European Spine Journal (2024) 33:2495–2503
https://doi.org/10.1007/s00586-024-08225-6

ORIGINAL ARTICLE

Minimally invasive surgery versus standard posterior approach in the treatment of adolescent idiopathic scoliosis: a 2-year follow-up retrospective study

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Received: 6 February 2023 / Revised: 2 January 2024 / Accepted: 8 March 2024 / Published online: 26 April 2024

Abstract

Purpose This is a monocentric retrospective controlled study that compares the safety and efficacy of posterior minimally invasive surgery (MISS) to standard posterior spinal fusion (PSF) surgery in adolescent idiopathic scoliosis (AIS).

Methods We retrospectively collected 111 patients with Lenke type 1–6 AIS who were treated with MIS ($n=47$) or PSF ($n=64$) between February 2019 and January 2021 with a 2-year clinical and radiological follow-up. MIS technique was applied via two midline noncontiguous skin incisions ranging from 3 to 7 cm in length, so we obtained the arthrodesis only in the exposed tract, passing the rods below the fascia, avoiding the complete muscular sparing. Values of Cobb angles degrees were collected to study the correction rate of the structural major curve. Postoperative AP direct radiography and preoperative AP direct radiography were compared with the last follow-up examination. Operative time, preoperative hemoglobin (Hb) and second postoperative day Hb, full length of hospitalization, time to achieve verticalization and time to remove the drainage were recorded. NRS medium score was assessed immediately after surgery and during the whole postoperative rehabilitation treatment to estimate pain reduction. Complications were collected postoperatively and throughout the whole follow-up period.

Results There was no significant difference between the two groups in terms of radiographic and clinical features. The correction rates of the structural curve resulted to be not significantly different between MISS and PSF (64.6 ± 11.7 vs 60.9 ± 13.2, $p=0.1292$) as well as for the correction rate of the secondary curve between the two compared techniques (59.1 ± 13.2 vs 59.2 ± 12.4, $p=0.9865$). The two groups had comparable operative time (210 min vs 215 min). The MIS group had a significantly lower reduction of postoperative Hb in comparison with PSF group (2.8 ± 1.3 mg/dl vs 4.3 ± 1.5 mg/dl, $p<0.0001$). The postoperative NRS score was lower in MIS group (1.9 ± 0.8 vs 3.3 ± 1.3). PSF group was observed to have a significantly longer period of hospitalization than MIS (5.2 ± 1.4 days vs 6.3 ± 2.9 days, $p=0.206$). Complications were more frequent in PSF group rather than in MFS group.

Conclusions MISS is a safe and capable alternative to PSF for AIS patients with curves $<70°$, with analogue capacity of scoliosis correction and same operative time and with advantages in blood loss, length of stay and postoperative pain.

Keywords Adolescent idiopathic scoliosis · Minimally invasive spine surgery · Posterior spine fusion · Spine deformity

Introduction

Minimally invasive spine surgery (MISS) is becoming more common for the treatment of multilevel pathology and evolved to decrease the rate of approach-related morbidity concerning conventional open procedures. It is generally agreed today that a minimal invasive approach could be a feasible option in patients with adolescent idiopathic scoliosis (AIS). Nevertheless, there are significant technical

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challenges of performing MISS on this patients' population [1]. There has been a rapid evolution of MISS for degenerative spinal disorders; however, curves in AIS patients are much larger than in adult degenerative scoliosis, the number of instrumented levels is higher and vertebral rotation can be significant. Multiple stab incisions in the pediatric population limit access to perform an adequate facetectomy and MISS depends upon facet and inter-body fusion, the latter of which is not part of routine AIS surgery [2]. For these reasons, the use of MISS in patients with spinal deformity remains limited, even if it may significantly improve peri- and postoperative morbidity. The few studies reported in the literature demonstrate that the use of MISS can reduce intraoperative blood loss and postoperative pain while allowing earlier mobilization and discharge [3]. De Bodman et al. [4] performed three-incision MISS in 70 consecutive AIS patients and showed a significant correction of spinal deformity with low blood loss, short length of hospital stay and similar complication rate as open technique [4]. This is consistent with data reported by Miyanji et al. [5] who prospectively compared a cohort of patients treated by MISS with a cohort of patients treated by standard posterior spinal fusion surgery (PSF) for AIS and demonstrated that the estimated blood loss and the length of stay were considerably reduced in the MISS group. Even though they found that operative time was longer in this group, similar results between PSF and MISS groups were reached as far as the curve correction was concerned [5].

The main objective of our study was to point out the advantages and practicability of MISS technique compared to PSF in the setting of AIS. We evaluated clinical and radiological outcomes of MISS in terms of operative time, estimated blood loss, length of intensive care support and hospitalization, curve correction, time to verticalization, time to remove the drainage, and we compared these results to those obtained with standard PSF.

