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ORIGINAL ARTICLE

Safety and effectiveness of minimally invasive scoliosis surgery for adolescent idiopathic scoliosis: a retrospective case series of 84 patients

Jae Hyuk Yang[1] · Dong-Gune Chang[2] · Seung Woo Suh[1] · Neelesh Damani[1] · Hoon-Nyun Lee[1] · Jungwook Lim[1] · Frederick Mun[3]

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Abstract

Purpose The aim of this study was to retrospectively evaluate a prospective series of patients with adolescent idiopathic scoliosis (AIS) who were treated with minimally invasive scoliosis surgery (MISS) technique with a minimum follow-up more than 1 year.

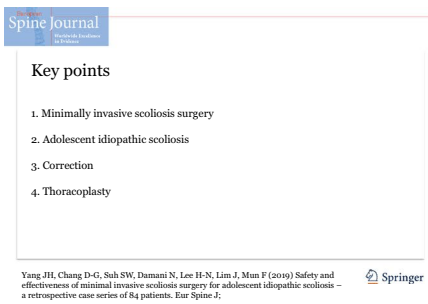
Materials and methods We retrospectively analyzed the prospectively collected data of 84 patients with AIS treated with MIS technique using two or three coin hole size incisions and a muscle-splitting approach. The clinical and radiological data such as the correction of deformity, coronal and sagittal profile and record of the perioperative morbidity of the patients were analyzed.

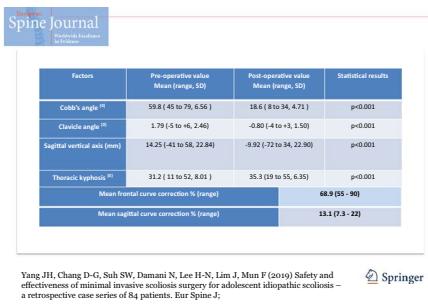
Results The mean primary Cobb angle was corrected from 59.8° preoperatively to 18.6° postoperatively with a mean correction of 68.9% ($p < 0.001$). The mean kyphosis at T2 to T12 was maintained within normal range with an increase from 31.2° preoperatively to 35.3° postoperatively ($p < 0.001$). The 30-day perioperative complication rate was 7.14% with one deep infection and five cases of hemothorax. The mean operation time was 312.8 min; mean estimated blood loss was 846.6 ml (range 420–2800); and mean length of stay was 8.5 days (range 5 to 14). All data of postoperative SRS-22 questionnaire were significantly improved ($p < 0.001$).

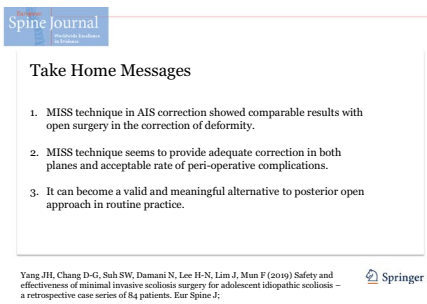
Conclusion MISS used for AIS provides adequate correction in both planes and acceptable rate of perioperative complications, with a low estimated blood loss and short length of stay. Considering all the positives, the application of MISS technique for AIS seems meaningful and can become a valid alternative to posterior approach in the routine use.

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.







Dong-Gune Chang and Seung Woo Suh have equally contributed to this study as the co-corresponding author.

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Extended author information available on the last page of the article

Keywords Spine · Adolescent idiopathic scoliosis · Surgical correction · Minimally invasive scoliosis surgery

Introduction

Spinal surgery in adolescent idiopathic scoliosis (AIS) using a traditional posterior open approach has been associated with significant perioperative and postoperative morbidity, related to long incisions, stripping of paraspinal muscles over large segments, severe blood loss and increased hospital stay. The mini-open or minimally invasive surgery approach was developed to avoid these adverse events and is now accepted practice for traumatic, neoplastic or degenerative lesions in adults [1]. The application of minimally invasive scoliosis surgery (MISS) in surgery for AIS is relatively new to the literature except for a few reports in the recent past. However, there are significant technical challenges of performing MISS on this patient population. In contrast to adult degenerative scoliosis, the curves in AIS patients are much larger (usually 45–50° or more), the number of levels instrumented is longer (7–13), the deformity exists in three planes, and the vertebral rotation can be significant [2]. Despite early encouraging results, there is a lack of literature over the use of minimally invasive surgery in scoliosis and most of the previous studies have a small sample size that may be inadequate to reach a conclusion. The authors have developed their own technique of MISS and reported their results in a preliminary study in the past [3]. The purpose of this study is to present the novel modifications in the technique with the experience gained, to measure the coronal and sagittal correction of deformity and record the perioperative morbidity in a large sample of AIS patients operated with MISS technique.

