; and (3) posterior instrumentation
Anand, N	2010	Mid-term to long-term clinical and functional outcomes of minimally invasive correction and fusion for adults with scoliosis	retrospective	MIS	combination of single use of: 1) XLIF (NuVasive, Inc.); 2) DLIF (Medtronic Sofamor Danek, Inc.); or 3) AxialLIF for L5-S1 fusion, or in some cases L4-5 and L5-S1 fusion (TranS1, Inc.)
Hamilton, D	2016	Reoperation rates in minimally invasive, hybrid and open surgical treatment for adult spinal deformity with minimum 2-year follow-up	retrospective	MIS vs. hybrid vs. open	lateral or transforaminal LIF
Chan, A	2021	Two- and three-year outcomes of minimally invasive and hybrid correction of adult spinal deformity	retrospective	MIS vs. hybrid	circumferential MIS (cMIS), which uses percutaneous posterior fixation

Table 2
Demographics, peri and post operative, and complication characteristics of MIS patient.

Variable	Value
N	482
Demographics	
Mean [range] age (years)	65.4 [60.4, 72]
Gender (female)	241 (64.4%)
Peri and post-operative characteristics	
Mean [range] levels fused	6.3 [4.4, 11]
Mean [range] follow up time (months)	28.3 [12, 39]
Mean [range] blood loss (mL)	527.1 [241, 1466]
Mean [range] operating time (seconds)	297.9 [183, 475]
Mean [range] length of stay (days)	7.7 [5, 10]
Complications	
Rate of pseudarthrosis	28 (5.8%)
Reoperation rate due to pseudarthrosis	15 (4.0%)

Information on reoperation rates due to pseudarthrosis was available for 8 out of the 9 articles. Excluding the patients from the Chan et al that did not specifically indicate reasons for reoperation, 15 of the remaining 18 patients in the pseudarthrosis pool underwent a reoperation. This figure represents a 4.0% risk in the remaining pooled 374 patients who required revision surgery specifically for pseudarthrosis. Specifically, all pseudarthrosis patients underwent revision surgery in the cohorts described by Hamilton et al, Anand et al (2013) and Anand et al (2014). A revision rate of 25% was reported by Eastlack et al.

4. Discussion

The success of ASD correction is predicated on restoration of sagittal and coronal balance, sufficient neural decompression, and solid fusion. While these aims have traditionally been accomplished with open interventions, recent advances in minimally invasive techniques have reduced morbidity associated with surgical ASD correction.^{3,14} Although MIS has been reported to have similar clinical and radiological outcomes as open surgery and a similar post-operative complication rate, the types of the complications experienced between MIS and open/hybrid surgery patients differ.¹⁴ In our analysis, we compiled reports specifically

regarding solid fusion and found a measurable rate of pseudarthrosis when using MIS to treat ASD, overwhelmingly requiring revision surgery.

Specifically, our summative review reveals a 5.8% rate of pseudarthrosis in MIS only cohorts, and a 4.0% risk of requiring a reoperation specifically for pseudarthrosis. Once pseudarthrosis has been diagnosed, there was a noted 83.3% chance of requiring reoperation (15 of 18 patients) to correct the nonunion. Our review reveals only small number of reports directly comparing MIS versus open deformity correction outcomes. Among the four papers in this review, Chan et al reports that while MIS patients had fewer overall complications compared to hybrid patients, MIS patients had significantly more pseudarthroses (9.3% vs. 1.1%, $p = 0.039$). However, non-significant differences in pseudarthrosis rates between open/hybrid and MIS patients were reported by Eastlack et al and Leveque et al; Eastlack reports a higher incidence of pseudarthrosis in MIS versus open patients (5.9% vs. 1.5%), while Leveque et al reports a higher incidence of pseudarthrosis among open patients compared to MIS patients (14.3% vs. 0%). Larger cohort studies are necessary to rigorously characterize this observed discrepancy between studies.