Methods

Data collection

This is a monocentric retrospective controlled study approved by the Comitato Etico di Area Vasta Emilia Romagna-AVEC (Protocol N. 0005114 of March 25th, 2022). We retrospectively collected 111 patients with radiological and clinical diagnosis of AIS, surgically treated in our Institution between February 2019 and January 2021. Additional inclusion criteria were: Cobb angles degrees equal or less than 70° and a minimum of 24-month follow-up period. All patients underwent surgery and were treated with PSF ($n=64$) (Fig. 1) or MISS ($n=47$) (Fig. 2). All MISS procedures were performed by a single surgeon to reduce inter-operator variability. All patients attended an outpatient follow-up visit consisting of clinical and radiological evaluation for at least 2 years from primary surgery. The Lenke type was assessed by evaluating preoperative antero-posterior (AP) direct radiography. Values of Cobb angles were collected to study the correction rate of the structural curve by comparing preoperative and postoperative AP direct radiography with the last follow-up examination. Thoracic kyphosis (TK) and lumbar lordosis (LL) were evaluated before surgery and during the follow-up period. All radiographic data measurements were performed by an independent observer with at least 5 years of experience. The clinical data of each patient were collected from the hospital archive of electronic medical records. The data collected included operative time, preoperative and second postoperative day hemoglobin values, full length of hospitalization, time to achieve verticalization, time to remove the drainage and Numeric Rating Scale (NRS) score to evaluate pain level. Time to verticalization was expressed in days after surgery as registered in the Rehabilitation diary by physiotherapists. NRS score was assessed immediately after surgery, throughout the whole hospital stay and at the patient discharge. It was reported in the Rehabilitation diary at the end of each physiotherapy session. We considered the mean value of all NRS scores recorded in the Rehabilitation diary to compare postoperative pain levels between MISS and PSF groups.

Moreover, surgical complications were collected during the postoperative period and during the follow-up.

MISS surgical technique

Our MISS technique is performed through two small midline skin incisions (5–6 cm), instead of an extended one performed in PSF (Fig. 3), followed by subcutaneous and muscular dissection to mobilize laterally skin incisions. The muscles fibers are dissected from the bone with subperiosteal skeletonization. An adequate facetectomy is obtained at all levels instrumented with osteotomy and usually at one or two levels proximally for distal incision and distally for proximal incision. Three or four levels are instrumented for incision. Resect facets are used as autograft to facilitate arthrodesis. We use uniplanar pedicle screws bilaterally and polyaxially screw for the proximal and distal levels, according to free hand anatomic technique. No apical levels usually were instrumented in our MIS technique. Considering that apical rotation is the result of the bending moment and the torque moment acting concurrently at the transitional zones of the curves, which also turn out to be the most unstable ones, by stabilizing these, which turn out to be the areas of greatest instability, the resultant forces in action are neutralized at the apex of the curve. Two rods contoured with planned sagittal lordosis and kyphosis are passed from proximal to distal incision in cephalocaudal direction, passing below the fascia in the not exposed tract.