Materials and methods

This study was performed under approval of institutional review board of our hospital. We performed a retrospective evaluation of prospectively collected data of 84 consecutive patients with AIS, treated surgically with MISS technique between July 2015 and September 2017. All cases were operated by a single surgeon who has vast experience in doing open scoliosis surgery more than decade, but these surgeries are his early surgeries performed with this new technique for AIS correction. The demographic and radiographic data (included whole spine anterior–posterior (AP), lateral view and bending views) of the patients included: age, gender, menstruation status, body mass index, the type of curve according to the Lenke classification as well as King classification, the pre- and postoperative Cobb angles of the primary curve, shoulder imbalance (clavicle angle), thoracic hump, sagittal vertical axis (SVA) distance and thoracic kyphosis at T2 to T12. The radiological analysis was performed by a well-trained, experienced spine fellow who was familiar with all the techniques used in the study [4]. All the patients included in the study had a minimum of 1 year of follow-up after surgery. Bone fusion status was determined (confirmed indirectly in the absence of implant failure/breakage) from plain radiographs as we do not perform computed tomography (CT) scans routinely when our patients with AIS are reviewed 1 year postoperatively due to the radiation hazards. Perioperative (30 days postoperatively) complications were recorded, as were further subsequent complications within 1 year. Assessment of other perioperative variables included the number of pedicle screws which were used, the number of levels fused, operative time (ORT), expected blood loss (EBL) and length of stay (LOS). ORT was calculated from the time of incision to wound closure. The LOS was calculated from the time the patient left the operating theater (day 0) to the time of discharge from the hospital. Additionally to evaluate the clinical satisfaction of patients, pre- and postoperative clinical outcomes were evaluated using Korean version SRS-22 questionnaire [5].

The statistical analysis was performed using SPSS version 20 software (IBM, New York). A p value < 0.05 was considered statistically significant.

Surgical technique

After induction of anesthesia, each patient was positioned aptly in prone position with the operating table in reverse bending to increase the redundancy of soft tissues of the back that led to easy retraction for making space for putting pedicle screws. After marking the pedicle position, site and number of skin incisions were decided. Depending on the number of levels to be fused, two or three midline incisions measuring around two inches were given. A total of 4 to 7 functional segments of the thoracic vertebrae were covered through single skin incision, whereas 3 to 4 functional segments of lumbar vertebrae were covered with the similar incision over the lumbar region (Fig. 1). Following the incisions, pedicle screw insertion was performed using free-hand technique through retracted muscle and other soft tissue by right angled retractor or tubular retractor. The facet capsule was removed, and the pedicle screw entry point was marked at the junction of outer third of the superior facet and the transverse process (Fig. 2). The entry point was made with an awl or a motorized drill, and the pedicle screw trajectory was made with a curved Lenke probe. The safety of the pedicle walls was confirmed with a ball tip probe. Then, in order to insert pedicle screws more safely, a guide wire was inserted. Over the

