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Original Article

Advancements in minimally invasive surgery for adolescent idiopathic scoliosis: A case series and literature review

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Abstract

Objectives: Minimally invasive surgery (MIS) has emerged as a promising alternative to conventional open techniques in the management of adolescent idiopathic scoliosis (AIS). **Materials and Methods:** This study presents a case series of six patients who underwent MIS for AIS at a spine center, employing a synergistic blend of intraoperative fluoroscopy, cone-beam computed tomography scans, and three-dimensional navigation technology. The surgical procedures were meticulously guided, with a focus on ensuring safety and precision in posterior pedicle fixation. **Results:** Our findings demonstrate substantial correction of spinal curvature postoperatively, with a mean Cobb's angle reduction of 51.75%. In addition, MIS facilitated a mean estimated blood loss of 241.67 ml and a mean surgical duration of 391.33 min. **Conclusion:** Comparison with conventional open techniques reveals comparable or superior outcomes in terms of correction rates, patient recovery, and opioid usage. This study underscores the potential of MIS in achieving favorable clinical outcomes while minimizing surgical impact and advancing the treatment landscape for AIS.

Keywords: *Adolescent idiopathic scoliosis, Minimally invasive spine surgery, Navigation surgery*

Introduction

Adolescent idiopathic scoliosis (AIS) is a common type of spinal deformity that affects a significant number of adolescents. Historically, conventional open scoliosis surgery was the primary method used to treat this condition. However, this surgical approach is associated with several drawbacks, including significant blood loss, postoperative pain, muscle damage, high infection rates, and large incisions. Minimally invasive surgery (MIS) has emerged as a promising alternative to conventional open scoliosis surgery. In recent years, this surgical approach has gained popularity in various fields of spinal surgery, including the treatment of disc herniation, stenosis, and spinal deformities [1]. Studies have shown that MIS is not only equivalent to but in some cases even superior to conventional open techniques when it comes to spinal deformity correction. These studies have demonstrated that MIS results in better patient outcomes, such as reduced blood loss, postoperative pain, and muscle damage. In addition, MIS is associated with smaller incisions, which translates to a lower risk of infection and improved cosmetic outcomes [2].

Materials and Methods

The current investigation scrutinized the encounters of six patients subjected to minimally invasive scoliosis surgery at the spine center under the authors' purview. Our research was exempt from the Institutional Review Board (IRB) because it involves retrospective chart reviews. Retrospective chart reviews involve the examination of existing data collected for clinical or administrative purposes, without any intervention or interaction with individuals. Since our study does not involve direct interaction with human subjects, it does not pose any risks to their privacy or well-being. In addition, because the data being analyzed are already collected and stored in a de-identified manner, there are no concerns regarding confidentiality or informed consent. Therefore, IRB approval is not necessary for our research.

The surgical intervention was meticulously orchestrated, guided by a harmonious amalgamation of intraoperative fluoroscopy, cone-beam computed tomography (CT) scans, and state-of-the-art three-dimensional (3D) navigation technology. To ensure the safety and precision of posterior pedicle fixation, the authors instituted a series of precautionary measures,

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which included a cap of eight intraoperative CT scans and a conclusive scan performed before wound closure. Moreover, the authors employed derotation techniques subsequent to the insertion of rods to rectify any deformities encountered.

Surgical techniques

Former technique

Sarwahi *et al*. [3] introduced the pioneering MIS technique for AIS patients. This approach entailed three midline skin incisions, each measuring 2 inches, guided by intraoperative fluoroscopy to target the approach to 11–13 vertebrae. In the thoracic spine, the tip of the upper vertebra's spinous process served as a reference point for locating the facet joints, given its alignment with the distal facet joint level. In the lumbar spine, stab incisions on the fascia were made along the muscle fibers, directly over the palpable facet joints. Facetectomy was performed to facilitate the identification of pedicle screw entry points. Following the preparation of the fusion bed, a sponge saturated with bone morphogenetic protein or alternative bone substitute material, along with local autograft, was applied to promote fusion before pedicle screw insertion. Skin incisions were separately made for levels without instrumentation. To prevent inadvertent penetration into the spinal canal, rods were inserted in a cranial-to-caudal direction, leveraging the overlapping laminae of the thoracic spine as a safeguard. In addition, a variety of reduction maneuvers, including rod derotation, translation, direct vertebral rotation, additional compression, distraction, and *in situ* rod bending, were executed as necessary.

