J Turk Spinal Surg 2025;36(4):161-167
DOI: 10.4274/jtss.galenos.2025.97659

ASYMMETRIC PEDICLE SUBTRACTION OSTEOTOMY FOR ADULT FIXED CORONAL DEFORMITY: SURGICAL STRATEGY AND OUTCOMES BASED ON MALALIGNMENT SUBTYPE

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ABSTRACT

Objective: This study aimed to evaluate the radiological and clinical outcomes of asymmetric pedicle subtraction osteotomy (APSO) in the treatment of rigid coronal malalignment (CM), and to investigate the impact of deformity subtype-based on the Obeid classification-on surgical strategy and outcomes.

Materials and Methods: A total of 24 patients with rigid CM underwent APSO between 2015-2020. Patients were classified as type 1 or type 2 CM according to the T1 plumbline deviation. Radiological parameters, including Cobb angle, coronal vertical axis (CVA), sagittal vertical axis, pelvic incidence-lumbar lordosis (PI-LL) mismatch, and thoracic kyphosis, were compared pre- and postoperatively. Clinical outcomes were assessed using the visual analogue scale (VAS) and Oswestry disability index (ODI) scores at baseline, postoperative day 10, and one-year. Surgical maneuvers were stratified based on CM subtype. Statistical analysis included paired and independent t-tests and chi-square tests, with $p<0.05$ considered significant.

Results: Radiographic correction was significant across the cohort, with mean Cobb angle improving from 34.8° to 8.1° ($p<0.001$), CVA from 9.1 cm to 2.2 cm ($p<0.001$), and PI-LL mismatch from 21.1° to 7.8° ($p<0.001$). Clinical scores improved significantly at both postoperative time points (VAS: 8.7 to 3.1; ODI: 84.5% to 27.4%, $p<0.001$). Type 2 CM patients required more extensive correction techniques, including interbody cages (88.9% vs. 40.0%, $p=0.002$), iliac screws (77.8% vs. 13.3%, $p<0.001$), and kickstand rods (66.7% vs. 6.7%, $p<0.001$), compared to type 1 CM patients. The overall complication rate was 16.7%, including dural tear (n=1), proximal junctional kyphosis (n=2), and implant loosening (n=1); no neurological deficits were observed.

Conclusion: APSO provides effective three-dimensional correction in patients with rigid coronal deformity, yielding favorable clinical and radiological outcomes at one-year follow-up. CM subtype plays a critical role in surgical planning, in the need for distal extension and lumbosacral interventions. When tailored to deformity morphology, APSO is a safe and reliable alternative to more aggressive osteotomy techniques.

Keywords: Asymmetric osteotomy, pedicle subtraction osteotomy, rigid deformity, coronal deformity, adult spinal deformity

INTRODUCTION

Coronal malalignment (CM) is defined as a lateral displacement of the T1 plumbline from the midline of the sacrum by more than 2 cm(1). Although frequently associated with sagittal imbalance in adult spinal deformity (ASD), CM can also occur as an isolated deformity due to lower extremity length discrepancy, hip contractures, or neurological conditions such as Parkinson's disease or Pisa syndrome(2). Clinically, CM is associated with functional limitations including gait disturbances, difficulty in standing, and impaired quality of life. Moreover, CM may contribute to pelvic obliquity and lumbosacral fractional curves, further complicating surgical correction(3).

Several studies have demonstrated that persistent or postoperative CM negatively affects patient-reported outcomes, particularly in patients undergoing long-segment spinal fusion(4-6). In this context, appropriate correction of the coronal plane has become increasingly recognized as a critical goal in ASD surgery.

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Received: 03.07.2025 **Accepted:** 12.09.2025 **Epub:** 30.09.2025 **Publication Date:** 16.10.2025
Cite this article as: Sarıgül B, Aydın L, Yılmaz M, Öndüç GG, Ramazanoğlu AF, Dalbayrak S. Asymmetric pedicle subtraction osteotomy for adult fixed coronal deformity: surgical strategy and outcomes based on malalignment subtype. J Turk Spinal Surg. 2025;36(4):161-167

While posterior instrumentation alone may suffice in flexible deformities, rigid curves often require osteotomies to restore alignment. Vertebral column resection (VCR) remains the most feasible technique for fixed multiplanar deformities but is associated with high complication rates, including neurological injury, excessive blood loss, and prolonged operative time[7,8]. Pedicle subtraction osteotomy (PSO) was initially described by Thomasen[9] in 1985 for patients with ankylosing spondylitis. Although it has been traditionally used for sagittal correction, it can be modified asymmetrically to achieve coronal realignment with less morbidity[10].