guide wire, the facet was ground with a specially designed facet miller (Fig. 3). The allo-chip bone with demineralized cancellous bone matrix (Genesis Sponge, HANS Biomed, Seoul, Korea) was placed and grafted before screw insertion. A 6.0- or 5.5-mm cannulated poly-axial reduction screw was inserted over the guide wire. Reduction screws were used for easy assembly between rod and screws. In the thoraco-lumbar or lumbar area, Wiltse's paraspinal approach was applied for the muscle sparing [6]. Pedicle screw insertion and facet fusion were repeated in the thoraco-lumbar and lumbar area as was done in the thoracic area. Due to trajectory of pedicle screw on upper or lower end of vertebrae, additional percutaneous stab incisions sometimes were utilized. To maintain minimized additional skin stab incision, authors used specific type of telescoping screws (Fig. 4). These stab incisions could be also utilized for the exit of Hemovac drain while closure A 6.0-mm rod of appropriate length, which was suitably contoured to reproduce desired sagittal plane thoracic kyphosis and lumbar lordosis, was prepared after inserting all the screws. The rod was inserted (first on convex side) from the cephalad incision as overlapping laminae in the thoracic spine prevented its inadvertent entry into the spinal canal [7]. Inner set screw was inserted sequentially as the rod passed from one screw to the other. A similar technique was used to insert the rod on the concave side. Then, a modified direct vertebral rotation maneuver was used to rotate the rod and correct the deformity.

In patients with residual rib humps after correction, short apical rib resection thoracoplasty was done using 5-mm diamond burr. Before operation, targeted ribs were marked after taking Adam's forward bending view. Through the same posterior skin incision for pedicle screw, marked ribs were dissected under the skin and resected until hump was subside cosmetically. Wound lavage was done with saline, and tight closure was done in layers under two suction drains. Mobilization was started on the next day and the physical rehabilitation after 3 days. The patients were discharged after 6th to 9th postoperative day without any complications.

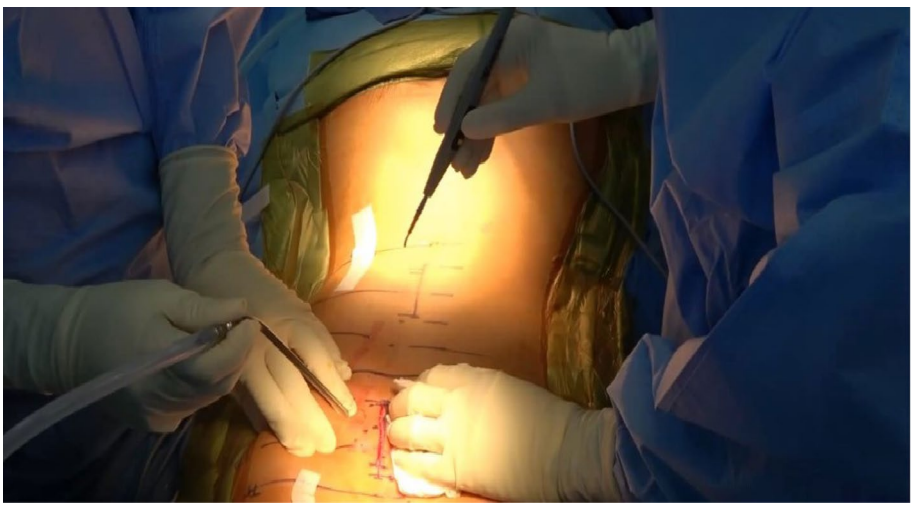

Fig. 1 Skin incisions: marking for the pedicle of vertebrae was performed using image intensifier, and the probable site of skin incision is marked after assessing redundancy of back skin

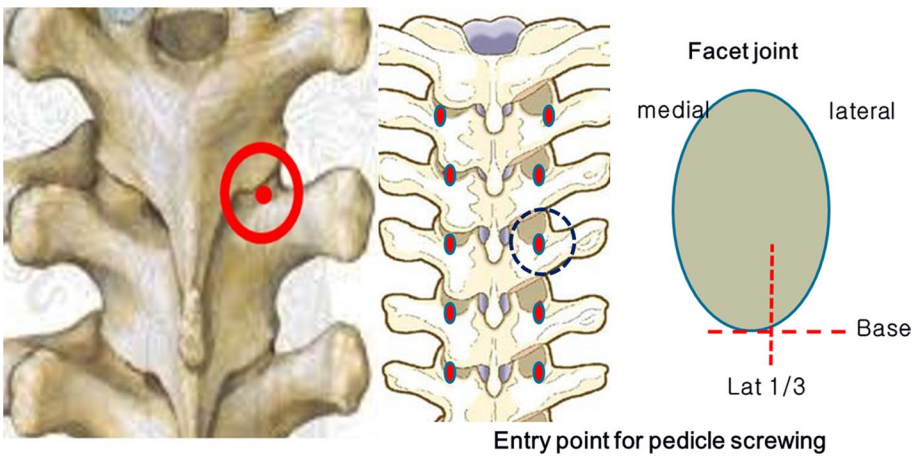

Fig. 2 Anatomical relationship between locations of entry point for pedicle and facet joint. Ideal entry point taken in this study for inserting pedicle screws is located at the junction between the tangential line drawn on the base of the superior articular process and the vertical line drawn on lateral 1/3rd of the superior articular process. This entry point was located around facet of thoracic vertebrae, so facetal fusion can be done during pedicle screw insertion process

