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JOURNAL OF TURKISH SPINAL SURGERY

EDITORIAL

Dear Colleagues,

It is my honor, once again, to have the privilege of producing our professional journal for you. This is the 2nd issue of the year, and. I am deeply grateful to all the authors, reviewers, assistant editors, secretaries, and the Galenos publishing team for the efforts they contributed to getting it published. We are thrilled to announce that JTSS is currently indexed in eleven indices; Scopus, Ulakbim, Türkiye Atıf Dizini, J-Gate, ProQuest, Gale Cengage Learning, Embase, EBSCO Host, Türk Medline, Ideal Online and China Knowledge Resource Integrated.

In this issue, you will find eight clinical research studies. The first is a retrospective clinical study which examines the "Mid-term Results of Young Adult Patients Who Underwent Autograft and Direct Pars Repair Using U-rod Technique for Lumbar Spondylolysis". The second is a study that discusses "Lumbar Spondylolysis: Are Ancillary Magnetic Resonance Imaging Findings Useful in Diagnosis?". The third is entitled, "The Impacts of Instrumented Posterior Fusion Surgery on Pulmonary Volume and Function in Adolescent Idiopathic Scoliosis". The fourth is about the "Intermediate to Long-Term Clinical and Radiological Results of Cervical Disc Prosthesis: A Comparative Study with Anterior Cervical Discectomy and Fusion". The authors of the fifth study looked at an "Intraoperative Evaluation of Spinal Coronal Alignment via T-square Shaped Tool in Thoracolumbar Instrumentation". The sixth study is entitled, "A Rare Cause of Postpartum Lower Back Pain: Sacrum Stress Fractures" while, in the seventh, the authors evaluated "Who Is More Successful in a Spinal Surgery Examination? ChatGPT-3.5/4.0 or an Orthopedic Resident?" The eighth article discusses "Warming Patients During Spinal Surgery."

I hope that each of you value these articles and the information that they contain, and that you find the insights they provide valuable to your daily practices. Our goal is to keep you on the cutting edge of all the latest developments in your respective fields. It is my sincere hope that this newsletter helps make this happen.

With kindest regards,

Editor in Chief

Metin Özalay, M.D.,

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MID-TERM RESULTS OF YOUNG ADULT PATIENTS WHO UNDERWENT AUTOGRAFT AND DIRECT PARS REPAIR USING U-ROD TECHNIQUE FOR LUMBAR SPONDYLOLYSIS

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ABSTRACT

Objective: This study aimed to present the clinical and radiological results of patients with spondylolysis (SL) with pars interarticularis defect who were treated with a pedicle screw and a U-shaped rod system passed under the spinous process.

Materials and Methods: A total of 26 patients with lumbar SL and pars fracture were included in the study. Their demographic characteristics were recorded. Patients with adjacent disc pathology and Grade 2, 3, 4 spondylolistheses were excluded. Clinical outcomes were evaluated with visual analog score (VAS) and Oswestry Disability Index (ODI) preoperatively and at the postoperative 3-year follow-up. Radiologically, union was evaluated with plain radiographs and computed tomography if necessary. Patients' return to their daily routine and sports were also evaluated.

Results: Of the 26 patients included in the study, 16 were male (57.1%) and 12 were female (42.8%). The mean age of the patients was 16.7±12.1 years (13-20). Patients were followed up for an average of 51.2 (36-78) months. The mean ODI score was 33.4±21.2 (24-46) and the mean VAS score was 8.1±1.2 (7-10) preoperatively, whereas the mean ODI score was 16.8±11.6 (10-21.4) and the mean VAS score was 1.4±2.3 (1-3) at the postoperative third year follow-up. Six patients who were professional athletes returned to their sports life at the eighth month. Patients' pars fractures were united. One (3.5%) patient underwent revision surgery due to delayed union. Superficial tissue infection developed on the wound site in one patient and was treated with daily dressing and oral antibiotherapy.

Conclusion: Good clinical and radiological results can be obtained in the young adult population with SL accompanied by pars fractures via polyaxial pedicle screws and U-shaped rod surgery.

Keywords: Lumbar spondylolysis, U-rod technique, pars defect, ODI, VAS

INTRODUCTION

Spondylolysis (SL) is a bone defect in the vertebral pars interarticularis with no slippage into the adjacent segment. SL is mostly seen at the L4 and L5 levels by 60%[1,2]. It is usually asymptomatic, and the majority of patients are treated with conservative therapies such as physical therapy, medical therapy, and lumbar corsets[3]. In cases where conservative treatment is unresponsive and the patient's complaints do not regress, surgical treatments stand out[4].

In surgical treatments, the most preferred method is lumbar interbody fusion surgery[5]. In fusion surgeries, both the mobile segment is sacrificed, and patients are exposed to the risk of adjacent segment disease. Therefore, direct repair of pars fractures is recommended especially for young patients[6,7].

Kimura[8] described bone grafting of the bone defect without using implants, but patients required prolonged postoperative bed rest and casting. Gillet and Petit[7] described pedicle screws and V-shaped smiley face rod, and later this surgical technique was modified and used with different names[9,10]. The authors reported that the protection of the capsuloligamentous structures is of vital importance in this surgery. In this technique, the aim is to close the defect by compression using a U-shaped bent rod that passes under the spinous process and is fixed with bilateral pedicle screws. In the literature, high satisfaction rates have been reported for this surgical technique[11-13].

In this study, we treated young adult SL patients with a u-shaped titanium rod and autograft and achieved good clinical and radiological outcomes. We aimed to share our mid-term results with the literature.

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MATERIALS AND METHODS

Ethical approval for the study was obtained from Memorial Şişli Hospital Ethics Committee (approval number: 004, date: 26.12.2024). In this retrospective study, datas were obtained retrospectively from the hospital database. This retrospective study was conducted in compliance with the ethical principles outlined in the Declaration of Helsinki. All patients were thoroughly informed about the study process, and written informed consent was obtained, detailing the surgical risks and potential complications.

A total of 28 patients diagnosed with lumbar SL and operated with the U-rod technique in our clinic between January 2018 and January 2022 were included in the study. The age, gender, and pars defect level of the patients were recorded. Demographic information of the patients was obtained from the hospital database. Patients were followed up for at least 3 years.

The inclusion criteria included being diagnosed with SL without spondylolisthesis, having persistent low back pain unresponsive to conservative treatment, having no weakness or loss of sensation in the lower extremities, having accessible data, and having regular follow-up visits. Patients with Grade 2, 3, 4 spondylolisthesis, radicular complaints and adjacent segment disc degeneration were excluded.

Patients were clinically evaluated according to their Oswestry Disability Index (ODI) and visual analog scale (VAS) scores in the preoperative period, early postoperative period, and postoperative third year follow-up. The time the patients returned to daily life and sports was recorded.

Radiological Evaluation

Spondylolisthesis was evaluated with anterior-posterior, lateral, flexion-extension dynamic radiographs in the preoperative period. Adjacent segment disc degeneration was assessed with preoperative lumbar MR imaging. Pars union was assessed with CT and radiographs taken in the postoperative period.

Statistical Analysis

Mean, standard deviation, median, minimum and maximum values were reported for numerical variables while frequency (n) and percentages (%) were given for categorical ones. Normality assumption was tested via Kolmogorov-Smirnov test. Student t-test was applied to compare 2 independent groups, and Wilcoxon test was performed to assess the dependent pre-op and post-op measures. Spearman correlation coefficients were provided to evaluate the relationship between preop-postop measures and other parameters in dataset. SPSS 21.0 IBM Corp. Released 2012. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp. was used for all analyses. Statistical significance was taken as $p \leq 0.05$ in all analyses.

Surgical Procedure

Surgical procedure performed in the study by Gillet and Petit[7] was performed. Patients were placed in the prone position and total intravenous anesthesia was administered. The L5 vertebra was marked with scopy and exposed with a midline insertion. Attention was paid to preserve the capsuloligamentous structures. Bilateral L5 pedicle screws were sent. Then the pars defect was debrided. Using the same incision, spongiosis autologous bone graft was taken from the iliac bone and the debrided fracture line was grafted. A 6 mm titanium rod was bent in the U-shape and passed under the L5 vertebral spinous process and fixed to the pedicle screws (Figure 1). The fractured pars defect was gently compressed over the rod. Hemovac drains were used in all patients and the layers were closed anatomically.

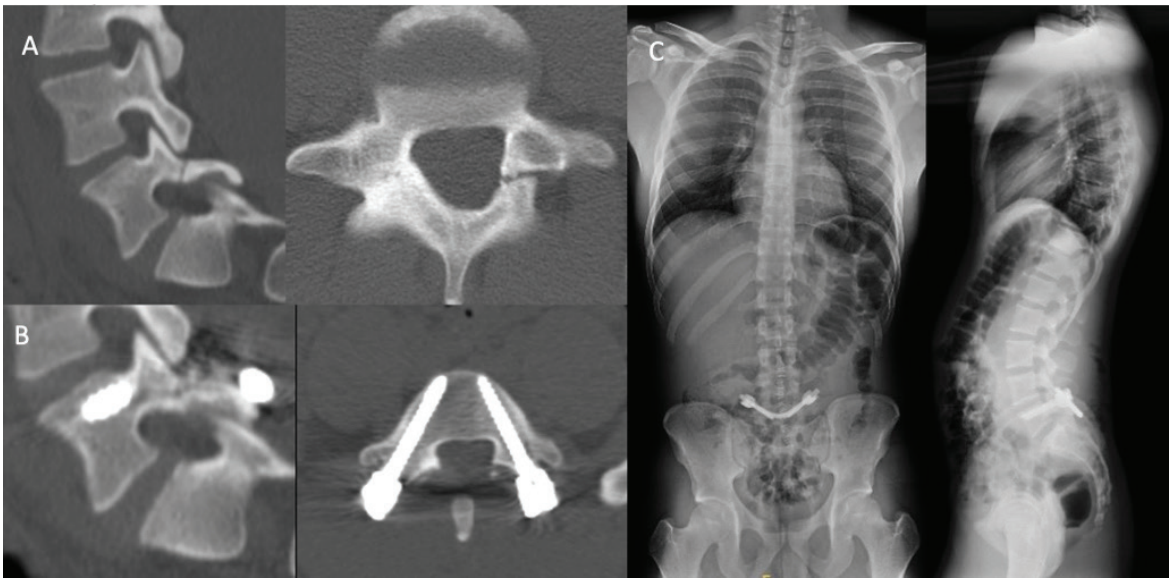

Figure 1. (A) Preoperative CT image of pars defect in one of the patients (B) CT image of complete fusion (C) postoperative radiographs
CT: Computed tomography

RESULTS

Of the 28 patients included in the study, 16 (57.1%) were female and 12 (42.8%) were male. The mean age of the patients was 16.7±12.1 years (range between 13-20). Patients were followed up for 51.2 months (range between 36-78). All patients had L5 pars fracture. The mean preoperative ODI score was 33.4±21.2 (24-46) and the mean VAS score was 8.1±1.2 (7-10). The mean ODI score was 16.8±11.6 (10-21.4) ($p<0.001$) and the mean VAS score was 1.4±2.3 (1-3) ($p<0.001$) at the postoperative third-year follow-up. Patients were able to perform their daily activities in the early postoperative period. At the first-year follow-up, all patients had no restriction in their lives and reached their pre-fracture sports activity levels. Six patients who were professional athletes returned to their sports life at the eighth month. In 28 patients, the pars fracture completely united, while one (3.5%) patient underwent revision surgery at the fourth month due to delayed union. In revision surgery, the fracture was debrided and grafted again with a graft taken from the iliac crest. Union was completed at the fifth month following revision surgery. Wound healing was delayed in one (3.5%) patient. The patient was treated with daily dressing and oral antibiotherapy.

DISCUSSION

In this retrospective study reports the mid-term results of autograft and U-shaped bent rod system applied in the treatment of young adult patients diagnosed with SL. Direct pars repair was performed with bone grafts taken from the patients' iliac bones and in this way, satisfactory clinical and radiology results were obtained.

In previous studies in the literature, similar results were obtained with the V-rod system in young patients with L5 SL[14]. In a systematic review conducted in 2011, 18 studies in which lumbar SL was directly repaired in young athletes were analyzed. It was reported that most of the patients had L5 vertebral fractures and that the average time to return to sports after surgery was 5-12 months[15]. In our study, young adult patients with pars defects at the L5 level were included in the study. Six patients who were professional athletes were allowed to return to sports at the end of the eighth month. Similar to the literature, we obtained good clinical and radiological results in our study.

In a previous study, 10-year results of patients treated with the U-rod technique were reported and a statistically significant decrease in ODI scores was observed[6]. In another study, patients who underwent scoliosis surgery and had a pars fracture were included in the study. In these patients, instead of including the fractured segment in the fusion, direct repair with V-rod was performed and good clinical results were achieved[16]. In this study, when the preoperative and postoperative third year postoperative ODI results were analyzed, a significant decrease was observed.

When the VAS scores of the patients were compared with their preoperative VAS scores, a statistically significant decrease was observed in the VAS score at the postoperative 3rd year follow-up. In the study conducted by Chen et al.[17] in 2013, 21 patients were operated with the V-rod system and a significant decrease was observed in the VAS score. In similar studies, a decrease was reported in the VAS scores of patients[6,16]. It was observed that the change in the VAS score in our study was consistent with the literature.

Although union was observed in all the 28 patients, revision surgery was performed in one patient due to delayed union. Superficial tissue infection in one patient was treated with daily dressing and oral antibiotics. There was no predisposing factor in the patient with delayed union. Despite these complications, this study demonstrated that good results can be achieved with the U-rod technique combined with autografting in the treatment of pars fractures without spondylolisthesis in the young adult population.

Study Limitations

This study had some limitations. In particular, the small number of cases and the single-center design were the most important limitations. In addition, the relatively short follow-up period and lack of evaluation of cost-effectiveness were other limitations.

CONCLUSION

Good results can be achieved with autologous bone graft from the iliac bone and the U-rod technique in young adult patients with pars defects and without spondylolisthesis. This technique can enable early return to sports, especially in young athletes.

Ethics

Ethics Committee Approval: The study was approved by the Memorial Şişli Hospital Ethics Committee (approval number: 004, date: 26.12.2024).

Informed Consent: All patients written informed consent was obtained.

Footnotes

Authorship Contributions

Surgical and Medical Practices: A.A., T.P., M.A., Concept: M.A., Design: M.A., Data Collection or Processing: T.P., Analysis or Interpretation: T.P., Literature Search: A.A., Writing: A.A.

Conflict of Interest: One author of this article, Tuna Pehlivanoğlu, is a member of the editorial board of the The Journal of Turkish Spinal Surgery. However, he did not take part in any stage of the editorial decision of the manuscript. The other authors declared no conflict of interest.

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

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ORIGINAL ARTICLE
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LUMBAR SPONDYLOLYSIS: ARE ANCILLARY MAGNETIC RESONANCE IMAGING FINDINGS USEFUL IN DIAGNOSIS?

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ABSTRACT

Objective: To determine the frequency of ancillary magnetic resonance (MR) findings in patients with lumbar spondylolysis.

Materials and Methods: The MR images of 88 patients (41 male, 47 female; 14-80 years old) diagnosed with lumbar spondylolysis at 90 levels were retrospectively reviewed. The control group consisted of 58 patients in the same age group who had only lumbar disc degeneration. The rates of ancillary findings were determined, including increased sagittal canal ratio (SCR), posterior wedging of the vertebral body lumbar index (LI), reactive marrow changes in the pedicle, and epidural fat interposition (EFI) on sagittal MR images. These rates were then directly compared with those obtained from direct interpretation of pars interarticularis defects on MR images.

Results: Pars defects were misdiagnosed in 25 levels (28%) when the MR images were evaluated directly. EFI was the most common finding, present in 73 levels (81%) of lumbar spondylolysis. An increase in SCR was observed in 66 pars defect levels (73%), and LI was present in 62 levels (69%). EFI showed the highest sensitivity (81.1%), while SCR demonstrated the highest specificity (96.6%) and positive predictive value (97.1%). Reactive bone marrow changes were observed in the pedicle in 20 levels (22%). In the absence of spondylolisthesis at the level of the lumbar pars defect, EFI was present in 78%, SCR in 60%, and LI of the vertebrae in 60%. Spondylolysis was correctly diagnosed in 84 of 90 levels (93%) when at least one ancillary finding was included in the MR evaluation.

Conclusion: Direct visualization and evaluation of the pars interarticularis defects in lumbar spondylolysis, combined with ancillary findings, enhances the diagnostic sensitivity of MR imaging.

Keywords: Spondylolysis, MR imaging, spine, pars interarticularis, isthmic spondylolisthesis

INTRODUCTION

Spondylolysis is a bony defect of the pars interarticularis (isthmus) of a vertebra, typically resulting from repetitive microtrauma in vertebral regions that are congenitally prone to stress fractures[1-3]. It occurs in approximately 6-8% of the general population, but among young adults engaged in intensive sports, the prevalence can exceed 40%, making it a significant cause of lower back pain[3-6]. Early conservative treatment is the gold standard for spondylolysis, providing an opportunity for intervention before the pars defect progresses to more severe stages. If left untreated, it can lead to instability and spondylolisthesis over time[5,7].

Magnetic resonance imaging (MRI) is the first-choice diagnostic modality for patients presenting with back pain or radiculopathy. However, because MRI primarily focuses on the intervertebral discs and foramina, bone defects in the pars interarticularis are often overlooked, owing to congenital morphological variations in the pars, as well as its sagittal or transverse obliquity[8]. In contrast, certain indirect MRI findings indicating a pars defect may support the diagnosis of spondylolysis[4]. These include an increased anteroposterior diameter of the spinal canal[9,10], wedging of the posterior vertebral body[4,11], bone marrow changes in the posterior elements at the defect level[12], and epidural fat interposition (EFI), which is an important indirect sign supports the diagnosis of a pars interarticularis defect, it has been addressed in only a few studies[13].

This study aimed to evaluate the frequency and diagnostic value of indirect MRI findings in patients with pars interarticularis defects, with or without spondylolisthesis.

MATERIALS AND METHODS

This retrospective study was approved by the institutional review board, which waived the requirement for informed consent. The study was approved by the İstanbul Medipol

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University of Non-Interventional Clinical Research Ethics Committee (approval number: 802, date: 29.08.2024).

The MRI of 88 patients diagnosed with lumbar spondylolysis between July 2016 and September 2024 were reviewed. Unilateral or bilateral pars interarticularis defects in these patients were diagnosed using conventional radiography. Lumbar computed tomography (CT) images were available for 32 patients. Patients with endogenous or exogenous cortisol exposure, scoliosis, spinal stenosis, disc herniation, sacral spinal canal enlargement, dural ectasia, or insufficient clinical data were excluded.