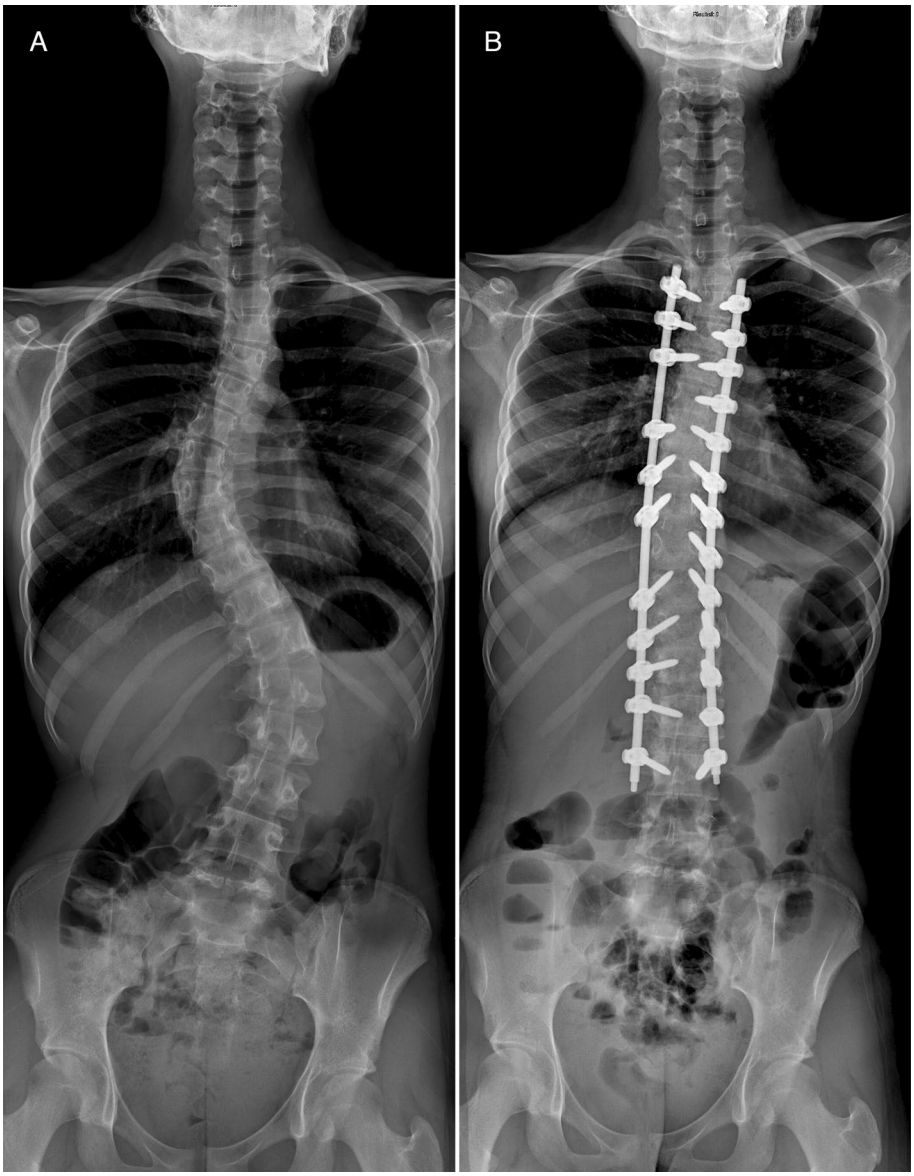

Fig. 1 **A** Preoperative X-ray of a case of AIS treated with posterior spinal fusion technique (**B**)

The screws are capped as the rod pass on the tulip. Rod reduction devices can be used to facilitate the correct positioning on the screw heads. We perform rod translation maneuver but also a Cotrel–Dubousset (CD) maneuver on distal part: we generally put a temporary rod slightly longer on the contralateral side only in distal tract, and perform a derotation using a rod wrench on the distal part of temporary rod and reducers on definitive rod. A reverse force is applied on the thorax of the patient using assistant hands during the maneuver. In some cases, according to the surgeon's preference, we used a multiple-rod construct with a second rod on the concavity side to ensure better stability against longitudinal forces. We lock the definitive rod, remove the temporary rod and repeat the positioning of the rod on the contralateral side with the same technique. Distraction and compression maneuvers are performed as conventionally. Sub-fascial drain is not always used, and normally removed one or two days after the surgery.

Radiographic assessment

The following parameters were measured according to the Spinal Deformity Study Group guidelines [6]: Cobb angles of the main curve (obtained by measuring the angle between the superior endplate of the superior end vertebra and the inferior endplate of the inferior end vertebra involved in the curve), correction rate of the main curve ([preoperative angle − postoperative angle]/ preoperative angle × 100%), thoracic kyphosis (TK) and lumbar lordosis (LL). Preoperative side bending radiographs were performed to evaluate the flexibility of the curve.