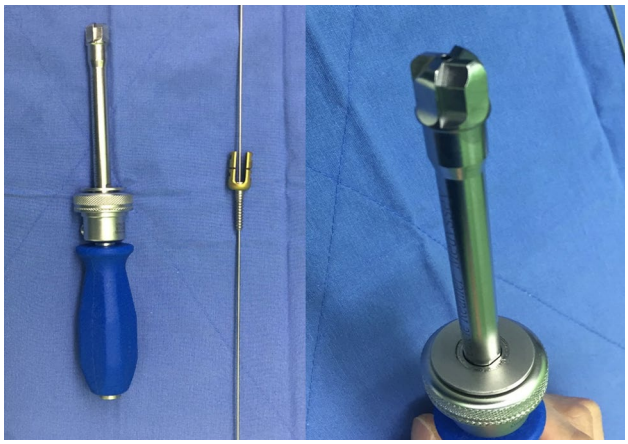

Fig. 3 Specially designed cannulated facet miller which encompass adequate grinding of facet joints. Specially designed cannulated facet miller grind over facet joint with the help of guide wire

Results

The demographic characteristics of the patients are summarized in Table 1. All the patients were operated at the skeletal maturity grade 4 or 5 according to Risser's grading system. The mean preoperative Cobb's angle was 59.8° (range: 45–79°), and the mean flexibility of the main curve was 35.3%. A total of 51 patients were operated using two midline incisions and 33 patients with three midline incisions. The radiological postoperative results are summarized in Table 2. The mean postoperative Cobb's angle was 18.6° (range: 8°–34°) with a significant correction rate of 68.9% ($p < 0.001$). The average postoperative clavicular angle was −0.98 with a significant correction rate ($p < 0.001$). There was a significant correction of the sagittal vertical axis ($p < 0.001$), with average postoperative SVA being −9.92 mm. The thoracic kyphosis at T2 to T12 was maintained within normal range, with a mean postoperative kyphosis of 35.3°. The average ORT was 312.8 min (range: 212–556 min), and the average EBL was 846.6 ml (range: 420–2800 ml).

The mean final scar length was 10.2 cm (range: 8–13 cm). The LOS (duration from day of surgery to day of discharge from hospital) ranged from 5 to 14 days. The perioperative complications are summarized in Table 3. All the patients were followed for a minimum of 1 year postoperatively with standard radiographs, and correction was well maintained over the years (Fig. 5). None of the patients had any indirect evidence of pseudo-arthrosis such as implant breakage or screw pull-out or loss of correction. The 30-day perioperative complication rate was 7.14%, with one deep infection and five cases of hemothorax. Three further complications occurred in three patients (3.57%); two delayed deep infections and one hypertrophic scar. Five cases of hemothorax occurred in the first 35 cases operated by this technique. The latter two infections were also encountered among the first 30 patients treated with MISS. Deep delayed infection required thorough debridement and irrigation of the entire surgical wound. Broad spectrum antibiotics were administrated and therapy tailored after culture results were finalized. Debridement and irrigation were repeated every week until the surgical wound became sterilized. The instrumentation was not removed.

In clinical evaluation, the average preoperative SRS-22 score was measured as 3.9 (range: 3.5–4.4) and it was improved to 4.2 (range: 3.2–4.7) ($p < 0.001$). All clinical outcomes are summarized in Table 2.