Among the patients, 41 were male and 47 were female, with ages ranging from 14 to 80 years, and a mean age of 46 years. Bilateral spondylolysis was present in 83 patients. In 78 (94%) of these patients, the pars defect was at the L5 level. The pars defect was recorded at the L4 and L3 levels in two patients each, and at the L2 level in one patient. Two patients with bilateral spondylolysis had pars interarticularis defects at two levels (L3 and L5, L4 and L5). Unilateral pars interarticularis defects were observed in five patients: four defects at L5 and one at L4. Spondylolisthesis was observed in 45 out of 90 levels. Only one level showed a Grade 2 slip, whereas all other levels exhibited Grade 1 slips. MRIs 58 aged matched (12-75 years old) patients selected to serve as a control subjects were also analyzed. This patients did have only disc degenerations and had never had lumbar surgery.

MRI was performed with a 1.5T system (Avanto; Siemens; Erlangen, Germany) using a spine coil. All patients were examined in the supine position. The MRI pulse sequences were as follows: sagittal, turbo spin- echo T1-weighted sequences [repetetion time/echo time (TR/TE), 704/11 msec; field of view (FOV), 30 cm; matrix, 320x256; section thickness, 4 mm]; sagittal, turbo spin- echo T2-weighted images (TR/TE, 4250/109 msec; FOV, 30; matrix, 384x288; section thickness 4 mm); sagittal, T2- fat suppressed sequences (TR/TE/inversion time, 5000/62/160 msec; FOV, 30 cm; matrix, 320x240; section thickness 4 mm); axial, turbo spin-echo T2-weighted sequences (TR/TE, 5010/112 msec; FOV, 20 cm; matrix, 256x166; section thickness 3 mm). Fat suppression was performed using the short-tau inversion recovery technique.

The CT examinations were conducted using a 16-section CT system (Scope 16, Siemens, Erlangen, Germany).

The imaging parameters were as follows: 80-130 kilovolt peak tube voltage, 100-300 milliampere-seconds effective tube current, 0.75 s rotation time, and 0.75-1.5 mm detector collimation.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 21.0 (IBM Corp., Armonk, NY, USA). Continuous variables were presented as mean ± standard deviation (SD) and median (minimum-maximum values), while categorical variables were expressed as frequencies (n) and percentages (%). A p-value <0.05 was considered statistically significant.

Sagittal Diameter of the Spinal Canal

The anteroposterior diameter of the spinal canal at the levels of spondylolysis and at L1 was measured using T1-weighted sagittal images[4,9,14]. At both levels, the first reference line was drawn tangent and parallel to the posterior border of the middle part of the vertebral body. Subsequently, a second parallel line was drawn along the anterior surface of the lamina at the spinolaminar junction of the same vertebrae. The midsagittal diameter of the spinal canal at this level was defined as the perpendicular distance between the two tangents (Figure 1).

The sagittal canal ratio (SCR) was used to normalize these measurements to the patient's anatomical variation. The SCR was calculated by dividing the midsagittal diameter of the spinal canal at the spondylolysis level by the midsagittal diameter at the L1 vertebral level. The normal mean values (±SD) of the SCR for each vertebral level were based on the analysis of data from 100 control subjects without spondylolysis[4,9]. The upper limit of the SCR (1.25) was adopted as a threshold to distinguish normal from abnormal values. When the SCR exceeded this limit at any level, an abnormally large midsagittal diameter was diagnosed[4,9], suggesting an open arch defect.

Wedging of the Posterior Vertebral Body

Wedging of the posterior aspect of the vertebral body at the level of spondylolysis is a characteristic finding observed in

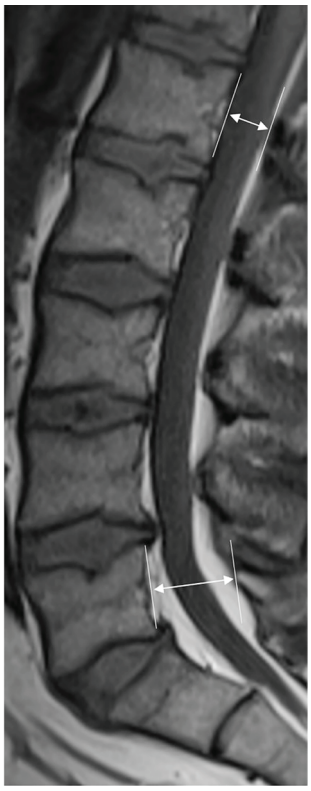

Figure 1. Thirty-eight-year-old woman with L5 spondylolysis. Midsagittal T1-weighted MR image shows that the midsagittal diameter of the spinal canal at the L5 level is increased compared to the diameter at L1 [sagittal canal ratio, (L5:L1)=1.39]
MR: Magnetic resonance

conventional radiography[4,11]. This wedging is also visible on the sagittal T1-weighted MRI of patients with spondylolysis. The lumbar index (LI) is calculated by dividing the height of the posterior aspect of the vertebral body by the height of the anterior aspect (normally, 0.87±0.06) (Figure 2). The LI is used to normalize the degree of wedging relative to the patient's anatomy. At the level of spondylolysis, an LI>2 SD below the normal range (<0.75) is classified as abnormal wedging of the posterior vertebral body.

Reactive Bone Marrow Changes

The signal intensity of the pedicles adjacent to the pars interarticularis defects was evaluated on T1- and T2-weighted sagittal MRI and compared with the signal intensity of the next higher-level pedicle on the same side of the spine (Figures 3, 4). Classification was based on the system developed by Modic et al.[15] for vertebral body changes in patients with degenerative disc disease.

- Type 1 changes; were characterized by decreased signal intensity on T1-weighted images and increased signal intensity on T2-weighted images of the pedicles adjacent to the defect. These changes are indicative of fibrovascular tissue in the pars interarticularis.

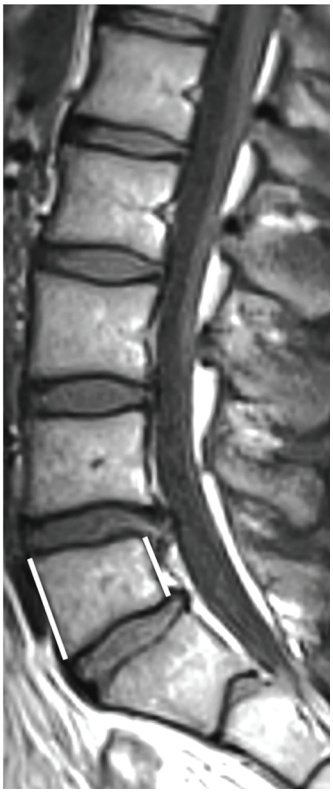

Figure 2. Twenty-four-year-old man with bilateral spondylolysis. Midsagittal T1-weighted MR image shows abnormally low ratio of height of posterior aspect of vertebral body (line 2) relative to height of anterior aspect of vertebral body (line 1) (lumbar index=line 2:line 1=0.55) at L5 level of spondylolysis. Also note increased midsagittal diameter of spinal canal at L5 level
MR: Magnetic resonance

- Type 2 changes; were characterized by increased signal intensity on both T1- and T2-weighted images, indicating fatty changes.
- Type 3 changes; showed decreased signal intensity in the pedicles on both T1- and T2-weighted images, indicative of sclerosis.

Epidural Fat Interposition

EFI refers to the fusion of posterior epidural fat pads, which are normally separated and layered between the dura mater and the spinous process. In spondylolysis, a pars defect in the isthmic lamina leads to biomechanical abnormalities in the vertebrae. The epidural fat pad, located between the dura mater and the spinous process of the vertebra, detaches from its usual position, causing the previously separated fat pads to merge. This appearance is described as the "continuous double hump sign" or EFI.[7,13] In patients with spondylolysis, the fusion of the epidural fat pads was assessed on midsagittal T1-weighted MRI at the vertebral level with a pars interarticularis defect (Figure 5).

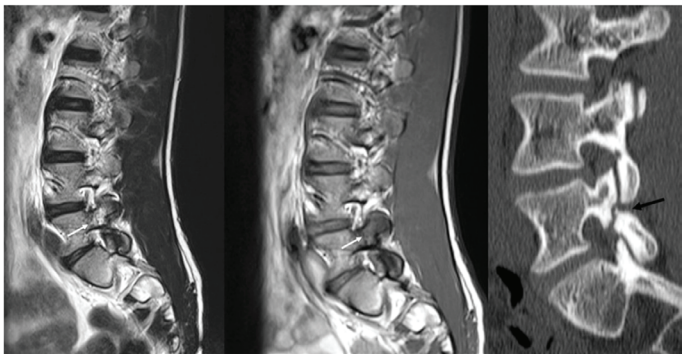

Figure 3. Seventeen-year-old man with spondylolysis and type 1 reactive marrow change at L5 level (arrows, A and B). It is characterized by increased signal intensity on T2-weighted images and decreased signal intensity on T1-weighted images. The sagittal reformatted CT scan confirms presence of defect in pars interarticularis at L5
CT: Computed tomography

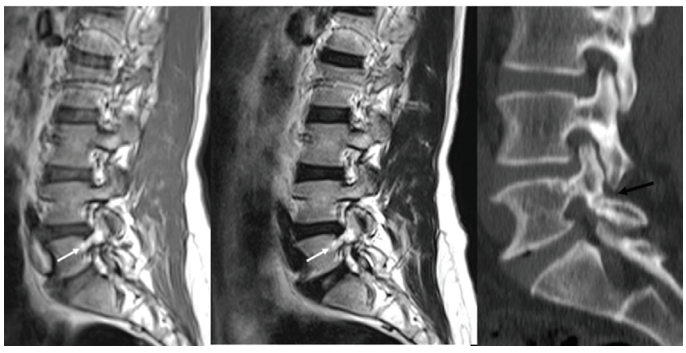

Figure 4. Forty-three-year-old man with spondylolysis and type 2 reactive marrow change at L5 level (arrows, A and B). It is characterized by increased signal intensity on T1 and T2-weighted. The sagittal reformatted CT scan confirms presence of defect in pars interarticularis at L5
CT: Computed tomography

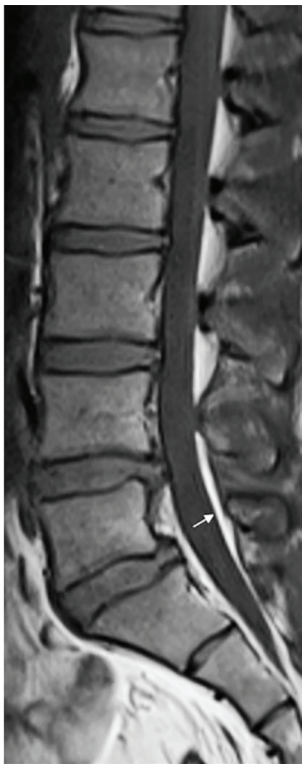

Figure 5. Twenty-two-year-old man with L5 spondylolysis. Mid-sagittal T1-weighted MR image demonstrates the separation between the dura mater and the spinous process of L5 with interposition of epidural fat between the two structures
MR: Magnetic resonance

Quality Assessment of Original Image Interpretation

In this study, we reviewed the initial radiological reports for all patients. Original interpretations were made by an experienced radiologist at our institution. The diagnostic accuracy of these interpretations was compared with the diagnoses established using conventional radiography or CT.

The sensitivity of the original interpretations was evaluated by comparing the frequency of supportive diagnostic findings observed in sagittal MRI with the total number of patients with spondylolysis. In most cases, conventional radiographs were obtained on the same day as the MRI. Consequently, the interpreting radiologist was unaware of the lumbar spondylolysis diagnosis when reviewing the MRI. Similarly, most CT examinations were performed at a later date, following the MRI studies, as is common in many hospitals.

RESULTS

Of the 88 patients referred for MRI, 63 (72%) were aged between 30 and 60 years. Spondylolysis was identified in 65 of the 90 levels (72%) on the initial MRI scans (Figure 6). Among the 25 misdiagnosed levels, 14 (56%) did not exhibit spondylolisthesis. Of the 25 patients with misdiagnosed levels, 17 (68%) were aged >40 years old. This aligns with the findings of Ulmer et al.[4], who suggested that pars interarticularis defects may be confused with findings of facet arthropathy or degenerative spondylolisthesis.

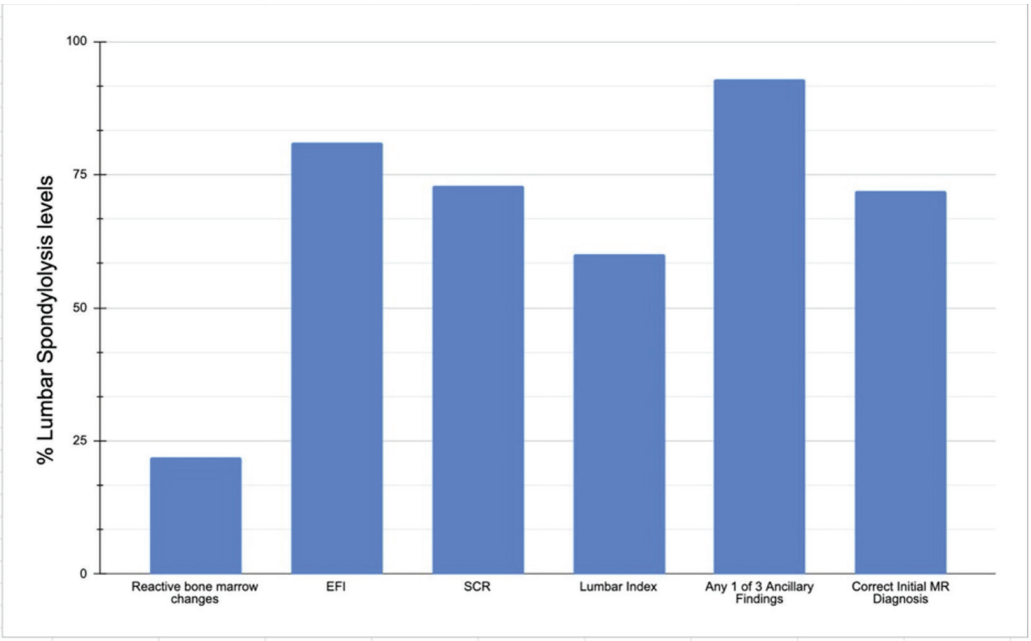

Figure 6. Bar chart shows proportion of patients with spondylolysis who had ancillary findings on sagittal MR images. Most patients showed epidural fat interposition (EFI) at level of spondylolysis. Fewer patients showed abnormally reactive marrow changes. Any one of three ancillary findings were present in 93% of patients examined. Spondylolysis was correctly diagnosed in 72% when the MR images were initially evaluated directly
MR: Magnetic resonance

Sagittal Canal Ratio

At 66 of the 90 lumbar spondylolysis levels (73%), the SCR was >1.25 (Figure 1), i.e., the anteroposterior diameter of the spinal canal was increased at the level of spondylolysis.

In 39 out of 44 levels (89%) with Grade 1 spondylolisthesis, an increased SCR was observed (range, 1.26-2.09). Elevated SCR (1.30) was also recorded in a single patient with Grade 2 isthmic spondylolisthesis.

Of the 45 levels with pars interarticularis defects but no spondylolisthesis, 25 (60%) exhibited abnormally elevated SCR values (range, 1.27-2.05). This finding is significant because it suggests the presence of isolated subluxation of the posterior elements[4].

In two of five patients with unilateral spondylolysis, an increased SCR was observed. In these patients, the pars interarticularis defect was located on the right side of L5. Increased SCR was present in only two patients (3.4%) in the control group.

Lumbar Index

In 62 of the 90 lumbar levels (69%), the LI measured on sagittal T1-weighted images was <0.75, indicating posterior wedging of the vertebral body (Figure 2). Of these, 61 were at the L5 level, and one at the L4 level.

Among the 45 levels without spondylolisthesis, 27 (60%) exhibited an LI <0.75. Of the 44 levels with Grade 1 spondylolisthesis, 32 (73%) had an LI <0.75. A single patient with Grade 2 spondylolisthesis also demonstrated an LI <0.75.

Posterior vertebral wedging was observed in three of the five patients with unilateral pars defects. Posterior vertebral wedging was presented in ten of 58 patients (%17) in the control group

Reactive Bone Marrow Changes

Reactive bone marrow changes were observed in 20 of the 90 lumbar levels with spondylolysis (22%), either in the pedicle of the vertebra with a pars defect or on the articular surface adjacent to the pars interarticularis defect (Figures 3, 4).

- Type 1 bone marrow changes associated with fibrovascular tissue in the posterior elements were noted in nine levels.
- Type 2 fatty bone marrow changes were observed in three levels.
- Type 3 changes, characterized by sclerosis, were present on the articular surfaces of eight lumbar levels.

The group with type 1 bone marrow changes in the posterior elements (average age, 27 years) was notably younger than the other two groups. Reactive bone marrow changes were observed in seven of 58 patients (12%) in the control group. Type 2 fatty bone marrow changes were presented in all patients

Epidural Fat Interposition

EFI was observed in 73 of 90 lumbar levels (81%) (Figure 5).

- Seventy-one were at the L5 level.
- Two were at the L2 and L3 vertebral levels.

In the L5 vertebra, three patients had unilateral pars interarticularis defects, while 68 exhibited bilateral defects.

Of the 45 levels without spondylolisthesis, EFI was present in 35 levels (78%). EFI was observed in only five of 58 patients (8.6%) in the control group.

The diagnostic performances of lumbar spondylolysis ancillary MRI findings are detailed in Table 1.

DISCUSSION

Pars interarticularis defects are typically first observed in radiographs obtained during late childhood or adolescence. These defects are often bridged by tissues comprising a mixture of fibrous, cartilaginous, or osseous materials, resulting in chronic non-unions. In some cases, healing and bony fusion may occur, accounting for 10-15% of cases with unilateral defects[4,5]. Pars interarticularis defects are located at the L5 vertebra in 90-95% of cases and are almost always bilateral. These defects are 2-4 times more common in males than in females[4].

In our study, spondylolysis was found at the L5 vertebra in 94% of cases and was bilateral in all but five patients. However, we observed no significant differences in the number of male and female patients.

Approximately 25% of the patients with lumbar spondylolysis develop lower back pain or radiculopathy later in life. The symptoms in these patients may stem from musculoskeletal strain, foraminal stenosis, facet or disc degeneration, disc herniation, or spinal canal narrowing[1,2,4].

Ulmer et al.[4] reported that a significant proportion of patients with lumbar spondylolysis are diagnosed using MRI at an age when degenerative facet disease and associated degenerative spondylolisthesis have developed. In their study, 40% of patients were diagnosed between the ages of 30 and 50 years, and 30% were diagnosed after the age of 50 years. In our study, the age of lumbar spondylolysis diagnosis based on MRI findings was 30-50 years in 50% of patients and >50 years in 40% of.

