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INTRAOPERATIVE EVALUATION OF SPINAL CORONAL ALIGNMENT VIA T-SQUARE SHAPED TOOL IN THORACOLUMBAR INSTRUMENTATION

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ABSTRACT

Objective: Postoperative coronal malalignment (CM) is associated with suboptimal surgical outcomes and a diminished quality of life in spinal deformity patients. Several risk factors for postoperative CM are proposed, including type 2 CM, pelvic obliquity, and lumbosacral fractional curve. Intraoperative assessment of coronal alignment plays a pivotal role in avoiding postoperative CM. A T-square-shaped tool (T-tool) has been proposed as a surgical device to evaluate the coronal balance intraoperatively. In this study, we evaluate the effectiveness of the T-tool in intraoperative coronal alignment correction in patients undergoing thoracolumbar spinal instrumentation.

Materials and Methods: The study includes patients who had preoperative coronal spinal deformity and/or sagittal imbalance. The T-tool was used intraoperatively in all patients. Radiological measurements were obtained using pre- and postoperative standing scoliosis X-rays. Pelvic obliquity and leg-length discrepancy were also evaluated. Preoperative and postoperative C7-coronal vertical axis (CVA) and Cobb angle of the coronal curve were measured. CM was classified according to the Obeid-CM classification. The results were compared statistically.

Results: Six hundred twenty-nine patients were included in the study. Degenerative deformity was observed in 553 (87.92%) patients, while adolescent idiopathic scoliosis was observed in 76 (12.08%) patients. The preoperative and postoperative C7-CVA were 27.16±11.44 and 8.64±5.21, respectively. The mean coronal Cobb angle decreased from 24.90±21.13° to 14.03±5.68°. No patient demonstrated postoperative worsening of CM.

Conclusion: The T-tool is a feasible and cost-effective instrument for intraoperative assessment of the coronal spinal alignment, and it may contribute to the improvement of surgical outcomes and reduced postoperative complications.

Keywords: Thoracolumbar instrumentation, T-tool, coronal balance, coronal malalignment

INTRODUCTION

Achievement of a well-balanced spine is a fundamental objective of spinal instrumentation surgery since it has an impact on the postoperative pain and functional outcomes especially in spinal deformity patients[1,2]. Many studies have focused on the radiological improvement of sagittal balance and its implications for postoperative outcomes. Recent studies have shown that the incidence of postoperative coronal malalignment (CM) is reported to be as high as 30%. CM may worsen the patient-reported outcomes and increase the risk of perioperative complications[3,4]. CM is also associated with postoperative leg length discrepancy (LLD), pelvic obliquity, truncal deformity, pain and pulmonary dysfunction[1].

Various studies have investigated the optimal evaluation method of intraoperative coronal alignment. Initial reports advocated that long-casette anteroposterior radiographs are ideal for determining the coronal balance, intraoperatively. However, this method requires a radiolucent operation table and the radiation exposure is high[5]. The distance between the central sacral vertical line (CSVL) and C7 plumb line has been accepted as the gold standard for the assessment of coronal alignment. However, intraoperative determination of the C7 plumbline can be challenging and the measurement of this parameter may not always be consistent with the

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standing or ambulatory state[4]. The horizontal distance from the midpoint of C7 to the central sacral pelvic line (CSPL) has also been suggested to be superior to C7-CSVL distance[1]. For the evaluation of the coronal balance, T-square shaped tool (T-tool) was introduced and first used in the treatment of neuromuscular scoliosis in children[6]. Henceforth, many reports suggested the use of T-tool to reduce postoperative CM rates[7,8]. In our practice, we routinely use the T-tool in all pediatric and adult spinal deformity patients, as well as patients without preoperative deformity but requiring thoracolumbar instrumentation. In this clinical study; we present the radiological outcomes of patients in whom the coronal alignment was confirmed via T-tool during spinal instrumentation surgery.