Fig. 4 Specially designed telescoping screw. Specially designed screws were used where additional skin incisions were needed due to anatomical limitations and trajectory of pedicle screw. After inserting the guide wire, connect the screw head and body to the guide wire. As the screw body inserted into vertebral body, it is automatically coupled to the head. For this reason, the screw can be inserted with a skin incision of about 7 mm (size of screw body itself)

Table 1 Demographic data of enrolled patients

Factors	Values
Gender (M:F)	7:77
King classification and patients (n)	I/II/III/IV/V (23/4/42/15/0)
Lenke classification and patients (n)	I/II/III/IV/V/VI (55/7/11/1/7/3)
Mean age (years) (range)	15.2 years (12.9–24)
Mean BMI (kg/m^2) (range)	19.2 (12.6–30.8)
Menarchial status of females	Pre-menarchial: 8 Post-menarchial: 69
Mean pre-op major Cobb's angle (°) (range)	59.8 (45–79)
Mean pre-op thoracic kyphosis T2–T12 (°) (range)	35.2 (12–54)
Mean curve flexibility^0/percent (range)	19/35.3 (15–100)
Mean screws (n) (range)	19.2 (14–26)
Mean levels fused (n) (range)	10.7 (7–13)
Mean ORT (min) (range)	312.8 (212–556)
Mean EBL (ml) (range)	846.6 ml (420 to 2800)
ICU care	0
Mean length of stay (days) (range)	8.5 (5–14)
Thoracoplasty (yes/no)	76/8

Table 3 Complications

Duration	Factors		Total patients (*n*, %)
	Infections	Others	
< 30 days	1	5, haemothorax	6, 7.14
> 30 days	2, delayed surgical site infections	1, hypertrophic scar	3, 3.57
Total patients (*n*, %)	3, 3.57%	6, 7.14%	

Discussion

MISS technique for AIS needs specialized surgical instruments, intraoperative image intensifier, neurosensory monitoring and great skill to expose the intervertebral junction and put free-hand screws, in case of deformed spine. All these aspects make it difficult to adopt the MISS technique, as correcting AIS needs multiple-level instrumentation and fusion of vertebrae, higher radiation exposure to both patient and surgeon, discomfort in correcting the deformity due to small skin incisions and numerous stab incisions needed for inserting percutaneous pedicle screws, resulting in unsightly scars [8]. Sarwahi et al. [2, 9] for the first time used minimally invasive surgery technique for correcting AIS, which consisted of using three midline incisions (4 cm each) and skip fixation of vertebral segments with pedicle screws using free-hand technique (3–3–3) but fused all facet joints. Complications such as dislodgement of rod, wound breakdown, late wound infection and hypertrophied scars were reported in his described technique. In order to counter these complications and limitations, we adopted few changes in the surgical technique to get favorable results. Firstly, in order to overcome the rod dislodgement and the limitations in correction, pedicle screws were inserted on all functional segments of spine, dispersing the load equally on all the pedicle screws. This in turn created a favorable environment for the fusion of all the facet joints through bone grafting and compressing grafted bone with the pedicle screws. Secondly, soft tissue and muscle damages during pedicle screw insertion through multiple stab incisions are thought to be the main sources of wound breakdown and late infection. Therefore, two or three small-sized incisions were used to minimize the damage on muscles. Furthermore, Wiltse's approach was applied in the lumbothoracic and lumbar vertebrae in order

Table 2 Radiological and clinical outcomes

Factors	Preoperative value Mean (range, SD)	Postoperative value Mean (range, SD)	Statistical results
Radiological outcomes			
Cobb's angle (°)	59.8 (45 to 79, 6.56)	18.6 (8 to 34, 4.71)	$p < 0.001$
Clavicle angle (°)	1.79 (−5 to +6, 2.46)	−0.80 (−4 to +3, 1.50)	$p < 0.001$
Sagittal vertical axis (mm)	14.25 (−41 to 58, 22.84)	−9.92 (−72 to 34, 22.90)	$p < 0.001$
Thoracic kyphosis (°)	31.2 (11 to 52, 8.01)	35.3 (19 to 55, 6.35)	$p < 0.001$
Clinical outcomes			
Total SRS-22 score	3.9 (3.5 to 4.4, 0.2)	4.2 (3.2 to 4.7, 03)	$p < 0.001$
Function	3.8 (3.2 to 4.6, 0.4)	4.3 (3.6 to 5.0, 0.5)	$p < 0.001$
Pain	3.9 (3.1 to 4.6, 0.5)	4.3 (3.0 to 5.0, 0.4)	$p < 0.001$
Self-image	3.9 (3.1 to 4.7, 0.4)	4.1 (2.8 to 5.0, 0.4)	$p < 0.001$
Mental health	4.0 (3.2 to 4.6, 0.4)	4.1 (2.6 to 5.0, 0.5)	$p = 0.022$
Satisfaction		4.1 (2.0 to 5.0, 0.5)	