Table 1. The diagnostic performances of lumbar spondylolysis ancillary MRI findings

	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Negative predictive value (%)	Accuracy (%)
Sagittal canal ratio	73.3%	96.6%	97.1%	70.0%	82.4%
Lumbar index	68.9%	82.8%	86.1%	63.2%	74.3%
Reactive bone marrow changes	22.2%	87.9%	74.1%	75.0%	48.0%
Epidural fat interposition	81.1%	91.4%	93.6%	75.7%	85.1%

MRI: Magnetic resonance imaging

Direct radiography and CT are the imaging modalities that best visualize bony structures. CT is the most effective imaging technique for detecting spondylolysis in the presence of pars defects. However, CT can not clearly differentiate between active fractures and chronic non-unions[5,6,16].

On MRI, the fatty bone marrow in the normal pars appears bright on T1-weighted images, and this brightness is continuous. This appearance is present in only 30-66% of intact pars interarticularis structures[13]. Fat-suppressed T2-weighted MRI can detect acute bone marrow edema associated with spondylolysis[17]. Thin-section T1- and T2-weighted or contrast-enhanced MRI can increase the detection rate of pars defects[18,19]. Despite these advancements, there are certain limitations in the detection of pars interarticularis defects using MRI. Since MRI for back pain is generally performed with a focus on the intervertebral discs, oblique orientation of the pars interarticularis relative to the sagittal and transverse planes, sclerosis of the pars, facet osteoarthritis, or the partial volume effect caused by surrounding soft tissues can complicate the diagnosis of spondylolysis[5,6,13,16-18]. Additionally, incomplete pars defects in the absence of sclerosis or spondylolisthesis may present diagnostic challenges on MRI[4-6]. Progression of spondylolysis to spondylolisthesis in adults is rare and occurs infrequently after the age of 16 years[1,5].

In cases of spondylolisthesis, the anteroposterior diameter of the spinal canal increases with the anterior displacement of the vertebral body on midsagittal MRI is diagnostic without requiring additional markers. In spondylolysis without spondylolisthesis, isolated subluxation of the posterior elements can lead to expansion of the sagittal diameter of the spinal canal. This expansion is beneficial in distinguishing isthmic spondylolysis from degenerative spondylolisthesis[4-6].

In cases of spondylolysis without advanced displacement, the increase in the anteroposterior diameter of the spinal canal may be subtle, necessitating the calculation of the ratio between the spinal canal diameters at L5 and L1. In this study, 66 of 90 lumbar levels with spondylolysis (73%) exhibited a SCR >1.25. An increased SCR was observed in 89% of the 45 levels with isthmic spondylolisthesis. Additionally, 60% of the 45 levels without spondylolisthesis showed an increased SCR. These findings are consistent with those reported by Ulmer et al.[4].

The degree of wedging of the posterior vertebral body is associated with the degree of spondylolisthesis at the level of the pars interarticularis defect on radiography[4,10,11]. In our study, wedging of the posterior vertebral body was identified in 62 of the 90 lumbar levels (69%) on sagittal T1-weighted MRI. Of the 44 levels with Grade 1 spondylolisthesis, 32 (73%) exhibited wedging, whereas one level with Grade 2 spondylolisthesis exhibited wedging. However, as none of the patients had advanced spondylolisthesis beyond Grade 2, we could not evaluate the relationship between the degree of wedging and advanced spondylolisthesis.

Consistent with the findings of Ulmer et al.[4] We observed wedging of the posterior vertebral body in patients with spondylolysis without anterolisthesis. Wedging was observed in 27 of 45 levels without anterolisthesis (60%). Furthermore, wedging of the posterior vertebral body was identified in three of the five patients with unilateral pars defects.

We observed that wedging in a subset of patients with diagnostic difficulties may indicate the presence of a pars interarticularis defect[4].

In our study, reactive bone marrow changes were recorded in 22% of the 90 lumbar levels with spondylolysis, either in the pedicle of the vertebra with a pars defect or at the articular surface adjacent to the pars interarticularis defect. Reactive bone marrow changes were the least frequently observed indirect MRI finding supporting the pars defect in our study, which is consistent with previous research[4,12].

Type 1 reactive bone marrow changes are more common among adolescents[12,16]. These changes likely represent an intermediate phase between bone marrow damage in the pars interarticularis and the transition to regional fatty marrow, indicating a reparative response[12]. If the cause of bone injury is eliminated at this stage, the defect may not progress to a complete defect. However, if the injury persists, reactive fatty marrow changes (type 2) may develop, and chronic injury leads to bone sclerosis (type 3)[4,12].

In their study of 93 adolescents and young adults, Rush et al.[16] reported that reactive bone marrow edema in the pedicle or pars interarticularis observed on lumbar MRI during stress reactions may indicate a developing pars defect before a visible fracture is apparent on CT. The authors emphasized that early treatment at this stage could prevent the progression to a fracture.

In our study, the average ages of patients with type 1 and ype type 2 marrow changes were 38 and 33 years, respectively, whereas the group with type 3 changes, characterized by sclerosis in the pars interarticularis, had an average age of 61.

Reactive marrow changes associated with defects in the pars interarticularis can appear independent of other supporting observations, making them crucial clues for diagnosing spondylolysis using MRI[4,12].

In our study, EFI was observed in 81% of the 90 lumbar levels with spondylolysis. Sherif and Mahfouz[13] stated that the EFI observed on midsagittal T1-weighted MRIs between the dura mater and the spinous process of L5 represents the same pathological process as the increased anteroposterior diameter of the spinal canal at the level of a fractured pars interarticularis. In our study, EFI was the most common MRI finding indicating a pars interarticularis fracture. EFI was present in 78% of the 45 levels without spondylolisthesis. In cases of spondylolysis without displacement but associated with lumbar disc herniation, the specificity of EFI was reported to be 95%, sensitivity was 88.8%, positive predictive value was 94.11%, negative predictive value was 90.47%, and accuracy rate was 92.10%[7]. In a previous study by Güdü et al.[20], EFI was reported in 85% of 115 patients with spondylolysis. In our study, EFI showed the highest sensitivity (81.1%), while

SCR demonstrated the highest specificity (96.6%) and positive predictive value (97.1%). Reactive bone marrow changes had the lowest sensitivity (22.2%) and accuracy (48.0%), indicating limited diagnostic effectiveness as a standalone criterion. Conversely, EFI presented with the highest overall accuracy (85.1%), suggesting it as a robust ancillary MRI finding. LI demonstrated moderate sensitivity (68.9%) and specificity (82.8%) but relatively lower negative predictive value (63.2%). These findings suggest that while EFI and SCR are reliable indicators for lumbar spondylolysis, reactive bone marrow changes have limited diagnostic utility.

In this study, spondylolysis was correctly diagnosed in 93% (84 out of 90 levels) when assessed with one or more supporting findings on MRI.

Study Limitations

However, this study has some limitations. First, the retrospective nature of the study. Secondly, the relatively small sample size. As noted by Ulmer et al.[4], SCR may also increase in patients with dysplastic but intact neural arches. Posterior wedging of the vertebral body may be observed in patients with degenerative disc disease, and fatty changes in the pedicle or pars defects may be obscured by normal fatty marrow changes. The true sensitivity and specificity of MRI for lumbar spondylolysis requires further studies using blinded paradigms.

CONCLUSION

Although this study has some limitations, direct visualization of pars interarticularis defects combined with the assessment of ancillary findings, enhances the diagnostic sensitivity of MRI for lumbar spondylolysis.

Ethics

Ethics Committee Approval: The study was approved by the İstanbul Medipol University of Non-Interventional Clinical Research Ethics Committee (approval number: 802, date: 29.08.2024).

Informed Consent: Retrospectively study.

Authorship Contributions

Surgical and Medical Practices: B.K., B.O.G., Concept: B.K., B.O.G., Design: B.K., B.O.G., Data Collection or Processing: B.K., B.O.G., Analysis or Interpretation: B.K., B.O.G., Literature Search: B.K., B.O.G., Writing: B.K., B.O.G.

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

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THE IMPACTS OF INSTRUMENTED POSTERIOR FUSION SURGERY ON PULMONARY VOLUME AND FUNCTION IN ADOLESCENTS IDIOPATHIC SCOLIOSIS

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ABSTRACT

Objective: There is conflicting evidence regarding the effect of spinal deformity correction on pulmonary function in adolescent idiopathic scoliosis (AIS).

Materials and Methods: This study evaluated postoperative pulmonary function and capacity in AIS patients undergoing instrumented posterior fusion. Pulmonary parameters assessed included forced vital capacity (FVC), forced expiratory volume in 1 second (FEV1), total lung capacity (TLC), residual volume (RV), and the RV/TLC ratio. Postoperative results were compared with predicted values from a healthy community cohort. Subgroup analyses based on Cobb angle, age, and gender were also conducted.

Results: Instrumented posterior fusion surgery led to significant changes in TLC (p=0.000) and RV (p=0.014), with increased lung volumes postoperatively. However, there were no significant changes in the FEV1 and FVC ratios compared to predicted values (p=0.070 and p=0.142, respectively). When categorized by age, significant differences in FEV1 were observed in patients aged >16 years (p=0.037). Despite increased lung volumes, no significant impact on functional pulmonary capacity was found during the two-year follow-up.

Conclusion: Instrumented posterior fusion surgery increases lung volumes, such as TLC and RV, in AIS. However, these volume changes do not result in significant improvements in functional pulmonary capacity, like FVC and FEV1. This suggests that while the surgery may relieve some mechanical constraints, it does not fully restore pulmonary function. The limited functional recovery may be due to incomplete alveolar maturation during childhood. Further research is needed to explore the relationship between spinal deformities and pulmonary function, focusing on genetic and histological factors.

Keywords: Adolescent idiopathic scoliosis, instrumented posterior fusion surgery, pulmonary function, pulmonary volume, respiratory outcomes

INTRODUCTION

The main complaints of people with scoliosis include not only cosmetic problems, back pain, and psychological and social problems, but also cardiopulmonary disorders[1]. It is reported that pulmonary problems caused by scoliosis not only interfere with daily activities but also lead to premature death[2,3]. It has also been shown that thoracic scoliosis in particular is responsible for a significant reduction in lung capacity[4]. This can be attributed to either a decline in the biomechanics of the thorax or the completion of alveoli development during early infancy, namely between the ages of two and three years[2,5]. According to reports, individuals with AIS have inferior lung function and capacity in comparison to the healthy population with similar physiological features[6].

While the ultimate impact of instrumented posterior fusion surgery on pulmonary function remains undetermined, some studies have reported that this surgical method enhances pulmonary function[6-9]. However, other data suggest that posterior fusion surgery does not have a significant effect on pulmonary function[10-12]. The results of a study conducted by Lenke et al.[13] in 2002 on a total of 42 people showed that spinal fusion (both anterior and posterior) reduces the maximum oxygen uptake without affecting the overall capacity

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of the lungs. After a thorough review of the existing literature, we have come to the conclusion that the debates on this topic are still not closed.

An accurate diagnosis of respiratory diseases requires the use of reliable normal values. Lung capacity is strongly influenced by factors such as height, gender, and age. It is highly recommended that reference values should be updated regularly, especially as the paediatric and adolescent population continues to develop. Over the past three decades, there has been an improvement in nutrition and overall health. Additionally, there has been a shift in maturation patterns, with the onset of puberty occurring at a younger age. A comprehensive description of the computation of predictive values for lung volume based on population data has also been provided. Whole-body plethysmography is a technique employed to quantify lung volume, capacity, and resistance. This approach is very standardised, but it necessitates the use of specialised equipment, professionals with expertise in the field, and the patient's cooperation. Plethysmography utilises Boyle's law to quantify the intrathoracic gas volume, specifically the functional residual capacity. After establishing this, the remaining volume and total lung capacity (TLC) can be approximated[14].

This research aims to investigate the impact of instrumented posterior fusion surgery on lung function and lung capacity in adolescents diagnosed with idiopathic scoliosis.

MATERIALS AND METHODS

This study evaluated the preoperative and two-year postoperative plethysmography data of 40 patients who had instrumented posterior fusion surgery for adolescent idiopathic scoliosis (AIS) between 2015 and 2020. Consent form was filled out by all participants. The study was approved by Atatürk University Faculty of Medicine Clinical Research Ethics Committee (decision no: 03, date: 31.03.2023). During this period, approximately 30 cases per year underwent surgery at our center. However, only patients meeting the inclusion criteria were selected, which resulted in a total of 40 cases being analyzed in this study. Although the number of eligible patients was higher, many were excluded due to challenges in follow-up. Some patients were unable to complete the pulmonary function tests, while others declined participation. Additionally, a portion of the patients lived in rural areas and could not attend follow-up visits, and some relocated to different cities, making long-term evaluation difficult. Consequently, the final study cohort consisted of 40 patients who met the inclusion criteria and completed the necessary assessments. All surgeries were performed using a standard posterior approach, and intraoperative neuromonitoring was used in all cases. Patients with neuromuscular, congenital and early-onset were excluded from this study. At the time of surgery, some of these patients were already adults but had been diagnosed with AIS in the past, although they had not received any treatment for it (Figure 1).

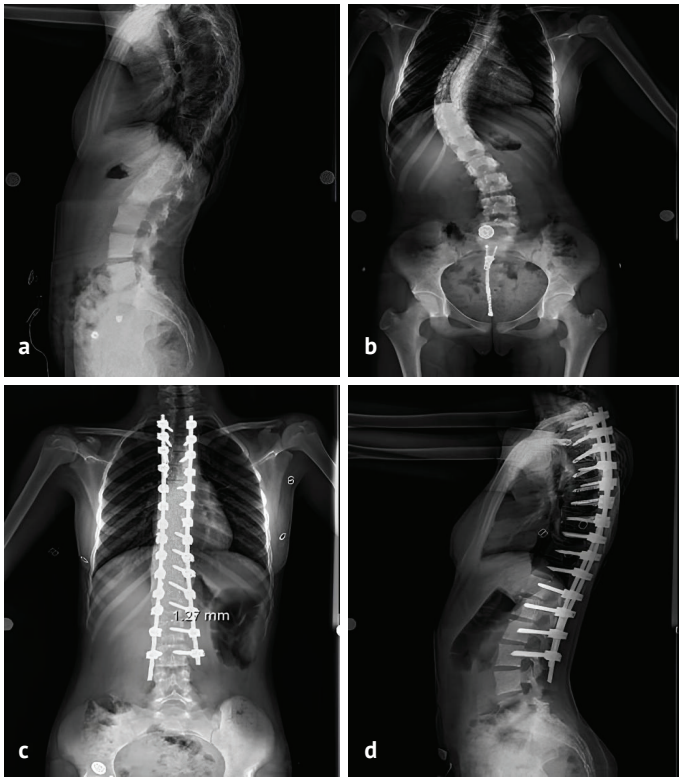


Figure 1. (a) Exemplary X-ray AP images of the patient before the surgical procedure, (b) exemplary X-ray lateral images of the patient before the surgical procedure, (c) exemplary X-ray AP images of the patient after the surgical procedure, (d) exemplary X-ray lateral images of the patient after the surgical procedure
AP: Anteroposterior

This is done with the help of plethysmography, taking into account factors such as age, gender, and Cobb angle. Measuring lung volume is essential for determining if the decrease in vital capacity is caused by a mechanical restriction or an increased dead space. Furthermore, the ratios of respiratory parameters to predictive values were calculated in this study in order to minimise the impact of physiological development and corrected actual height on the change in pulmonary function in adolescent patients.

All patients underwent instrumented posterior fusion surgery by the same surgeon. Furthermore, all patients underwent a breath test three times by the same technician and with the same device. Maximum exhaled air volume data were recorded and analysed by the body plethysmography method using a mouthpiece in a constant pressure cabin. The parameters of TLC, residual volume (RV), forced vital capacity (FVC), and forced expiratory volume in one second (FEV1) were all assessed. The data analysis and comparison were analysed by the same pulmonologist. Throughout the whole period of the trial, the patients did not undergo any type of rehabilitation. We presumed that establishing the correlation between these criteria and the data obtained from the patients, as well as the predictive data from healthy populations with similar features, would provide us with a more objective perspective (Figure 2).

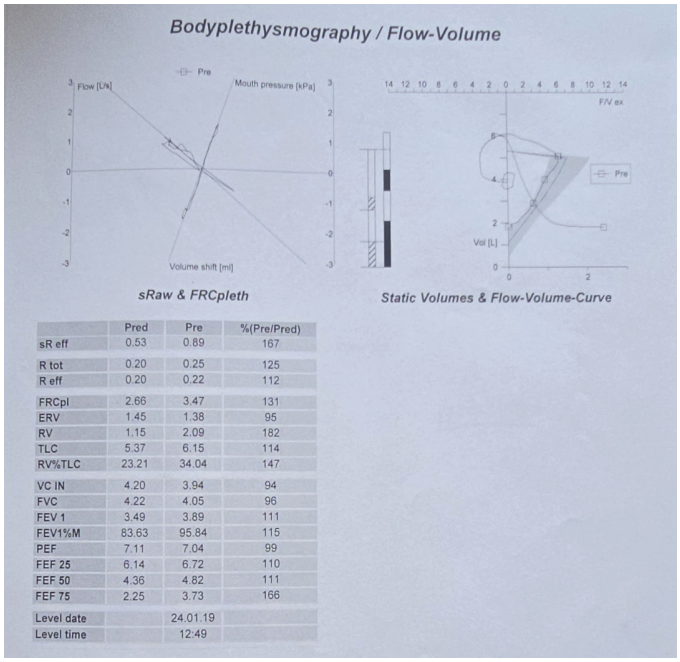
At the time of surgery, some of these patients were already adults but had been diagnosed with AIS during adolescence. Specifically, the 25-year-old patient included in the study was diagnosed with AIS in early adolescence but had not undergone treatment until adulthood. Therefore, the inclusion of this patient aligns with the study criteria.

Furthermore, all patients underwent a breath test three times by the same technician and with the same device. The tests were conducted by an experienced pulmonary function technician, and all data were evaluated by a pulmonologist specialized in respiratory function analysis. Maximum exhaled air volume data were recorded and analyzed by the body plethysmography method using a mouthpiece in a constant pressure cabin.

Statistical Analysis

The data were analysed using the Statistical Package for the Social Sciences (SPSS v20) software. While categorical variables were presented as numbers and percentages, numerical variables were presented as mean ± standard deviation and median (first quartile: Q1-third quartile: Q3). While the suitability of the numerical variables for the normal distribution was examined using the Kolmogorov-Smirnov test, the z-values calculated for skewness and kurtosis were analysed using graphical methods. The paired-samples t-test was used to compare subsequent measurements of variables that follow a normal distribution, while the independent-samples t-test was used to compare measurements between two independent groups. Consecutive measurements of non-normally distributed variables and comparisons for independent groups were carried out using the Wilcoxon test or the Mann-Whitney U test, respectively. The statistical significance level for all the analyses was set at $p<0.05$.

In the statistical power analysis of our study, a G*Power value of 67.56% was determined for the RV/TLC parameter.



