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Outcome and complication following single-staged posterior minimally invasive surgery in adult spinal deformity

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Abstract

Background The aging population is experiencing a rising incidence of musculoskeletal problems and degenerative spinal deformities. Adult spinal deformity (ASD) presents challenges, with associated risks in open surgery. Minimally invasive surgery (MIS) is becoming increasingly popular due to its positive outcomes and potential benefits. This study aims to explore the clinical outcome and complications of posterior approach MIS in patients with ASD.

Methods We conducted a retrospective analysis of patients with adult spinal deformity who underwent posterior minimally invasive surgery. 46 patients meeting the criteria were identified between June 2017 and September 2023. Comprehensive data were collected, including demographic details, surgical information, full-length radiographic measurements, and visual analog scale (VAS) pain scores. These data were obtained preoperatively, postoperatively, and at the final follow-up.

Results A total of 46 patients were included in the study, with a mean age of 68.58 years and a minimum follow-up period of 6 months. The mean operative time was 327 min, and the mean blood loss was 307 ml. Preoperative radiographic measurements were as follows: Coronal Cobb angle, 18.60 ± 11.35°; lumbar lordosis (LL), 22.79 ± 21.87°; pelvic incidence (PI), 53.05 ± 14.13°; PI-LL mismatch, 30.26 ± 23.48°; pelvic tilt (PT), 32.53 ± 10.38°; T1 pelvic angle (TPA), 31.91 ± 12.39°; and sagittal vertical axis (SVA), 77.77 ± 60.47 mm. At the final follow-up, coronal Cobb angle was 10.08 ± 6.47° ($P < 0.0001$), LL was 26.16 ± 16.92° ($P = 0.4293$), PI was 54.17 ± 12.13° ($P = 0.6965$), PI-LL mismatch was 28.00 ± 17.03° ($P = 0.6144$), PT was 27.74 ± 10.24° ($P = 0.0345$), TPA was 25.10 ± 10.95 ($P = 0.0090$) and SVA was 47.91 ± 46.94 mm ($P = 0.0129$). Functional outcomes improved as well, with the mean Oswestry Disability Index (ODI) decreasing from 34.9 to 23.6 and the Visual Analog Scale (VAS) score for back pain reducing from 8.4 to 3.4. Surgical complications occurred in 39.1% of cases, with a low reoperation rate of 4.3%.

Conclusion Single-staged posterior MIS effectively corrects global alignment in adult spinal deformities, satisfying patient demand and yielding positive clinical outcome with low re-operation rate.

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Keywords Adult spinal deformity, ASD, Minimal invasive spinal surgery, MISS, Minimal invasive surgery, MIS, Posterior minimal invasive spinal surgery

Introduction

People worldwide are living longer lives. In Taiwan, the proportion of population aged over 65 in 2023 was 18.4%, and according to projections, the proportion of the population aged 65 and older is expected to reach 34.3% by the year 2045, reflecting a trend of an aging demographic [1]. With the aging of the population, musculoskeletal diseases and degenerative spinal deformities are on the rise. [2–3] Adult spinal deformity (ASD) is a complex spinal disorder caused by various factors such as uneven degeneration of spinal components, trauma, infection, rheumatoid arthritis, and medical procedures. This can result in deformities in the coronal and/or sagittal planes, such as an elevated sagittal vertical axis, excessive pelvic tilt, or an increased coronal Cobb angle. [4–5] Adult spinal deformity (ASD) is a prevalent and disabling condition that affects many older adults. It is estimated to affect as much as 32% of the general population and can be even more prevalent, reaching up to 68%, among older individuals [6]. These conditions involve painful abnormalities in muscles, tendons, joints, and nerves, affecting the curvature of the spine. Symptoms may include tingling, stiffness, or restricted movement in the upper back and waist, higher risk of vertebral fractures and falls with back or leg pain [7–9].

While open surgery is a successful approach to treating ASD, it frequently comes with a notable risk of medical complications and significant blood loss among older patients [10]. Minimally invasive surgery (MIS) in spinal deformity has gained widespread adoption in recent time, and numerous studies have reported positive clinical and radiological outcomes associated with its use [11–13]. It is believed to decrease damage to tissues, minimize blood loss, reduce reoperation rate, lower morbidity, decrease infections at the surgical site, expedite patient recovery, shorten hospital stays, reduce costs, and alleviate postoperative pain and complications [14–17]. Anand et al. shared their experiences from a single center regarding the treatment of ASD using minimally invasive surgery (MIS) over a 10-year follow-up period. Their findings offer valuable insights into long-term outcomes and demonstrate the effectiveness of the treatment protocol. Additionally, these results underscore the accumulated expertise and advancements in the learning curve over the decade, which have contributed to optimizing surgical outcomes [18].

Due to the growing demand for ASD surgery in older individuals, it is crucial to conduct regular follow-up in clinical research. It is necessary to identify effective strategies of optimal surgery for good outcome achievement and complication prevention. The study objective is to offer a thorough outcomes and complications evaluation following single stage posterior minimally invasive surgery for adult spinal deformity.

Methods

Patients

We conducted a retrospective review of patients with adult spinal deformities who underwent single stage posterior minimally invasive surgery between June 2017 and September 2023. All procedures were performed by the same surgeon. A total of 46 patients met the final criteria. Demographic data that were collected included patient age, gender, body mass index (BMI), bone mineral density (BMD), history of previous spine surgeries. Surgical characteristics such as the indication for surgery, surgical approaches, levels of spinal fusion, operative time, length of hospital stay, estimated blood loss and uses of intraoperative blood salvage were recorded.

Inclusion and exclusion criteria

The criteria for inclusion in the study are: (1) Patients over 50-year-old who clinically diagnosed with adult spinal deformity. (2) Radiographic assessment showing a Sagittal Vertical Axis (SVA) greater than 50 mm and a Pelvic Incidence-Lumbar Lordosis (PI-LL) mismatch greater than 10 degrees [19]. (3) Presence of noticeable symptoms and receipt of one stage posterior MIS. (4) Follow-up duration at least 6 months after the surgery. The exclusion criteria are: (1) Insufficient information, including demographics, surgical data, and radiographic data. (2) Patients with deformities due to neuromuscular issues, tumors, inflammation, or infections.

Surgical outcome parameter

Full-length free-standing radiographic parameters, including lumbar lordosis (LL), pelvic tilt (PT), pelvic incidence (PI), sagittal vertical axis (SVA), pelvic incidence minus lumbar lordosis (PI-LL), and T1 pelvic angle (TPA) were measured preoperatively, postoperatively, and at the latest follow-up. Patient-reported outcome measures (PROMs) included the Oswestry Disability Index (ODI) and Visual Analogue Scale (VAS) score for leg and back pain.

SRS-Schwab system & etiology classification

The most world-wild used radiography criteria for diagnosing spinal deformity in adults is the Scoliosis Research Society (SRS)-Schwab Classification [20]. The SRS-Schwab system classifies adult spinal deformity by coronal curve types (T, L, D, N) based on curve location and Cobb's angle and sagittal modifiers (PI–LL mismatch, PT, SVA) indicating alignment severity. Etiologies include de novo scoliosis, progressive adolescent idiopathic scoliosis in adulthood, hyperkyphosis, iatrogenic sagittal deformity, focal deformity due to multiple degenerative disc disease with global deformity, and post-traumatic spinal deformity [21].