MATERIALS AND METHODS

This retrospective clinical study includes patients diagnosed with preoperative spinal deformity and underwent thoracolumbar or lumbar spinal instrumentation between years 2013 and 2023. Ethical approvement for this study was obtained from University of Health Sciences Türkiye, Ümraniye Training and Research Hospital, Ethical Committee (approval number: B.10.1.TKH.4.34.H.GP.0.01/435, date: 26.12.2024).

Preoperative Evaluation

The T-tool is constructed with radio-opaque stainless steel. It consists of a horizontal arm which is 40 cm in length and a vertical arm with a length of 70 cm (Figure 1). In our institute, T-tool is routinely employed in all thoracolumbar/lumbar instrumentation surgeries since 2013. This retrospective study only includes patients with a preoperative spinal deformity.

Preoperative coronal and sagittal balance were evaluated via anteroposterior and lateral scoliosis X-rays. In cases with a suspected pelvic obliquity, orthorontgenograms were also obtained to measure the LLD. CT was used to evaluate osseous anatomy and the previous instrumentation construct. Intervertebral disc pathologies and the status of the spinal canal were assessed via magnetic resonance imaging.

Radiological parameters measured included C7-CVA distance, coronal Cobb angle, pelvic obliquity, leg-length discrepancy. Sagittal imbalance was defined as a sagittal vertical axis (SVA) ⩾5 cm and/or pelvic incidence minus lumbar lordosis value more than 11. The preoperative and postoperative difference between Cobb angle of the coronal curve, and C7-CVA were compared. Age, gender, number of instrumented levels, insertion of anterior interbody cages and iliac screws, insertion of accessory rods were also recorded.

Surgical Procedure

The instrumentation construction was applied according to preoperative planning and necessary decompression of the neural structures are performed. Lateral flouroscopic images confirmed the correct positioning of the screws and the sagittal balance. The anteroposterior images were obtained with the T-tool for the evaluation of the coronal alignment.

In patients without any pelvic obliquity and/or LLD (<2 cm), the horizontal arm of the tool was aligned parallel to the superior border of the acetabular sourcil, targeting the midpoint of C7 spinous process to lay in the CSVL. In patients with pelvic obliquity and/or LLD (⩾2 cm), the horizontal arm is placed across the superior borders of the iliac crests and the vertical arm targets the CSPL. Coronal balance is confirmed if the superior end of the vertical arm is intersecting with the spinous process and the midline of the C7 spinous process. Malalignment was corrected with distraction or compression maneuvers as needed (Figure 2). The correction maneuvers were tailored based on the direction of the trunkal shift. In type 1 CM, distraction is applied on the convex side and compression is applied on the concave side. In type 2 CM, which is characterized by a trunkal shift toward the concavity, the distraction was performed on the concavity whereas the compression was applied on the convexity.

Statistical Analysis

The Microsoft Excel Programme for Windows v.16.91 was utilized for the statistical analysis of data. Descriptive statistics, including mean and standard deviation, were calculated for both preoperative and postoperative parameters. The statistical

Figure 1. The horizontal arm of the T-tool is 40 cm and the vertical arm is 70 cm. The device is constructed with stainless steel

comparison between the preoperative and postoperative Cobb angle of the coronal curve and the C7-CVA distance were conducted using paired sample t-tests. P-value <0.05 was accepted as statistical significance with a 95% confidence interval.

RESULTS

Between 2013 and 2023, a total of 1,882 patients received thoracolumbar/lumbar instrumentation surgery in our institution. Of 1,882 patients, 629 (33.42%) had a preoperative coronal plane deformity and were included in the study. The demographic information of the patients are presented in Table 1. The mean age was 55.79±22.74. One hundred and forty (22.26%) patients were male and 489 (77.74%) patients were female. Four hundred and one (63.75%) patients had an accompanying sagittal imbalance. The underlying pathology was degenerative in 553 patients (87.92%) and adolescent idiopathic scoliosis (AIS) in 76 patients (12.08%). Two hundred and ninety-one (46.26%) patients had a previous spinal surgery and 103 (16.38%) of these patients had a previously inserted instrumentation construct.