Asymmetric PSO (APSO) involves greater bone resection on the convex side of the deformity. It has emerged as a viable alternative to VCR in selected patients with rigid coronal deformities. However, data on the outcomes of APSO remain limited, and prior studies have often lacked standardized classification-based comparisons[10,11].

This study aims to evaluate the radiological and clinical outcomes of patients who underwent APSO for rigid coronal deformity and to assess whether outcomes differ between CM types as defined by the Obeid classification. Additionally, we aim to highlight practical surgical strategies tailored to CM subtypes.

MATERIALS AND METHODS

Study Data and Patient Selection

This retrospective clinical study included 24 patients who underwent APSO for rigid coronal deformity between January 2015 and March 2020. All patients were operated on a single institution by the same surgical team. Inclusion criteria were age >18 years, rigid (the rigidity was evaluated according to the positional changes in the curve magnitude, including supine-standing position and lateral bending), coronal deformity with or without sagittal imbalance, a minimum clinical and radiological follow-up period of 12 months, and radiographic confirmation of fixed deformity which is uncorrectable with postural and positional maneuvers. Exclusion criteria were neuromuscular scoliosis, spinal tumors, infections, and prior surgery with osteotomy.

Institutional Review Board approval was obtained from University of Health Sciences Türkiye, Ümraniye Training and Research Hospital Ethics Committee (approval no: 436, date: 26.12.2024), and informed consent was acquired from all patients prior to inclusion.

Radiological and Clinical Evaluation

Preoperative planning was based on standing anteroposterior/lateral full spine X-rays. Cobb angle of the coronal deformity, coronal vertical axis (CVA), sagittal vertical axis (SVA), spinopelvic harmony pelvic incidence-lumbar lordosis (PI-LL) mismatch, LL between L1 and S1, and thoracic kyphosis (TK) between T2 and T12 were calculated.

CM was accepted as a CVA >4 cm. Sagittal imbalance was defined as either SVA >5 cm or PI-LL mismatch >11°. Thoracolumbar computed tomography and magnetic resonance images were also obtained to determine the fused vertebral segments, neural compression, ankylosis, and bone quality. The flexibility of the deformity was assessed through the alterations of the curve between supine and standing radiological images. Bending films were obtained when necessary. According to the Obeid classification[1], the CM was grouped into two types: in type 1 CM, the T1 plumbline is on the side of the concavity of the main curve (Figure 1), and in type 2 CM, the T1 plumbline is on the convexity of the main curve (Figure 2).

The visual analogue scale (VAS) score and Oswestry disability index (ODI) scores were evaluated preoperatively, on the 10th postoperative day, and 1st year. Perioperative complications and revision surgeries were also recorded.

Surgical Technique

All surgeries were performed under general anesthesia in the prone position. A midline posterior incision and subperiosteal dissection for exposure of the posterior spinal elements are performed. Pedicle screws are inserted bilaterally at the planned levels above and below the osteotomy site. A temporary rod is placed on one side for stabilization. Laminectomy and bilateral facetectomies are performed at the index level, followed by wide decompression of the spinal canal. The pedicles of the target vertebra are removed, and a wedge-shaped resection of the vertebral body is carried out using osteotomes and rongeurs under fluoroscopic guidance. On the convex side, a wider wedge of the vertebral body is resected, including partial removal of the adjacent disc if necessary, while the concave side is preserved more to allow asymmetric closure. The anterior cortex on the concave side is left intact to serve as a hinge. After achieving the desired correction via controlled closure of the osteotomy gap, final rods are placed, compression is applied, and the construct is secured. Hemostasis and layered closure follow.

