ORIGINAL RESEARCH

Med J SDU / SDÜ Tıp Fak Derg ▸ 2025:32(4):327-335 ▸ doi: 10.17343/sdutfd.1771453

Reliability and Agreement of Four Radiographic Methods for Measuring Posterior Tibial Slope on Lateral Knee Radiographs

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Cite this article as: Yuksel Y, Kose O. Reliability and Agreement of Four Radiographic Methods for Measuring Posterior Tibial Slope on Lateral Knee Radiographs. Med J SDU 2025;32(4):327-335.

Abstract

Objective

The posterior tibial slope (PTS) is a critical anatomical parameter influencing knee biomechanics and ligamentous stability. Despite its clinical relevance, no consensus exists on the most reliable radiographic method for measuring PTS. This study aimed to evaluate the inter- and intra-observer reliability and agreement of four radiographic techniques for PTS measurement on standard lateral knee radiographs.

Material and Method

A retrospective analysis was conducted on 70 adult patients with high-quality true lateral knee radiographs. Four commonly used methods were applied to measure the PTS: the fibular shaft axis (FSA), anterior cortical line (ACL), posterior cortical line (PCL), and proximal anatomical axis (PAA). Two experienced observers performed all measurements twice, 15 days apart, using a standardized protocol. Intraclass correlation coefficients (ICCs) were calculated to assess reliability, and Pearson correlation coefficients were used to evaluate the agreement between measurements and demographic characteristics.

Results

All four methods showed excellent intra-observer reliability (ICC, range 0.916–0.975) and good-to-excellent inter-observer reliability (ICC, range 0.813–0.968). Mean PTS values differed by method: ACL 12.4° ± 3.2°, PCL 7.2° ± 3.1°, FSA 10.1° ± 3.2°, PAA 9.6° ± 3.0° ($p = 0.001$). Pairwise correlations were strong for all methods ($p < 0.001$). PTS showed no significant association with age, sex, height, weight, or body mass index.

Conclusion

Although reliability was high for all techniques, differences in absolute values indicate that methods are not interchangeable. Standardized reference axes should be specified to ensure consistent reporting across clinical and research settings.

Keywords: posterior tibial slope, knee radiograph, measurement reliability, observer agreement, anatomical axis

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Received: 24.08.2025 • **Accepted:** 31.10.2025

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Introduction

The posterior tibial slope (PTS) is the posterior inclination of the tibial plateau relative to the tibial axis in the sagittal plane. It plays a crucial role in maintaining knee biomechanics, influencing the ligamentous stability and kinematic behavior of the joint (1). An increased PTS has been associated with anterior tibial translation, heightened risk of anterior cruciate ligament injury, and increased stress on knee prostheses. In contrast, a reduced slope may impair the function of the posterior cruciate ligament and restrict flexion in total knee arthroplasty settings (2, 3).

Despite its clinical relevance, no universally accepted method for measuring PTS on plain radiographs exists. Various anatomical reference axes have been proposed, including the proximal anatomical axis, posterior cortex, anterior cortex, and fibular shaft axis, which yield different angular values (4–6). The variability in reference lines used in the literature contributes to inconsistencies across studies, complicating the comparison and interpretation of findings (7–10).

The accuracy of PTS measurements is also affected by the type of imaging modality used. Long-leg computed tomography (CT) and long-leg lateral radiographs are considered most accurate due to their ability to encompass the entire tibial shaft, which minimizes errors introduced by tibial bowing (11–14). However, in daily clinical practice, standard short lateral knee radiographs are more commonly available, despite their limited representation of the tibial longitudinal axis. Previous studies have also demonstrated that the degree of anterior tibial bowing can lead to significant underestimation of the true PTS on short radiographs (12).

Multiple studies have investigated the absolute values of PTS in different populations and using various methods. However, few have comprehensively compared the inter- and intra-observer reliability of various radiographic techniques on lateral knee X-rays (15–18). Establishing the reproducibility of PTS measurements is crucial for informed clinical decision-making, particularly in surgical planning for ligament reconstruction or joint replacement. The purpose of this study was to compare the inter- and intra-observer reliability and the level of agreement among four commonly used radiographic methods for measuring the PTS on standard lateral knee radiographs. By evaluating the consistency and agreement of these methods, we aimed to identify the most reliable approach for clinical and research applications.