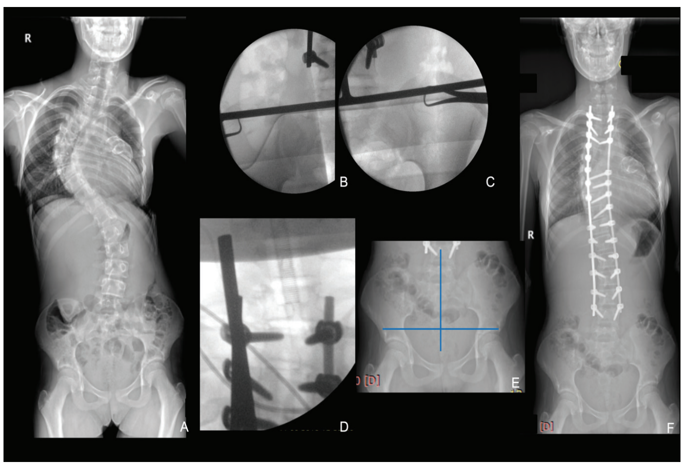

Figure 2. A 16-years old patient was operated on for AIS. (A) Preoperative scoliosis X-ray of the patient. (B-E) The patient had a preoperative LLD, therefore the T-tool was placed on the superior borders of the iliac crests and the construct was fixed considering the LLD. To achieve an optimal coronal alignment, the vertical arm should intersect the midline of the spinous process. (F) Postoperative scoliosis X-ray showed that the coronal balance was achieved in the patient
AIS: Adolescent idiopathic scoliosis, LLD: Leg length discrepancy

Preoperative radiographs showed that 31 (4.93%) patients had an isolated pelvic obliquity and 24 had pelvic obliquity with LLD. The mean number of instrumented vertebral levels was 8.78±4.62 per patient. Transforaminal lumbar interbody fusion cage was inserted in 374 (59.46%) and iliac screws were inserted in 211 (33.55%) patients.

According to the Obeid-CM classification[9], 349 (55.48%) patients had type 0 CM preoperatively. None of these patients had a postoperative iatrogenic CM. In 178 (99.36%) of 182 patients in the preoperative type 1 CM group, coronal alignment was achieved. In 93 (99.21%) of 98 patients with a preoperative type 2 CM, the malalignment was improved into type 0 CM. No patient exhibited progression or new-onset CM during the postoperative follow-up period. The difference in correction rates between CM types was not statistically significant ($p>0.05$). The mean preoperative C7-CVA was 27.16±11.44 and postoperative C7-CVA was 8.64±5.21 ($p<0.05$). The coronal Cobb angle was 24.90±21.13 degrees preoperatively and improved to 14.03±5.68 degrees postoperatively ($p<0.05$). These results indicate a statistically and clinically significant improvement in coronal alignment following surgery (Table 2).

Table 1. Preoperative demographic information of the patients

Age (mean ± SD)	55.79±22.74
Gender	
Female (n %)	489 (77.74%)
Male (n %)	140 (22.26%)
Deformity plane	
Coronal (n %)	228 (36.25%)
Coronal and sagittal (n %)	401 (63.75%)
Etiology	
AIS (n %)	76 (12.08%)
Degeneration (n %)	553 (87.92%)
History of previous spinal surgery	291 (46.26%)
Presence of spinal instrumentation (n %)	103 (16.38%)

SD: Standard deviation, AIS: Adolescent idiopathic scoliosis

Table 2. Preoperative and postoperative comparison of the radiological parameters and evaluation of the CM according to the Obeid-CM classification

	Preoperative	Postoperative
Obeid classification		
Type 0 (n %)	349 (55.48%)	620 (98.56%)
Type 1 (>3 cm; CSVL ipsilateral to the concavity) (n %)	182 (28.93%)	4 (0.64%)
Type 2 (>3 cm; CSVL contralateral to the concavity) (n %)	98 (15.58%)	5 (0.79%)
C7-CVA(o)	27.16±11.44	8.64±5.21
Coronal Cobb angle(o)	24.90±21.13	14.03±5.68