Different surgical maneuvers were employed for CM type 1 and type 2 patients. In type 1 CM, correction mainly targets the apical segment of the primary curve. Distraction was applied to the concave side of the osteotomy level. The convex side was allowed to collapse with controlled closure of the wedge. No additional iliac fixation was routinely required. A unilateral interbody cage was inserted in the L4-L5 or L5-S1 disc space, depending on lumbosacral flexibility. Coronal balance was confirmed intraoperatively using a T-square tool. Type 2 CM is frequently associated with a prominent lumbosacral fractional curve and pelvic obliquity. Therefore, correction involves both the apex and the lumbosacral region. Distraction was applied on the concave side of the apical curve. Simultaneous compression was applied to the convex L5-S1 junction to reduce lumbosacral obliquity. Additional correction maneuvers included insertion of unilateral transforaminal lumbar interbody fusion (TLIF) cages at L4-5 or L5-S1, bilateral iliac screws for enhanced pelvic anchorage, and placement of kickstand rods on the convex side to correct severe

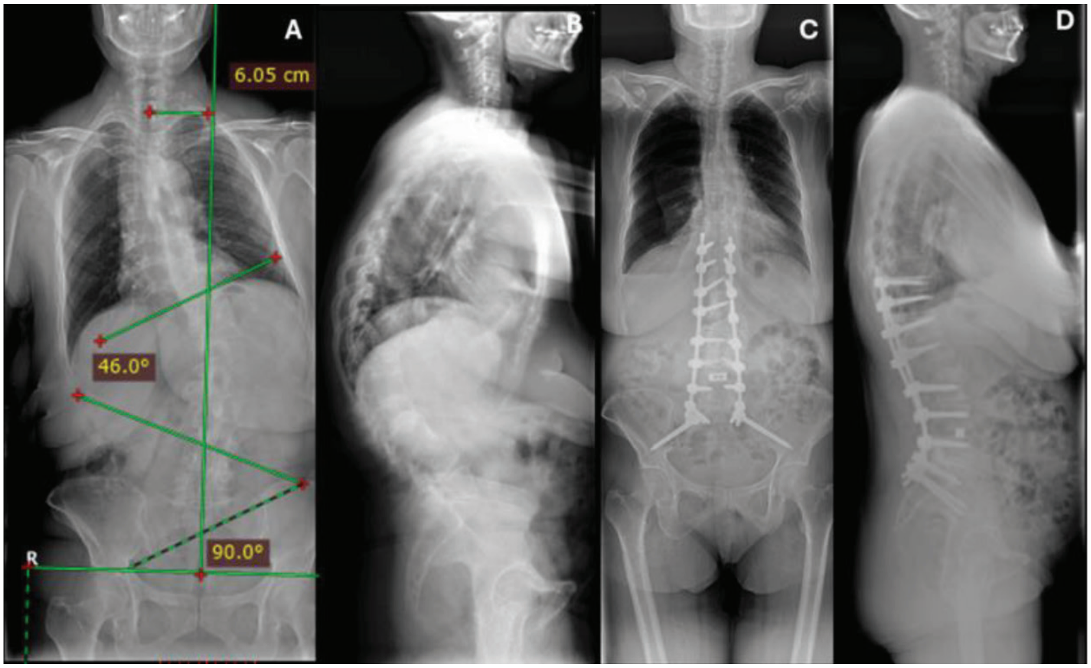

Figure 1. Pre- and postoperative radiographs of a 68-year-old female patient with Obeid type 1 CM (A, B). Preoperative standing AP and lateral scoliosis radiographs. The main thoracolumbar curve shows a Cobb angle of 46°, with a CVA of 6.05 cm. The T1 plumbline lies on the concavity of the curve, consistent with type 1 CM. The patient had a PI-LL mismatch of 15° and a TK of 33° (T11-L2) (C, D). Postoperative radiographs after L2 APSO and T10-iliac posterior instrumentation. A unilateral TLIF cage was placed at L4-L5 with additional decompression. Coronal and sagittal alignment was successfully restored. AP: Anteroposterior, CVA: Coronal vertical axis, CM: Coronal malalignment, PI: Pelvic incidence, LL: Lumbar lordosis, TK: Thoracic kyphosis, APSO: Asymmetric pedicle subtraction osteotomy, TLIF: Transforaminal lumbar interbody fusion