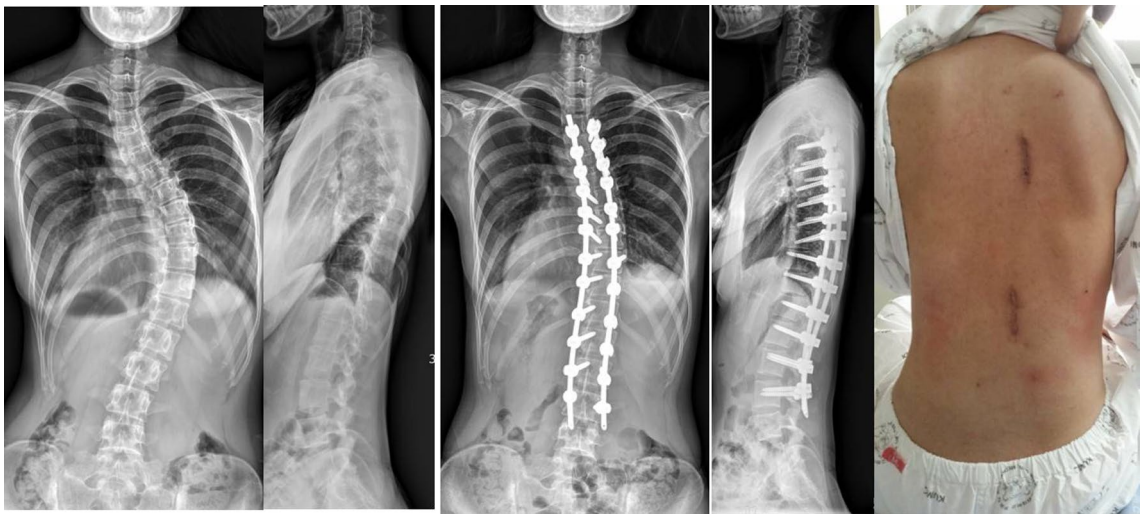

Fig. 5 One of our cases. 16-year-old female with Risser's stage 5 and Lenke type 1 curve. The surgery was performed through two skin incisions. Altogether, 24 pedicle screws were inserted from T4 to L3. Preoperative Cobb's angle was 62 degree, which was corrected to 12 degree postoperatively, and note the cosmetically superior scar

to minimize the muscle damage, approaching the surgical site through intervals of multifidus and other spinal muscles. Thirdly, natural back skin redundancy was utilized to reduce the length of skin incisions. The redundancy of the skin was increased by putting the operating table in hyperextension. However, little difficulties were faced while inserting pedicle screws on the concave side of the curve, but was well managed by manual retraction using right angled retractors. In order to achieve better cosmesis, a simultaneous small apical rib resection thoracoplasty was done using a high-speed 5-mm diamond burr.

There was significant correction of deformity in both the frontal and sagittal planes. The primary curve was corrected by a mean of 68.9%. In flexible curves, correction of 70–80% can be achieved, with the highest being of 86%, i.e., from 72^0 to 10^0. In the literature, using an all pedicle screw construct with a routine posterior approach, the reported mean correction in the frontal plane ranged between 64 and 84% [10–12]. Using an minimally invasive approach, Miyanji and Desai [13] and Sarwahi et al. [9] reported a mean correction in the frontal plane of 63% and 79.2%, respectively. Furthermore, loss of reduction and implant failure were not observed. The sagittal alignment was also maintained within normal values in our patients: the mean kyphosis at T2 to T12 increased from 31.2° preoperatively to 35.3° postoperatively. These results suggest that a similar correction of AIS may be obtained in both the frontal and sagittal planes using either MIS or a routine open posterior approach (Fig. 5).