Surgical technique

After induction of general anesthesia, the patient was positioned in a prone posture, and posture reduction was applied to partially correct hypo-lordosis. For patients with significant scoliosis, lateral compression pads were utilized. These pads were mounted on the side rails of the operating table, enabling a strong compressive force at the apex of the scoliotic curve, counteracted by cranial and/or caudal forces on the opposite side of the trunk. This technique achieved partial correction of the scoliotic curvature while stabilizing the patient securely on the surgical table. (Fig. 1)

After proper padding and positioning of the patient on the surgical table, the O-arm imaging system was activated to assess its movement path, ensuring there were no collisions with table accessories during navigation. The surgical field was then draped in a sterile manner, and the spinal processes were marked to evaluate the severity of the deformity. Upon completion of navigation scanning, the surgeon will identify and delineate the incision sites according to the most superior and inferior pedicle screw locations. Utilizing the Wiltse approach, the para-spinal muscles were carefully dissected to reveal the surgical field. Subsequently, a drill guide was utilized to verify the trajectory of the pedicle screws (see Fig. 2). For patients undergoing PPS correction, the connect rod was pre-contoured to facilitate the anticipated harmonious alignment necessary for effective deformity correction. Various techniques, including de-rotation, in-situ bending, and cantilever manipulation, were employed, tailored to the patient's bone quality and the pull-out strength of the pedicle screws. For patients requiring a combination of PPS and MIS-TLIF, pedicle screws were inserted immediately following the drilling and tapering process on the non-decompression side. Conversely, on the decompression side, the insertion of screws was postponed to prevent interference with decompression and interbody fusion procedures. A bone scalpel was employed for osteotomy and nerve decompression, which facilitated a more efficient surgical process and reduced blood loss. Under navigational guidance, a cage was inserted into the concave side and positioned within the anterior interbody space to address scoliosis and hypolordosis. In cases involving osteotomy, all pedicle screws were implanted prior to the osteotomy to ensure navigational accuracy. The angle and direction of the osteotomy were meticulously planned with navigational assistance, while preserving the spinal process and interspinous ligament to maintain structural integrity. Despite the minimal damage to the posterior ligamentous complex and the well-maintained posterior spinal stability, we still employed salvage rods on either side to prevent potentially hazardous movements during the mini-PSO procedure. Following the completion of mini-Ponte osteotomy or mini-pedicle subtraction osteotomy (PSO), a contoured rod was affixed to the pedicle screws. The correction of predicted alignment was achieved through a combination of posture reduction and the forces exerted by the spinal implants.

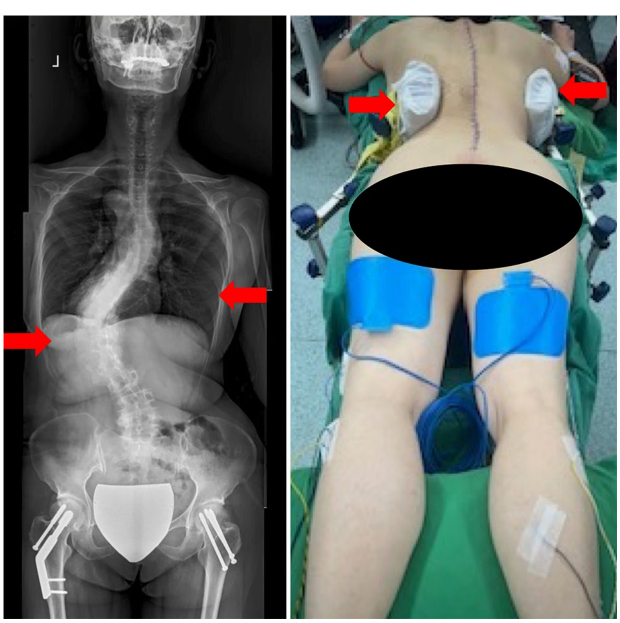

Fig. 1 Compression pads exert a strong force at the apex of the scoliotic curve, countered by opposing forces to achieve partial correction

In the Ponte osteotomy or MIS-TLIF group, we performed TLIF exclusive to achieve solid anterior fusion for our patients. In the percutaneous pedicle screw fixation group, previous literature has reported numerous cases of spontaneous facet arthrodesis following long-term follow-up observed in long-segment spinal pedicle screw fixation. In our cases, the minimally invasive procedure, combined with the preservation of midline structures, prolonged protective Boston bracing for 4 to 6 months, and administration of anti-osteoporosis medication, may enhance spinal stability and promote facet arthrodesis.

The surgical methods were categorized into four types based on the patient's etiology and Schwab classification. All surgical patients undergo full-spine X-rays prior to the operation and also receive a pillow test (Fulcrum test). If the pillow test indicates that the patient's kyphoscoliosis is flexible, the patient can be successfully treated with PPS alone. For patients with flexible kyphoscoliosis

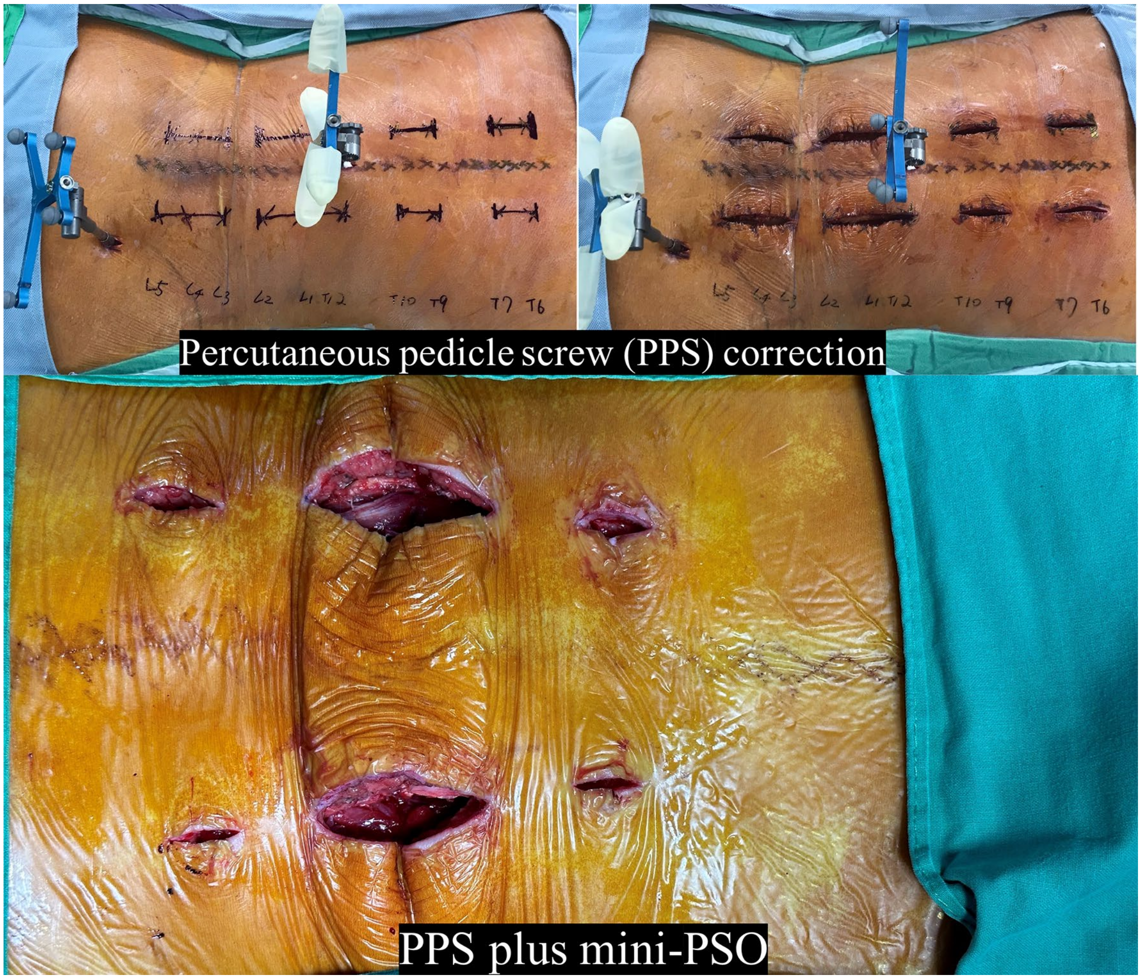

Fig. 2 The incision was planned according to the most superior and inferior pedicle screw locations and was deepened utilizing the Wiltse approach

and neurological compression symptoms, both PPS and MIS-TLIF will be chosen to correct the deformity and relieve the nerve compression. For patients who cannot achieve satisfactory correction angles in the pillow test or side-bending view, we prefer Ponte osteotomy with TLIF to achieve adequate decompression and correction. For those patients with rigid kyphoscoliosis requiring correction of more than 25 degrees, we will opt for mini-PSO to achieve the necessary correction.