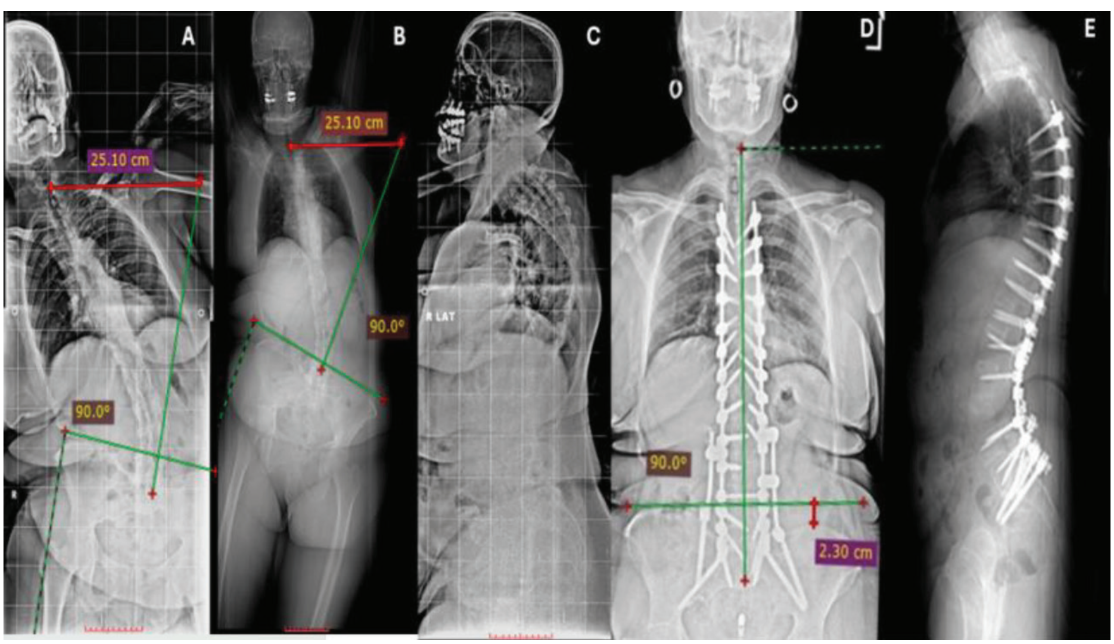

Figure 2. Pre- and postoperative imaging of a 55-year-old female patient with Obeid type 2 CM and pelvic obliquity (A, B). Standing AP scoliosis radiograph and CT scanogram demonstrate a 25.1 cm coronal shift and fixed pelvic obliquity due to leg length discrepancy. The T1 plumbline lies on the convex side of the main curve (C). Preoperative lateral radiograph shows preserved sagittal balance (D, E). Postoperative AP and lateral images following L3 APSO and T4-iliac pedicle screw instrumentation. Two kickstand rods were used to correct the lumbosacral fractional curve. Despite correction of spinal alignment, the pelvic obliquity persisted with a residual 2.3 cm leg length discrepancy. CM: Coronal malalignment, AP: Anteroposterior, CT: Computed tomography, APSO: Asymmetric pedicle subtraction osteotomy

obliquity. Correction was titrated to avoid overcorrection of the thoracolumbar segment relative to the fractional curve. Final alignment was checked using intraoperative fluoroscopy and T-square assessment.

Statistical Analysis

All statistical analyses were performed using Microsoft Excel version 16.91 (Microsoft Corp., Redmond, WA). Continuous variables were presented as mean ± standard deviation. The distribution of variables was assessed visually and analytically; given the approximate normal distribution, parametric tests were employed.

Preoperative and postoperative values for radiographic and clinical parameters (e.g., Cobb angle, CVA, PI-LL mismatch, LL, SVA, VAS, and ODI scores) were compared using paired t-tests, assuming matched dependent samples.

Subgroup comparisons between patients with type 1 and type 2 CM were performed using the independent-samples t-test for continuous variables and Pearson's chi-square test for categorical variables (e.g., presence of interbody fusion, iliac screw usage, and kickstand rod placement).

The level of statistical significance was set at $p<0.05$, with all p-values reported as two-tailed. No correction for multiple comparisons was applied due to the exploratory nature of the subgroup analyses. Confidence intervals (95%) were calculated where relevant but not reported in the text to preserve clarity.