Our rate of perioperative complications was 7.14%. The 30-day rate of complications for the surgical treatment of AIS reported from the Scoliosis Research Society Morbidity and mortality database is 6.2% [14]. Five patients had hemothorax (that resolved spontaneously), and one got wound infection in the early postoperative period, which was settled after debridement. We have a routine practice of doing thoracoplasty, if any residual hump is present after correction of the curve. 90.5% of our patients required thoracoplasty. Five cases of hemothorax occurred in the first 35 cases operated by this technique. We believe that the use of Kerrison rongeur for thoracoplasty was responsible for the high incidence of hemothorax in our study (due to increase in bleeding from the cut edges of raw bone when using Kerrison rongeur). We used to perform thoracoplasty using Kerrison rongeur in the past (first 35 cases). With gaining experience, we started performing thoracoplasty using the high-speed large caliber (usually 5-mm) diamond burr, with a smooth Cobb's elevator underneath the rib. There was a definite decrease in blood loss, when diamond burr was used, as the heat generated by burr caused burning of the vessels at cut edges, resulting in coagulation of blood vessels and decreased blood loss. He had no incidence of haemothorax in cases with thoracoplasty using a diamond burr. Hypertrophied wound scar was observed in one patient, which resulted in an enlarged wound length. However, this scar formation was thought to be due to individual differences in healing character and can be adequately controlled through the scar revision surgery. Three further complications occurred in three patients (3.57%) at a minimum follow-up of 1 year. Two of these three patients needed additional surgeries. Miyanji et al. [15] reported five complications in 23 patients with AIS treated by minimally invasive surgery, 2 years postoperatively. Three of these complications were delayed infections. The long operative times as compared to conventional open surgery and learning curve may be a

cause of delayed infections. Our total rate of complications (10.7%) is comparable with that reported by others. Yoshihara and Yoneoka [16] reported, between 2000 and 2009, an in-hospital overall complication rate of 14.4% for a total of 43,983 patients who underwent surgery for AIS.

The surgical time in our technique was longer than that of conventional open surgery. Brodano et al. [17] in his case report mentioned that it took 3 h to use the minimally invasive technique in AIS, whereas average operative time in our cases was approximately 5.2 h (312.8 min). The significant difference in duration of surgery might be due to additional procedure of thoracoplasty, additional instrumentation and fusion in all vertebrae of the curve, and finally learning curve of the operating surgeon, as these cases included his first series of cases operated with this technique. Sarwahi et al. [9] reported a mean ORT of 538 min fused, and Miyanji et al. [15] reported a mean ORT of 444 min. In both series, the mean ORT was significantly increased compared with a routine posterior approach. Our ORT was comparable to other studies on minimally invasive approach to scoliosis surgery, and it kept on decreasing with increasing experience.

The mean EBL was 846.6 ml. This also showed a decreasing pattern with increasing experience. Only three of our patients (3.6%) needed a blood transfusion. Yoshihara and Yoneoka [16] estimated a rate of transfusion of 30.4% in 43,983 children who underwent surgery for scoliosis (standard posterior approach), whatever its etiology and the type of transfusion. It seems that EBL substantially decreased using MISS. Two comparative studies have shown a significant decrease in EBL using MIS in patients with AIS. Miyanji and Desai [13] (23 patients) and Miyanji et al. [15] (16 patients) found reduced EBL in a minimally invasive group compared with an open group. Despite an increased ORT, a minimally invasive approach seems to contribute to a decrease in EBL, probably because of the decreased length of the incision, less extensive soft tissue dissection and decreased area of subperiosteal exposure [18].