1. Percutaneous pedicle screw (PPS) implantation correction is indicated for patients primarily with sagittal imbalance due to kyphotic deformity and mild scoliosis (Schwab Type N). (Fig. 3)
2. PPS combined with minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) is performed for patients with nerve compression syndrome, mild lumbar scoliosis, hypo-lordosis, or mild kyphosis (Schwab Type L or N). (Fig. 4)
3. PPS and MIS-TLIF combined with mini-Ponte osteotomy is used for patients with nerve compression syndrome associated with greater lumbar scoliosis, hypolordosis, or kyphosis (Schwab Type L or N). (Fig. 5)
4. PPS combined with mini-pedicle subtraction osteotomy (PSO) is applied for patients with lumbar kyphosis and scoliosis, presenting with a high PI-LL mismatch and increased SVA (Schwab Type L or N). (Fig. 6)

Complications

Our analysis of medical and surgical complications adhered to the criteria outlined by the Klineberg et al., ISSG-AO ASD spine complications classification system [22]. This classification system encompasses both medical and surgical complications, providing a comprehensive framework for the assessment of complications associated with spinal interventions in individuals with adult spinal deformity.

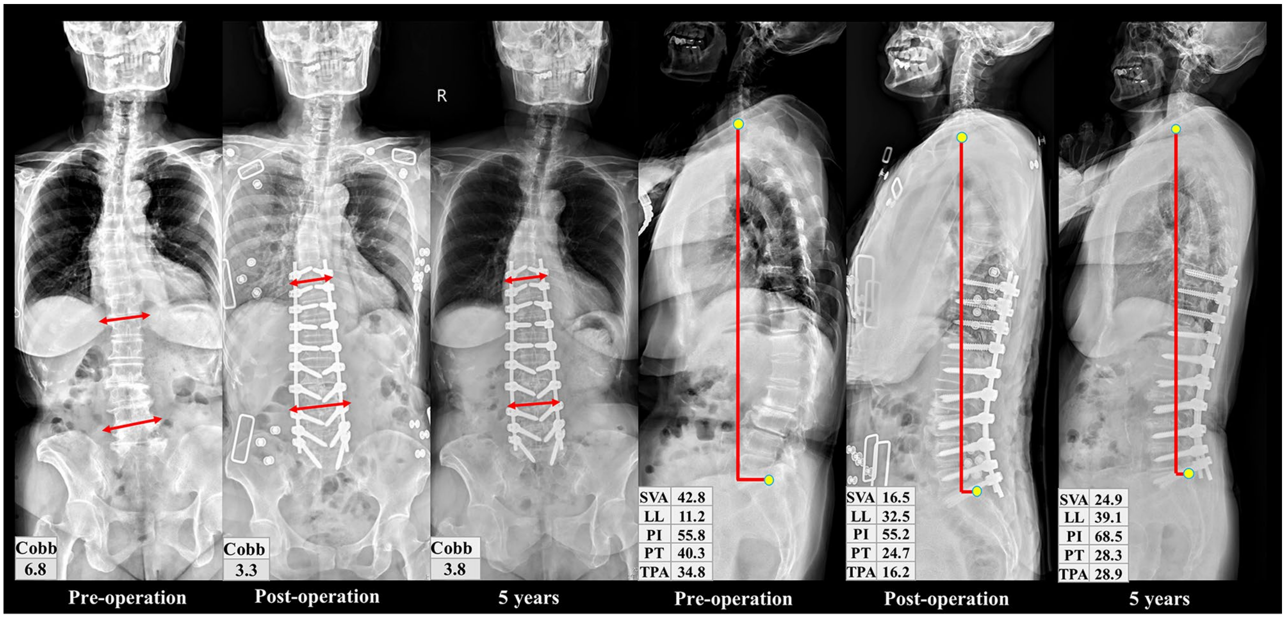

Fig. 3 A 72-year-old female with ASD from multiple degenerative disc diseases underwent PPS correction. X-rays showed satisfactory sagittal plane correction, maintained at the 5-year follow-up

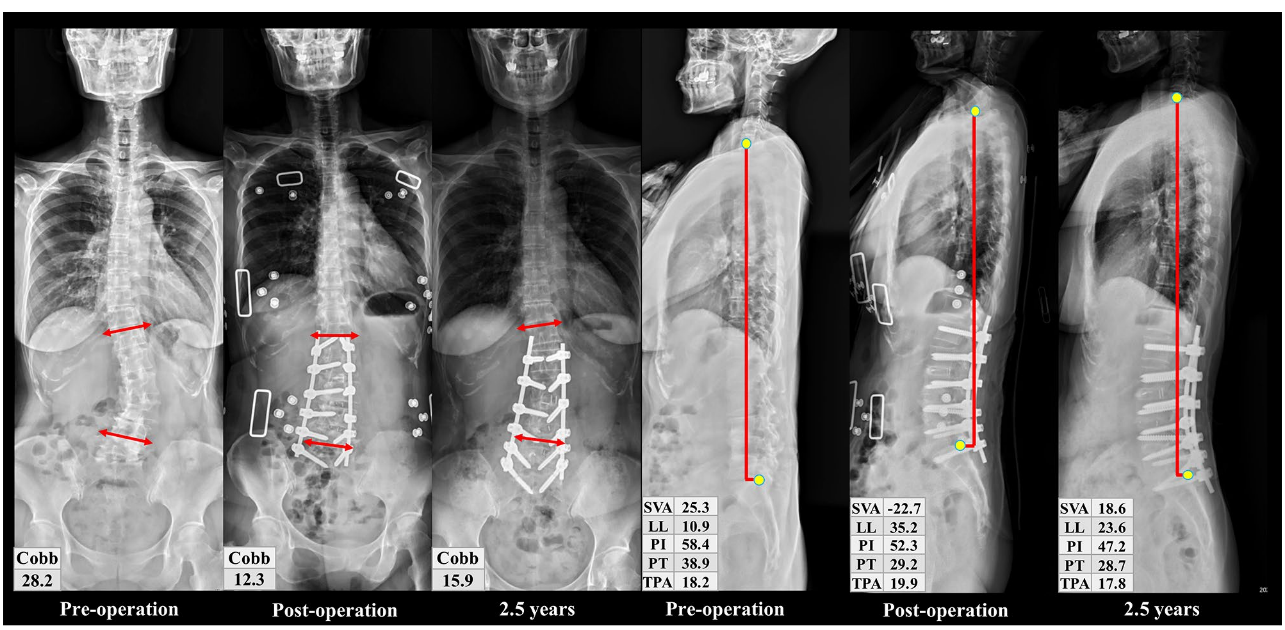

Fig. 4 A 62-year-old female with de novo type ASD underwent PPS and MIS-TLIF surgery, showing satisfactory correction and stable alignment at the 2.5-year follow-up

Statistical analysis

Data for continuous variables were presented as mean and standard deviation, while data for categorical variables were presented as count numbers (n) and percentages (%). Analysis was conducted using a paired sample T-test to investigate any potential significant differences between perioperative, postoperative and last follow-up radiographic parameters and patient-reported outcome. All reported P-values were one-tailed, with a significance level set at 0.05. $P<0.05$ was regarded as statistically significant.

Results

Perioperative parameters were described in Table 1. A total of 46 patients with adult spinal deformity who met the inclusion criteria were included in the study. These patients underwent posterior minimally invasive surgery from June 2017 to September 2023. The average age