RESULTS

A total of 24 patients, consisting of 16 females and 8 males, underwent asymmetric APSO for rigid coronal deformity. The mean age was 64.2±8.1 years (range: 43-75), and the mean follow-up duration was 13.6±1.2 months. Thirteen patients (54.2%) had undergone prior spinal surgery, including 5 with a history of previous instrumentation. According to the Obeid classification, 15 patients (62.5%) had type 1 CM, while 9 patients (37.5%) were classified as type 2.

Radiologically, significant improvements were observed in coronal and sagittal alignment following surgery. The mean preoperative Cobb angle of the main curve was 34.8±13.9 degrees, which improved to 8.1±4.6 degrees postoperatively ($p<0.001$, paired t-test). Similarly, the mean CVA decreased from 9.12±3.6 cm to 2.18±1.3 cm ($p<0.001$), while the PI-LL mismatch improved from 21.1±6.7 degrees to 7.8±5.1 degrees ($p<0.001$). LL increased significantly from 33.4±10.8 degrees to 50.212.1 degrees ($p=0.041$). Although TK showed a slight reduction from 27.3±11.2 to 25.6±10.9 degrees, this change did not reach statistical significance ($p=0.18$). The SVA decreased significantly from 4.9±2.1 cm to 2.3±1.5 cm ($p=0.013$) (Table 1).

When comparing CM subtypes, patients with type 1 CM achieved a mean Cobb angle correction of 27.3±8.5 degrees, whereas those with type 2 CM achieved 24.8±7.9 degrees; this difference was not statistically significant ($p=0.29$, independent-samples t-test). CVA correction was also comparable between groups (6.4±2.1 cm vs. 7.3±2.6 cm, $p=0.18$). The degree of improvement in PI-LL mismatch and SVA was similar in both groups ($p=0.67$ and $p=0.49$, respectively). However, significant differences were found in surgical strategies between CM types. Interbody fusion was performed in 88.9% of patients with type 2 CM, compared to 40.0% in type 1 ($p=0.002$, chi-square test). Iliac screws were used in 77.8% of type 2 patients versus only 13.3% in type 1 ($p<0.001$), and kickstand rods were employed in 66.7% of type 2 cases compared to just 6.7% of type 1 ($p<0.001$) (Table 2).

Clinically, all patients demonstrated significant functional and pain-related improvement. The mean preoperative VAS score was 8.7±1.2, which decreased to 2.3±1.4 on postoperative day 10 and remained stable at 3.1±2.4 at the one-year follow-up ($p<0.001$ for both comparisons). ODI scores showed a similar trend, improving from a preoperative mean of 84.5±14.2% to 22.6±8.9% at day 10 and 27.4±10.7% at one year (both $p<0.001$, paired t-test) (Table 3).

The overall complication rate was 16.7% (n=4). One patient experienced an intraoperative dural tear, which we repaired successfully without postoperative cerebrospinal fluid (CSF) leakage or neurological deficit. Two patients developed proximal junctional kyphosis (PJK), one of whom required revision surgery. One patient experienced implant loosening and pseudoarthrosis, necessitating reoperation with extension of fusion levels. No permanent neurological deficits were observed. The mean length of hospital stay was 3.2±1.4 days.

Table 1. Preoperative and postoperative comparison of radiological spinal parameters

Parameter	Preoperative	Postoperative	p-value
Cobb angle (°)	34.8±13.9	8.1±4.6	<0.001
CVA (cm)	9.12±3.6	2.18±1.3	<0.001
PI-LL mismatch (°)	21.1±6.7	7.8±5.1	<0.001
LL (°)	33.4±10.8	50.2±12.1	0.041
TK (°)	27.3±11.2	25.6±10.9	0.18
SVA (cm)	4.9±2.1	2.3±1.5	0.013

Radiographic measurements include coronal Cobb angle, CVA, PI-LL mismatch, LL, TK, and SVA. CVA: Coronal vertical axis, PI: Pelvic incidence, LL: Lumbar lordosis, TK: Thoracic kyphosis, SVA: Sagittal vertical axis

Table 2. Comparison of surgical parameters and outcomes between CM type 1 and type 2 patients

Parameter	Type 1 CM (n=15)	Type 2 CM (n=9)	p-value
Cobb angle correction (°)	27.3±8.5	24.8±7.9	0.29
CVA correction (cm)	6.4±2.1	7.3±2.6	0.18
PI-LL correction (°)	13.2±5.7	12.5±6.3	0.67
SVA correction (cm)	2.6±1.4	2.3±1.3	0.49
Interbody fusion performed (%)	40.0%	88.9%	0.002
Iliac screw use (%)	13.3%	77.8%	<0.001
Kickstand rod used (%)	6.7%	66.7%	<0.001