Our technique

The procedures were conducted within a hybrid operating room, with patients positioned in the standard prone position [Figure 1]. Fusion levels were determined utilizing standing whole-spine radiographs based on either Lenke's or King's classification. Subsequently, cone-beam CT scans were obtained following the placement of a reference array on a spinal process. A navigation system, aided by the stationary array, facilitated the determination of incision positioning, entry points, trajectory direction, and screw length.

The surgical approach employed either a juxtapedicular or transpedicular trajectory, necessitating a series of 0.5–1.5-inch incisions to access multiple segments of vertebrae. Guidewires were initially inserted, followed by cone-beam CT scans to validate proper positioning. Cannulated screws were subsequently inserted through the guidewires to ensure the correct trajectory. Rods were contoured to the desired curvature using preoperative radiographs and intraoperative images, then inserted from a cranial to caudal direction.

Figure 1: All surgeries were conducted in a hybrid operating room

Importantly, the authors refrained from conducting any muscular incisions, such as Wiltse's approach, bony cutting, or facetectomy. Upon completion of the procedure, the entire assembly was meticulously examined using cone-beam CT to verify proper positioning.

Results

The case series comprised six patients with an average age of 21.5 years, with 66.67% being female. The majority of patients (66.67%) were classified as Lenke type 1, while the remaining 33.33% were categorized as type 5. The mean preoperative Cobb's angle was 58.62°, with the curve flexibility (of the major curve) averaging 22.11%. Following surgery, the mean postoperative Cobb's angle was 28.13°, indicating a correction rate of 51.75% (calculated as the difference between pre- and postoperative Cobb's angle of 30.49°). The mean duration of surgery was 391.33 min, accompanied by a mean estimated blood loss of 241.67 mL [Table 1].

These findings underscore the efficacy of minimally invasive scoliosis surgery utilizing 3D navigation within a hybrid operating room, demonstrating substantial correction of spinal curvature while concurrently minimizing blood loss and surgical duration. Such outcomes are in line with the overarching objectives of MIS, which prioritize achieving favorable clinical results while mitigating the surgical impact on patients.

Case report

A 24-year-old female patient diagnosed with AIS underwent MIS spine surgery. The patient's history indicates a diagnosis

Table 1: Baseline characteristics and outcomes of the patients who underwent minimally invasive scoliosis surgery using three-dimensional navigator with hybrid odds ratio

	Value
Total number of patients	6
Age	21.5±3.51
Sex (*n*): Men/women	2/4
BMI (kg/m^2)	18.66±1.63
Lenke classification (*n*): 1/2/3/4/5/6	4/0/0/0/2/0
King classification (*n*): 1/2/3/4/5	2/1/1/2/0
Duration of surgery (min)	391.33±90.49
Estimated blood loss (mL)	241.67±131.97
Number of levels operated (*n*)	8.67±1.03
Radiological parameters	
Preoperative Cobb angle (°)	58.62±15.30
Cobb angle in bending films (°)*	43.68±13.16
Flexibility (%)*	22.11±17.35
Postoperative Cobb angle (±)	28.13±10.04
Δ Cobb angle (°)	30.49±9.78
Correction rate (%)	51.75±11.23

*Only three patients have preoperative bending films. BMI: Body mass index

of AIS since the age of 12, with chronic back pain persisting over several years. Recent exacerbation of symptoms included progressive left waist soreness, intermittent difficulty breathing, and noticeable asymmetry of the shoulders and rib cage. Clinical examination revealed evident shoulder asymmetry, positive pelvic obliquity, and a positive Adams forward bend test, with no observed neurological deficits. Muscle strength was full in all extremities, with intact sensation and normal reflexes.

The radiographic assessment demonstrated an 85° main thoracic curve with King type V classification, accompanied by thoracic hyperkyphosis [Figure 2]. Progressive scoliotic curvature was noted from previous imaging, increasing from 51° at age 12 to 60° at age 18 and 85° at present. Preoperative planning based on Lenke's or King's classification, utilizing whole spine standing plain films, guided fusion level determination [Figure 3]. Skipped levels without instrumentation were identified, with the notable observation of thin pedicles and the absence of pedicles in some levels, necessitating the use of a navigation system. T6 was selected as the reference point, and transpedicular screws were inserted in 11 different levels along with rods [Figures 4 and 5].