Material and Method

Patients and Study Design

This retrospective observational study included adult patients (>18 years of age) who underwent lateral knee radiographs for various clinical indications between January 2023 and March 2025 at a tertiary care institution. Radiographs were retrospectively retrieved and screened from the institutional Picture Archiving and Communication System (PACS) database to assess eligibility. Patients were excluded if they had severe osteoarthritis, a history of previous surgery involving the tibia or femur, acute or healed fractures, any type of orthopedic implant, or congenital deformities. Additionally, radiographs deemed unsuitable for PTS measurement were excluded. The radiographic inclusion criteria required (i) a true lateral view of the knee, characterized by complete overlap of the posterior femoral condyles, and (ii) adequate tibial length, defined as the inclusion of at least 15 cm of the tibial shaft distal to the joint line. Radiographs failing to meet these criteria, such as those obtained with excessive rotational malalignment or insufficient tibial length, were excluded from the study.

Sample Size Calculation

The sample size estimation was guided by the expected level of agreement among two raters, quantified using the intraclass correlation coefficient (ICC) for radiographic angular measurements (continuous variable). The expected ICC was set at 0.800, with an acceptable minimum ICC of 0.700, based on a two-way random-effects model for consistency. To achieve 95% power at a significance level of 0.05, each of the two raters performed two repeated measurements per patient. According to Bonett's method, a minimum of 52 patients was required to reliably detect the expected ICC (19). Although the minimum required sample size was calculated as 52, the study was conducted on 70 patients to account for potential exclusions due to suboptimal radiographs and increase the statistical power of the reliability analysis.

Radiological Measurements

The PTS was measured using four radiographic methods, as illustrated in Figure 1 (5). Fibular shaft axis (FSA) method (Figure 1a): The reference axis was defined by a line drawn along the shaft of the fibula, and the posterior tibial slope angle was measured between a line tangent to the lateral tibial plateau and a line perpendicular to this fibular axis. Anterior cortical line (ACL) method (Figure 1b): The anterior cortical line was constructed by connecting mid-diaphyseal points located 5 cm and 15 cm distal to the tibial plateau along the anterior

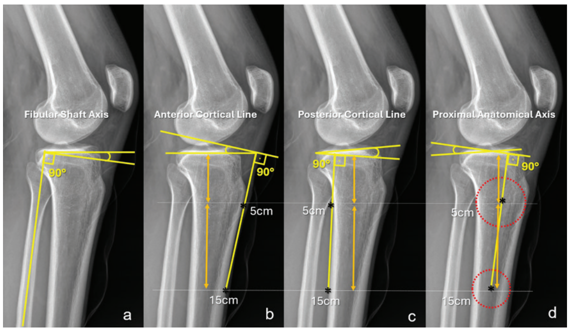

Figure 1

Radiographic illustration of four different posterior tibial slope measurement methods: (a) Fibular Shaft Axis, (b) Anterior Cortical Line, (c) Posterior Cortical Line, and (d) Proximal Anatomical Axis.

cortex. The angle between the plateau tangent and the perpendicular to this anterior cortical line was recorded as the posterior tibial slope angle. Posterior cortical line (PCL) method (Figure 1c): This method used the posterior tibial cortex as the reference. The posterior cortical line was constructed by connecting mid-diaphyseal points located 5 cm and 15 cm distal to the tibial plateau along the posterior cortex, and the posterior tibial slope angle was defined as that between the plateau tangent and a line perpendicular to the posterior cortical line. Proximal anatomical axis (PAA) method (Figure 1d): The anatomical axis of the proximal tibia was determined by connecting two mid-diaphyseal points located 5 cm and 15 cm distal to the tibial plateau. Posterior tibial slope was measured as the angle between the plateau tangent and a line perpendicular to this proximal anatomical axis.

PTS was measured using a global tibial plateau tangent. Specifically, the tangent was drawn to the native subchondral contour spanning the medial and lateral plateaus, providing a single global slope reference. In the presence of osteophytes or marginal irregularities, the tangent was fitted to the presumed anatomic plateau by excluding osteophytic lips and remodeled edges and following the smooth subchondral line of the load-bearing region on each side. All radiographic measurements were performed digitally using RadiAnt DICOM Viewer software (Version 2022.2, Medixant), with calibration applied to a standardized scale to ensure accuracy and reproducibility.