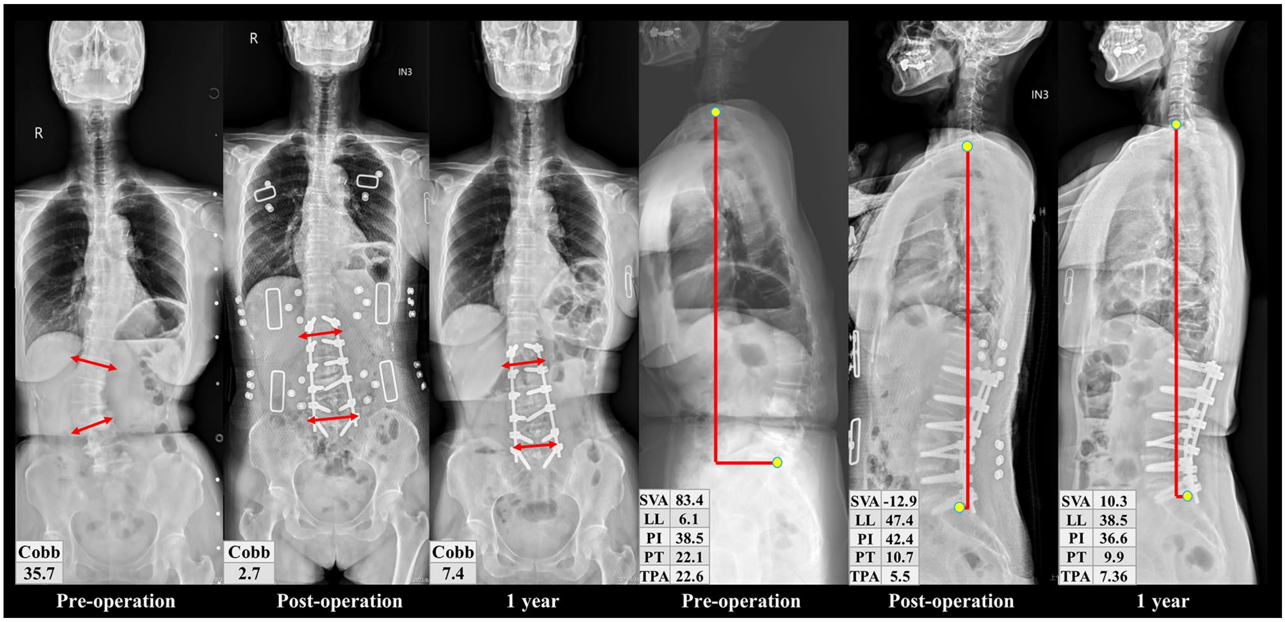

Fig. 5 A 67-year-old female with kyphoscoliosis and sagittal imbalance underwent MIS-TLIF and mini-Ponte osteotomy, achieving satisfactory correction after surgery and at the one-year follow-up

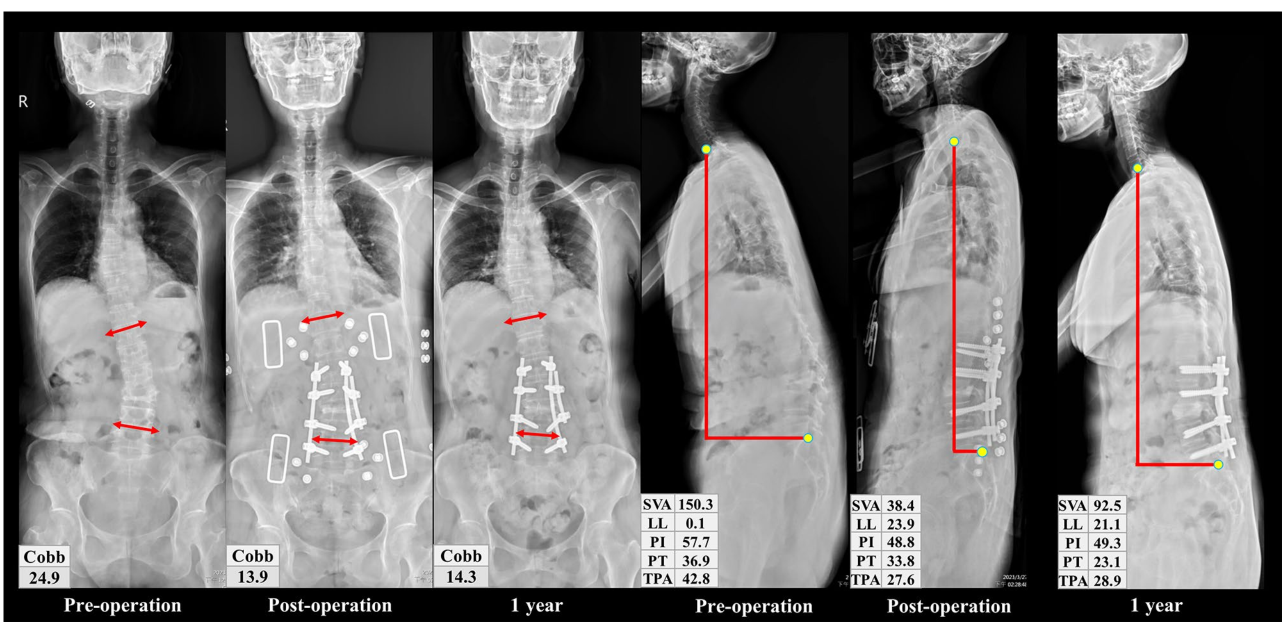

Fig. 6 A 61-year-old female with post-traumatic kyphoscoliosis and nerve compression underwent mini-PSO and PPS surgery, achieving satisfactory correction of sagittal and coronal planes at one-year post-operation

of all patients was 68.58 years (50–86). Among them, 15 patients were between 50 and 64.9 years old, 17 patients were between 65 and 74.9 years old, and 14 patients were 75 years old or older. There were 36 females and 10 males. The mean height was 153.82 ± 10.77 cm with the mean weight of 59.36 ± 12.53 kg and the mean body mass index (BMI) was 25.14 ± 4.73 kg/m2. The mean bone mineral density (T score) was −2.13 ± 1.34. Patients were classified using the SRS-Schwab system and etiology classification, with corresponding surgical procedures performed based on these classifications, as demonstrated in Table 2.

The mean total operative time was 326.77 min (99–722 min). The mean blood loss was 306.79 ± 249.66 cc (30-1200 cc). During the surgery, an intraoperative blood salvage system was used, 14 patients (30%) required allogeneic blood transfusion and the mean blood transfusion amount was 191.50 ± 121.58 cc (50–530 cc). Mean

Table 1 The demographic characteristics and operative data

Variable	Value
No. of patients	46
Male / female ratio	10:36
Mean age (years)	68.58±8.58 (51-86)
BMI (kg/m^2)	25.14 ± 4.73 (16.02-36.53)
BMD (T-score)	-2.13± 1.34 (-4.6 to 0.6)
Mean follow-up (months)	17.85 ± 12.97 (6-54)
No. of fixation levels	8.23 ± 3.06 (3-13)
Operative time (min)	326.77±143.17 (99-722)
Blood loss (mL)	306.79±249.66 (30-1200)
Length of hospital stay (day)	7.69 ± 3.31 (4-19)
Discharge disposition	
Home	46
Rehabilitation	0
Mean values are presented ± SD (minimum-Maximum)	

BMI: Body Mass Index; BMD: Bone Mineral Density

Table 2 Patients were classified using the SRS-Schwab system, with etiology determined from clinical and radiographic findings to guide surgical procedures

SRS-Schwab classification

Sagittal modifier	No. of patients (%)
PT modifier	
0: PT < 20°	6 (13%)
+: PT 20-30°	11 (24%)
++: PT > 30°	29 (63%)
PI-LL modifier	
0: PI-LL < 10°	10 (22%)
+: PI-LL 10-20°	4 (8%)
++: PI-LL > 20°	32 (70%)
SAV modifier	
0: SVA < 40 mm	16 (35%)
+: SVA 40-95 mm	12 (26%)
++: SVA > 95 mm	18 (39%)

Coronal curves type	No. of patients (%)
T	0 (0%)
L	7 (15.2%)
D	0 (0%)
N	39 (84.8%)

Etiology	No. of patients (%)
De-novo scoliosis	3 (6.5%)
Progressive adolescent idiopathic scoliosis in adulthood	0 (0%)
Hyper-kyphosis	0 (0%)
Iatrogenic sagittal deformity	3 (6.5%)
Focal deformity due to multiple degenerative disc disease	22 (47.9%)
Post-traumatic spinal deformity	18 (39.1%)

Surgical method	No. of patients (%)
Extension across TL junction	31 (67.4%)
Extension across LS junction	12 (26.1%)
Iliac fixation	2 (4.3%)
PPS	28 (60.9%)
PPS + mini-Ponte + MIS-TLIF	4 (8.7%)
PPS + mini-PSO	1 (2.2%)
PPS + MIS-TLIF	13 (28.3%)

PT: pelvic tilt; PI-LL: pelvic incidence minus lumbar lordosis; SVA: sagittal vertical axis; T: thoracic only L: thoracolumbar or lumbar only; D: double curve; N: no major coronal deformity; TL: Thoracolumbar; LS: Lumbosacral; PPS: Percutaneous pedicle screw; MIS-TLIF: minimally invasive transforaminal lumbar interbody fusion; PSO: pedicle subtraction osteotomy

number of fusion levels per patient was 8.23 ± 3.32 levels (3–13 levels).