The long-term occurrence of pseudarthrosis after open surgery is reported at 9.8% in a cohort of 1895 ASD patients.¹⁵ Charosky et al similarly report a pseudarthrosis rate of 12.4% among a cohort of 306 ASD patients.¹⁶ While our present study highlights a notable pseudarthrosis risk after MIS of 5.8%, whether the general risk for pseudarthrosis is truly lower in MIS versus open correction still remains unclear. Four studies in our analysis reported MIS related pseudarthrosis rates of 0%, less than the average in our analysis. We did not identify any appreciably different patient factors between these studies compared to others in this review. It is possible that differences in technique and/or reporting standards contributed to this discrepancy.

When MIS patients were seen to have pseudarthrosis, this was followed by a return to the operating room for correction and treatment of this complication 83.3% of the time. Hamilton et al report pseudarthrosis as the most common reason for revision surgery among their MIS cohort, making up 7.9% of MIS revision cases, while pseudarthrosis was not a common indication for revision surgery among their open and hybrid patients. While this finding is echoed by other studies analyzing

complication rates for MIS to treat ASD,^{4,8} this trend is not mirrored across the literature. In fact, Leveque et al report a non-significant difference in the rate of reoperation due to pseudarthrosis between MIS and open surgery patients, which is consistent with their report of a non-significant difference between open and MIS pseudarthrosis incidence.

It is out of scope of this paper to recommend criteria for clinical decision making to pursue open versus minimally invasive approaches. However, it must be noted that less severe deformities and spinopelvic mismatches have been reported more amenable to MIS procedures.³ Specifically, the MISDEF algorithm created by Mummaneni et al¹⁷ provides a framework for evaluating candidacy for MIS procedures based on the radiographic metrics of sagittal vertebral axis, pelvic tilt, and lumbar lordosis/pelvic incidence mismatch, and this algorithm generally recommends MIS only for less severe deformity cases. There is also a general view that MIS can be better tolerated by the highly comorbid patient, due to well-established reports of lower blood loss, length of stay, and operating time in MIS cases. However, our findings propose that at least some of the proposed benefits from MIS are balanced by a different complication profile, specifically the relatively higher pseudarthrosis rate by virtue of the minimally invasive access. If pseudarthrosis is seen, this is usually followed by readmission, a reoperation for revision, and all potential risks associated with the return to the operating room and subsequent length of stay.¹⁸

Limitations of this analysis include patient population heterogeneity, limited demographics, and multiple surgical techniques within the two defined categories. Inherent to a review of this nature, variations between surgeon skill and technique cannot be controlled. Because of the heterogeneity of the papers reviewed, it could not always be determined whether pseudarthrosis occurred proximally at the thoracolumbar junction or distally at the lumbosacral junction; these data would have helped further inform improved techniques for achieving fusion at those very different biomechanical levels. Further, while we selected studies with a minimum of a mean one year follow up, the mean follow up duration was not consistent across all of the studies. As pseudarthrosis is a complication whose risk compounds with time, it is possible that our current figure underestimates the true incidence of pseudarthrosis post-MIS, as we are limited by the varying follow up times between studies.

5. Conclusion

MIS has well-established benefits with several studies consistently reporting lower blood loss and operating time compared to traditional approaches to treat ASD, which may increase the feasibility of ASD correction for patients who are less likely to tolerate high risk spinal reconstruction. In this systematic review, we report a measurable rate of pseudarthrosis and subsequent reoperation when using MIS to treat ASD. As a result, the benefits of MIS must be weighed against this demonstrated risk of pseudarthrosis and revision surgery when evaluating the best surgical treatment option for ASD.

Funding and disclosures

None.

CRedit authorship contribution statement

Sandhya Kalavacherla: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Lauren E. Stone:** Conceptualization, Data curation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Carson P. McCann:** Data curation. **Megana Saripella:** Data curation. **Martin H. Pham:** Conceptualization, Methodology, Project administration, Resources, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

None.

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Abbreviation

ALIF: anterior lumbar interbody fusion
ASD: Adult spinal deformity; **EBL:** estimated blood loss
LLIF: lateral approaches inclusive of lateral lumbar interbody fusion

LOS: length of stay

MIS: Minimally invasive surgery

MISDEF: minimally invasive spinal deformity surgery

OLIF: oblique lumbar interbody fusion

abrTLIF: transforaminal lumbar interbody fusion