Reliability Study

To evaluate the reliability of the measurements, the PTS was independently assessed on all radiographs by two observers: an orthopedic surgeon with over 15 years of clinical experience in knee surgery and a radiologist with 10 years of experience. Each observer measured the PTS using all four methods described. To assess intra-observer reliability, all measurements were repeated by the same observers following a 15-day washout period to minimize recall bias. Both observers were masked to each other's measurements and their own previous assessments. Before the evaluations, a standardized measurement protocol and an illustrative reference diagram were provided to ensure consistency across measurements.

Statistical Analysis

Descriptive statistics were reported as means and standard deviations for continuous variables and as frequencies and percentages for categorical variables. The normality of continuous data was evaluated using the Shapiro–Wilk test. Sex-based comparisons of PTS measurements obtained using the four methods were conducted using the Mann–Whitney U test due to non-normal data distribution. Friedman's test was used to compare PTS values across the four measurement techniques within each sex subgroup. Intra- and inter-observer reliability were assessed using the ICC with 95% confidence intervals, based on a two-way random-effects model for absolute agreement. Both single- and average-measure ICCs were calculated. According to commonly accepted thresholds, ICC values below 0.50 were interpreted as poor, between 0.50 and 0.75 as moderate, between 0.75 and 0.90 as good, and above 0.90 as excellent reliability (20). The relationship between demographic variables (age, weight, height, and body mass index) and PTS values obtained from each method was examined using Pearson correlation coefficients. A p-value <0.05 was considered statistically significant.

Results

A total of 70 patients (50 men (71.4%), 20 women (28.6%)) with a mean age of 34.6 ± 14.4 years (range: 18–76) were included. The mean body mass index (BMI) was 25.5 ± 3.3 kg/m², the mean height was 171.1 ± 7.3 cm, and the mean weight was 74.7 ±

Table 1 Demographic characteristics of the patients.

Variables	**Data**
Number of patients	70
Age (years ±SD) (min-max)	34.6±14.4 (18-76)
Gender (n,%)	
Male	50 (71.4%)
Female	20 (28.6%)
Weight (kg±SD)	74.7±11.0
Height (cm±SD)	171.1±7.3
Body Mass Index (kg/m²±SD)	25.5±3.3
Side (n,%)	
Right	27 (38.6%)
Left	43 (61.4%)

Abbreviations, SD: Standard deviation

11.0 kg. The right knee was evaluated in 27 patients (38.6%) and the left knee in 43 patients (61.4%). The demographic characteristics of the participants are presented in Table 1.

The inter- and intra-observer reliability for each PTS measurement method is summarized in Table 2. All four methods demonstrated excellent intra-observer reliability, with ICCs ranging from 0.916 to 0.975. The highest intra-observer reliability was noted for the anterior cortical line method by Observer B (ICC = 0.975), whereas the lowest was for the posterior cortical line by the same observer (ICC = 0.916). Inter-observer reliability was also high across all methods, with ICC values ranging from 0.813 to 0.968. The anterior cortical line and fibular shaft axis methods demonstrated excellent inter-observer agreement (ICC up to 0.966). The proximal anatomical axis showed slightly lower, yet still good, reliability in the first measurement round (ICC = 0.813), improving to excellent (ICC = 0.955) in the second round.