The mean preoperative and postoperative radiographic parameters were summarized in Table 3. At pre-operation, the coronal angle was 18.60 ± 11.35°, the LL was 22.79 ± 21.87°, the PI was 53.05 ± 14.13°, the PI-LL mismatch was 30.26 ± 23.48°, the PT was 32.53 ± 10°, the SVA was 77.77 ± 60.47 mm, and the TPA was 31.91 ± 12.39°. At post-operation immediately, the coronal angle was 9.71 ± 6.99° (P = < 0.0001), the LL was 28.24 ± 17.26° (*P* = 0.1997), the PI was 52.03 ± 12.75° (*P* = 0.7220), the PI-LL mismatch was 23.79 ± 15.95° (*P* = 0.1360), the PT was 25.17 ± 10.20° (*P* = 0.0012), the SVA was 33.02 ± 34.84 mm (P = < 0.0001), and the TPA was 22.11 ± 9.88° (*P* = 0.0001). At the last follow up, the coronal angle was 10.08 ± 6.47° (P = < 0.0001), the LL was 26.16 ± 16.92° (*P* = 0.4293), the PI was 54.17 ± 12.13° (*P* = 0.6965), the PI-LL mismatch was 28.00 ± 17.03° (*P* = 0. 6144), the PT was 27.74 ± 10.24° (*P* = 0.0345), the SVA was 47.91 ± 46.94 mm (*P* = 0. 0129), and the TPA was 25.10 ± 10.95° (*P* = 0.009). Mean Oswestry Disability Index (ODI) and Visual Analogue Scale (VAS) scores for back pain at baseline and at last follow-up were 34.9 to 23.6 and 8.4 to 3.4, respectively.

Complications

In this study, a total of 23 patients developed one or more complications, which were demonstrated in Table 4. According to the ISSG-AO spine complications classification system, 5 patients had medical complications,

Table 3 A comparison of radiological parameters among preoperative, postoperative, and last follow-up measurements

	Pre-op	Post-op	Last-f/u	Pre/post P	Pre/Last P
Coronal (°)	18.60±11.35	9.71±6.99	10.08±6.47	< 0.0001	< 0.0001
LL(°)	22.79±21.87	28.24±17.26	26.16±16.92	0.1997	0.4293
PI(°)	53.05±14.13	52.03±12.75	54.17±12.13	0.7220	0.6965
PI-LL(°)	30.26±23.48	23.79±15.95	28.00±17.03	0.1360	0.6144
PT(°)	32.47±10.23	25.17±10.20	27.74±10.24	0.0012	0.0345
SVA(mm)	77.77±60.47	33.02±34.84	47.91±46.94	< 0.0001	0.0013
TPA(°)	31.91±12.39	22.11±9.88	25.10±10.95	< 0.0001	0.0090

LL: lumbar lordosis; PI: pelvic incidence; PI-LL: pelvic incidence minus lumbar lordosis; PT: pelvic tilt; SVA: sagittal vertical axis; TPA: T1 Pelvic Angle

Table 4 Postoperative complications, interventions, and the resolution of complications

	Complication	No.	%	Readmission	Reoperation
Medical	UTI	3	6.5	0	0
	Non-surgical site spine fracture	2	4.3	1 (resolved)	0
Surgery	Rod breakage	1	2.2	1	1 (resolved)
	Screw loosening	12	26.1	0	0
	Implant prominence	1	2.2	1	1 (resolved)
	Adjacent segment degeneration	2	4.3	0	0
	PJK	1	2.2	0	0
	PJF	0	0	0	0
	Neuropathy (right L5 palsy)	1 (unresolved)	2.2	0	0

PJK: Proximal junctional kyphosis; PJF: Proximal junctional failure

representing 10.9% of the patients, including UTI and non-surgical spine site fractures unrelated to the spine operation. Three patients developed UTIs after surgery, accounting for 6.5% of the patients. One patient suffered a sacral fracture after a motorcycle accident 2 months after surgery. Another patient experienced a lacking awareness compression fracture of L3 vertebra two years after the spine surgery. 18 patients experienced surgical complications, accounting for 39.1% of the patient population. Twelve patients exhibited halo sign of pedicle screw without prominent symptoms and no revision surgery was needed for the screw loosening. Among them, two patients showed halo sign on both cranial and caudal screws, while twelve patients showed the same halo sign on caudal screws. In one case, a 55-year-old male underwent navigation assisted MIS-TLIF at L2-3-4-5 for decompression and correction developed a right-side drop foot after surgery. Another 49-year-old female patient presented with subcutaneous irritation attributed to the excessive length of the left cranial rod end. We shortened the cranial rod's end to alleviate subcutaneous irritation. Additionally, one patient presented with asymptomatic PJK at T9 after PPS revision surgery from T9 to L5 for previous morbidity of screw penetration at L1 vertebra. Another Parkinsonism patient associated kyphoscoliosis, experienced asymptomatic rod breakage and PJF at T11 after PPS correction surgery from T11 to S1. Due to only mild soreness on back, no additional surgery was needed. One patient with previous surgery by Dynesys and Coflex system on L1-5 level underwent PPS implantation correction T6-L5 due to iatrogenic kyphoscoliosis. This patient was noted with right rod broken between L2-3 level in regular follow-up exam, a distal broken rod was replaced and linked to the upper rod with a longitudinal connector.

Discussion

MIS has garnered significant attention and acceptance, particularly in recent decades, for its effectiveness in treating degenerative spinal diseases. In our study, employing posterior MIS on 46 patients have consistently shown that MIS techniques offer substantial benefits for ASD. These advantages include restoring sagittal balance and the coronal plane while simultaneously reducing major surgical complications, with notably lower reoperation rates observed in MIS patients. The positive impact on patients' quality of life is evident across various clinical settings, mirroring findings from traditional open ASD surgery and MIS procedures [12, 23, 24].

The concept of "ideal" sagittal alignment evolves with age. Elderly patients naturally undergo changes in spinal curvature, and their alignment goals differ from those of younger individuals. For the elderly population, the primary focus of treatment should be on improving functionality, alleviating pain, and enhancing quality of life, rather than achieving perfect alignment. Although the correctability of minimally invasive surgery (MIS) techniques may not be as robust as that of open surgery, the less invasive nature of MIS techniques provides an advantage by facilitating individualized treatments that prioritize symptom relief and functionality over rigid alignment standards. In our patient cohort, based on the radiological parameters observed shortly after surgery and during subsequent follow-ups, it is acknowledged that these parameters may not remain perfectly stable over time. However, patient feedback, including VAS and ODI scores, reveals favorable outcomes with an average follow-up of two years (ranging from one to five years), indicating that the surgical intervention effectively meets patient expectations. Among the 46 patients of this study, 40 were successfully followed up at the one-year mark, with an average ODI score of 25.05, compared to a preoperative ODI score of 35.1. At the two-year follow-up, 36 patients were successfully assessed, revealing an average ODI score of 23.6, which corresponds to a 32.3% reduction. Additionally, the mean VAS scores for back pain decreased from 8.4 preoperatively to 3.5 at the one-year follow-up and further to 3.4 at the two-year follow-up, resulting in a 59.5% reduction in pain levels. Further longitudinal studies will be necessary to yield additional insights in radiological and clinical outcome. Currently, the surgical treatment for adult spinal deformities involves an anterior procedure followed by posterior instrumentation and fusion. The circumferential approach has been considered necessary to enhance deformity correction especially in kyphosis correction [25]. However, compared to circumferential MIS or the anterior approach, many articles also mention the favorable outcomes of the posterior-only MIS approach. A study illustrated that using a posterior-only approach for the treatment of degenerative lumbar scoliosis, kyphosis, or both combined with spondylolisthesis showed an improved positive correlation between the increase in JOA score and the increase in the lumbar lordosis angle [26]. Kim et al.'s published study demonstrated that posterior segmental spinal instrumentation and fusion without anterior apical release of lumbar curves resulted in superior total SRS scores, comparable complication rates, and analogous radiographic parameters [27]. Verde et al. conducted both double-route and isolated posterior-route procedures, achieving significant corrections in both approaches [28]. Good et al. proposed that single-way access is effective in correcting moderate and severe curves, potentially reducing the side effects associated with the double approach [29].