The mean LOS for a patient undergoing surgery for AIS is between 5 and 6 days, according to recent studies [19]. In our study, the mean LOS was 8.5 days. Two comparative studies, with a maximum of 23 patients treated with MISS, reported a significantly shorter LOS with the use of MISS. In the minimally invasive groups, the mean LOS was 4.6 days and 4.4 days, respectively, and 6.2 days and 5.9 days in the routine open groups, respectively [13]. The hospital stay, in our study, LOS, was more as compared to other studies, as the postoperative physiotherapy and physical rehabilitation were very easily accessible to the patients in hospital. Hence, the patients felt more comfortable to stay in the hospital, despite being mobile and having an uneventful postoperative period. Moreover, our hospital is a government-owned organization, and the in-bed charges for the patients are very cheap. We had a routine practice of shifting the operated patients directly from the operation theater to general orthopedic ward. None of our patients operated with this technique required any ICU stays postoperatively. The initial postoperative transfer of patients with AIS postoperatively to a general orthopedic ward rather than to an intensive care unit has been associated with a reduced LOS, fewer blood tests, a reduced use of analgesic and anxiolytic medication and less physiotherapy [13, 20]. The mean scar length after complete healing was 10.2 cm, which is almost 1/4–1/5 of scar in conventional surgery. The scar appearance is a significant factor when considering the functional outcome of surgery. Two studies have reported a significant impact of the length of incision on patients' perception of the success of surgery (where a shorter scar is better) [21, 22]. Patient satisfaction for radiological deformity correction and small incision scar could be confirmed with SRS-22 questionnaires. Postoperative total SRS-22 scores were statistically significant than preoperative score and showed significantly higher scores in all aspects of function, pain, self-image and mental health section. In the evaluation of patient's satisfaction at surgery, the average score was 4.1, which was high.

These studies have some limitations: Firstly, the authors did not compare the degree of correction of scoliosis deformation according to the flexibility of curve and type of curve. Flexibility of curve in scoliosis patient will have a significant impact on spinal correction and fusion extent. However, the reported method of measuring the flexibility using bending radiography is known to be affected by the patient's posture and measurement method, curve position and amount, etc., so there are many problems in reproducibility [23, 24]. Secondly, in this study, only rod rotation and second-hand correction of screw head to correct scoliosis of patients were performed as correction maneuver. Derotation maneuver after pedicle screwing can cause hypokyphosis of the thoracic vertebrae in Lenke type 1, so additional spinal osteotomy can be necessary in some cases [25]. In this MISS surgery technique, the skin incision is limited and additional osteotomy cannot be performed, which may be a problem for hypokyphosis of the thoracic spine. However, our results suggest that the average posterior angle of the thoracic spine is 31 degrees, which is higher than 23 degrees as critical kyphosis for global sagittal balance [25]. Lastly, for giving more clear suggestion MISS technique as one of the surgical options for scoliosis to surgeon, better designed studies will be necessary, because this study has some limitations like retrospective study design, low level of study design (no control group treated with a routine posterior approach) and only short-term follow-up (no objective evaluation of the fusion mass).

Conclusion

Our technique had fewer complications than the previously described minimally invasive techniques for AIS correction by other authors. Considering all the positives described, along with good cosmetic and functional outcome, such as minimal back muscle injury, less damaging soft tissue exposure with low EBL and a reduced LOS, the application of this surgical technique is meaningful. In conclusion, MISS could be used for patients with AIS which seems to provide adequate correction in both planes and acceptable rate of perioperative complications, and could become a valid alternative to posterior open approach in routine practice.

Compliance with ethical standards

Conflict of interest No funds were received in support of this work. No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this manuscript. The manuscript submitted does not contain information about medical device(s)/drug(s).

Ethical approval This study received the approval of the institutional review board of Korea University Guro Hospital.

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Affiliations

Jae Hyuk Yang[1] · Dong-Gune Chang[2] · Seung Woo Suh[1] · Neelesh Damani[1] · Hoon-Nyun Lee[1] · Jungwook Lim[1] · Frederick Mun[3]

✉ Dong-Gune Chang
spine@paik.ac.kr

✉ Seung Woo Suh
spine@korea.ac.kr

[1] Department of Orthopedics, Spine and Scoliosis Research Institute, Korea University Medical Centre, Guro Hospital, 148 Gurodong-ro, Guro-dong, Guro-gu, Seoul 152-703, Republic of Korea

[2] Department of Orthopaedic Surgery, Sanggye Paik Hospital, College of Medicine, Inje University, 1342, Dongil-Ro, Nowon-Gu, Seoul 01757, Republic of Korea

[3] Penn State College of Medicine, Hershey, PA, USA