CM: Coronal malalignment, CSVL: Central sacral vertical line, C7-CVA: C7-coronal vertical axis

DISCUSSION

The primary aim of the spinal deformity surgery is to improve the quality of life and reduce pain via restoration of the sagittal and coronal balance[10]. Given the impact of studies concerning the role of coronal alignment on the postoperative outcomes, we evaluated the radiological outcomes of patients in whom we evaluated the coronal alignment intraoperatively via the T-tool. Our findings suggest that intraoperative T-tool is a simple and feasible device that improves C7-CVA distance even in patients with a preoperative pelvic obliquity with or without LLD.

Traditional approach for the coronal deformities of the spine consisted of performing a distraction maneuver on the concave side and compression on the convex side of the coronal curve[11]. However, this strategy was not universally applicable especially in complex deformities, thus it exacerbated the truncal imbalance in some patients. Therefore, classifications of the CM were proposed by several authors and tailored surgical strategies were adopted based on curve morphology and flexibility[9,12,13]. Obeid CM classification includes 6 distinct types of coronal deformity with a comprehensive review of surgical strategies for each type. The classification is based on the concavity of the CM, the flexibility and the localization of the coronal curve.

In our study, we subgrouped the patients preoperatively and postoperatively according to the Obeid classification. Most of our patients were in the CM 0 group. Four patients in the type 1 and 5 patients in the type 2 groups remained in the same group, despite an improvement in the Cobb angle and C7-CVA distance. These cases involved rigid deformities, which remained resistant to correction even after Schwab grade 3 or 4 osteotomies.

Several studies have highlighted the risk factors for postoperative CM and its impact on outcomes. In a retrospective cohort study, Zuckerman et al.[3] reported postoperative CM in 18% of adult spinal deformity patients and the most common risk factors were preoperative CVA/SVA, pelvic obliquity, Qiu B/C curves, lumbosacral fractional curve concavity to the same side of the CVA and the maximum Cobb angle concavity on the opposite side of the CVA. Interestingly, postoperative CM increased the complication rates, but was not associated with 2-year patient-reported outcomes, readmission and reoperation rates. Ruffilli et al.[14] identified preoperative trunk shift towards the convexity of the main curve (type C) and preoperative L5 tilt as the main risk factors for postoperative coronal imbalance. Lewis et al.[15] showed that patients with a postoperative coronal balance had an average L4 tilt of 11.2° while imbalanced patients had an average of 18.9°. A meta-analysis by Barile et al.[11] resulted in an overall incidence of CM of 26%. This study emphasized the role of preoperative SVA in iatrogenic CM.

In our cohort, patients with a preoperative type 0 and type 1 Obeid-CM patients showed better improvement in C7-CVA distance and coronal Cobb angle particularly in flexible curves. Several osteotomy types were used to correct the sagittal and coronal balance when the deformity was rigid. Anterior interbody cages and distraction at the concavity of the apical segment effectively reduced coronal deformity and shortened the number of instrumented levels. Rigid curves, however, required asymmetrical osteotomies or vertebral column resection for sufficient correction.

Intraoperative long-length anteroposterior radiographs remain the gold standard for evaluating the coronal alignment, however this method is not feasible in every institute because it requires long-length casettes and radiolucent operating table, increases the surgical time and radiation exposure[5]. Furthermore, in a study including 148 patients who had undergone AIS surgery, frontal balance goals were achieved in only 64.8% patients and residual shoulder and/or T1 imbalance persisted in one third of patients[5]. Several authors have presented their results with T-shaped device for intraoperative alignment assessment. Kurra et al.[8] presented the improved outcomes of 50 patients in whom five or more levels of fusion and extension to pelvis were performed with a usage of T-tool. The patients who underwent T-tool-guided surgery showed better improvement in CM and major coronal Cobb angle correction. Andras et al.[6] reported the use of T-square technique in neuromuscular scoliosis surgery optimized the postoperative sitting position of the patients.