CM: Coronal malalignment, CVA: Coronal vertical axis, PI: Pelvic incidence, LL: Lumbar lordosis

Table 3. Clinical outcomes assessed by VAS and ODI scores

Time point	VAS	ODI (%)	p-value (VAS/ODI)
Preoperative	8.7±1.2	84.5±14.2	-
Postop day 10	2.3±1.4	22.6±8.9	<0.001/<0.001
Postop 1 year	3.1±2.4	27.4±10.7	<0.001/<0.001

VAS: Visual analog scale, ODI: Oswestry disability index

DISCUSSION

Rigid spinal deformities often require osteotomies to achieve adequate correction in both sagittal and coronal planes. APSO evolved as a less invasive alternative to CR for selected cases with fixed coronal deformities. In our series with 24 patients, APSO provided significant improvement in radiographic and clinical outcomes, supporting its feasibility and efficacy, even in the presence of sagittal imbalance.

Recent studies have emphasized the importance of coronal alignment in ASD surgery. Postoperative residual CM has been associated with poor clinical outcomes(5,12,13). Ploumis et al.(5) reported that CM was present in 20.4% of ASD patients who underwent long-segment posterior spinal fusion and the incidence increased in the long-term follow-up. Zhang et al.(12) retrospectively reviewed 121 patients who underwent long-segment spinal fusion and found that Cobb angularity more than 20 degrees was associated with poor outcomes, thus it should be avoided during surgery. A preoperative CM greater than 3 cm towards the convexity has also been linked to worse postoperative results(4). Even though some studies did not find a direct correlation between CM and patient-reported scores(14,15) others have reported significantly lower the scoliosis research society-22 patient questionnaire and ODI scores with persistent CM(16). In our series, we observed significant improvement in CVA, PI-LL mismatch, and clinical outcomes across all patients at one-year follow-up.

Our surgical planning was established through the Obeid classification, which categorizes the CM according to the position of T1 plumbline relative to the concavity or the convexity of the main curve(1). While other classification models-such as Bao et al.(4) CSVL-based types and the angular threshold recommendations by Zhang et al.(12) provide a descriptive framework, their utilization is limited in surgical guidance. Buell et al.(13) and the international spine study group modifiers further integrate sagittal parameters but are less operative in nature. The Obeid system was selected in our practice due to its criteria for applicability and feasibility of real-time surgical planning.

In our series, correction strategies were explicitly projected relative to the CM subtype. In type 1 CM, where the plumbline is on the concavity of the main curve, correction was maintained through asymmetric wedge resection and concave distraction at the apical segment. Minimal distal extension of the instrumentation and selective interbody fusion were typically adequate. However, type 2 CM, which is characterized with convex plumbline deviation and lumbosacral curve required a more extensive correction strategy. In both studies, Lewis et al.(17) and Theologis et al.(18) demonstrated the critical impact of L4 and L5 tilt and lumbosacral fractional curve on coronal balance; therefore, we performed additional interventions, including compression at the convex L5-S1 junction, TLIF cages at L4-5 or L5-S1, and frequent use of bilateral iliac screws and kickstand rods. We utilized a t-square tool following final rod contouring to ensure coronal alignment intraoperatively, as described by Kurra et al.(19) and a previous report by our team. This deformity-specific, graduated surgical strategy allowed for consistent and reproducible correction in both CM types, hence minimizing the need for more aggressive osteotomies such as VCR(20).