	Pred	Pre	%(Pre/Pred)
sR eff	0.53	0.89	167
R tot	0.20	0.25	125
R eff	0.20	0.22	112
FRCpl	2.66	3.47	131
ERV	1.45	1.38	95
RV	1.15	2.09	182
TLC	5.37	6.15	114
RV%TLC	23.21	34.04	147
VC IN	4.20	3.94	94
FVC	4.22	4.05	96
FEV 1	3.49	3.89	111
FEV1%M	83.63	95.84	115
PEF	7.11	7.04	99
FEF 25	6.14	6.72	110
FEF 50	4.36	4.82	111
FEF 75	2.25	3.73	166
Level date		24.01.19	
Level time		12:49	

Figure 2. Results of a patient who underwent body plethysmography
FRCpl: Functional residual capacity (plethysmographic), ERV: Expiratory reserve volume, RV: Residual volume, TLC: Total lung capacity, VC IN: Inspiratory capacity, FVC: Forced vital capacity, FEV1: Forced expiratory volume in 1 second, PEF: Peak expiratory flow, FEF: Forced expiratory flow

RESULTS

Out of the total of 40 patients, 30 (75%) were female and 10 (25%) were male. Upon examination of the patients' ages at the time of surgery, we found that our youngest patient was 13 years old and our oldest patient was 25 years old. The mean age of our research group was 16.5 years. The patients' preoperative Cobb angles were measured, with the lowest angle recorded at 40°, the greatest angle at 115°, and the average Cobb angle at 67.90°.

Apart from minor skin infections, there were no complications. These infections were controlled with intravenous antibiotic treatment. There were no subacute or chronic infections, neurological complications, or complications associated with the pedicle screw. Additionally, no surgery-related issues were observed in the follow-up period, and all patients showed uneventful recovery.

Upon analysing the pulmonary function tests of the patients, we observed that the average FVC prior to the surgical procedure was 2,824, while the average FVC post-surgery was 3,164, which was determined to be of statistical significance (p=0.000). Prior to surgery, the average FVC to predictive values ratio was 79.25%. Nonetheless, it was observed that this ratio increased to 83.05% after the operation, even though this change did not meet the standards for statistical significance with a p-value of 0.142. Upon reviewing the data for FEV1, it was observed that the average value prior to the procedure was 2,476; however, this number increased to 2,835 after surgery. The observed change was deemed to be statistically significant, with a p-value of 0.000. The ratio of FEV1 to predictive values was 81.25% before surgery and increased to 86.55% postoperatively. However, this improvement was not of statistical significance (p=0.070).

The investigation of TLC revealed that the mean preoperative value was 4,052, which subsequently rose to 4,787 after surgery. This increase was found to be statistically significant (p=0.000). The preoperative average ratio of TLC to predicted values was 79.25%, which subsequently improved to 92.60% postoperatively, which was also found to be of statistical significance (p=0.000). The average preoperative RV in the lung was 1,408 but increased to 1,678 postoperatively. The RV in the lungs increased from 1,408 before surgery to 1,678 after surgery. The observed change was deemed to have statistical significance (p=0.014). The preoperative average ratio of RV to predicted values was 111.23%, which subsequently rose to 124.53% postoperatively. This shift was similarly deemed to be statistically significant (p=0.046).

The average RV/TLC% of the patients prior to surgery was 36,643, which fell to 35,170 after surgery. Nevertheless, this change did not fulfil the criteria for statistical significance (p=0.388). The preoperative ratio of RV/TLC% to predicted values was 142.237%, which decreased to 133.612% post-surgery. This change did not reach statistical significance (p=0.146). A more comprehensive analysis can be found in Table 1 with the full data.

Gender-based Parameter Comparison

We conducted an analysis of the patient population, categorizing them into two groups based on gender: female (n=30) and male (n=10). We first examined each group separately and then compared the two groups to each other. The statistically significant parameters in the changes in PFT data in our group of female patients were the TLC, the percentage of predicted TLC (pre/pred TLC%), the FEV1, the percentage of predicted FEV1 (pre/pred FEV1%), the FVC, the percentage of predicted FVC (pre/pred FVC%), the RV, and the percentage of predicted RV to TLC (pre/pred RV/TLC%).

Among our sample of male patients, the parameters TLC, pre/pred TLC%, pre/pred FMC%, and pre/pred RV% were shown to have a statistically significant impact on the changes seen in the PFT results. The data are displayed in Table 2.

Upon comparing two distinct gender groups, no statistically significant difference was seen for any of the parameters (Table 3).

An Analysis of Parameters Based on Age

We categorised our patients into two groups based on their age: those under 16 years of age (n=17) and those aged 16 years and older (n=23). We analyzed each group individually and then performed a comparative analysis. Our statistically significant parameters for changes in respiratory test data in the patient population aged 16 years and older were TLC, pre/pred TLC%, FEV1, FVC, RV, and pre/pred RV% values (Table 4).

Our statistically significant parameters for changes in respiratory test data in the patient population under 16 years of age were TLC, pre/pred TLC%, FEV1, FVC, RV, and pre/pred RV% values (Table 4).

Our statistical analysis revealed a statistically significant difference between the age groups only for the FEV1 metric (p=0.037) (Table 5).

Comparison of the Parameters According to the Cobb Angle

We divided the patients into two different groups according to their preoperative Cobb angle. Two different groups were formed: those with a Cobb angle below 80° (mild to moderate) (n=24) and those with a Cobb angle above 80° (severe) (n=16).

Table 1. Statistical data of the patients before and after surgery for comparison

	Mean	N	Std. deviation	95% Confidence interval	t	Significance (two-tailed)
TLC-preop	4,052	40	1.3409	-0.5229	-6,998	0.000
TLC-postop	4,787	40	1.4469			
TLC-pre/pred-preop%	79.25	40	17,859	-9,973	-7,997	0.000
TLC-pre/pred-postop%	92.60	40	19,910			
FEV1-preop	2,476	40	1.0568	-0.2096	-4,854	0.000
FEV1--postop	2,835	40	0.9775			
FEV1- pre/pred-preop%	81.25	40	25,964	0.456	-1,862	0.070
FEV1 -pre/pred-postop%	86.55	40	20,400			
FVC-preop	2,824	40	1.2196	-0.1890	-4,552	0.000
FVC-postop	3,164	40	1.1283			
FVC-pre/pred-preop%	79.25	40	23,697	1,333	-1,497	0.142
FVC-pre/pred-postop%	83.05	40	18,330			
RV-preop	1,408	40	0.6053	-0.0586	-2,585	0.014
RV-postop	1,678	40	1.0504			
RV-pre/pred-preop%	111.23	40	38,855	-0.265	-2,064	0.046
RV-pre/pred-postop%	124.53	40	60,868			
RV/TLC-preop%	36,643	40	15.3274	4.8827	0.874	0.388
RV/TLC-postop%	35,170	40	17.0022			
RV/TLC-pre/pred-preop%	142.237	40	45.7620	20.3708	1,485	0.146
RV/TLC-pre/pred-postop%	133.612	40	49.5038			

Pre/pred: Percentage of patient data to predictive data, Preop: Before surgery, Postop: After surgery, TLC: Total lung capacity, FEV1: Forced expiratory volume in 1 second, FVC: Forced vital capacity, RV: Residual volume, Std: Standard

Table 2. Evaluation and statistical analysis of the respiratory parameters within the groups according to gender

Gender		TLC	Pre/pred TLC%	FEV1	Pre/pred FEV1%	FVC
Female	Z	-4,021[b]	-4,209[b]	-3,692[b]	-3,137[b]	-3,569[b]
	Asymptotic significance (two-tailed)	0.000	0.000	0.000	0.002	0.000
Male	Z	-2,803[b]	-2,666[b]	-1,478[b]	-1,632[c]	-1,478[b]
	Asymptotic significance (two-tailed)	0.005	0.008	0.139	0.103	0.139
Gender		Pre/pred FVC%	RV	Pre/pred RV%	RV/TLC%	Pre/pred RV/TLC%
Female	Z	-2,488[b]	-2,531[b]	-1,337[b]	-1,265[c]	-2,108[c]
	Asymptotic significance (two-tailed)	0.013	0.011	0.181	0.206	0.035
Male	Z	-2,052[c]	-1,326[b]	-2,142[b]	-0.051[c]	-0.866[c]
	Asymptotic significance (two-tailed)	0.040	0.185	0.032	0.959	0.386

Pre/pred: Percentage of patient data to predictive data, [b]Based on negative ranks, [c]Based on positive ranks, TLC: Total lung capacity, FEV1: Forced expiratory volume in 1 second, RV: Residual volume

Table 3. Statistical analysis of the values of male and female gender as two different groups

	TLC	Pre/pred TLC%	FEV1	Pre/pred FEV1%	FVC
Mann-Whitney U test	124.000	144.500	136.000	141.000	115.500
Wilcoxon W	589.000	609.500	191.000	196.000	170.500
Z	-0.812	-0.172	-0.437	-0.282	-1,078
Asymptotic significance (two-tailed)	0.417	0.863	0.662	0.778	0.281
	Pre/pred FVC%	RV	Pre/pred RV%	RV/TLC%	Pre/pred RV/TLC%
Mann-Whitney U test	108.000	149.500	139.500	102.000	115.000
Wilcoxon W	163.000	614.500	194.500	567.000	170.000
Z	-1,316	-0.016	-0.328	-1,499	-1,093
Asymptotic significance (two-tailed)	0.188	0.988	0.743	0.134	0.274

Pre/pred: Percentage of patient data to predictive data, TLC: Total lung capacity, FEV1: Forced expiratory volume in 1 second, FVC: Forced vital capacity

Table 4. Evaluation and statistical analysis of patients under and over 16 years of age within the groups

Age		TLC	Pre/pred TLC%	FEV1	Pre/pred FEV1%	FVC
<16	Z	-3,351[b]	-3,012[b]	-2,642[b]	-0.994[b]	-2,272[b]
	Asymptotic significance (two-tailed)	0.001	0.003	0.008	0.320	0.023
⩾16	Z	-3,619[b]	-3,916[b]	-2,840[b]	-1,887[b]	-3,243[b]
	Asymptotic significance (two-tailed)	0.000	0.000	0.005	0.059	0.001
Age		Pre/pred FVC%	RV	Pre/pred RV%	RV/TLC%	Pre/pred RV/TLC%
<16	Z	-0.398[b]	-3,297[b]	-2,926[b]	-0.454[c]	-1,306[c]
	Asymptotic significance (two-tailed)	0.691	0.001	0.003	0.650	0.191
⩾16	Z	-1,502[b]	-1,292[b]	-0.969[b]	-1,386[c]	-1,655[c]
	Asymptotic significance (two-tailed)	0.133	0.196	0.333	0.166	0.098

Pre/pred: Percentage of patient data to predictive data, [b]Based on negative ranks, [c]Based on positive ranks, TLC: Total lung capacity, FEV1: Forced expiratory volume in 1 second, FVC: Forced vital capacity, RV: Residual volume

The statistically significant parameters in our group of patients with Cobb angles <80°, both before and after surgery, were TLC, pre/pred TLC%, FEV1, pre/pred FEV1%, FVC, and RV values (Table 6).

When comparing two different groups separated by the Cobb angle, no statistically significant difference was found for any of the parameters (Table 7).

Table 5. Data from the statistical comparison of the two groups by age

	TLC	Pre/pred TLC%	FEV1	Pre/pred FEV1%	FVC
Mann-Whitney U test	182.000	150.000	113.000	180.500	134.000
Wilcoxon W	302.000	475.000	438.000	505.500	459.000
Z	-0.154	-1,049	-2,082	-0.196	-1,495
Asymptotic significance (two-tailed)	0.878	0.294	0.037	0.845	0.135
	Pre/pred FVC%	RV	Pre/pred RV%	RV/TLC%	Pre/pred RV/TLC%
Mann-Whitney U test	153.500	175.000	118.500	138.000	179.000
Wilcoxon W	478.500	295.000	238.500	258.000	299.000
Z	-0.953	-0.350	-1,929	-1,383	-0.237
Asymptotic significance (two-tailed)	0.341	0.727	0.054	0.167	0.812

Pre/pred: Percentage of patient data to predictive data, TLC: Total lung capacity, FEV1: Forced expiratory volume in 1 second, FVC: Forced vital capacity, RV: Residual volume

Table 6. Evaluation and statistical analysis of the data within the groups according to the Cobb angle

Cobb		TLC	Pre/pred TLC%	FEV1	Pre/pred FEV1%	FVC
<80	Z	-3,670[b]	-3,700[b]	-3,150[b]	-2,221[b]	-3,112[b]
	Asymptotic significance (two-tailed)	0.000	0.000	0.002	0.026	0.002
⩾80	Z	-3,296[b]	-3,299[b]	-2,732[b]	-0.440[b]	-2,480[b]
	Asymptotic significance (two-tailed)	0.001	0.001	0.006	0.660	0.013
Cobb		Pre/pred FVC%	RV	Pre/pred RV%	RV/TLC%	Pre/pred RV/TLC%
<80	Z	-1,657[b]	-2,109[b]	-1,690[b]	-0.902[c]	-1,511[c]
	Asymptotic significance (two-tailed)	0.098	0.035	0.091	0.367	0.131
⩾80	Z	-0.189[b]	-2,041[b]	-1,508[b]	-0.973[c]	-1,287[c]
	Asymptotic significance (two-tailed)	0.850	0.041	0.131	0.331	0.198

Pre/pred: Percentage of patient data to predictive data, [a]Wilcoxon signed ranks test, [b]Based on negative ranks, [c]Based on positive ranks, TLC: Total lung capacity, FEV1: Forced expiratory volume in 1 second, FVC: Forced vital capacity, RV: Residual volume

Table 7. Comparison and statistical analysis between the two groups according to the Cobb angle

	TLC	Pre/pred TLC%	FEV1	Pre/pred FEV1%	FVC
Mann-Whitney U	176.500	158.500	118.000	179.000	138.500
Wilcoxon W	527.500	509.500	223.000	530.000	243.500
Z	-0.156	-0.667	-1,816	-0.085	-1,234
Asymptotic significance (two-tailed)	0.876	0.505	0.069	0.932	0.217
	Pre/pred FVC%	RV	Pre/pred RV%	RV/TLC%	Pre/pred RV/TLC%
Mann-Whitney U	151.000	160.000	162.000	177.000	136.000
Wilcoxon W	502.000	265.000	267.000	282.000	487.000
Z	-0.882	-0.624	-0.568	-0.142	-1,304
Asymptotic significance (two-tailed)	0.378	0.532	0.570	0.887	0.192

Pre/pred: Percentage of patient data to predictive data, TLC: Total lung capacity, FEV1: Forced expiratory volume in 1 second, FVC: Forced vital capacity, RV: Residual volume

Apart from minor skin infections, there were no complications. These infections were controlled with intravenous antibiotic treatment. There were no subacute or chronic infections, neurological complications, or complications associated with the pedicle screw.

DISCUSSION

Studies have already been conducted on the relationship between instrumented posterior fusion surgery and pulmonary function in individuals with scoliosis. To add to the existing knowledge in literature, the present study investigated the previously unexplored relationship between the ratio of RV to TLC (RV/TLC%) and its association with predictive values.

Our study has demonstrated that while surgical therapy led to an increase in lung capacity, it did not have a significant impact on pulmonary function. Furthermore, no significant correlation was found between patients' age, gender, Cobb angle values, and lung capacities and functions. The patients' postoperative measurements of TLC and RV indicate that the surgical treatment successfully addressed the deformity in three dimensions but did not have any impact on lung parenchyma or function. Given that the development of deformity began after the age of 10 in the AIS patients investigated in the present study, the lack of recovery of the lungs suggests that the problem should be considered earlier or as multifactorial. Previous publications have reported that patients complete ninety per cent of their alveolar maturation by the age of seven[5]. It has been noted that the lung, which has reached its advanced stage of development at the age of seven years, does not return to its original state after correction of the chest wall deformity that occurs after the age of ten years. One possible explanation for this condition is that it may be related to the limited ability of the alveoli to regenerate. Alternatively, it might be due to the interaction between the collagens that affect the alveolar surface. Another issue to consider is the role of hereditary factors in the development of both alveoli and scoliosis. Further investigation is needed to determine the exact cause.

In our study, all patients had thoracic scoliosis, and sagittal plane deformities such as hypokyphosis or hyper kyphosis were also considered. The extent of postoperative correction was evaluated; however, its direct impact on pulmonary function tests remains unclear. Although thoracic deformities and sagittal balance may influence respiratory mechanics, further studies with larger cohorts and detailed subgroup analyses are required to clarify their role in pulmonary function outcomes.

Ankylosing spondylitis is known to hinder lung capacity and pulmonary functions as a result of kyphosis. Research done in individuals with ankylosing spondylitis found that lung volume and lung function showed considerable improvement at the two-year follow-up after correcting the spinal deformity with osteotomy and fusion[15,16]. Although surgical correction can restore lung function in people with kyphosis, a condition that affects the connective tissue of the skeletal system and leads to lung damage, scoliosis patients can potentially increase their lung volume. Nevertheless, the lack of improvement in pulmonary function leads us to assume that there could be a link between lung tissue and AIS. Studies have been conducted on abnormal collagen metabolism and the impact of hereditary variables on the collagen structure of intervertebral discs as potential causes of scoliosis[17].

In a study in which the individual volumes of the right and left lungs were analysed using computed tomography scans in people with scoliosis, no statistically significant difference was found in the total volume changes and the differences between the two sides[12]. Our study, in contrast, has revealed a notable rise in the overall volume. Furthermore, after this study, the question of whether there is an increase in volume on the convex side and a decrease in volume on the concave side after the reconstructed deformity is no longer relevant.

There are studies that show an improvement in pulmonary parameters and functional capacity after a 12-week supervised physiotherapy programmed in children and adolescents with mild or moderate idiopathic scoliosis. Nevertheless, patients who underwent rehabilitation still exhibit poorer values for respiratory parameters and assessments of functional capacity compared to the control group. This study demonstrates the essentiality of engaging in physical exercise following deformity treatment to enhance pulmonary function and overall functioning[18]. Non-invasive rehabilitation techniques may not stimulate lung growth and maturation, but they do prevent lung function from deteriorating[19]. In our study, patients had a standard physiotherapy regimen for six months starting from the third month post-surgery. However, no specialized rehabilitation targeting respiratory function was administered.

The limited population of our study can be attributed to the extended duration of the follow-up period and the challenges associated with conducting pulmonary function tests. Despite initially enrolling 96 patients in the trial, we were only able to evaluate the data of 40 individuals at the conclusion of the follow-up period.

Our study would not only be more useful but also more significant if we had the opportunity to compare it with patients who needed scoliosis surgery but were not operated on. Our study has neither a control group nor results. Therefore, we do not know how respiratory function changes in patients that undergo surgery compared to when surgery is not performed on scoliosis patients.

We are currently conducting ongoing research on this subject. Our primary objectives are to enhance patient volume and extend the duration of follow-up. In addition, patients with scoliosis who have not yet undergone surgery are also being registered. A control group was established by taking advantage of spirometry and plethysmography techniques for measurements. Upon the completion of our forthcoming study, which serves as a direct extension of the ongoing study, its findings will be made publicly available.