Postoperatively, the patient demonstrated satisfactory recovery, achieving ambulation without assistance on postoperative day 1, and discharge within 3 days of surgery [Figures 6-8].

Figure 2: A 24-year-old female adolescent idiopathic scoliosis (AIS) patient who underwent minimally invasive surgery. The patient was diagnosed of AIS since she was 12 years old

Figure 4: Reference points were usually set at T6 or T10 level. We would adjust the direction of reference according to the levels

Discussion

AIS represents a notable spinal condition prevalent among teenagers, characterized by a coronal plane deformity primarily affecting adolescent girls between the ages of 10 and 18. Diagnosis typically relies on full-length standing posterior–anterior and lateral spine radiographs. Treatment strategies encompass observation, bracing, or surgical intervention, contingent upon factors such as skeletal maturity, deformity severity, and progression [4].

The prevalence of AIS within the affected population ranges from 3% for curves between 10° and 20° to 0.3% for curves exceeding 30° [4]. Notably, there exists a distinct gender disparity, with a female-to-male ratio of 1:1 in smaller curve groups, escalating significantly to 10:1 in cases exceeding 30° [5]. Right thoracic curvature predominates, while left thoracic curves, although rare, may prompt further investigation, including magnetic resonance imaging, to rule out underlying pathologies such as cysts or syrinx [6].

Historically, surgical intervention has emerged as the cornerstone of management for progressive adolescent idiopathic spinal deformities since the early 1960s [3]. Conventional approaches, notably posterior spinal fusion (PSF), have conventionally entailed extensive tissue dissection through large incisions. However, contemporary

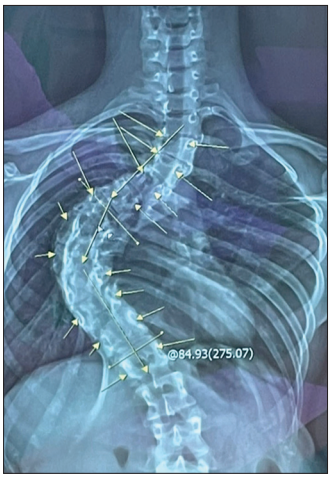

Figure 3: Preoperative planning on fusion levels based on Lenke's or King's classification using whole-spine standing plain film. Arrows indicate the pedicles we plan to insert screws

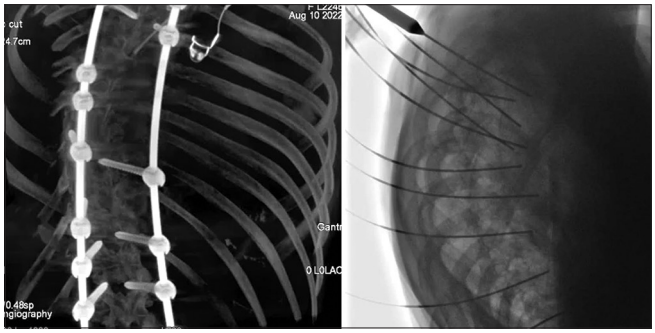

Figure 5: Guidewires were inserted. We would perform several cone-beam computed tomography scans to confirm the proper positioning of guidewires and screws

Figure 6: The postoperative whole spine lateral plain radiographs revealed satisfactory result

trends indicate a shift toward MIS, particularly in the management of degenerative spine disorders such as disc herniation, stenosis, and spinal deformity.

While MIS techniques offer notable advantages in terms of reduced blood loss [7], shorter hospital stays, and minimized scarring, their implementation is coupled with technical intricacies and potential challenges, including prolonged operation times and increased radiation exposure for both surgeons and patients [8,9].