Compared to anterior or circumferential approaches, the posterior only approach provides several advantages. Firstly, the posterior only approach offers the convenience of a single-stage procedure performed in a single position, eliminating the need to reposition the patient, which is a source of increased surgical time and potentially patient risk correlation with anesthesia. Secondly, the surgical technique outlined in this study combines posterior decompression and correction, optionally supplemented with other decompression methods such as TLIF, PONTE, and PSO, as necessary. Thirdly, unlike anterior fusion, which carries risks of injuring major vessels and abdominal organs, posterior procedure only minimizes the likelihood of damaging intra-abdominal structures.

Despite the effectiveness of MIS techniques in addressing degenerative pathologies and their evident advantages over open surgical approaches, significant challenges still remain. For patients requiring extensive fusions into the thoracic spine or those with prior instrumentation or individuals with coronal deformities exceeding 20°may not be suitable candidates for MIS techniques. [30–31] Eastlack et al. found that patients selected for MIS had smaller coronal deformity correction compared to those eventually offered open surgery [32]. Anand et al. with similar reported significant correction of the Cobb's angle from 18.93° to 6.19° through minimally invasive multilevel percutaneous screw fixation [33]. In our study, a retrospective review of radiographs revealed a notable improvement resulting in a 45.8% decrease in the Cobb's angle (from 18.60 to 10.08). This surgical results demonstrate that the posterior MIS procedure provides a straight forward method for correcting not only improvement of SVA but also coronal deformity.

In our study, utilizing the posterior MIS approach, significant improvements ($P\text{-value} < 0.05$) were observed not only in the coronal angle but also PT, TPA, and SVA after surgery. Kumar et al. published that lateral access MIS (OLIF and PPS) for adult spinal deformity revealed preoperatively, the measurement of initial SVA was 96.5 mm and improved to 24.1 mm postoperatively [34]. Another study, Park et al. revealed the circumferential MIS approach for treating ASD, demonstrating that it led to an improvement of 3.0° in LL and an increase of 2.1 mm in the SVA, and a decrease of 2.2° in PI-LL [35]. Compared to our results from studies involving lateral access or circumferential MIS, the single-stage posterior MIS approach appears to offer similar corrective effects. The improvement observed in SVA of this study, which decreased from average 78 mm preoperatively to 33 mm postoperatively, reflecting a 57.7% reduction, suggesting a notable improvement. However, the effectiveness of each approach can be influenced by various factors, including, age, bone mineral density, medical comorbidity, the extent of deformity and the surgical expertise involved.

The complication was higher in ASD surgery, especially in the cases need with aggressive deformity correction. Traditional open surgery, exemplified by osteotomy, is effective in restoring sagittal balance but is prone to various complications, including excessive blood loss, neurological deficits, and pseudoarthrosis [36]. In our surgical outcomes, 18 patients experienced surgical complications, accounting for 39.1% of the patient population. Although the complication rate still appears high, most cases were only identified through radiographic findings. Specifically, the majority of cases involve asymptomatic (69.6%) or mild pain with low reoperation rate 4.3% for revision surgery. Compared to traditional open surgery, which is associated with relatively high perioperative and postoperative complication rates and medical complications following surgery range from 35 to 40%, and the reoperation rate varies between 10 and 50% [37–39]. At the same time, we need to note that complications in MIS techniques can vary depending on the surgical approach, patient population, and follow-up duration. Regarding the MIS, the diverse nature of approaches such as LLIF, TLIF, PPS, OLIF, etc., introduces considerable variation and contributes to the occurrence of different types of complications. Chan et al. reported that those undergoing cMIS had fewer overall complications compared to hybrid techniques ($p = 0.006$) [40]. Sleiman et al. found that while both the combined approach and the posterior-only approach had similar complication rates [41].

Regarding the reoperation rate, Scheer et al. reported that data collected from a multicenter adult spinal deformity database show an overall reoperation rate of 17% among those who underwent open surgery [42]. Another study published by Hamilton et al. reported an 11% revision rate for MIS, including lumbar interbody fusion (LIF) or transforaminal lumbar interbody fusion (TLIF), and percutaneous pedicle instrumentation [43]. Compared to our statistics, there were two individuals (4.3%) required reoperation, a rate consistent with the 6% reoperation rate reported in a meta-analysis of 10 studies on posterior-MIS surgery, highlighting the alignment of our findings with previously published data [44].

Our study suggests that the posterior-only approach combined with minimally invasive techniques may offer effective clinical outcomes, with improvements observed in various measures. Despite surgery-related complications, such as screws loosening, rod breakage, and PJK, the technique appears to offer advantages in correcting overall sagittal and coronal balance. Furthermore, it boasts benefits, including minimal muscle damage, a low risk of nerve injury, minimal bleeding, prompt post-operative recovery, and high patient satisfaction [45]. Several adjunctive therapies have contributed to the low reoperation rate observed in our patient cohort. First, we strictly require patients to wear a Boston brace for a minimum of 4 to 6 months postoperatively. Second, patients diagnosed with osteoporosis or osteopenia are treated with anti-osteoporosis medications, including anabolic agents when deemed necessary. Third, we have implemented stringent regulations regarding their daily activities following surgery, emphasizing the importance of minimizing bending and heavy lifting to mitigate the risk of proximal junctional kyphosis (PJK) and proximal junctional failure (PJF). A critical factor in our approach is the implantation of high-density pedicle screws under navigational assistance, which enhances the pull-out strength of the pedicle screws, thereby allowing for more effective in deformity correction and spinal fusion.

The utilization of a posterior-only minimally invasive approach is a secure and effective strategy for managing adult spinal deformity (ASD) and reducing the rate of revision surgeries. As minimally invasive surgery (MIS) for spinal deformities continues to be employed, the inclusion of a larger patient population in future prospective studies will strengthen the validation and corroboration of the findings from this study.

Limitation

There are several limitations to the study. Firstly, it lacks relatively long-term follow-up results. The majority of patients were followed up for six months to five years, lacking sufficient data for a long-term analysis. Since the pattern of early functional improvement, followed by maximal benefit, and then a slight decline, is observed in many interventions for degenerative pathologies [46]. Secondly, this study represents a case series without a comparator, either a younger group of patients undergoing MIS or patients of all ages undergoing open surgery. A relatively small number of patients and common biases associated with retrospective studies, such as selection and reporting biases, were also observed. Thirdly, this study categorized complications based on the classification proposed by the Klineberg et al., ISSG-AO ASD spine complications classification system, making it comparable only with other studies using this classification. Fourthly, the majority of patients are concentrated in the

N and L type of coronal curve. Regarding T-type patients, our series did not include any such case. Consequently, we are unable to assess the outcomes associated with the application of MIS correction for T-type patient. We need further data to ascertain the feasibility of utilizing Ponte or performing PSO procedures on T type patient.

Conclusion

While various surgical approaches efficiently correct ASD disease with good results, they also carry higher complication and re-operation rates compared to common degenerative disease surgery. The posterior-only MIS approach provides an alternative method for reducing re-operation rates while yielding similar outcomes. As MIS surgery for spinal deformities continues to be utilized, including more patients in future studies will strengthen and validate the results of this study. Further research, including extended follow-up and multi-center studies, is needed to confirm these findings.