CONCLUSION

This study investigated the relationship between instrumented posterior fusion surgery and pulmonary function in individuals with scoliosis, focusing on the previously unexplored association between the ratio of RV to TLC (RV/TLC%) and its predictive value. Our findings indicate that while surgical intervention effectively increased lung volume, it did not significantly improve pulmonary function. This suggests that the structural correction of the deformity does not directly translate into functional recovery of lung tissue.

The absence of a significant correlation between patients' age, gender, Cobb angle, and pulmonary function supports the notion that multiple factors contribute to the respiratory limitations observed in scoliosis patients. The lack of lung function improvement despite increased lung volume highlights the need for further investigation into the role of alveolar development, collagen metabolism, and hereditary factors in scoliosis-related pulmonary dysfunction.

Ethics

Ethics Committee Approval: The study was approved by Atatürk University Faculty of Medicine Clinical Research Ethics Committee (decision no: 03, date: 31.03.2023).

Informed Consent: Consent form was filled out by all participants.

Footnotes

Authorship Contributions

Surgical and Medical Practices: B.P., S.Y., O.K., Concept: B.P., O.K., Design: B.P., S.Y., S.Yılm., B.K., Data Collection or Processing: B.P., S.Y., B.K., Analysis or Interpretation: S.Yılm., B.K., Literature Search: B.P., S.Yılm., E.Ş., Writing: B.P., S.Y., E.Ş., O.K.

Conflict of Interest: The authors have no conflicts of interest to declare.

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INTERMEDIATE TO LONG-TERM CLINICAL AND RADIOLOGICAL RESULTS OF CERVICAL DISC PROSTHESIS: A COMPARATIVE STUDY WITH ANTERIOR CERVICAL DISCECTOMY AND FUSION

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ABSTRACT

Objective: As an alternative to anterior cervical discectomy and fusion (ACDF), cervical disc replacement (CDR) has become more popular over time because it is more suitable for cervical biomechanics. The aim of this study was to evaluate the intermediate- to long-term clinical and radiological results of polyetheretherketone cage CDR and compare them with the results of ACDF.

Materials and Methods: We retrospectively analyzed 39 cases following single-level CDR and 36 cases following single-level ACDF. Surgical levels treated in both groups included C3-4, C4-5, and C5-6, without any procedure performed on C6-7. Evaluations included adjacent segment disease (ASD), segmental range of motion (ROM), disc height, cervical lordosis, neck disability index (NDI), and the Visual Analogue Scale (VAS).

Results: At a mean follow-up of over 5 years, both groups were significantly improved in VAS and NDI ($p<0.01$). Both groups had an increase in cervical lordosis and disc height, albeit greater in the CDR group ($p<0.05$). Segmental ROM was maintained in the CDR group (9.0°), whereas it was significantly restricted in the ACDF group (1.1°, $p<0.001$). Moreover, the rate of postoperative ASD was significantly lower in the CDR group (2.6%) than that in the ACDF group (16.7%, $p=0.03$). Heterotopic ossification developed in 10.2% of the CDR group, without any symptomatic manifestations. Two revision surgeries were needed in the ACDF group, whereas none were needed in the CDR group.

Conclusion: CDR provides comparable symptom alleviation to ACDF, and also enables greater maintenance of motion, better alignment, and significantly less risk of ASD.

Keywords: Cervical disc prosthesis, disc height, cervical lordosis, motion preserve, spine motion

INTRODUCTION

Anterior cervical discectomy and fusion (ACDF) has been the gold standard treatment method for many years in the treatment of cervical degenerative disc disease (CDDD) refractory to conservative treatment[1]. However, in the future, a secondary surgery may be needed to treat the adjacent segment disease (ASD) that develops in patients. In addition, complications such as instrument related complications and failure to develop fusion may create disadvantages in fusion surgery[2]. On the other hand, as an alternative to arthrodesis, cervical disc replacement (CDR) has become more popular over time because it is more suitable for cervical biomechanics[3]. CDR theoretically provides anatomical disc space, normal segmental lordosis, and demonstrates a physiological movement pattern[4]. It is a new generation cervical disc prosthesis and is used in the surgical treatment of symptomatic CDDD. This study aims the compare the intermediate to long-term outcomes of polyetheretherketone (PEEK)-based disc prostheses to the clinical and radiologic outcomes of ACDF in a matched cohort.

MATERIALS AND METHODS

This was a retrospective study of 39 patients (21 males and 18 females, of mean age 38.9 years, range, 26-58 years) underwent single-level CDR using a PEEK cervical disc prosthesis. In another group 36 patients (19 males, 17 females; mean age: 39.3 years, range: 27-60) underwent single-level ACDF. In the ACDF group, a standard PEEK interbody cage was used for fusion at the operated level. Surgical levels were C3-4 in 3 CDR (7.7%) and 4 ACDF (11.1%) cases, C4-5 in 9 CDR (23.1%) and 8 ACDF (22.2%) cases, C5-6 in 22 CDR (56.4%) and 19 ACDF (52.8%) cases, and C6-7 in 5 CDR (12.8%) and 5 ACDF (13.9%) cases.

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All participants were observed for at least 18 months. Informed consent was obtained from each of them and the study was approved by the Ağrı İbrahim Çeçen University Institutional Ethics Committee (decision number: 189, date: 28.09.2023). All procedures were strictly followed in accordance with relevant guidelines and regulations.

Surgical indications included single-level symptomatic CDDD between C3 and T1, with radiculopathy or myelopathy that failed to improve after at least 6 weeks of conservative treatment. Patients were excluded from the study if they were older than 65 years of age, had osteoporosis, metabolic bone disease, congenital or post-traumatic deformity, segmental instability (translation >3.5 mm or angulation >11°), or if they had a history of cervical surgery. Patients without complete preoperative or follow-up clinical data were also excluded from analysis.

A clinical assessment, which included the Visual Analog Scale (VAS) and neck disability index (NDI), was obtained preoperatively and upon final follow-up. Radiologic parameters were disc height (measured as the average of the anterior and posterior vertebral heights), cervical lordosis (range of C2-C7 Cobb angle), segmental range of motion (ROM), and assessment of ASD. Preoperative modalities included anterior-posterior (AP) and dynamic X-rays, computed tomography, and magnetic resonance imaging. Follow-up was assessed using AP, lateral, and dynamic lateral X-rays (Figure 1). ROM was recorded using the Cobb method as obtained on flexion-extension X-rays. In 10 cases, segmental ROM in C6-7 was impossible to measure due to shoulder overlap. Measurements were conducted using QMA™ software (Medical Metrics, Inc., Houston, TX) by two blinded spine surgeons.

The patients were assisted in walking on the day of discharge from the operation and drains were removed in 24 hours. Patients were active but wore a collars for 3 weeks. Patients were able to resume working depending on how fast they recovered. Meloxicam (15 mg twice a day) was administered postoperatively for 6 weeks in a bid to prevent heterotopic ossification (HO).

Statistical Analysis

Statistical analysis was carried out using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA). Continuous data was expressed as mean ± standard deviation, while categorical data was expressed in the form of frequencies and percentages. Paired samples t-test was used to compare preoperative and postoperative parameters among both groups (ACDF and CDR) including of NDI, VAS, lordosis of the cervical spine, disc height, and segmental ROM. An independent samples t-test for was used to compare the continuous postoperative outcomes between both groups, which included the last follow-up NDI, VAS, ROM, disc height, and cervical lordosis. Analysis of categorical data, namely distribution of gender, occurrence of HO, presence of ASD, and requirement of revision surgery, was done using the chi-square test or, where appropriate, Fisher's exact test. A p-value of <0.05 was considered statistically significant for all the analyses done.

RESULTS

The mean age of the participants in the CDR group was 38.9 years (range 26-58 years) and 39.3 years (range 27-60 years) in the ACDF group. Gender distribution was similar in both groups (CDR: 21 males, 18 females; ACDF: 19 males, 17 females).

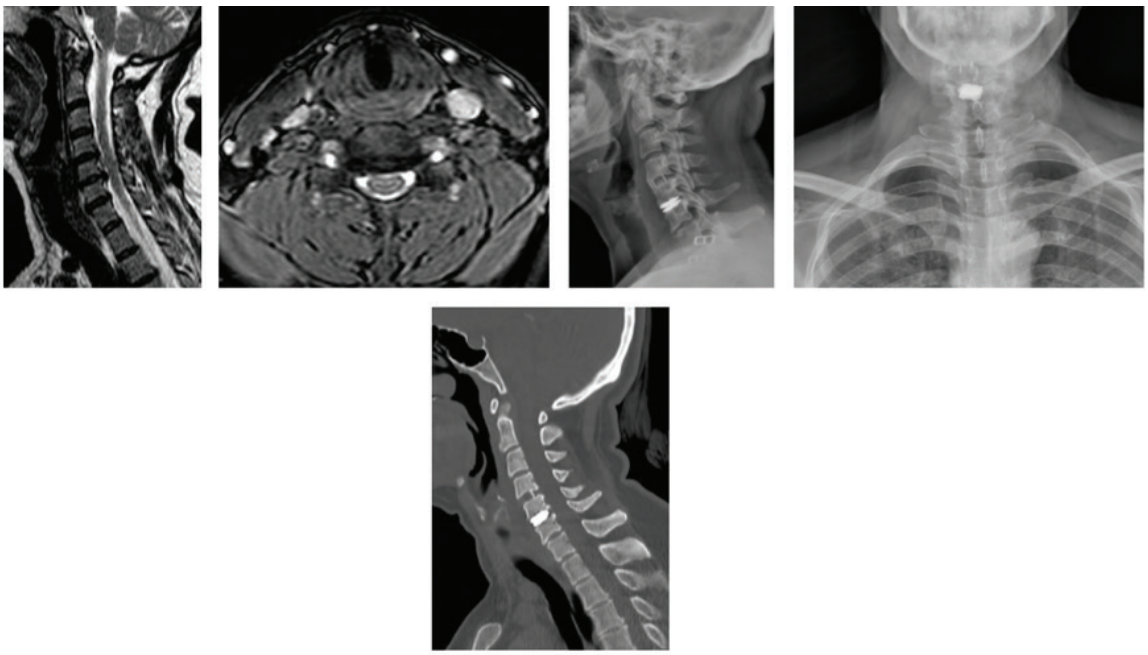

Figure 1. Preoperative magnetic resonance imaging (MRI) and postoperative X-ray-computed tomography and MRI of patient operated cervical disc prosthesis

Follow-up was of similar length in both groups (58.3±11.6 months in the CDR group and 56.9±10.9 months in the ACDF group; p=0.62). Hospital stay was also of similar length in both groups (2.6±1.1 days in the CDR group and 2.7±1.2 days in the ACDF group; p=0.77).

Both groups showed a statistically significant improvement in clinical scores after surgery. In the CDR group, the mean NDI score decreased from 50.8±12.1 to 10.2±5.1 (p<0.01), and the ACDF group showed a decrease from 49.6±11.7 to 11.1±5.3 (p<0.01); however, no statistically significant difference was found between the two groups in the final NDI scores (p=0.41). VAS scores improved, from 7.4±2.0 to 1.8±1.0 for the CDR group and from 7.3±1.9 to 2.0±1.1 for the ACDF group (both p<0.01), with no statistically significant difference found in the postoperative values (p=0.38).

Cervical lordosis improved significantly in both groups: it increased from 7.0°±9.6° to 14.8°±10.7° in the group which received CDR, and in the group that received ACDF, it increased from 6.5°±8.7° to 11.2°±9.4° (p<0.01 in both groups). Final lordosis was also significantly greater in the group that received CDR (p=0.034). Finally, disc height increased by 2.2±0.4 mm in the group that received CDR, and by 1.2±0.3 mm in the group that received ACDF (p<0.01 in both groups); the between-group difference in end-disc height was also significant (p<0.01).

Segmental ROM showed improvement in the cohort of CDR, from 5.5°±2.7° to 9.0°±3.1° (p<0.01), while that of the ACDF cohort decreased from 5.3°±2.5° to 1.1°±0.5° (p<0.001). Statistical analysis detected a significant postoperative ROM difference between both groups (p<0.001).

HO was observed in 4 patients (10.2%) in the CDR group, with no impact on motion or symptoms. No HO was detected in the ACDF group. ASD occurred in 1 patient (2.6%) in the CDR group and 6 patients (16.7%) in the ACDF group, which was statistically significant (p=0.03). Revision surgery was required in 2 ACDF patients (5.5%) due to pseudarthrosis, while no reoperations were needed in the CDR group (Table 1). Dysphagia was observed in 1 patient, and the patient did not have any problems in the last follow-up.

DISCUSSION

Results of this series demonstrate that CDR is a very effective and safe surgical procedure for CDDD. Relief in pain, improvement in functional outcome, and restoration of radiological parameters, including cervical lordosis, disc height, and ROM, were in accordance with the literature. CDR allows for the preservation of segmental motion unlike ACDF and might avoid the risk of ASD, which is the major drawback of the fusion techniques. These results strongly support CDR for both clinical and biomechanical success in properly selected patients.

There are many studies in the literature comparing ACDF, which is the gold standard treatment method in CDDD, and CDR, which has been increasing in popularity and use in recent years[4-9]. In this article, many data about CDR are presented to the reader with comparative studies with ACDF. In the meta-analysis study of Aragonés et al.[10], it was reported that CDR had lower NDI scores compared to ACDF, SF-36 score was more favorable, adverse events were seen at half the rate, and revision surgery was performed much less frequently. Shangguan et al.[11] reported that there was no difference between clinical scores between CDR and ACDF, but ROM were higher in CDR. Zigler et al.[12] reported that there was a significant improvement in VAS and NDI scores in patients who underwent CDR after 5 years of follow-up. In our study, CDR provides comparable symptom alleviation to ACDF, and also enables greater maintenance of motion, superior alignment, and significantly less risk of ASD.

The most common reason for revision after CDDD surgery

Table 1. Comparison of clinical and radiological outcomes between cervical disc replacement and anterior cervical discectomy and fusion groups

Parameter	CDR Group	ACDF Group	p-value
Number of patients	39	36	
Mean age (years)	38.9 (26-58)	39.3 (27-60)	
Sex (M/F)	21/18	19/17	
Mean follow-up (months)	58.3±11.6	56.9±10.9	0.62
Hospital stay (days)	2.6±1.1	2.7±1.2	0.77
NDI (pre → post)	50.8±12.1 → 10.2±5.1	49.6±11.7 → 11.1±5.3	0.41
VAS (pre → post)	7.4±2.0 → 1.8±1.0	7.3±1.9 → 2.0±1.1	0.38
Cervical lordosis (°)	7.0±9.6 → 14.8±10.7	6.5±8.7 → 11.2±9.4	0.034
Disc height (mm)	3.1±0.5 → 5.3±0.6	3.0±0.4 → 4.2±0.5	<0.01 (post-op)
Segmental ROM (°)	5.5±2.7 → 9.0±3.1	5.3±2.5 → 1.1±0.5	<0.001 (post-op)
HO occurrence	4 patients (10.2%)	0	-
ASD incidence	1 patient (2.6%)	6 patients (16.7%)	0.03
Revision surgery	0	2 patients (5.5%)	-

NDI: Neck disability index, VAS: Visual Analogue Score, ROM: Range of motion, HO: Heterotopic ossification, ASD: Adjacent segment disease, CDR: Cervical disc replacement, ACDF: Anterior cervical discectomy and fusion, M: Male, F: Female

is ASD[3]. The biggest advantages of CDR over ACDF are preservation of motion and less incidence of ASD[13]. In the meta-analysis of Findlay et al.[4], it was found that CDR is as effective as ACDF, and even in the mid-long term clinical results of CDR, patient satisfaction is mora favorable and ASD is less common. Goffin et al.[14] reported that radiological evidence of degeneration was observed at a rate of 92% approximately 8.6 years after ACDF. In addition, Hilibrand et al.[15] stated that the rate of symptomatic ASD 10 years after ACDF was 25.6%, and 72% of these patients were operated on. In the literature review of Chang et al.[16], it was reported that while ASD requiring reoperation was 6% after ACDF, it was 3% after CDR. In another literature review, it was reported that the reoperation rate due to ASD was between 0% and 0.4% after 5 years of follow-up in CDR[7]. In the study of Shin et al.[3], it was reported that complication rates and reoperation rate were significantly lower when compared to ACDF, although many physicians had a bias against CDR.

Many studies in the literature shows improvement in neurological status in patients undergoing CDR[6,17,18]. Moreover, in the study of Lanman et al.[19], neurological recovery was found to be superior in patients who underwent CDR compared to patients who underwent ACDF (91.6% vs 82.1%).

Postoperative complications include cerebrospinal fluid leakage, esophageal injury, nerve root injury, prevertebral hematoma, dysphagia, prosthesis migration, implant collapse, hoarseness, and C5 paralysis[8]. In the study of Li et al.[20], 10.9% migration was determined. None of these complications, except dysphagia in 1 patient, were detected in our patients. In the study of Radcliff et al.[9], less mechanical complications were found in the CDR group in comparisons between the ACDF and CDR groups. At the same time, it was observed that the total overall cost was less in the CDR group. Shangguan et al.[11] found that dysphagia was found to be significantly less common in the CDR group compared to the patients who underwent ACDF, and they attributed this to less esophageal retraction in the CDR group. In our study, dysphagia was observed in 1 patient, and the patient did not have any problems in the last follow-up.

There is a lot of knowledge in the literature about HO detected after CDR. In the meta-analysis of Hui et al.[21], the incidence of HO was 24.8%, and the incidence of HO cause ROM limitation was 11%. At the same time, they reported that it was more common in patients who underwent single-level CDR. They stated that cervical kinematics was provided better in patients with multiple-level disc prosthesis compared to patients with single-level disc prosthesis, and less HO was seen due to less deterioration in spinal biomechanics. In the meta-analysis of Chen et al.[22], HO was observed between 44.6% and 58.3% up to 2 years after surgery, while in another meta-analysis of Kong et al.[23], 38% HO was detected. As an undesirable complication after HO, spontaneous fusion may develop and may cause ROM limitation. In the study of Marques et al.[24] HO was detected in 92% of the patients after 5 years, and severe HO (grade 3-4) was reported in 71% and complete fusion (grade 4) was reported in 27% of the patients. In the study of Hou et al.[25], HO was not found in any of the 51 patients who underwent CDR at the end of a mean follow-up period of 61 months. In our study HO was observed in 4 patients (10.2%) in the CDR group, with no impact on motion or symptoms.