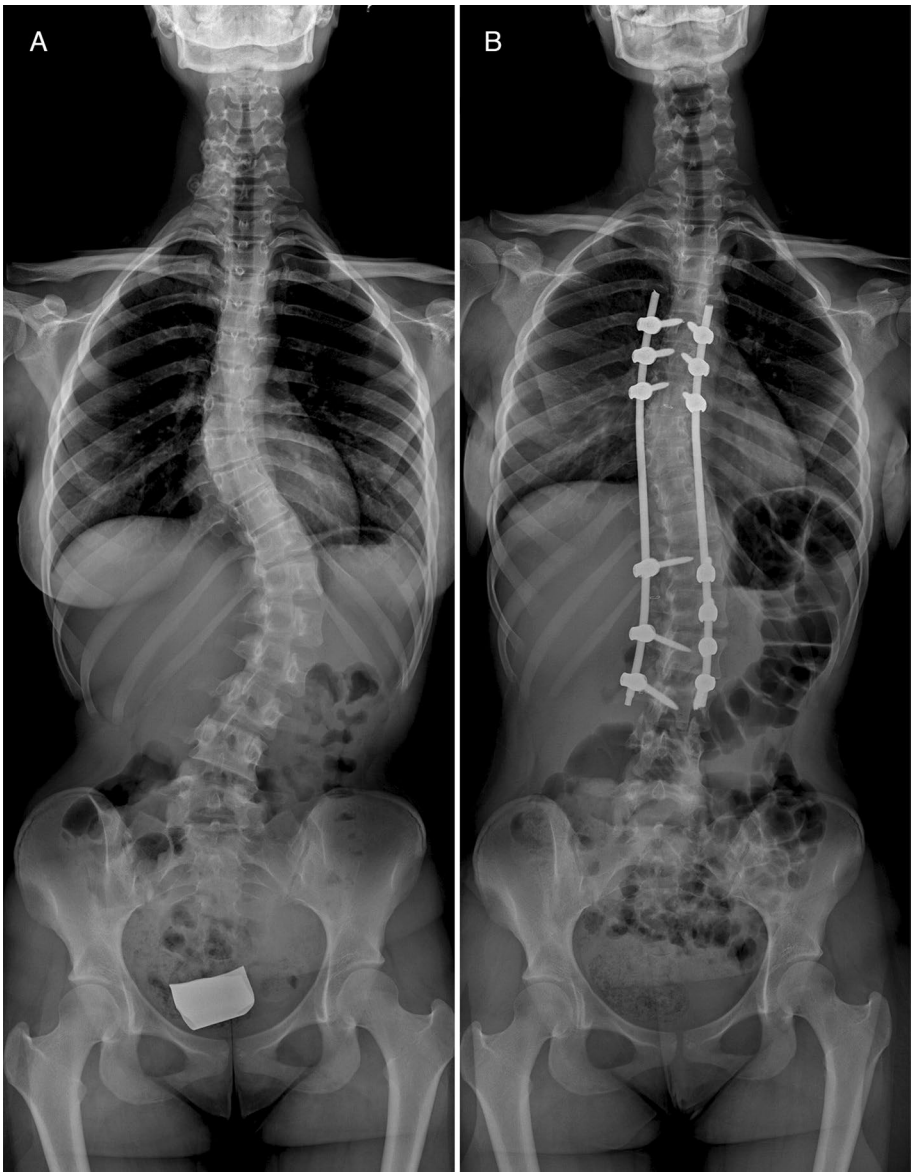

Fig. 2 **A** preoperative X-ray of a case of AIS treated with minimally invasive spine surgery (**B**)

Moreover, preoperative AP direct radiography was used to define the excursion of the iliac crest apophysis and the apophysis of the ischial tuberosity to examine the Risser sign. The Risser sign was used to estimate the skeletal maturity as a marker of scoliosis progression.

We perform radiographic checks every 6 months for the first 2 years of follow-up.

Statistical analysis

Continuous variables were summarized as median (range) or mean ± SD and categorical variables as percentage frequencies. Kolmogorov–Smirnov and Shapiro–Wilk tests were used to verify normal distribution of the continuous variables. Groups were compared using the Chi-square or Fisher's exact test, as appropriate, for categorical variables, or by the t test or Wilcoxon–Mann Whitney test, as appropriate, for continuous variables. Repeated measure analysis of variance was used for assessing the difference in sagittal parameters over time with Tukey test adjustment for post hoc comparisons. All p values were two-sided and a $p < 0.05$ was considered as statistically significant. Statistical analyses were carried out with SAS software 9.4 (SAS Institute Inc., Cary, NC).

Results

A total of 111 patients with Lenke Type 1–6 AIS were collected, 47 (10 males, 37 females) who underwent MISS and 64 (19 males, 45 females) who underwent PSF (Table 1). The median age of MISS group was 16 years (range