The prevailing consensus in literature suggests that executing surgical procedures such as segmental spinal instrumentation and PSF utilizing pedicle screws through a posterior MIS approach yields coronal deformity corrections comparable to those achieved through a standard posterior midline approach [10]. Substantial support for this assertion is derived from the comprehensive meta-analysis conducted by Yang *et al*. [11] in 2022. This meta-analysis synthesized findings from five comparative series encompassing 713 patients, culminating in a weighted mean difference of −0.01 (95% CI −0.03–0.01; $P = 0.518$) for this parameter. Noteworthy is the variability in follow-up durations across these series, spanning from 2 to 9 years, underscoring the robustness and temporal breadth of the analysis. However, some studies suggested different view from this. Miyanji and Desai [12] conducted a study in 2015 that encompassed 46 cases of AIS, with a follow-up duration of 2 years. The study compared outcomes between patients undergoing MIS and those treated through the open posterior midline approach. Their findings revealed a coronal curve correction rate of 58% in the MIS group and 68% in the open posterior midline approach group ($P < 0.001$). The authors

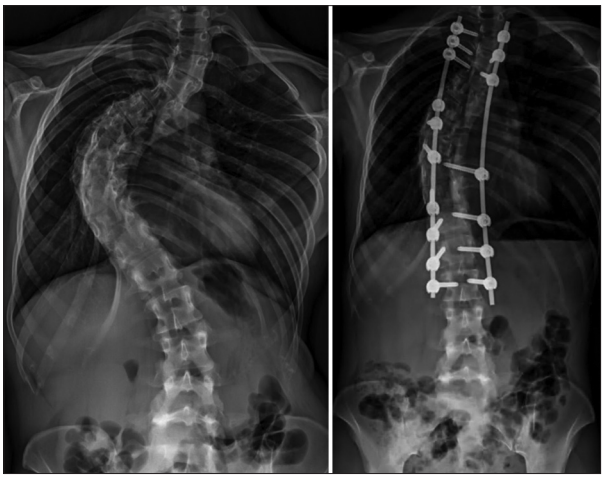

Figure 7: The postoperative whole spine anteroposterior radiographs also revealed satisfactory result

posited that this discrepancy in correction rates might be attributable to the learning curve associated with the adoption of the new technique.

In the management of AIS, spine surgeons historically emphasized the correction of coronal deformities as a primary objective. However, over the past two decades, there has been a burgeoning body of evidence highlighting the significance of physiological sagittal balance in maintaining an erect posture devoid of pain. The initial two comparative series, as documented by Miyanji and Desai [12] and Sarwahi *et al*. [8], did not observe significant disparities in sagittal deformity correction between their cohorts treated with MIS and those managed through the open posterior midline approach. Remarkably, the five studies incorporated into Yang *et al.*'s [11] meta-analysis, which specifically assessed sagittal correction, unveiled a notable distinction in the correction rate concerning thoracic kyphosis. At their latest follow-up, which ranged from 2 to 9 years, the combined MIS group and the combined open posterior midline approach group exhibited mean thoracic kyphosis values of 25.80° and 22.71°, respectively. Notably, this disparity appeared particularly pronounced among patients with more than 10 levels fused. In a comparative analysis involving 485 cases of AIS with a minimum follow-up duration of 2 years (ranging from 2 to 5 years), Sarwahi *et al*. [8] once again observed a significantly greater correction of kyphosis in MIS-treated patients compared to those managed through the open posterior midline approach (kyphosis increase of 17.9% vs. −5.3%; $P = 0.007$).

MIS scoliosis surgery, characterized by smaller incisions and diminished tissue disruption, leverages advanced imaging modalities such as intraoperative fluoroscopy, CT scans, and 3D navigation to enhance visualization and surgical precision [13].

Urbanski *et al*. [14] observed a noteworthy discrepancy in the duration of opioid usage, with a reduced requirement in the MIS group. Conversely, Sarwahi *et al*. [8] reported no discernible distinction in opioid needs between the two cohorts, whereas our analysis favored the MIS group in this