Many studies have been conducted on the types of cervical disc prosthesis. In the study of Miao et al.[26], Discover prosthesis (DePuy Spine, Raynham USA) was used and the VAS score decreased from 7.2 to 1.4 at the end of a 24-month follow-up. Obernauer et al.[27] reported that the clinical results were good and excellent at a rate of 95.7% at the end of the 24-month follow-up in patients who underwent ROTAIO Cervical Disc Prosthesis (SIGNUS Medizintechnik GmbH, Alzenau, Germany), and they mentioned that the need for painkillers decreased significantly. Other prostheses, the results of which have been reported quite successfully in the literature; Baguera®C (Spineart, Switzerland)[18], Bryan® (Medtronic Sofamor Danek, Memphis, USA)[28], Porous Coated Motion cervical disc (NuVasive Inc., San Diego, CA)[29], Prestige LP ADR (Medtronic Sofamor Danek)[30], Mobi-C (LDR Medical, Troyes, France)[31] and ProDisc-C (Synthes Spine USA Products; LLC, West Chester, PA)[12].

Study Limitations

Our study has several limitations. First, only one type of prosthesis was used, so it may not be correct to generalize to the results of all disc prostheses. Another limitation of the study in question is that the participants' neurological status, including specific motor and sensory findings, was not evaluated in a uniform manner by the use of standard neurological scoring systems. Lack of inclusion of the SF-36 assessment is a significant limitation in that it precludes thorough analysis of health-related quality of life.

CONCLUSION

CDR is a promising alternative to ACDF because it preserves motion and reduces ASD, Our midterm results has shown that there was a significant improvement in pain relief, functional outcome, and cervical alignment without implant-related complication or HO. This study confirm that the CDR procedure with PEEK prostheses ensures good clinical and radiological scores, proving its effectiveness and safety. On the other hand, the relatively small sample size and the lack of the control group in this series is a limitation to generalization of these results and would call for a larger series with longer follow-up in a variety of prosthesis designs in order to compare their effectiveness.

Ethics

Ethics Committee Approval: The study was approved by Ağrı İbrahim Çeçen University Institutional Ethics Committee (decision number: 189, date: 28.09.2023).

Informed Consent: Informed consent was obtained from all participants.

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Footnotes

Authorship Contributions

Surgical and Medical Practices: Y.K., E.B., Concept: Y.K., E.B., Design: Y.K., E.B., Data Collection or Processing: Y.K., Analysis or Interpretation: Y.K., E.B., Literature Search: Y.K., E.B., Writing: Y.K., E.B.

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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

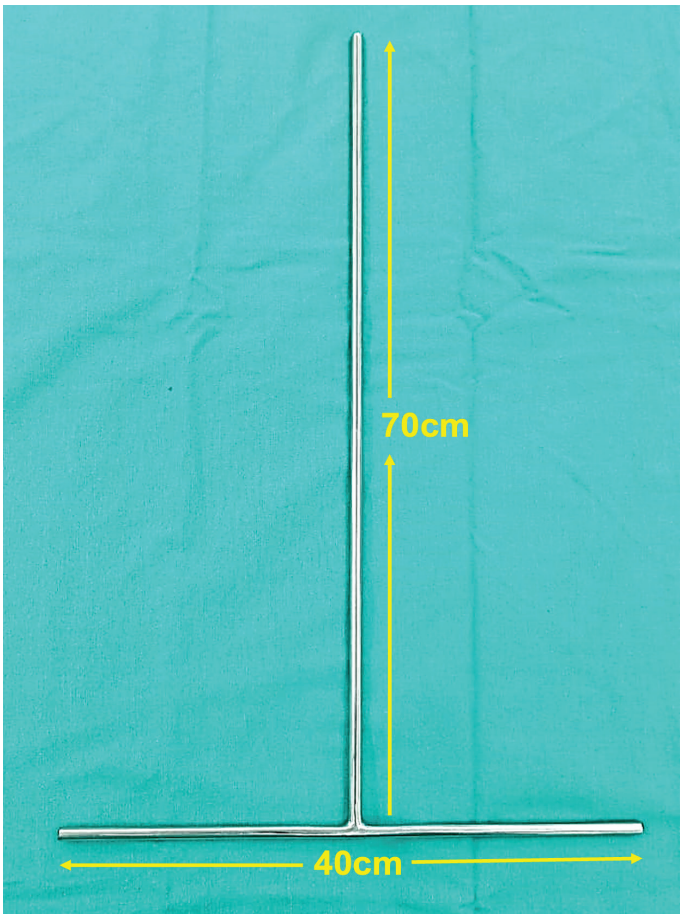

Figure 1. The horizontal arm of the T-tool is 40 cm and the vertical arm is 70 cm. The device is constructed with stainless steel

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.

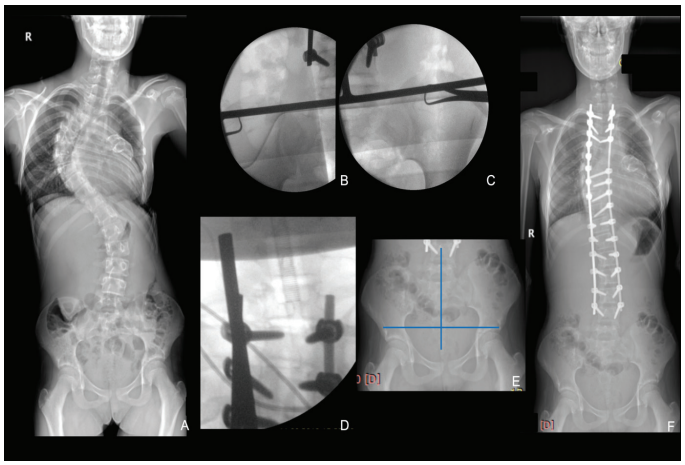

Figure 2. A 16-years old patient was operated on for AIS. (A) Preoperative scoliosis X-ray of the patient. (B-E) The patient had a preoperative LLD, therefore the T-tool was placed on the superior borders of the iliac crests and the construct was fixed considering the LLD. To achieve an optimal coronal 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.

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

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A RARE CAUSE OF POSTPARTUM LOWER BACK PAIN: SACRUM STRESS FRACTURES

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ABSTRACT

Objective: Although lower back pain is one of the most frequent complaints during pregnancy, a rare but very important cause is a sacral stress fracture. Although rarely seen, the condition should form one of the differential diagnoses for back pain during pregnancy and the postpartum. This study aims to present one of those uncommon causes of postpartum lower back pain in order to improve awareness and aid diagnosis.

Materials and Methods: Six postpartum patients with no previous history of osteoporosis or trauma were diagnosed with sacral stress fractures. Of these, four presented within two weeks from delivery, and two presented three months after delivery (mean: 39.3 days). All patients had normal laboratory findings and bone mineral density, thus excluding metabolic bone diseases. All direct radiographs were normal, but magnetic resonance imaging (MRI) detected an isolated fracture of the wing of the sacrum in all cases.

Results: Mean age of patients was 33 years (range: 30-35 years). All had pain in the sacral region, which was accentuated by weight-bearing and improved by rest. MRI revealed an isolated fracture of the sacral wing with no adjacent bony or soft tissue abnormality. Conservative management with activity modification, analgesia, and physiotherapy led to complete resolution within 8-12 weeks.

Conclusion: Although less common, sacral stress fractures must be considered in the differential diagnosis in the postpartum period of low back pain. An early MRI study is crucial for an accurate diagnosis. Conservative treatment usually ensures complete recovery. This series highlights the need for early diagnosis and intervention to treat this uncommon condition.

Keywords: Postpartum, sacrum, stress fracture, pregnancy

INTRODUCTION

Pregnancy is a period of accelerated metabolism. In the second and third trimester, there is an increased mineral and nutritional requirement due to the rapid growth of the fetus. Particularly, there is an increased need for calcium in the third trimester parallel to the growth of the fetal skeletal system[1,2]. Additionally, the increased size of the uterus causes greater mechanical stress on the pelvis, spine and lower extremities[3]. The most common cause of back pain throughout pregnancy and into the early postpartum period. The effects of increased mechanical stress together with the increased need for calcium because of the fetus, raise the risk of stress fractures developing in the mother. Although the exact incidence is not known, sacral stress fractures in pregnancy complications that are rarely seen. Still, they represent one of the reasons for hip and back pains in pregnancy and in the early postpartum period[1,4-7]. To date, there have been very few reports in literature of postpartum sacral stress fractures. In this paper, 6 cases of postpartum sacral stress fractures are presented and discussed in the light of relevant literature.

MATERIALS AND METHODS

This is a retrospective study of six postpartum women who were diagnosed to have sacral stress fractures. Inclusion criteria are:

- Sacral stress fracture confirmed by magnetic resonance imaging (MRI).
- No history of previous osteoporosis or trauma and other metabolic bone diseases.
- Patients presented within six months of delivery.

We reviewed the demographic data, clinical presentations, laboratory results, and imaging findings. All patients were subjected to comprehensive evaluations that included complete blood counts, calcium, alkaline phosphatase levels, and bone mineral density (BMD) studies. All of them had

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unremarkable radiographs; thus, MRI confirmation was needed for the confirmation of the diagnosis. Our retrospective data were approved by the ethics committee of İstanbul Yeni Yüzyıl University (approval number: 2025/01-1434, date: 09.01.2025).

Statistical Analysis

No statistical analysis was made for this study since the data in respect to these six patients included just age and postpartum follow-ups.

RESULTS

The mean age of patients was 33 years (range: 30-35 years). All patients presented with lower back pain localized to the sacral region that worsened on weight bearing or walking and improved on rest. Four patients presented to us within fifteen days of delivery while two patients presented three months after delivery (mean 39.3 day).

MRI studies revealed isolated sacral wing fractures without any evidence of associated adjacent bony or soft tissue abnormality. The laboratory and BMD studies were normal, ruling out metabolic bone pathologies. All cases resolved under conservative management that included modification of activity, analgesia, and physiotherapy over 8-12 weeks.

Clinical Cases and Management Approaches

Case 1

A 35-year-old woman was referred to our outpatient clinic with a history of lower back pain after delivery. It was the patient's second pregnancy and she had no complaints during either of her pregnancies. During her second pregnancy, she gained 14 kg, of which 4 kg was within the last trimester. She was managed conservatively throughout her pregnancy and was delivered of a 3200 g baby by cesarean section without any complications. The baby was breastfed after birth. Her complaints began 10 days after delivery. There was no history of lower back pain the past or any previous trauma. There were also no endocrine or metabolic disorders, no obesity, no smoking, and no drug intake. She complained of her back pain being worse on the left side and radiating to the front of the groin. Her gait had been affected and she could not bear full weight on her left leg.

On clinical examination, the spine appeared normal. There was tenderness over the region to the left side of the sacrum. The hips had full ranges of movement and the sacroiliac joint (SIJ) stress tests were positive. Straight leg-raising test was negative in both lower limbs. Serum parathormone level was 28 pg/mL (15-68), calcium level was 9 mg/dL (8.5-9.4 mg/dL), alkaline phosphatase level was 50 (30-130 IU/L) and 25-(OH) vitamin D3 44 µg/L (9-59). Plain radiographs, computed tomography (CT) scan, and bone densitometry did not reveal anything abnormal. However, the Coronal MRI image of the sacrum revealed a vertical fracture line (Figure 1).

After bed rest and limited daily activities for eight weeks, there was no evidence of the lower back pain which had been evident on the left side of the groin. Normal gait was regained with full weight-bearing and range of motion of the hip.

Case 2

A 31-year-old woman was referred to our outpatient clinic with lower back pain in the sacral region, reflecting to her right buttock, which had increased within five days after delivery by a cesarean section. It was her first pregnancy, and she did not have any abnormalities during gestation. Her 3400 g baby was delivered with no complications. There was no history or record of menstrual irregularity, previous fracture, smoking or nutritional disorders. Her family history was negative for metabolic bone disease. During the gestation period, the patient gained 15.5 kg.

Examination showed normal spine. There was tenderness in the region to the right side of the sacrum. Hip joints examination were normal. Trendelenburg test was positive on the right side. Internal rotation of the right hip was restricted and painful. Pressure on the groin was not painful but the sacral area was sensitive. She had pain in her lower back and groin when lifting her baby but no irradiating sciatic pain. Neurological examination, plain radiographs, CT scans and bone densitometry were all normal. Serum parathormone level was 37 pg/mL (15-68), calcium level was 9.4 mg/dL (8.5-9.4 mg/dL), alkaline phosphatase level was 72 (30-130 IU/L) and 25-(OH) vitamin D3 52 µg/L (9-59). The Coronal MRI of the sacrum revealed a vertical fracture through the upper part of the right sacral wing (Figure 2).

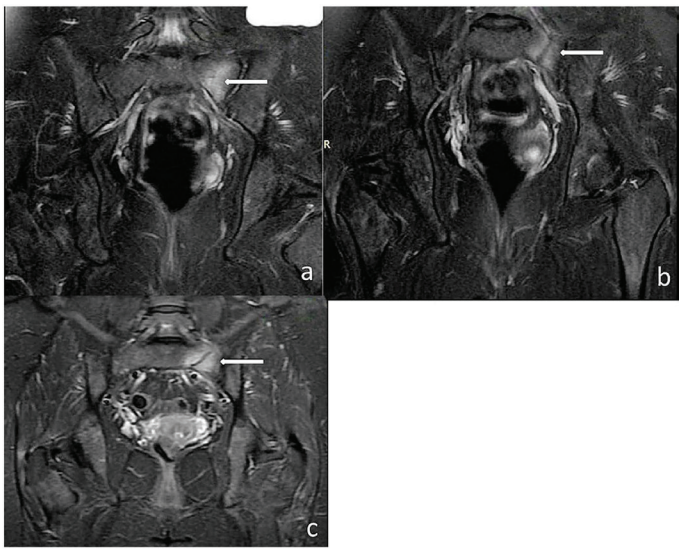

Figure 1. (a) Coronal T2 fr FSE FSat MRI of the sacrum showing bone marrow edema in the left sacrum (arrow). (b) Coronal fr FSE T2-weighted image demonstrating the fracture line in the left sacrum (arrow). (c) Coronal STIR image demonstrating the fracture line in the left sacrum (arrow)
FSE: Fast spin echo, FSat: Fat saturation, MRI: Magnetic resonance imaging, STIR: Short tau inversion recovery

After bed rest and limited daily activities for eight weeks, normal gait was regained with full weight-bearing and range of motion of the hip. She had no evidence of lower back pain.

Case 3

A 32-year-old woman was referred to our outpatient clinic with lower back and left buttock pain, which started two weeks after delivery by cesarean section. It was her first pregnancy. During gestation, she gained 12 kg and delivered a healthy, 3700 g baby with no complications. Within two weeks, the pain became such that the patient was obliged to support herself with a crutch in order to walk. No history of trauma was reported. The patient did not report pain in the pelvis or spine either during or before her pregnancy, neither were there endocrinological nor metabolic disease. She had no history of smoking. Because of a fall in the 3rd month of pregnancy which resulted in a right radius and ulna fracture, closed reduction and percutaneous pinning was performed.

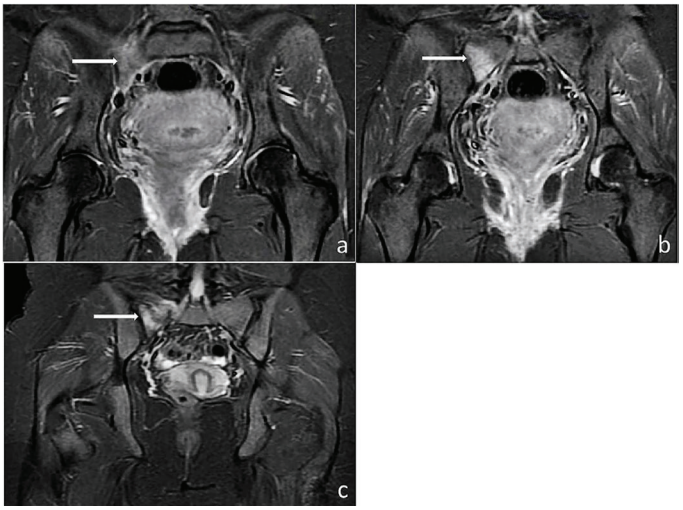

Figure 2. (a,b) Coronal STIR images demonstrating the fracture line in the right sacrum (arrow). (c) Coronal T2 fr FSE FSat MRI image of the same fracture (arrow)
STIR: Short tau inversion recovery, FSE: Fast spin echo, FSat: Fat saturation, MRI: Magnetic resonance imaging

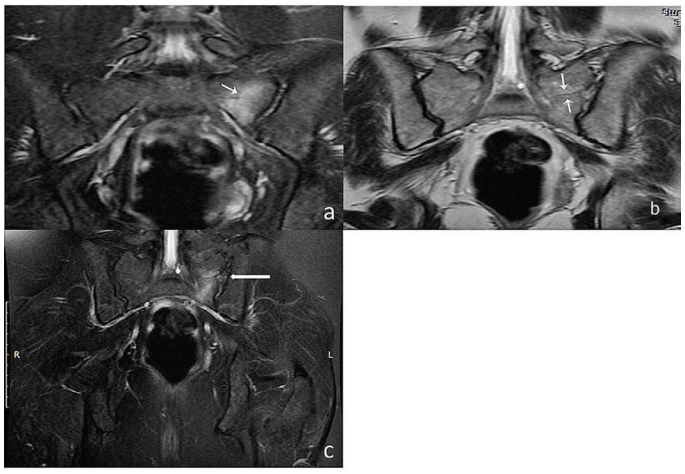

Figure 3. (a) Coronal STIR images demonstrating the fracture line in the left sacrum (arrow). (b,c) Coronal T2 and Coronal T2 fr FSE FSat MRI images of the same fracture (arrows)
STIR: Short tau inversion recovery, FSE: Fast spin echo, FSat: Fat saturation, MRI: Magnetic resonance imaging

On physical examination, there was tenderness on mild palpation of the left SIJ. There was considerable tenderness over the region of the right gluteal, and excruciating pain during sacral and iliac compression. During ambulation, there was an antalgic gait pattern which presented with limping. There was no neurovascular abnormality and bone densitometry was normal. Serum parathormone level was 21 pg/mL (15-68), calcium level was 9.2 mg/dL (8.5-9.4 mg/dL), alkaline phosphatase level was 74 (30-130 IU/L) and 25-(OH) vitamin D3 48 µg/L (9-59). Due to increasing pain within one week of delivery, the patient was checked at another hospital and prescribed non-steroidal anti-inflammatory drugs. The patient was referred to our orthopedic clinic two months after delivery because of continuous pain and gait abnormality. X-rays of the pelvis and thoracolumbar spine revealed no osteoarticular abnormalities. MRI pelvis showed a transverse fracture through the upper part of left sacral wing (Figure 3). Bed rest and medical treatment were recommended. Two months later at the follow-up examination, the patient had no pain and the gait was normal.

All the patients were treated with conservative methods. The management of the treatment included bed rest, analgesics, and calcium supplement (1 g/day) and vitamin D (2000 IU/day). There was no recurrence during the 2 year follow-up period. After two months, symptoms had resolved and clinical outcomes were recovered.