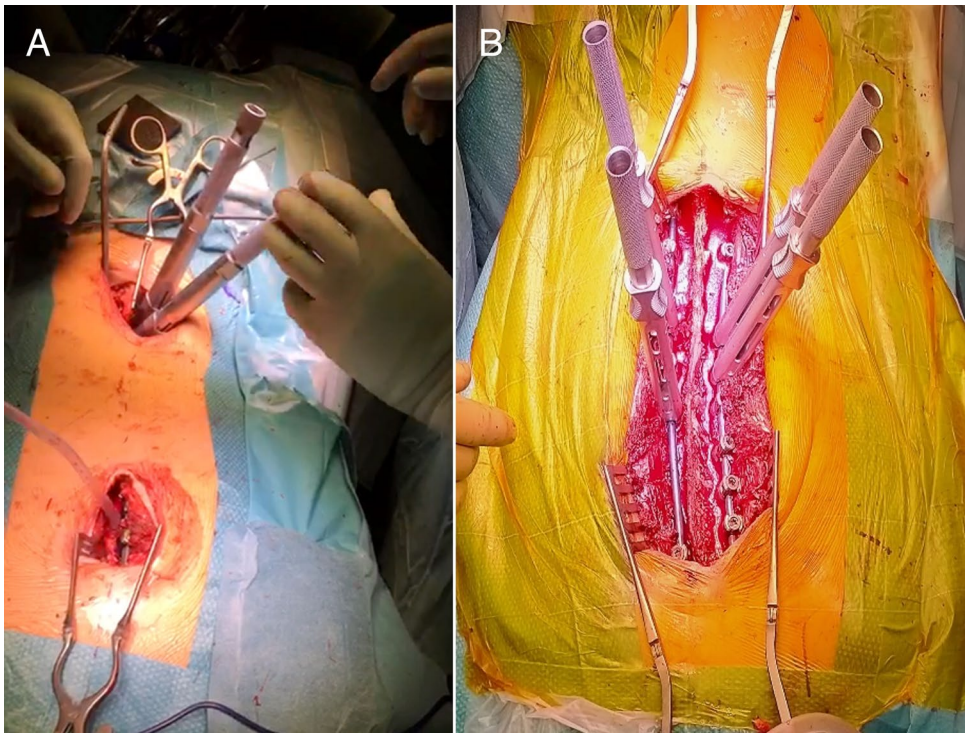

Fig. 3 Surgical exposure in MISSS (**A**) and PSF (**B**)

Table 1 Demographic and clinical data

Characteristics	MIS ($n=47$)	PFS ($n=64$)	P value between groups
Age, median (range)	17 (12–25)	16 (11–24)	0.6928
Gender, n (%)			
Female	37 (78.7)	45 (70.3)	0.3189
Male	10 (21.3)	19 (29.7)	
Lenke type, n (%)			0.1676
I	3 (6.4)	6 (9.4)	
II	3 (6.4)	10 (15.6)	
III	11 (23.4)	22 (34.4)	
IV	4 (8.5)	6 (9.4)	
V	10 (21.3)	10 (15.6)	
VI	16 (34.0)	10 (15.6)	
Risser, n (%)			0.3525
I	3 (6.4)	1 (1.6)	
II	–	3 (4.7)	
III	8 (17.0)	8 (12.5)	
IV	10 (21.3)	14 (21.9)	
V	26 (55.3)	38 (59.4)	

12–25 years), and the median age of PSF group was 16 years (range 11–24 years). As reported in Table 1, the Risser stages at operating time were similar in the two groups and we observed no statistical difference in the distribution of Lenke scoliosis type between the two groups. As reported in Table 2, the MISS group had a mean preoperative primary Cobb angle of 59.8 ± 9.4 degrees and secondary Cobb angle of 37.3 ± 7.8 degrees. The PSF group had a mean preoperative primary Cobb angle of 60.1 ± 10.6 degrees and secondary Cobb angle of 40.5 ± 10.5 degrees. As reported in Table 2, MIS group showed better reduction rate on bending X-ray of primary curve than PSF group. That is supported by the choice of more flexible curves for MIS technique. The postoperative correction rate of primary and secondary curves in MISS group was $64.6\% \pm 11.7$ and $59.1\% \pm 13.2$ with no relevant variation at the last follow-up. Compared to MISS, PFS had similar correction rate of main and secondary curves both at the postoperative assessment and at the last follow-up (Table 2). As reported in Table 2, the assessment of sagittal parameters showed a reduction of thoracic kyphosis in both groups after surgery, more significant in the MISS group compared to the PSF group ($p=0.0007$), the lumbar lordosis did not change after surgery from preoperative values, even between the two groups (Table 2).

As reported in Table 3, we observed a statistically significant difference in the number of instrumented levels, with 6.8 ± 0.7 levels in the MISS group and 12.4 ± 2.0 in the PSF group ($p<0.0001$), since in our MISS technique we only instrumented the proximal and distal levels of the treated scoliotic curves. We used a multiple-rod construct with a second rod on the concavity side in one patient for PSF group and primary in eight patients for MIS group (Table 4). Operating time was similar in both groups (210 min for MISS vs 215 min for PFS, $p=0.7782$). The

Table 2 Comparison of radiographic sagittal and coronal angle values between MIS and PSF