Abbreviations

ASD	Adult spinal deformity
MIS	Minimally invasive surgery
VAS	Visual analog pain score
LL	Lumbar lordosis
PI	Pelvic incidence
PT	Pelvic tilt
TPA	T1 pelvic angle
SVA	Sagittal vertical axis
ODI	Oswestry Disability Index
MISS	Minimal invasive spinal surgery
BMI	Body mass index
BMD	Bone mineral density
PROMs	Patient-reported outcome measures
SRS	Scoliosis Research Society
PPS	Percutaneous pedicle screw
HPLC	High Performance Liquid Chromatography
TLIF	Transforaminal Lumbar Interbody Fusion
PSO	Pedicle subtraction osteotomy
ISSG-AO	International Spine Study Group-AO
UTI	Urinary tract infection
PJK	Proximal junctional kyphosis
JOA	Japanese Orthopaedic Association
cMIS	Circumferential Minimally Invasive Surgical
LIF	Lumbar interbody fusion

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Author contributions
CY has made substantial contributions in the acquisition, analysis and interpretation of data; and was a contributor in writing the manuscript. PHH has made conception and design of the work, and substantively written and revised the manuscript. MJWC has made substantial contributions in the acquisition and interpretation of data. YSL has made substantial contributions in the acquisition and interpretation of data. CT has made substantial contributions in the acquisition and interpretation of data. CYL has made substantial contributions in the acquisition and interpretation of data. LYL has made substantial contributions in the acquisition and interpretation of data. CYL has made substantial contributions in the acquisition and interpretation of data. CCC has made substantial contributions in the acquisition and interpretation of data. HTC has made substantial contributions in conception and design of the work, and substantively written and revised the manuscript. All authors read and approved the final manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
This study was approved by the Research Ethics Committee of China Medical University Hospital and obtained the unique identification number of research registration (approval number: CMUH109-REC1-009). Each patient signed a written informed consent form. In this study, all methods were performed in accordance with the Declaration of Helsinki relevant guidelines and regulations.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References
1. Taiwan ND, Council. Executive Yuan. Population Projections for R.O.C (Taiwan).
2. Minetto MA, Giannini A, McConnell R, Busso C, Torre G, Massazza G. Common musculoskeletal disorders in the elderly: the star triad. J Clin Med. 2020;9(4):1216. https://doi.org/10.3390/jcm9041216.
3. O'Lynnger TM, Zuckerman SL, Morone PJ, Dewan MC, Vasquez-Castellanos RA, Cheng JS. Trends for spine surgery for the elderly: implications for access to healthcare in North America. Neurosurgery. 2015;77(Suppl 4):S136–41.
4. BessS,LineB,FuKM,etal. The health impact of symptomatic adult spinal deformity: comparison of deformity types to united States population norms and chronic diseases. Spine (Phila Pa 1976). 2016;41:224–33.
5. Fu KM, Bess S, et al. Patients with adult spinal deformity treated operatively report greater baseline pain and disability than patients treated nonoperatively; however, deformities differ between age groups. Spine (Phila Pa 1976). 2014;39(17):1401–7. https://doi.org/10.1097/BRS.0000000000000414.
6. Ames CP, et al. Adult spinal deformity: epidemiology, health impact, evaluation, and management. Spine Deform. 2016;4(4):310–22. https://doi.org/10.1016/j.jspd.2015.12.009.
7. Kim HJ, Yang JH, Chang DG, Suk SI, Suh SW, Song KS, Park JB, Cho W. Adult spinal deformity: current concepts and Decision-Making strategies for management. Asian Spine J. 2020;14(6):886–97. https://doi.org/10.31616/asj.2020.0568.