DISCUSSION

More than half of all pregnant women have some degree of back pain at some time in their pregnancy[1,2,8]. General causes of this include pelvic ligamentous laxity, mechanical factors, sacroiliac pain, vascular compression, spondylolisthesis, discogenic or radicular pain and hip pathologies[1,2,4]. Sacral stress fractures are an extremely rare condition reported in the literature as causing back pain during pregnancy and/or the early postpartum period[2,4,5].

A stress fracture develops because of unaccustomed stress loaded on to a bone of normal resistance or normal stress on a weak bone[5,9-12]. Stress fractures associated with insufficiency are generally seen in the elderly, in osteoporotic patients or in those who are undergoing radiotherapy for a pelvic malignancy[12,13]. Sacral fractures and mechanical SIJ disorders are likely grossly underestimated, largely because the nature of the manifestations that are generally non-specific and the overall unfamiliarity among clinicians about these disorders in pregnant patients[6,14]. In contrast, postpartum sacroiliitis are relatively easy to diagnose and are often caused by infection or by inflammatory processes and pregnancy recognized as being one potential causative or contributing factor[15].

Although the actual incidence is not known, there exist in literature few case reports of pregnancy-associated sacrum stress fractures. All these case reports were associated with either vaginal or postpartum early periods presentation with a description of a collection of possible risk factors; these may be listed as having a history of vaginal delivery with a large fetus, hydramnios, increased lumbar lordosis, excessive weight gain, quick vaginal delivery, lactational osteopenia, pregnancy-related osteoporosis, use of forceps, heparin use and excessive sports activities[1,3,16,17]. As the cases reported here were caesarian section deliveries, they did not have the above-mentioned risk factors.

It is unclear what the etiology of pregnancy-associated osteoporosis is. However, Black et al.[18] found that there was a mean loss of spinal BMD by 3.5% from the pregnancy stage to postpartum. Phillips et al.[19] reported that BMD usually recovers in the years following and that the condition would therefore seem reversible. It has been associated with high levels of relaxation causing ligamentous laxity, increased weight gain during pregnancy, hyperlordosis, and osteopenia caused by prolactin[20,21].

SIJ mechanical disorders usually do not present with symptoms; nonetheless, if they do present as pain and functional disability, imaging modalities-primarily MRI or CT-are needed to exclude sacral fractures. Isolated SIJ edema on MRI sometimes leads to the overdiagnosis of inflammatory sacroiliitis, and therefore careful differential diagnosis is necessary[6]. Pregnancy-and lactation-associated osteoporosis, while rare and not fully understood, can enhance women's vulnerability to fragility fractures, particularly sacral fractures. Nordin and Roper[22] were the first to describe this syndrome, reporting cases of vertebral compression fractures in women after delivery. Since their original report, several subtypes have been identified, such as idiopathic osteoporosis of pregnancy, transient osteoporosis of the hip, postpregnancy vertebral osteoporosis, and osteoporosis related to lactation[23]. This unique type of osteoporosis typically presents with vertebral or femoral neck fractures; however, sacral involvement is unusual, with few case reports in the literature[20].

Physical examination and appropriate radiological investigations are the key methods to demonstrate the pathology. Clinically, sacral stress fractures present as localized gluteal region tenderness and low back pain; however, radicular symptoms have also been described[17]. Physical examination is essential for eliminating other causes, while imaging tests are necessary for accurate diagnosis and differential diagnosis[10]. In the cases reported here, there were no specific findings in the physical examination. However, in these 3 patients the finding which was seen on one side of pain and sensitivity in the lower back and over the SIJ, was an important finding. The first step in radiological imaging of a stress fracture is plain radiographs but it is difficult to determine a sacrum stress fracture on a plain radiograph and generally there is a false negative result. Therefore, CT, bone scintigraphy or MRI should be used to confirm the diagnosis[1,7,8,12,24]. Bone scintigraphy and CT are harmful to a fetus because of their teratogenic effects and therefore, the use of these tests during pregnancy is problematic[25,26]. On CT examinations, continuing deterioration of cortical or spongious bone or sclerosis and new bone structures may be seen together with the fracture line[5]. However, if CT slices of sufficient thinness can not be obtained, indistinct sclerotic areas may be missed. MRI can be safely performed during pregnancy and is more sensitive than bone scintigraphy in demonstrating bone stress injuries. Because MRI remains the only imaging technique that does not involve exposing the fetus to ionized radiation, it is the most crucial modality in the diagnosis of pregnancy-related stress fractures[1,4,8,16]. In structured time-dependent inverse regression sequences, particularly in the frontal slices, oedema in both sacra is clearly seen. Diagnosis is made with the visualization of a fracture line in the same area on T1-weighted sequences[27]. As these fractures have a low risk of complications, conservative treatment is recommended. The treatment of sacral stress fractures is mainly focused on pain relief, with analgesics being a mainstay until the symptoms subside. While there is no consensus regarding the efficacy of total bed rest versus early mobilization, some authors advocate for the protocol of early supervised walking, with or without assistive devices, as long as it is not painful. This approach can help in fracture healing by stimulating osteoblast activity and in avoiding complications of long-term immobility[1,3,5,16,17].

The true incidence rate of these fractures is not known. Since the period of birth is a time of particularly high prevalence of back pain and this generally improves spontaneously in the postnatal period, birth-related sacral stress fractures are probably underdiagnosed. The avoidance of using radiological imaging methods during pregnancy and the healthy course of stress fractures can be considered major factors in the lack of knowledge of the true incidence of this occurrence. Together with the cases presented herein, increased awareness of sacral stress fractures in the differential diagnosis of back pain in pregnancy and postpartum will lead to defining the true incidence and the formulation of treatment approaches.

Study Limitations

This study has several limitations. First, the retrospective nature of the study coupled with a small sample size leads to poor statistical power and limits the potential for extensive comparative analysis between the cases studied. Additionally, the lack of fetal biometrics and labor-induced mechanical stress parameters could potentially have precluded a complete insight into the etiology of these fractures. Also, widely recognized quantitative outcome measures like pain scales or functional assessment scores were not used; therefore, clinical recovery was assessed by subjective means.

CONCLUSION

Sacral stress fractures are rare but have to be considered within the differential diagnosis of postpartum low back pain. An early MRI study is crucial for the diagnosis. It has been seen in most cases that conservative management leads to a complete recovery. This series highlights the awareness and early intervention needed in the management of this rare condition.

Ethics

Ethics Committee Approval: The study was approved by the İstanbul Yeni Yüzyıl University (approval number: 2025/01-1434, date: 07.01.2025).
Informed Consent: Retrospectively study.

Footnotes

Authorship Contributions

Surgical and Medical Practices: M.N.E., Y.K., A.A., M.A., Concept: M.N.E., M.A., Design: M.N.E., M.A., Data Collection or Processing: M.N.E., Y.K., A.A., M.A., Analysis or Interpretation: M.N.E., Y.K., A.A., M.A., Literature Search: Y.K., A.A., Writing: M.N.E., Y.K., A.A., M.A.
Conflict of Interest: No conflict of interest was declared by the authors.
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ORIGINAL ARTICLE
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WHO IS MORE SUCCESSFUL IN A SPINAL SURGERY EXAMINATION? CHATGPT-3.5/4.0 OR A RESIDENT DOCTOR?

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ABSTRACT

Objective: As in all work sectors, artificial intelligence (AI) is now often used and has increased especially in the field of medicine with advances in technology. The aim of this study was to compare the responses given by Chat Generative Pre-trained Transformer (ChatGPT)-4.0, ChatGPT-3.5, and orthopaedics and traumatology residents to the Turkish Orthopedics and Traumatology Education Council (TOTEK) questions about the spine.

Materials and Methods: A total of 15 residents in the orthopaedics and traumatology clinic of a tertiary-level university hospital participated in an examination consisting of questions only related to the spine. The same questions were asked to ChatGPT-3.5 and ChatGPT-4.0 on two different days. The examination consisted of true/false questions, theoretical/classical and diagram/visual sections, with each section scored from 100 points. The average score was calculated and the results were evaluated by two instructors.

Results: The mean score obtained was 72.88 for ChatGPT-3.5 (p=0.005) and 69.38 for Chat GPT-4.0 (p=0.001), showing a 5.87% difference in success. The mean score obtained by the orthopaedic residents was 69.90 (p=0.779). Both the 3.5 and 4.0 versions of ChatGPT AI were observed to have a knowledge level equivalent to that of a 3rd year resident.

Conclusion: The 4th and 5th year orthopaedic residents were able to answer more questions correctly than ChatGPT-3.5 and GPT-4 on the spine assessment questions. Both ChatGPT-3.5 and GPT-4 performed better on text-only questions than on visual questions. It is unlikely that GPT-4 or ChatGPT-3.5 would pass the TOTEK written examination.

Keywords: ChatGPT, artificial intelligence, orthopaedics and traumatology, spinal surgery

INTRODUCTION

Artificial intelligence (AI) chatbots are computer programs that have the ability to understand human language and maintain a conversation with users with detailed responses. As in all sectors, there have been very rapid technological developments in medicine. The use of online resources to access correct medical information has increased especially since the beginning of the 2000s. It has been reported that 84% of the patients of an orthopaedics and traumatology clinic have access to the internet and 64% have used online sources of orthopaedic information[1,2]. Therefore, the accuracy of this information must be examined, and it should be ensured that people do not have incorrect information. Patient access to correct information can provide benefit in respect of patient compliance with treatment and better outcomes, and it can increase patient satisfaction.

Chat Generative Pre-trained Transformer (ChatGPT) is a large language model (LLM) with increasingly widespread use. LLMs have attracted great interest, especially in the field of medicine[3]. ChatGPT was developed by OpenAI. Due to the human-like responses generated, it is increasing in popularity with more than 100 million users currently[4]. It is trained by being exposed to various reference sources and it uses this information obtained from many books and articles. By learning past data as patterns, sequences of words and sentences according to the links are presented as the output. The number of parameters is very important for GPT, as a greater number of parameters provides a greater learning capacity. This has the advantage of resolving the complex structure of human language. While ChatGPT-2 has approximately 1.5 billion

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parameters, there are approximately 175 billion parameters in ChatGPT-3.5, which was launched in 2022[5].

In the ChatGPT-4.0 model, which was launched on 14 March 2023, it has been suggested that there are 1.76 trillion parameters[6]. AI has started to be used recently not only for reasoning skills but also for field-specific examinations. Previous studies have shown that ChatGPT-3.5 almost passed the first, second, and third stages of the United States Medical Licensing Examination (USMLE). Further studies have shown a 20% increase in the points of the three USMLE using ChatGPT-4.0[7].

Orthopaedic surgery in practice and on examinations is distinguished by the frequent need to synthesize imaging data in formulating treatment plans. There are studies in the literature to determine the clinical diagnosis and treatment process with ChatGPT-3.5. It has been attempted to determine the success rate of ChatGPT-3.5 in answering Board examination questions[7,8]. The questions in this study were taken from the examination for residents, which is organized regularly every year by the Turkish Orthopedics and Traumatology Education Council (TOTEK). The aim of the study was to present the comparative results of the responses of residents, ChatGPT-3.5 and ChatGPT-4.0 to these examination questions related to the spine.

MATERIALS AND METHODS

The questions of the in-clinic training examination, taken on 01.06.2024 by a total of 15 doctors undertaking residency as research assistants in the orthopaedics and traumatology clinic, were asked to ChatGPT-3.5 and ChatGPT-4.0. All the questions in the examination were related to spinal surgery. Ethics Committee approval was not required for this study. The examination consisted of 4 sections. The first section comprised 20 multiple-choice questions, each with 5 options and a value of 5 points. The second section comprised 20 classic questions as a theory examination and each question had a value of 5 points. In the third section, it was asked whether 40 sentences were true or false, and the correct response for each sentence was scored as 2.5 points. To determine the power of AI in visual interpretation, questions in the fourth section were related to diagrams and radiographs. There were 10 questions with a value of 10 points for each. As the examination was formed of 4 sections, with each section scored from 100 points, the average of the total points scored was recorded. The examination was repeated the next day with the same questions. The aim of this was to measure how similar the responses were that were given at different timepoints. All the examinations were evaluated by two specialist physicians. Taking the average of the total points obtained provided more objective examination results. The doctors were separated into 5 groups based on their years of seniority. The scores obtained were examined and compared between ChatGPT-3.5, ChatGPT-4.0 and with those obtained by the doctors.

Statistical Analysis

Data obtained in the study were analyzed statistically usisng SPSS vn. 29 software (IBM, Armonk, NY, USA). Categorical data such as correct or incorrect answers given by ChatGPT-3.5, GPT-4.0 and doctors were compared using chi-square analysis. Numerical data of the three groups were compared using analysis of variance with post-hoc testing using the Tukey test. Chi-square analysis was also used to compare the accuracy among the seven different subspecialties.

RESULTS

Scores were obtained according to the results of the examination, which consisted of 4 sections and was taken on two days. It was seen that in the multiple-choice section of the examination a better score was obtained by ChatGPT-3.5 than by ChatGPT-4.0 on the first day, and on the second day both versions obtained the same scores. Higher points were obtained by ChatGPT-3.5 in the true/false and theory/classic sections on both days. In the diagram/visual section of the examination, both versions obtained the same points on the first day, and on the second day ChatGPT-4.0 scored higher points than ChatGPT-3.5. According to the total mean points on the first day, the ChatGPT-3.5 version was seen to be more successful. The results of the examination on the second day were close to each other for both AI versions (Table 1).

Scoring was applied to the responses to the questions asked to both the residents and the two versions of AI. The doctors were separated into 5 groups according to their years of seniority. The mean points for each examination category were seen to be proportional to the years of seniority. The mean scores of both ChatGPT-3.5 and ChatGPT-4.0 were observed to be the equivalent of the knowledge level of 3rd year residents (Table 2).

Overall, the orthopaedic residents scored an average of 69.90 points (Table 3). ChatGPT-3.5 and ChatGPT-4 had overall scores of 72.88 and 69.38 points, respectively. The difference among the three groups in test success was statistically significant. ChatGPT-3.5 scored higher than the orthopaedic residents and ChatGPT-4 (p=0.001, p=0.779, respectively).

DISCUSSION

AI chatbot technology is trained on an abundance of information including peer-reviewed journal articles, texts, news articles, and online resources[9]. The results of this study showed that ChatGPT-3.5 outperformed orthopaedic residents and ChatGPT-4 in answering spine questions in the TOTEK question bank, although the 4th and 5th year orthopaedic residents were able to answer more questions correctly. This notable difference points to the extensive skill set required to answer orthopaedic assessment questions and can perhaps be translated into clinical practice. Unlike assessment examinations in other disciplines, orthopaedic examinations require special scrutiny

of radiographic images in conjunction with clinical assessment, which reflects the critical thinking that orthopaedic surgeons need every day and may currently be beyond the ability of these chatbots. Therefore, chatbots seem to be more successful in standard question patterns that do not require analytical thinking.

One of the most important points to be discussed in this study is that ChatGPT-3.5 was 11.12% more successful than ChatGPT-4.0 on the first day. On the second day, ChatGPT-3.5 was similarly 0.62% more successful. The crucial point here is that the same questions asked on different days received different answers. Thus, different answers and different scores in two examinations given at least 24 hours apart were compared. It was noticed that in previous studies in the literature, different answers given at different times were not taken into account or were ignored. It should be emphasized that this part remains important in terms of timing. In the current study analysis of the four different categories, it was seen that the most difficult section for AI was the diagram/visual section, which is based on interpretation. This means that AI bots such as ChatGPT need to be improved in matters of analytical thinking and interpretation. In a study by Massey et al.[10], the results of an examination using 180 questions from the ResStudy orthopaedic examination question bank were seen to be similar to the current study findings in that ChatGPT gave more correct responses to text questions than to diagram-based questions. Kung et al.[11] asked questions from the American Board of Orthopaedic Surgery part 1 examination to ChatGPT-4.0, and the AI exceeded the pass score of 67% of this examination. A dataset of 400 questions was used in a study by Lum[12], and it was reported that the ChatGPT results were similar to those of a first-year resident. In the current study, the results obtained by ChatGPT were at the knowledge level of a third-year resident.

Ali et al.[13], compared both ChatGPT-3.5 and GPT-4 on the American Board of Neurological Surgery self-assessment examination 1, and reported that ChatGPT-3.5 and ChatGPT-4 scored 73.4% and 83.4%, respectively. Those results were higher than the performance in the current study on orthopaedic assessment questions. However , 22% of the neurosurgery test questions had images in that study by Ali et al.[13], whereas at least 50% of orthopaedic examination questions have images, which could explain why ChatGPT-3.5 and ChatGPT-4 had more difficulties in the current study.

Before using AI-generated text for commercial purposes, it must be ensured that it does not violate existing copyright. According to the nature news team, ChatGPT cannot be accepted as the author of a study as it cannot take responsibility for the accuracy and legitimacy of scientific research[14].

Examination of AI in literature shows that it is useful in tasks ranging from data analysis to the formation of hypotheses and results. However, it must be accepted that there are certain

Table 1. ChatGPT examination results

Questions	1st day ChatGPT-3.5	1st day ChatGPT-4.0	2nd day Chat GPT-3.5	2nd day ChatGPT-4.0
Multiple-choice test	85.00	70.00	80.00	80.00
True/false	77.50	65.00	82.50	75.00
Theory/classic	84.00	67.00	88.00	74.00
Diagrams/visual	50.00	50.00	36.00	55.00
Total points	74.13	63.00	71.62	71.00

ChatGPT: Chat Generative Pre-trained Transformer

Table 2. Examination points of the residents

Questions	1st year resident	2nd year resident	3rd year resident	4th year resident	5th year resident
Test	50.00	65.00	70.00	85.00	90.00
True/false	45.00	57.50	72.50	85.00	90.00
Theory/classic	38.00	54.00	72.00	84.00	92.00
Diagrams/visual	40.00	58.00	70.00	86.00	94.00
Total points	43.25	58.62	71.12	85.00	91.50

Table 3. Orthopaedic assessment examination scores of residents, ChatGPT-3.5, and ChatGPT-4

	Overall scores		
	Mean	SD	p-value
ChatGPT-3.5	72.88	20.06	0.005
GPT-4.0	69.38	11.96	0.001
Orthopedic residents	69.90	3.60	0.779

ChatGPT: Chat Generative Pre-trained Transformer, SD: Standard deviation

potential difficulties and limitations related to the use of ChatGPT in orthopaedic research. Responses to the model may require specialisation and more specific information from orthopaedic specialists to avoid errors or incomplete information[15].

Study Limitations

Limitations of this study were that it was not a systematic examination and that no critical evaluation was performed. To compare categorical data versus numerical data, the sections were averaged to return an average score for each section. This resulted in a smaller sample size when comparing the averages of the sections, but notable differences were still seen. In addition, although comparisons of all 80 total questions were sufficiently powered, it should be noted that comparisons between sections with 20 and 40 questions respectively, were likely to have been underpowered.