A major limitation about the use of T-tool is that the device only evaluates the spinal coronal alignment but not the overall body balance in the standing position. Zhang et al.[7] proposed that even with the T-square rod technique, they have observed unsatisfactory postoperative coronal imbalance while standing or ambulation despite an optimal intraoperative coronal alignment. The reason for the persistent or iatrogenic malalignment was mainly attributed to the LLD or pelvic obliquity. To address this, the integrated global coronal aligner which consisted of a lower body aligner and an upper body part aligner was suggested[7]. Similarly, Lee et al.[4] compared the 2-year postoperative CVA in patients with/without pelvic obliquity, utilizing different intraoperative reference lines. The authors demonstrated that C7-intraoperative CSPL predicted the postoperative CVA at 2 years in patients without LLD with or without lower extremity compensation, while intraoperative CVA predicted the CVA at 2 years in patients with LLD with or without lower extremity compensation[4]. We adopted the same strategy and utilized the CSVL in patients without pelvic obliquity and LLD, and the CSPL in patients with pelvic obliquity and LLD. However, the patients with an LLD who accepted the use of a shoe lift postoperatively, the CSVL was utilized as a reference line to fix the instrumentation.

Operative treatment of CM is challenging since the coronal deformity is often complicated by coexisting sagittal imbalance and 3-dimensional correction maneuvers are usually necessary[16]. Makhni et al.[17] first described the kickstand rod technique for the correction of coronal imbalance, in which, bilateral support rods are inserted with additional iliac screws and a connector on the main rod in between the T10 and T12 vertebrae. Lateral lumbar interbody fusion (LLIF) has emerged as a less invasive option. Anterior vertebral release may correct the misalignment in coronal and sagittal planes along with the restoration of the disc height[18]. Hiyama et al.[19] presented the outcomes of LLIF in patients with CM and showed that the major Cobb angle improved significantly. In their series, 69.6% of patients with Obeid type 1A CM and 16.7% of patients with Obeid type 2A CM showed improvement in the coronal balance distance. The authors suggested that LLIF technique may be suitable in type 1 CM, however it may worsen the outcomes in type 2 CM, therefore alternative options such as the kickstand rod technique may be more feasible in type 2 CM[19]. Bao et al.[13] proposed a sequential correction technique integrating interbody fusion and compression-distraction maneuvers.

In our series, we applied compression-distraction techniques with the guidance of the T-tool. Insertion of an anterior interbody cage and distraction maneuver on the concavity of the apical segment of the coronal curve were feasible in all flexible deformities and decreased the C7-CVA and coronal Cobb angle. This technique also reduced the number of instrumented levels. In contrast, rigid curves were more resistant to correction often necessitating Schwab 3 or 4 osteotomies and/or vertebral column resection[20,21].

Study Limitations

There are several limitations to our study. This is a retrospective cohort study including only patients with a preoperative CM who underwent T-tool-guided instrumentation. We utilize the T-tool in almost all thoracolumbar instrumentation surgeries, especially in which the instrumented number of levels are three or more, therefore a true control group was not available. Moreover, the study population includes both AIS and degenerative deformity patients, which may affect generalizability. Further prospective studies are required to validate the impact of intraoperative T-tool use on specific deformity subtypes.

CONCLUSION

Postoperative coronal malalignment predisposes suboptimal clinical outcomes and negatively impacts the quality of life. Therefore, achievement of coronal alignment and avoiding iatrogenic CM are fundamental goals in spinal deformity surgery. T-tool is a feasible cost-effective and reliable device to determine the coronal balance intraoperatively. Based on our results, it should be used routinely in all thoracolumbar instrumentation procedures to enhance radiological outcomes and support optimal postoperative alignment.

Ethics

Ethics Committee Approval: Ethical approvement for this study was obtained from University of Health Sciences Türkiye, Ümraniye Training and Research Hospital, Ethical Committee (approval number: B.10.1.TKH.4.34.H.GP.0.01/435, date: 26.12.2024).

Informed Consent: Retrospective study.

Footnotes

Authorship Contributions

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

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