8. Scheer J, K, et al. Comprehensive study of back and leg pain improvements after adult spinal deformity surgery: analysis of 421 patients with 2-year follow-up and of the impact of the surgery on treatment satisfaction. J Neurosurg Spine. 2015;22(5):540–53. https://doi.org/10.3171/2014.10.
9. Ailon T, Shaffrey CI, Lenke LG, Harrop JS, Smith JS. Progressive spinal kyphosis in the aging population. Neurosurgery. 2015;77(Suppl 4):S164–72.
10. Lau D, Osorio JA, Deviren V, Ames CP. The relationship of older age and perioperative outcomes following thoracolumbar three-column osteotomy for adult spinal deformity: an analysis of 300 consecutive cases. J Neurosurg Spine. 2018;28(6):593–606. https://doi.org/10.3171/2017.10.
11. Mummaneni PV, Tu TH, Ziewacz JE, Akinbo OC, Deviren V, Mundis GM. The role of minimally invasive techniques in the treatment of adult spinal deformity. Neurosurg Clin N Am. 2013;24(2):231–48. https://doi.org/10.1016/j.nec.2012.12.004.
12. Haque RM, Mundis GM Jr, Ahmed Y, El Ahmadieh TY, Wang MY, Mummaneni PV, Uribe JS, Okonkwo DO, Eastlack RK, Anand N, Kanter AS, La Marca F, Akbarnia BA, Park P, Lafage V, Terran JS, Shaffrey CI, Klineberg E, Deviren V, Fessler RG, International Spine Study Group. Comparison of radiographic results after minimally invasive, hybrid, and open surgery for adult spinal deformity: a multicenter study of 184 patients. Neurosurg Focus. 2014;36(5):E13. https://doi.org/10.3171/2014.3.
13. Uribe JS, Deukmedjian AR, Mummaneni PV, Fu KM, Mundis GM Jr, Okonkwo DO, Kanter AS, Eastlack R, Wang MY, Anand N, Fessler RG, La Marca F, Park P, Lafage V, Deviren V, Bess S, Shaffrey CI, International Spine Study Group. Complications in adult spinal deformity surgery: an analysis of minimally invasive, hybrid, and open surgical techniques. Neurosurg Focus. 2014;36(5):E15. https://doi.org/10.3171/2014.3.
14. Bae J, Lee SH. Minimally invasive spinal surgery for adult spinal deformity. Neurospine. 2018;15(1):18–24. https://doi.org/10.14245/ns.1836022.011.
15. Hofstetter CP, Hofer AS, Wang MY. Economic impact of minimally invasive lumbar surgery. World J Orthop. 2015;6(2):190–201. https://doi.org/10.5312/wjo.v.
16. Hu W, Tang J, Wu X, Zhang L, Ke B. Minimally invasive versus open transforaminal lumbar fusion: a systematic review of complications. Int Orthop. 2016;40(9):1883–90. https://doi.org/10.1007/s00264-016-3153-z.
17. Phan K, Rao PJ, Kam AC, Mobbs RJ. Minimally invasive versus open transforaminal lumbar interbody fusion for treatment of degenerative lumbar disease: systematic review and meta-analysis. Eur Spine J. 2015;24(5):1017–30. https://doi.org/10.1007/s00586-015-3903-4.
18. Anand N, Cohen JE, Cohen RB, Khandehroo B, Kahwaty S, Baron E. Comparison of a newer versus older protocol for circumferential minimally invasive surgical (CMIS) correction of adult spinal deformity (ASD)-Evolution over a 10-Year experience. Spine Deform. 2017;5(3):213–23. https://doi.org/10.1016/j.jspd.2016.12.005.
19. Sciubba DM, Scheer JK, Yurter A, Smith JS, Lafage V, Klineberg E, Gupta M, Eastlack R, Mundis GM, Protopsaltis TS, Blaskiewicz D, Kim HJ, Koski T, Kebaish K, Shaffrey CI, Bess S, Hart RA, Schwab F, Ames CP, International Spine Study Group (ISSG). Patients with spinal deformity over the age of 75: a retrospective analysis of operative versus non-operative management. Eur Spine J. 2016;25(8):2433–41. https://doi.org/10.1007/s00586-015-3759-7. Epub 2015 Feb 6. PMID: 25657104.
20. Slattery C, Verma K. Classification in brief: SRS-Schwab classification of adult spinal deformity. Clin Orthop Relat Res. 2018;476(9):1890–4. https://doi.org/10.1007/s11999.0000000000000264.
21. Diebo BG, Shah NV, Boachie-Adjei O, Zhu F, Rothenfluh DA, Paulino CB, Schwab FJ, Lafage V. Adult spinal deformity. Lancet. 2019;394(10193):160–72. https://doi.org/10.1016/S0140-6736(19)31125-0.
22. Klineberg EO, Wick JB, Lafage R, Lafage V, Pellise F, Haddad S, Yilgor C, Núñez-Pereira S, Gupta M, Smith JS, Shaffrey C, Schwab F, Ames C, Bess S, Lewis S, Lenke LG, Berven S, International Spine Study Group. Development and validation of a multidomain surgical complication classification system for adult spinal deformity. Spine (Phila Pa 1976). 2021;46(4):E267–73. https://doi.org/10.1097/BRS.0000000000003766.
23. Li B, Hawryluk G, Mummaneni PV, Wang M, Mehra R, Wang M, Lau D, Mayer R, Fu KM, Chou D. Utility of the MISDEF2 algorithm and extent of fusion in open adult spinal deformity surgery with minimum 2-Year Follow-up. Neurospine. 2021;18(4):824–32. https://doi.org/10.14245/ns.2142508.254.
24. Ryu WHA, Cheong M, Platt A, Moses Z, O'Toole JE, Fontes R, Fessler RG. Patient satisfaction following minimally invasive and open surgeries for adult spinal deformity. World Neurosurg. 2021;155:e301–14. https://doi.org/10.1016/j.wneu.2021.08.047.
25. Anand N, Alayan A, Kong C, Kahwaty S, Khandehroo B, Gendelberg D, Chung A. Management of severe adult spinal deformity with circumferential minimally invasive surgical strategies without posterior column osteotomies: a 13-year experience. Spine Deform. 2022;10(5):1157–68. https://doi.org/10.1007/s43390-022-00478-9.
26. Nishimura Y, Hara M, Nakajima Y, Haimoto S, Yamamoto Y, Wakabayashi T. Outcomes and complications following posterior long lumbar fusions exceeding three levels. Neurol Med Chir (Tokyo). 2014;54(9):707–15. https://doi.org/10.2176/nmc.oa.2014-0026.
27. Kim YB, Lenke LG, Kim YJ, Kim YW, Bridwell KH, Stobbs G. Surgical treatment of adult scoliosis: is anterior apical release and fusion necessary for the lumbar curve? Spine (Phila Pa 1976). 2008;33(10):1125–32. https://doi.org/10.1097/BRS.0b013e31816f5f57.
28. Verde SRL, Lima-Verde EC, Dias Junior CPP, Teixeira GFD, Prado Filho CS, De Andrade CLA. Comparative analysis between isolated posterior and antero-posterior approaches for severe scoliosis treatment. Rev Bras Ortop (Sao Paulo). 2023;58(5):e712–8. https://doi.org/10.1055/s-0043-1768622.
29. Good CR et al. Can posterior-only surgery provide similar radiographic and clinical results as combined anterior (thoracotomy/thoracoabdominal)/posterior approaches for adult scoliosis? Spine Vol. 35,2 (2010): 210–8. https://doi.org/10.1097/BRS.0b013e3181c91163
30. Januszewski J, Vivas AC, Uribe JS. Limitations and complications of minimally invasive spinal surgery in adult deformity. Ann Transl Med. 2018;6(6):109. https://doi.org/10.21037/atm.2018.01.29.
31. Hussain I, Fu KM, Uribe JS, Chou D, Mummaneni PV. State of the Art advances in minimally invasive surgery for adult spinal deformity. Spine Deform. 2020;8(6):1143–58. https://doi.org/10.1007/s43390-020-00180-8.
32. Eastlack RK, Mundis GM Jr, Wang M, Mummaneni PV, Uribe J, Okonkwo D, Akbarnia BA, Anand N, Kanter A, Park P, Lafage V, Shaffrey C, Fessler R, Deviren V, International Spine Study Group. Is there a patient profile that characterizes a patient with adult spinal deformity as a candidate for minimally invasive surgery?? Global Spine J. 2017;7(7):703–8. https://doi.org/10.1177/2192568217716151.
33. Anand N, et al. Minimally invasive multilevel percutaneous correction and fusion for adult lumbar degenerative scoliosis: a technique and feasibility study. J Spinal Disorders Techniques Vol. 2008;21(7):459–67. https://doi.org/10.1097/BSD.0b013e318167b06b.
34. Kumar BS, Tanaka M, Arataki S, Fujiwara Y, Mushtaq M, Taoka T, Zygogiannnis K, Ruparel S. Lateral access minimally invasive spine surgery in adult spinal deformity. J Orthop. 2023;45:26–32. https://doi.org/10.1016/j.jor.2023.09.007.
35. Park P, Wang MY, Lafage V, Nguyen S, Ziewacz J, Okonkwo DO, Uribe JS, Eastlack RK, Anand N, Haque R, Fessler RG, Kanter AS, Deviren V, La Marca F, Smith JS, Shaffrey CI, Mundis GM Jr, Mummaneni PV, International Spine Study Group. Comparison of two minimally invasive surgery strategies to treat adult spinal deformity. J Neurosurg Spine. 2015;22(4):374–80. SPINE131004. Epub 2015 Jan 30. PMID: 25635632.
36. Liu H et al. Comparison of Smith-Petersen osteotomy and pedicle Subtraction osteotomy for the correction of thoracolumbar kyphotic deformity in ankylosing spondylitis: a systematic review and meta-analysis. Spine 40,8 (2015): 570–9. https://doi.org/10.1097/BRS.0000000000000815
37. Bhagat S et al. Morbidity and mortality in adult spinal deformity surgery: Norwich spinal unit experience. European spine journal: official publication of the European spine society, the European spinal deformity society, and the European section of the cervical spine research society 22 Suppl 1, Suppl 1 (2013): S42–6. https://doi.org/10.1007/s00586-012-2627-y
38. Scheer JK, Tang JA, Smith JS, Klineberg E, Hart RA, Mundis GM Jr, Burton DC, Hostin R, O'Brien MF, Bess S, Kebaish KM, Deviren V, Lafage V, Schwab F, Shaffrey CI, Ames CP, International Spine Study Group. Reoperation rates and impact on outcome in a large, prospective, multicenter, adult spinal deformity database: clinical Article. J Neurosurg Spine. 2013;19(4):464–70. SPINE 12901. Epub 2013 Aug 23. PMID: 23971763.
39. Akıntürk N, et al. Complications of adult spinal deformity surgery: A literature review. J Craniovertebral Junction Spine Vol. 2022;13(1):17–26. https://doi.org/10.4103/jcvjs.jcvjs_159_21.
40. Chan AK, Eastlack RK, Fessler RG, Than KD, Chou D, Fu KM, Park P, Wang MY, Kanter AS, Okonkwo DO, Nunley PD, Anand N, Uribe JS, Mundis GM, Bess S, Shaffrey CI, Le VP, Mummaneni PV, International Spine Study Group. Two- and three-year outcomes of minimally invasive and hybrid correction of adult spinal deformity. J Neurosurg Spine. 2021;36(4):595–608. https://doi.org/10.3171/2021.7. SPINE 21138.
41. Haddad S et al. Combined anterior-posterior versus all-posterior approaches for adult spinal deformity correction: a matched control study. European

spine journal: official publication of the European spine society, the European spinal deformity society, and the European section of the cervical spine research society 31,7 (2022): 1754–64. https://doi.org/10.1007/s00586-022-07249-0
42. Scheer JK, Tang JA, Smith JS, Klineberg E, Hart RA, Mundis GM Jr, Burton DC, Hostin R, O'Brien MF, Bess S, Kebaish KM, Deviren V, Lafage V, Schwab F, Shaffrey CI, Ames CP, International Spine Study Group. Reoperation rates and impact on outcome in a large, prospective, multicenter, adult spinal deformity database: clinical article. J Neurosurg Spine. 2013;19(4):464– 70. https://doi.org/10.3171/2013.7. SPINE 12901.
43. Hamilton DK, Kanter AS, Bolinger BD, Mundis GM Jr, Nguyen S, Mummaneni PV, Anand N, Fessler RG, Passias PG, Park P, La Marca F, Uribe JS, Wang MY, Akbarnia BA, Shaffrey CI, Okonkwo DO, International Spine Study Group (ISSG). Reoperation rates in minimally invasive, hybrid and open surgical treatment for adult spinal deformity with minimum 2-year follow-up. Eur Spine J. 2016;25(8):2605–11. https://doi.org/10.1007/s00586-016-4443-2.
44. Mittal S, Sudhakar PV, Ahuja K, Ifthekar S, Yadav G, Sinha S, Goyal N, Verma V, Sarkar B, Kandwal P. Deformity correction with interbody fusion using lateral versus posterior approach in adult degenerative scoliosis: A systematic review and observational Meta-analysis. Asian Spine J. 2023;17(2):431–51. https://doi.org/10.31616/asj.2022.0040.
45. Yen CP, Mosley YI, Uribe JS. Role of minimally invasive surgery for adult spinal deformity in preventing complications. Curr Rev Musculoskelet Med. 2016;9(3):309–15. https://doi.org/10.1007/s12178-016-9355-6.
46. Lurie JD, Tosteson TD, Tosteson A, Abdu WA, Zhao W, Morgan TS, Weinstein JN. Long-term outcomes of lumbar spinal stenosis: eight-year results of the spine patient outcomes research trial (SPORT). Spine (Phila Pa 1976). 2015;40(2):63–76. https://doi.org/10.1097/BRS.0000000000000731.

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