Variable	MIS ($n=47$)	PFS ($n=64$)	P value between groups
Main curve			
Cobb angle preop, mean ± SD	59.8 ± 9.4	60.1 ± 10.6	0.3990
Cobb angle postop, mean ± SD	20.9 ± 6.3	23.7 ± 9.8	0.2210
Cobb angle last follow-up, mean ± SD	21.7 ± 6.7	24.4 ± 9.8	0.2010
Correction rate postop, mean ± SD	64.6 ± 11.7	60.9 ± 13.2	0.1292
Correction rate last follow-up, mean ± SD	62.9 ± 12.9	59.6 ± 13.4	0.1999
Reduction of the curve (%) on bending X-ray	53.0 ± 13.3	42.10 ± 9.2	**0.0004**
Secondary curve			
Cobb angle preop, mean ± SD	37.3 ± 7.8	40.5 ± 10.5	0.2839
Cobb angle postop, mean ± SD	15.0 ± 5.1	16.1 ± 5.5	0.4445
Cobb angle last follow-up, mean ± SD	15.2 ± 5.1	16.5 ± 5.9	0.4322
Correction rate, mean ± SD	59.1 ± 13.2	59.2 ± 12.4	0.9865
Correction rate last follow-up, mean ± SD	58.1 ± 13.2	58.4 ± 12.4	0.9058
Reduction of the curve (%) on bending X-ray	57.4 ± 20.3	56.4 ± 23.5	0.6706
Kyphosis preop, mean ± SD	29.6 ± 10.9	32.7 ± 11.0	0.1143
Kyphosis postop, mean ± SD	23.4 ± 7.4	28.5 ± 7.8	0.0007
Kyphosis last follow-up, mean ± SD	24.3 ± 7.7	28.7 ± 7.5	0.0028
Lordosis preop, mean ± SD	44.8 ± 10.8	45.1 ± 9.4	0.8816
Lordosis postop, mean ± SD	43.3 ± 9.5	44.0 ± 8.8	0.9667
Lordosis last follow-up, mean ± SD	43.9 ± 9.3	44.5 ± 8.3	0.9881

Table 3 Postoperative clinical results

Variable	MIS ($n=47$)	PFS ($n=64$)	P value between groups
Length of stay (days) mean ± SD	5.2 ± 1.4	6.3 ± 2.9	0.0206
Days to verticalization mean ± SD	1.4 ± 0.8	1.8 ± 1.3	0.3016
Length of wound drain, mean ± SD	2.6 ± 1.2	2.5 ± 0.9	0.8364
Operating time (min)	209.9 ± 34.8	215.2 ± 45.2	0.7782
Instrumented levels, mean ± SD	6.8 ± 0.7	12.4 ± 2.0	< 0.0001
Preop Hb (mg/dl), mean ± SD	12.9 ± 1.5	13.4 ± 1.5	0.0822
Postop Hb (mg/dl), mean ± SD	10.1 ± 1.1	9.1 ± 1.1	< 0.0001
Hb reduction (post–pre) (mg/dl), mean ± SD	2.8 ± 1.3	4.3 ± 1.5	< 0.0001
Postop NRS score, mean ± SD	1.9 ± 0.8	3.3 ± 1.3	< 0.0001

Table 4 Multiple-rod constructs

Multiple-rod constructs	MIS	PSF
Primary surgery	8	1
Revision surgery	2	0

postoperative reduction of hemoglobin levels was significantly lower in the MISS group compared to PSF group (2.8 ± 1.3 mg/dl vs 4.3 ± 1.5 mg/dl, $p < 0.0001$). We also reported a significant reduction of the length of stay in the MISS group compared to the PSF group (5.2 ± 1.4 days vs 6.3 ± 2.9 days, $p = 0.0206$). The postoperative pain, calculated by NRS score during the hospitalization, was significantly lower in the MISS group than in the PSF group (1.9 ± 0.8 vs 3.3 ± 1.3, $p < 0.0001$).

During the follow-up period, postoperative complications occurred in 4 (8.51%) patients in the MISS group and 12 (18.75%) patients in the PSF group, as reported in Table 5. We observed no postoperative wound infection in the MISS group, while six patients in the PSF group had this complication. Mechanical complications requiring re-intervention occurred in three patients in the MISS group during the follow period: one case of proximal screw loosening and two

Table 5 Peri-operative and postoperative complications

Complications (*n*)	MIS	PFS
Neurological deficit	–	1
Postoperative wound infection	–	6
Screw loosening	1	–
Rod breakage	2	–
Adding on	–	1
Radiculopathy	1	2
Fever	–	1
Others	–	1

cases of rod breakage (Fig. 4). All these complications were successfully treated. We reported one case of adding on in the PSF group, after 6-month follow-up.

Discussion

Even though there is not much literature on this topic, most of the current evidence supports the use of MISS for AIS [1, 5–7]. Compared to traditional open surgery, the potential benefits of MISS include smaller incisions with less soft tissue disruption, decreased blood loss and infection, early mobilization and shorter postoperative hospitalization. However, there are significant technical challenges of performing MISS on patients with AIS and PSF still remains the gold standard treatment.

We report here a retrospective controlled study comparing MISS and PFS in a large population of patients affected by AIS treated at the same Institution. This study demonstrates that posterior MISS is a safe and valid alternative to the standard posterior fusion for Lenke type 1–6 AIS with curves < 70°, showing similar efficacy in the curve correction.