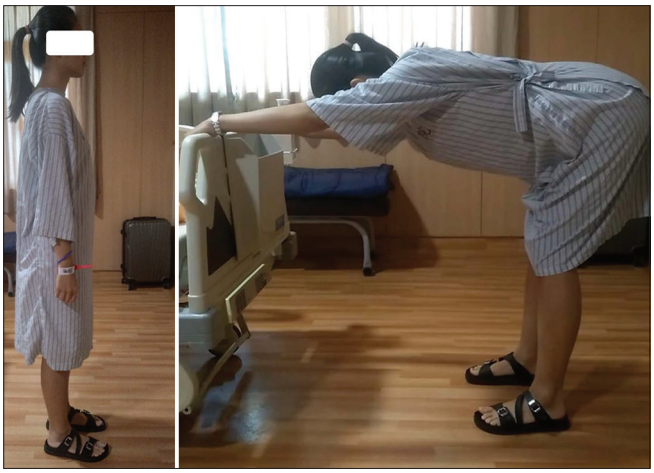

Figure 8: On the first postoperative day, the patient demonstrated a favorable recovery, experiencing only mild wound pain. She was able to ambulate freely with minimal restriction in the range of motion of her back. Additionally, she could stand upright and bend forward without discomfort

regard. In addition, Gómez *et al*. [15] and Sarwahi *et al*. [8] documented shorter hospital stays in the open surgery group, contrasting with findings from Miyanji and Desai [12] and Urbanski *et al.* [14], which indicated a briefer duration of stay in the MIS group.

Despite documented satisfactory radiological outcomes, including improvements in parameters such as the sagittal vertical axis, clavicle angle, and correction rate of the Cobb angle, comparative studies indicate a lower Cobb angle correction rate in MIS when juxtaposed with conventional open spine surgery (COS). This underscores the ongoing debate regarding the efficacy and nuances of MIS techniques in the context of AIS management.

In a previous study conducted by Si *et al*. [16], the mean operative time for COS in treating AIS was reported as 275 min. The mean blood loss during these procedures was 808 ml, accompanied by a 58.3% blood transfusion rate. Despite the relatively shorter operative time associated with conventional techniques, the disparity between the two methods is not considerable. Moreover, with the anticipated increase in surgeon proficiency with MIS techniques, a further reduction in operative time is foreseeable. Despite the lower Cobb angle correction rate observed with MIS, a significant improvement in patient condition postsurgery was still noted. Notably, there was no discernible difference in patient satisfaction levels between the COS and MIS cohorts.

However, it is important to acknowledge several limitations within this study. First, the sample size of the patient group was relatively small. Given that MIS techniques in AIS management are still relatively novel, while there have been more cases operated on after the study period, the follow-up duration remains insufficient to amalgamate their data effectively. Second, the focus of this article was primarily on detailing our technical expertise and general concepts of MIS, resulting in some important aspects, such as opiate use and hospital stay, not being addressed. Further systematic studies, accounting for the accumulation of experience, are warranted to comprehensively analyze MIS outcomes in AIS management. Third, within our spine center, there was a lack of experience in treating AIS patients using COS. Consequently, we were unable to furnish a direct comparison of surgical outcomes between the COS and MIS groups. Finally, notwithstanding the myriad advantages associated with MIS techniques, it is imperative to acknowledge the substantial costs associated with their utilization, particularly those related to the use of a hybrid operative room equipped with cone-beam CT setting, intraoperative navigation system, and a well-trained radiological technician. Therefore, engaging in shared decision-making with patients and their families regarding the costs of MIS and its potential benefits remains paramount.

Conclusion

AIS represents a significant spinal deformity affecting adolescents, with conventional open scoliosis surgery historically serving as the primary treatment modality. However, the advent of MIS has offered a promising alternative, addressing the limitations associated with conventional approaches while demonstrating comparable, if not superior, efficacy in spinal deformity correction. The findings from our investigation, encompassing the experiences of six patients undergoing MIS at our spine center, underscore the potential of MIS techniques in achieving substantial correction of spinal curvature while minimizing blood loss and surgical duration. Furthermore, advancements in surgical techniques, including the utilization of 3D navigation technology and intraoperative imaging modalities, have contributed to enhanced surgical precision and improved patient outcomes. However, it is essential to acknowledge the ongoing debate surrounding the efficacy and nuances of MIS techniques compared to COS, particularly regarding the correction rates of Cobb angle and sagittal deformities. Further research and comparative studies are warranted to elucidate the long-term outcomes and optimal patient selection criteria for MIS in the management of AIS. Despite these ongoing discussions, our findings support the continued exploration and refinement of MIS techniques, offering a promising avenue for improving outcomes, and minimizing the surgical burden on patients with AIS.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient has given her consent for her images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Data availability statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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