Asymmetric osteotomies have been shown initially for patients with congenital scoliosis secondary to a hemivertebra(21,22). APSO evolved as an alternative to VCR, which is associated with significant complications and high morbidity rates. APSO is reported to be associated with less blood loss, shorter duration of surgery, and less morbidity than VCR(11). Bakaloudis et al.[23] performed APSO in patients with kyphoscoliosis secondary to various etiologies. Several studies reported APSO in ASD. Thambiraj and Boszczyk.[24] performed APSO in 2 patients with lumbar and thoracic coronal deformity, respectively. Obeid et al.[25] performed APSO in the T5 vertebra in a patient with posttraumatic kyphoscoliosis. Chan et al.[11] performed APSO in 14 patients with coronal deformity of varying etiologies including iatrogenic coronal imbalance, pseudoarthrosis, adjacent segment disease, and congenital scoliosis with hemivertebra. Authors reported improvement in sagittal and coronal spinopelvic parameters and patient-reported outcomes. In their series, 11 patients had medical or surgical complications, including L5 radiculopathy, pseudoarthrosis and rod breakage. They concluded that APSO may provide favorable correction in CVA, SVA and PI-LL mismatch. Our results were consistent with the previous reports suggesting improvement in SVA and CVA, along with sagittal spinopelvic parameters[11].

Our 16.7% complication rate is consistent with the previous literature. One of the four patients who experienced complications, had intraoperative dural tear during neural decompression. She was managed with primary repair and had neither CSF leak nor neurological deficit. Two patients developed PJK, one required revision surgery due to progressive kyphotic deformity. In the last patient with a history of rheumatoid arthritis, extended instrumentation and revision with anterior support were necessary due to pseudoarthrosis and loosening of S1 and iliac screws. This complication profile is considerably more favorable than those reported in the literature for more aggressive osteotomy techniques. The Scoli-RISK-1 study, which evaluated the high-risk 3-column osteotomies reported a complication rate of 73.7% for VCR and 46.9% for PSO[26]. Similarly, Chan et al.[11] described complications in 11 out of 14 patients who underwent APSO, including delayed-onset L5 radiculopathy, pseudoarthrosis, and rod breakage. Toyone et al.[27] reported four complications in 14 APSO cases, including one dural tear, two patients with cephalad hook dislodgement, and one rod breakage. Lau et al.[28], in a comparative study of APSO versus PSO, found no significant difference in complication rates but noted that APSO was associated with extended intensive care unit stay and hospitalization. In our study, there were no cases of permanent neurological deficit, infection, or mortality, and all patients were discharged after a mean postoperative stay of 3.2±1.4 days. The low rate of complications may be attributed to the short follow-up period. We believe that preoperative patient selection and careful surgical planning are fundamental in preventing possible complications.

Study Limitations

This study has several limitations. It is retrospective and lacks a control group, limiting direct comparison with other techniques. The follow-up period was limited to one year, and long-term functional outcomes remain unknown. Further studies with long-term follow-up are necessary to evaluate the rate of mechanical complications, including pseudoarthrosis, adjacent segment pathologies, instrumentation failure, curve progression and correction loss. The relatively small sample size limits the ability to draw definitive conclusions regarding the superiority or overall success of this surgical technique compared to other methods. The sample size is relatively small. Finally, the choice of surgical strategy was based on the surgeon's experience rather than a fixed protocol. Despite these limitations, our findings support the role of APSO as a feasible and effective alternative for managing rigid coronal deformity with correct indications depending on the deformity morphology. Larger prospective studies are needed to confirm these results and optimize surgical planning.

CONCLUSION

APSO is a feasible and efficient surgical technique for the correction of rigid coronal spinal deformities and provides radiographic alignment and improvement in functional outcomes at one-year follow-up. Our findings demonstrate that APSO can be successfully performed in both type 1 and type 2 CM with tailored intraoperative strategies based on the deformity subtype. The necessity for utilization of more extensive correction maneuvers including kickstand rods and iliac fixation in type 2 CM, highlights the importance of patient-specific surgical strategies.

Even though APSO may not fully replace more aggressive techniques such as VCR, it may provide a less morbid alternative for selected cases with fixed deformity. Future prospective studies with larger patient population and a longer follow-up duration are necessary to validate our findings and to establish standardized surgical guidelines for deformity-specific APSO application.

Ethics

Ethics Committee Approval: Institutional Review Board approval was obtained from University of Health Sciences Türkiye, Ümraniye Training and Research Hospital Ethics Committee (approval no: 436, date: 26.12.2024).

Informed Consent: Informed consent was acquired from all patients prior to inclusion.

Footnotes

Authorship Contributions

Surgical and Medical Practices: M.Y., S.D., Concept: S.D., Design: B.S., Data Collection or Processing: B.S., Analysis or Interpretation: A.F.R., Literature Search: G.G.Ö., Writing: B.S., L.A.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study received no financial support.

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