We found that the correction rate of the main curves and secondary curves was 64.6% ± 11.7% in the MISS group and 60.9 ± 13.2% in PSF group ($p = 0.1292$), so that AIS patients obtained a comparable correction rate with MISS and PSF. This is consistent with previous findings from Sarwahi et al. [2] who demonstrated that in the MISS group, the Cobb angle was corrected to a median of 10° while the PSF group improved to 7°. This translates to a median of 79.25% curve correction in the MISS group compared to 84.78% curve correction in the PSF group (not significant, $p = 0.503$), even if less blood loss and reduced hospital stay with MISS technique were recorded [2]. A similar conclusion was achieved by Urbanski et al. [8], who demonstrated that open surgery provided slightly superior (by 10%) coronal curve correction than minimally invasive surgery, but with markedly increased intraoperative blood loss (by 312 ml on average).

Si et al. [7] achieved correction rates of primary and secondary curves similar to our study group, but with a mean of principal curves about 10° inferior to our study group. Zhu

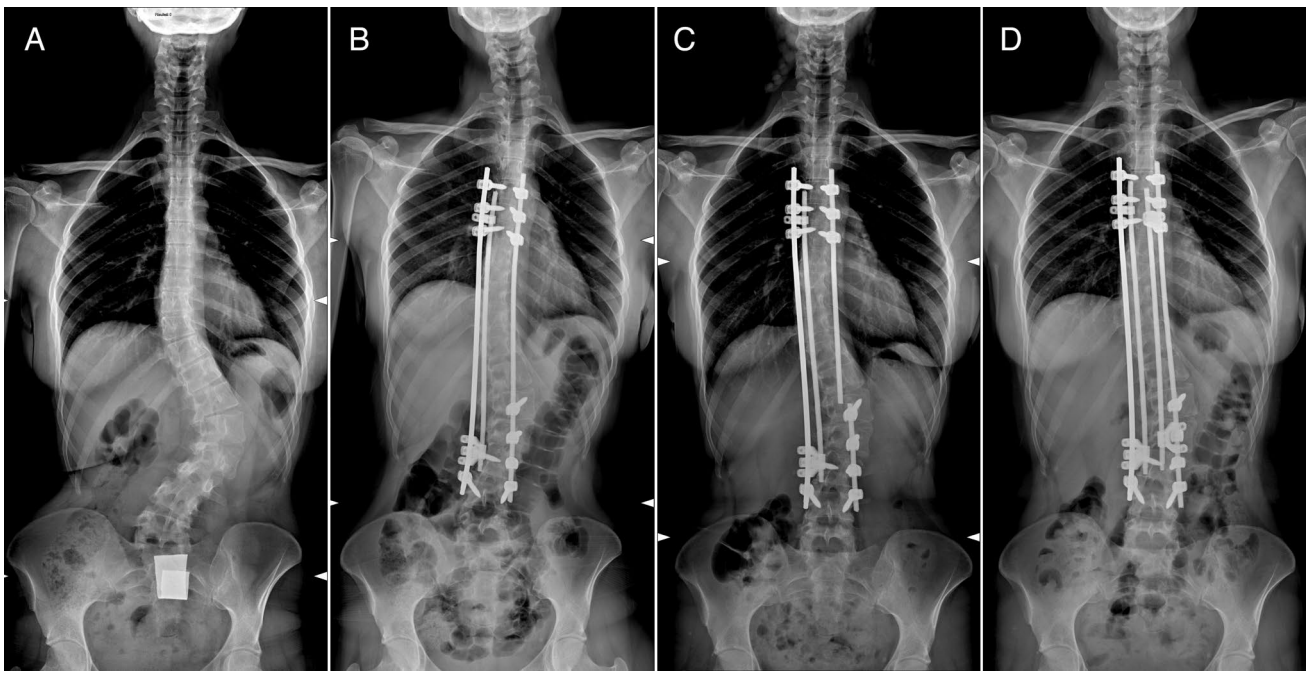

Fig. 4 X-rays showing a case of AIS treated with MISS technique pre (**A**) and after surgery (**B**). Rod breakage occurred 8 months after surgery with loss of 6° in major curve correction (**C**). Revision surgery with doubling of the rods and complete restoring of curve correction (**D**)

et al. [9] performed MISS in Lenke type 5C AIS patients and found no obvious difference in radiographic parameters with respect to PSF group.

Miyanji et al. [10] proved that there was a significantly better percentage coronal Cobb correction with open PSF compared to MISS; however, MISS patients had a significantly lower estimated blood loss and mean volume of cell saver blood transfused compared to the PSF group [10].