CONCLUSION

The accuracy and reliability of the answers provided by ChatGPT in the examination in this study depended on the quality of the training data and algorithms used. The 4th and 5th year orthopaedic residents were able to answer more of the TOTEK spine assessment questions correctly than ChatGPT-3.5 and ChatGPT-4. Both ChatGPT-3.5 and ChatGPT-4 performed better on text-only questions than on visual questions. It is unlikely that either ChatGPT-4 or ChatGPT-3.5 would pass the TOTEK and spine questions written examination.

Ethics

Ethics Committee Approval: Ethics committee approval is not required as this is not a clinical trial.
Informed Consent: As this is not a clinical trial, no consent form is required.

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Footnotes

Authorship Contributions

Surgical and Medical Practices: S.E.K., R.D., H.S.C., Ö.K., Concept: S.E.K., R.D., H.S.C., Ö.K., Design: S.E.K., R.D., H.S.C., Ö.K., Data Collection or Processing: S.E.K., R.D., H.S.C., Ö.K., Analysis or Interpretation: S.E.K., R.D., H.S.C., Ö.K., Literature Search: S.E.K., R.D., H.S.C., Ö.K., Writing: S.E.K., R.D., H.S.C., Ö.K.
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WARMING PATIENTS DURING SPINAL SURGERY

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ABSTRACT

Objective: The effect of active heating on the post-overative physiological parameters of patients who were operated on in the prone position and underwent laminectomy due to single-level lumbar stenosis was investigated.

Materials and Methods: The study was evaluated with 60 patients in the operating room environment between March 1, 2022, and September 1, 2022. The experimental group was heated with a blanket; the control group was heated with a blown air system. Vital signs and laboratory values of all patients were evaluated before, during, immediately after, 8 and 24 hours after surgery. Immediately after anesthesia was given, the patients' physiological changes/laboratory findings during the surgery, antibiotic monitoring schedule, and post-operative patient's physiological changes/laboratory findings recording data were evaluated.

Results: The patients received warmth from heated blankets in the recovery room both before and after the surgical procedure, while electrical devices were used for heating during the operation. Comparable outcomes were observed in the measurements of blood pressure, pulse, respiratory rate, and body temperature among the patients. Additionally, the blood test results for all patients showed similarities.

Conclusion: Both methods we used in our study were effective in preventing hypothermia. The physiological parameters of patients subjected to the two different warming techniques during surgery showed no significant difference (p>0.05).

Keywords: Nursing, surgery, warming, hypothermia

INTRODUCTION

Warming patients during surgery is a critical aspect of perioperative care to prevent hypothermia and its associated complications. Hypothermia, defined as a core body temperature below 36 °C, can lead to adverse outcomes such as increased surgical site infections, impaired wound healing, coagulopathy, and cardiovascular instability[1,2]. Therefore, maintaining normothermia is essential for optimal patient outcomes.

There are various strategies and techniques that can be employed to warm patients during surgery. One commonly used method is the administration of warm intravenous (IV) fluids. Spruce[3] found moderate-quality evidence that warm IV fluids kept patients warmer than room-temperature IV fluids during surgery. This method is effective in preventing heat loss and can help maintain core body temperature.

Another approach to warming patients during surgery is the use of active warming devices. Forced-air warming devices, such as surgical sheets or cotton blankets, are commonly used to warm patients passively. Nieh and Su[4] conducted a meta-analysis and systematic review that showed forced-air warming to be effective in preventing perioperative hypothermia in surgical patients. These devices blow warm air over the patient's body, creating a convective heat transfer that helps maintain body temperature.

In addition to active warming devices, other methods can be employed to warm patients during surgery. Lim and Lee[5] highlighted the importance of various warming strategies in keeping the body temperature stable in elderly patients undergoing surgery under general anesthesia or regional anesthesia. These strategies may include warm blankets, fluid warmers, and radiant warmers.

Furthermore, the use of warm cardioplegia during cardiac surgery is an essential technique for myocardial protection. James et al.[6] discussed the concepts and controversies surrounding warm blood cardioplegia and its role in preventing myocardial reperfusion injury during cardiac surgery. Warm cardioplegia involves the use of warm blood to arrest the heart, providing better myocardial protection compared to cold cardioplegia.

It is worth noting that warm ischemia time (WIT) is a critical factor to consider during surgical procedures. Prolonged warm ischemia is significantly associated with adverse post-

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operative renal function. Volpe et al.[7] reviewed the literature and found that minimizing WIT is crucial in surgeries such as partial nephrectomy and kidney transplantation.

Maintaining normothermia during surgery is essential to prevent hypothermia-associated complications. Strategies such as the administration of warm IV fluids, the use of active warming devices, and the implementation of various warming techniques can effectively warm patients during surgery. Additionally, specific considerations should be given to procedures involving WIT to minimize adverse outcomes. By implementing these warming strategies, healthcare providers can optimize patient outcomes and reduce the risk of perioperative complications.

This study was conducted to evaluate the perioperative effects of different active heating methods on patients who underwent spine surgery in the prone position.

MATERIALS AND METHODS

The study was conducted between March 1, 2022 and September 1, 2022 after approval by İzmir Tınaztepe University Health Sciences Scientific Research and Publication Ethics Committee (approval number: 2022/19, date: 25.03.2022). Consent forms were obtained from all patients participating in the study. In our study, which consisting of 60 patients, 30 patients were included as the experimental group and 30 patients as the control group. Both the experimental and control groups were warmed with heated green covers in the operating room for 30 minutes before the surgery. The fluids given to both groups were at 36 degrees, so they were at body temperature. The experimental group was taken to the operating room and heated with a bottom-heated blanket device throughout the surgery. The patients' tympanic fever was measured every 15 minutes during the entire heating period. The control group was heated during the surgery with a heating device blowing hot air, and the patients' tympanic fever was measured every 15 minutes during the heating period. The experimental and control groups taken to the recovery unit were covered with pre-heated warm blankets, and the patients were transferred to the service 20 minutes after their vital signs were measured in this unit. Laboratory values of the patients were also taken after they went to the ward: laboratory values of the patients before, during, and after the surgery were compared.

Those with Cushing's syndrome, respiratory failure, congestive heart disease, liver, kidney or pancreatic failure were not included in the study. It was thought that the physiological status of these patients might affect the current values, and therefore, these patients were excluded from the study.

Lumbar stenosis cases that were operated on in the prone position, without instrumentation, and underwent single-level laminectomy were included in this study.

Statistical Analysis

The statistical analysis of the data was conducted using Statistical Package for Social Sciences version 25.0. Categorical data were presented as counts and percentages, while continuous data were expressed as means and standard deviations (and medians along with minimum and maximum values when applicable). For the comparison of categorical variables, chi-square and Fisher's exact tests were employed. The Shapiro-Wilk test was utilized to assess the normality of the distribution of the study parameters. For parameters that exhibited a normal distribution, the independent samples t-test was applied, whereas the Mann-Whitney U test was used for those that did not follow a normal distribution. A significance level of 0.05 was established for all statistical tests.

RESULTS

Demographic characteristics and the diagnostic status of the patients participating in the study are given in Table 1. While the average age of the patients was 53.5±14.8 years, Although the average age of the patients in the experimental group was younger, the age difference between the experimental and control groups was not significant (p=0.224). While 31 (51.7%) of the patients were found to be women, there was no significant difference in gender variable rates between groups (p=0.196). No significant difference was found between the presence of chronic disease and the rates of typical chronic patients in the groups (p=0.796; p=0.568, respectively).

The patients in the control group were applied the air insufflation system for an average of 2.36±0.2 hours. It was determined that a bottom heated blanket was applied to the patients in the experimental group for an average of 2.00±0.1 hours (Table 2). While the average time to wake up from anesthesia was 6.03±1.5 minutes in patients, findings on recovery time from anesthesia were found to be homogeneous between the experimental and control groups (p=0.741). The average post-operative day of stay was 3.82±1.2 days in patients. Although the average post-operative stay day was lower in the experimental group than in the control group, the difference was insignificant (p=0.064).

Table 3 shows the clinical and laboratory findings and the differences between the groups. While the average operating room temperature was 20.5±0.7 °C, it was determined that both groups had a similar average value (p=0.942).

The average anesthesia duration was found to be 2.40±0.4 hours in patients. It was determined that the duration of anesthesia was shorter in the experimental group than in the patients in the control group (p<0.001). Differences between groups in terms of vital signs during surgery.

When intraoperative vital signs and differences between the groups were evaluated, it was determined that the 15th and 30th minute systolic blood pressure averages were higher in the control groups than in the experimental groups (p=0.012; p=0.020, respectively). It was determined that the 15th and 30th minute averages of diastolic blood pressure were higher in the control groups than in the experimental groups (p=0.001; p=0.002, respectively). It was determined that the averages of

Table 1. Demographic characteristics of the patients and differences between the groups (n=60)

	Control group (n=30)	Experiment group (n=30)	Total (n=60)	χ^2	p
	n (%)	n (%)	n (%)		
Gender					
Woman	18 (60)	13 (43.3)	31 (51.7)	1,669	0.196
Male	12 (40)	17 (56.7)	29 (48.3)		
Body mass index					
Weak	4 (13.3)	3 (10.0)	7 (11.7)	0.203	0.903
Normal	13 (43.3)	13 (43.3)	26 (45.0)		
Fat	13 (43.3)	14 (46.7)	27 (43.3)		
Chronic disease	14 (33.3)	10 (33.3)	20 (33.3)	0.067	0.796
In those with chronic diseases (n=24)					
DM	1 (7.1)	-	1 (3.4)	1,131	0.568
Hypertension	9 (64.3)	10 (66.7)	19 (65.5)		
Hypertension+DM	4 (28.6)	5 (33.3)	9 (31.0)		
Marital status					
Single	1 (3.3)	4 (13.3)	5 (8.3)	1,964	0.161
Married	29 (96.7)	26 (86.7)	55 (91.7)		
Smoking	14 (46.7)	5 (16.7)	19 (31.7)	6,239	**0.012***
History of previous surgery	4 (13.3)	1 (3.3)	5 (8.3)	1,964	0.161
Age (mean ± SD)	55.8±13.3	51.2±5.9	53.5±14.8	t=1,230	0.224

*p<0.05, χ^2: Chi-square test, t: Independent Student's t-test. DM: Diabetes mellitus, SD: Standard deviation

Table 2. Findings regarding the patients' surgical processes and differences between groups (n=60)

	Control group (n=30)	Experiment group (n=30)	Total (n=60)		
	mean ± SD	mean ± SD	mean ± SD	t	p
Surgery time (hours)	2.28±0.3	2.00±0.1	2.14±0.2	5,461	**<0.001****
Operating room temperature	20.5±0.8	20.5±0.6	20.5±0.7	0.072	0.942
Anesthesia duration (hours)	2.65±0.2	2.14±0.3	2.40±0.4	7,716	**<0.001****
solution temperature	36.2±0.3	36.4±0.2	36.3±0.3	-2,700	**0.009****
IV solution temperature	36.2±0.3	36.5±0.2	36.3±0.3	-4,154	**<0.001****
Washing solutions temperature	36.2±0.3	36.4±0.2	36.3±0.3	-3,096	**0.003****
Fasting period before surgery	9.17±1.4	9.67±1.6	9.42±1.5	-1,299	0.199
Air blowing system application time	2.36±0.2	-	-	-	-
Bottom heated blanket	-	2.00±0.1	-	-	-
Application time (hours)	5.96±1.1	6.10±1.9	6.03±1.5	-0.333	0.741
Recovery time from anesthesia (min)	4.10±1.4	3.53±0.9	3.82±1.2	1,890	0.064
Post-operative stay day	4.90±1.5	4.40±0.0	4.65±1.3	1,506	0.137
Antibiotics used [n (%)]					
Cefazole	25 (83.3)	23 (76.7)	48 (80)	0.417	0.519
Desefine	5 (16.7)	7 (23.3)	12 (20)		

p<0.05, **p<0.001, t: Independent Student's t-test. SD: Standard deviation, IV: Intravenous

Table 3. Clinical and laboratory findings and differences between groups (n=60)

	Control group (n=30)	Experimental group (n=30)	Total (n=60)		
	mean ± SD	mean ± SD	mean ± SD	t/u	p
Body temperature	36.2±0.4	36.2±0.3	36.2±0.3	t=-0.183	0.855
Room temperature	23.3±0.6	22.7±0.9	23.0±0.8	t=3,200	**0.002****
Lymphocyte	24.2±11.1	24.6±8.5	24.4±9.8	u=-0.377	0.706
Platelet	309.2±89.3	287.7±70.2	298.5±80.4	t=1,035	0.305
MAP	72.8±4.5	78.1±4.5	75.5±5.2	t=-4,544	**<0.001****
Respiratory rate	19.5±1.4	18.5±1.9	19.0±1.7	t=2,131	**0.037***
Glasgow coma score	15.0±0.0	15.0±0.0	15.0±0.0	-	-
HB	12.4±1.7	12.3±0.9	12.4±1.3	t=0.230	0819
AST	20.3±7.4	22.4±8.6	21.4±8.0	t=-1,032	0,.306
Erythrocyte	4.33±0.5	4.16±0.4	4.25±0.5	t=1,387	0,171
ALT	20.9±11.1	20.6±8.9	20.8±9.9	t=0.129	0.898
WBC	7.89±3.2	7.54±2.2	7.71±2.7	t=0.498	0.620
BUN	15.4±7.4	13.4±4.3	14.4±6.1	t=1,305	0,197
CRP	3.17±3.1	7.19±9.8	5.18±7.5	t=-2,152	**0.036***
Sedimentation	15.7±16.2	16.2±17.9	15.9±16.9	u=-0.252	0.801

p<0.05, **p<0.001, t: Independent Student's t-test, u: Mann-Whitney U test. SD: Standard deviation, MAP: Mean arterial pressure, HB: Hemoglobin, AST: Aspartat aminotransferaz, ALT: Alanine aminotransferaz, WBC: White blood cells, BUN: Blood urea nitrogen, CRP: C-reaktif protein

mean arterial pressure values at the 0th minute, 15th minute, 30th minute, 45th minute, and 60th minute were higher in the experimental groups than in the control groups (p=0.015; p=0.016; p=0.019, respectively) (p=0.001; p=0.016). No significant difference was detected between the respiratory averages of the experimental and control groups (p>0.05). No significant difference was found between the saturation averages of the patients in the experimental and control groups (p>0.05). No mortality was observed in our patient groups where both heating methods were used.

DISCUSSION

Blood pressure, pulse, respiration, and saturation values of all patients included in this study. When body temperatures were within normal limits, universally similar physiological findings retained their numerical values, unless any other complications arose. It is thought that warming the patients in the experimental group with an electric blanket, and the patients in the control group with a blanket heated with compressed air is essential to keep the vital signs of the patients at expected values. Heating techniques in different modalities may be preferred to prevent perioperative hypothermia. When determining the suitable device, factors such as surgical access, user-friendliness, the size of the device, patient positioning, IV access locations, and the performance of the device should be considered. All devices can prevent vital signs from deteriorating by increasing body temperature. This information was parallel to the findings in this research. In the study, patients' vital signs were kept within normal limits by using different heating techniques.

Hypothermia can lead to adverse outcomes such as increased surgical site infections, impaired wound healing, coagulopathy, and cardiovascular instability[8]. Therefore, maintaining normothermia is essential for optimal patient outcomes.

During the perioperative period, an effective warming strategy should incorporate various measures to maintain intraoperative normothermia. This encompasses pre-anesthetic active warming, active warming throughout the surgical procedure, and precise monitoring of core temperature[8]. Active warming can be implemented using methods such as administering warm IV fluids, utilizing forced-air warming devices, applying warm cardioplegia, and employing various other warming techniques.

The administration of warm IV fluids has been shown to be effective in preventing heat loss and maintaining core body temperature during surgery[9]. It is advised to initiate active warming at least 30 minutes prior to the induction of anesthesia, unless this would post-pone emergency surgical procedures[9]. Forced-air warming devices, including surgical blankets or cotton sheets, facilitate convective heat transfer, which aids in preserving body temperature[8]. These devices are frequently utilized in surgical environments to provide passive warming for patients.

In addition to active warming during surgery, it is crucial to continue warming patients after surgery to prevent post-operative hypothermia. A study conducted in France found that despite forced-air warming devices, the prevalence of hypothermia remained high in patients undergoing surgery[10]. Therefore, it is important to implement effective warming strategies in the post-operative period.

The benefits of warming patients extend beyond preventing hypothermia. Warming patients before surgery has been shown to reduce blood loss and transfusion requirements[11]. It can also have positive effects on wound healing and surgical site infection rates[12]. Additionally, warming techniques such as warm compression can be beneficial in melting abnormal meibum and improving dry eye symptoms[13].

It is important to note that the choice of warming technique may vary depending on the surgical procedure and patient population. For example, a study conducted in Beijing found that only a small percentage of patients received active warming with space heaters or electric blankets during general anesthesia[14]. The application of warmed abdominal lavage solutions has been demonstrated to elevate patient temperatures during anesthesia in celiotomy procedures[15].

Active warming techniques, such as the administration of warm IV fluids and the use of forced-air warming devices, are effective in maintaining normothermia during surgery. When our study is evaluated together with the literature, the application of effective warming strategies not only increases patient comfort but also improves outcomes, reduces the risk of complications, and promotes optimal recovery.

Study Limitations

In this study, patients' vital signs and blood laboratory values were monitored until 24 hours after surgery by using different electrical heating methods. The infection status of the patients could not be determined in the study. With other studies, this research can be repeated in different groups with different patients with different heating methods, and additional information, such as infection findings and hospital discharge times, can be investigated. Additionally, the methods of heating techniques to be used before, during and after surgery in emergency cases could be evaluated. Although the heating techniques generally used in our study were compared, more meaningful results could have been obtained if the heating techniques were evaluated one by one and their results were discussed. Evaluating the techniques we compared with the surgical results in longer surgeries will be the subject of other studies.

CONCLUSION

Our study compared two different heating methods with similar anesthetic and surgical techniques. The physiological values of the patients to whom we applied both methods were statistically similar ($p>0.05$). Heating methods may be helpful in protecting patients from surgical and anesthesia risks, increasing their comfort, and ensuring the physiological state of surgical patients. It is advisable to assess the warming of patients on an individual basis, taking into account the specific type of surgery and the patient's morbidity. Additionally, heating should be routinely incorporated in suitable situations during the surgical procedure.

Ethics

Ethics Committee Approval: The study was approved by İzmir Tınaztepe University Health Sciences Scientific Research and Publication Ethics Committee (approval number: 2022/19, date: 25.03.2022).

Informed Consent: Retrospective study.

Footnotes

Authorship Contributions

Surgical and Medical Practices: B.B., A.T., N.Ü., Concept: B.B., A.T., Design: A.T., Data Collection or Processing: B.B., Analysis or Interpretation: B.B., Literature Search: A.T., N.Ü., Writing: B.B., N.Ü.

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