In our retrospective study on 112 AIS patients, we evaluated the variation between preoperative and postoperative hemoglobin levels in the two groups (2.8% ± 1.3% in MISS group vs 4.3% ± 1.5% in PFS group) and found that the intraoperative blood loss was lower in the MISS group than in the PSF group, confirming previous results. Smaller incision and muscle spearing approach in MISS could explain the reduction of intraoperative blood loss.

Abduljabbar et al. [16] reported the first meta-analysis to examine MISS and traditional open approaches in the surgical management of AIS and confirmed that MISS was associated with less blood loss compared to open surgery. They further found no difference in curve correction, postoperative pain, hospital LOS, or complications and reoperations [16]. However, in our study PSF group was observed to have a significantly longer time of hospitalization than MISS group (6.3 ± 2.9 vs 5.2 ± 1.4, $p = 0.02$).

In our study, the two groups had no significant difference in the operative time (209.9 ± 34.8 min vs 215.2 ± 45.2 min, $p = 0.7782$). On the other hand, Gomez et al. [17] found a longer operative time in MISS group, maybe partially related to steep learning curve. However, the mean operative time per level fused using MISS was consistent with previous results of 30–53 min [4]. Therefore, small incisions may not limit the number of fusion segments. The number of segments involved in surgery was homogeneous between the two groups also stratified by Lenke type, especially regarding last instrumented vertebra (LIV). When selecting the LIV, all the three Lenke, Suk and Dubousset criteria sets were assessed [13], and we suppose that MISS technique could reduce the risk of postoperative adding on and permits to spare motion segments. Arthrodesis is not performed at the apex of the curve, but via small incisions we had the possibility to extend one or two level above LIV obtaining similar results in ankylosis of the vertebrae included in the segment. Consequently, we obtained an RD maneuver that takes advantages of the flexibility resulting from the rising of the level arm and the resultant force exerted at the caudocranial edges. On the other hand, intermittent pedicle screw insertion may increase the level of fusion. In our study, no cases of adding on were recorded for MISS technique, while one case was recorded for PSF technique, even if this result is not significant and further studies are necessary to confirm it.

The rational of MISS techniques in spine surgery is focused on minimizing approach-related morbidity associated with conventional open posterior procedures. In fact, it was previously reported on significant soft tissue and muscle morbidity in posterior spinal fusion, including denervation, atrophy and decreased extensor strength likely contributing to increased perioperative and long-term pain [11, 12]. In our population, the assessment of postoperative pain showed a lower score in MISS group compared to PSF group (1.9% ± 0.8% vs 3.3% ± 1.3%).

The overall complication profile and reoperation rate is a relevant issue for any surgical procedure. Sarwahi et al. [2] and Zhu et al. [9] found a comparable complication rate between MISS and PSF. According to our findings, complications were more frequent in the PSF group rather than in the MFS group, with no surgical infection in MISS group and six events of postoperative infection in the PSF group (5 of them requiring debridment procedure). This observation is in accordance with previous findings [7, 14, 15]. These authors showed that the most frequent complications were instrumentation-related, surgical site infection or wound dehiscence, and anemia [14, 15]. Despite our findings of adequate facet fusion and high screw placement accuracy, three mechanical complications were observed in the MISS group, requiring re-intervention. These patients were among the first treated with this technique. When the breakage of rods occurred, patients lost some degrees in correction, regained when they underwent revision surgery, performed with a multiple-rod construct with second rod on concavity side, with no more complication on this group.

This is a retrospective monocentric study concerning posterior MISS in Lenke type 1–6 AIS patients with a considerable sample size, which provides further evidence to support the safety of MISS. A major limitation of our study underlies the retrospective design so that the generalizability of our findings could be still limited. However, the inclusion of patients from a single center minimized the biases arising from different patient management. We restricted the use of MISS to AIS patients with curves less than 70 degrees and reasonable flexibility; this is a relatively novel technique, there is no consensus on the characteristics which make a patient appropriate for MISS, and its indication remains to be further verified.

Another limitation of our study is the relatively short follow-up period; a long-term follow-up is required to clarify the advantages of MISS for correction surgery in AIS. Another question concerns technical difficulties that arise while trying to perform properly all necessary elements of the procedure, like screw insertions, facetectomies and steep learning curve to master the technique. Further studies foresee to include an extensive analysis on these aspects of the surgical technique.

Conclusion

MISS technique seems to be a safe and effective treatment of AIS and could be used as an alternative to PSF in all Lenke type of scoliosis with < 70° Cobb angle. With same capacity of scoliosis correction, MISS had the advantage of less intraoperative blood loss, less infection risk and less postoperative pain.

Acknowledgements The authors thank Carlo Piovani for the collaboration in images' storage and editing.

Funding Authors have no financial interest directly or indirectly related to the work submitted for publication. No funds, grants or other support was received.

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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