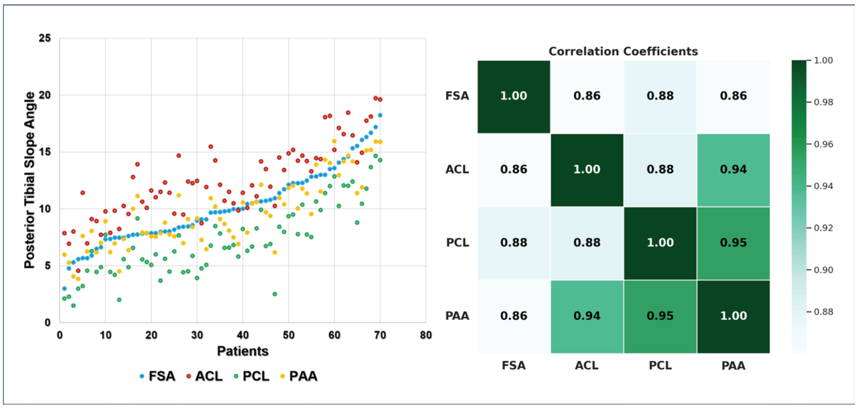

Figure 2
Distribution of posterior tibial slope measurements by method (left) and the correlation matrix of pairwise comparisons between the four radiographic techniques (right). Abbreviations: FSA: Fibular Shaft Axis, ACL: Anterior Cortical Line, PCL: Posterior Cortical Line, PAA: Proximal Anatomical Axis.

Table 2 Inter and Intra-observer Reliability of the Different Posterior Tibial Slope Measurements.

Variable	Reliability		ICC	95%CI	Interpretation
Fibular Shaft Axis	**Intra-observer reliability**				
	Observer A t_1	Observer A t_2	0.952	0.923-0.970	Excellent
	Observer B t_1	Observer B t_2	0.974	0.958-0.984	Excellent
	Inter-observer reliability				
	Observer A t_1	Observer B t_1	0.886	0.817-0.929	Good
	Observer A t_2	Observer B t_2	0.966	0.946-0.979	Excellent
Anterior Cortical Line	**Intra-observer reliability**				
	Observer A t_1	Observer A t_2	0.939	0.902-0.962	Excellent
	Observer B t_1	Observer B t_2	0.975	0.960-0.985	Excellent
	Inter-observer reliability				
	Observer A t_1	Observer B t_1	0.875	0.800-0.923	Good
	Observer A t_2	Observer B t_2	0.955	0.928-0.972	Excellent
Posterior Cortical Line	**Intra-observer reliability**				
	Observer A t_1	Observer A t_2	0.946	0.913-0.966	Excellent
	Observer B t_1	Observer B t_2	0.916	0.865-0.948	Excellent
	Inter-observer reliability				
	Observer A t_1	Observer B t_1	0.862	0.777-0.914	Good
	Observer A t_2	Observer B t_2	0.968	0.949-0.980	Excellent
Proximal Anatomical Axis	**Intra-observer reliability**				
	Observer A t_1	Observer A t_2	0.928	0.885-0.955	Excellent
	Observer B t_1	Observer B t_2	0.944	0.912-0.965	Excellent
	Inter-observer reliability				
	Observer A t_1	Observer B t_1	0.813	0.700-0.884	Good
	Observer A t_2	Observer B t_2	0.955	0.928-0.986	Excellent

Abbreviations: t^1: First time, t^2: Second time, ICC: Interclass Correlation Coefficient, CI: Confidence Interval

Sex-based comparisons of the PTS values are presented in Table 3. No statistically significant differences were found between men and women for any of the four measurement techniques ($p > 0.05$). The mean PTS values for the total cohort were 10.1° ± 3.2° (fibular shaft axis), 12.4° ± 3.2° (anterior cortical line), 7.2° ± 3.1° (posterior cortical line), and 9.6° ± 3.0° (proximal anatomical axis). The PTS angles demonstrated significant variability depending on the radiographic method used ($p = 0.001$).

Correlation analyses between demographic characteristics and the PTS measurements revealed no statistically significant associations ($p > 0.05$ for all).

The Pearson correlation coefficients between age, weight, height, BMI, and PTS values for each method ranged from –0.198 to +0.018, indicating weak and non-significant correlations (Table 4).

Scatter plots were generated to evaluate the pairwise correlations between the four measurement methods. The results demonstrated strong and statistically significant positive correlations ($p < 0.001$ for all pairwise analyses) between all methods (Figure 2). The highest correlation was observed between the proximal anatomical axis method and the anterior and posterior cortical line methods ($r = 0.94$ and $r = 0.95$, respectively).

Table 3 Comparison of the PTS measurement between genders.

Measurements	Total	Male	Female	p-value
Fibular Shaft Axis (°±SD)	10.1±3.2	10.4±3.4	9.2±2.6	0.200[1]
Anterior Cortical Line (°±SD)	12.4±3.2	12.4±3.6	12.4±2.4	0.750[1]
Posterior Cortical Line (°±SD)	7.2±3.1	7.2±3.3	7.2±2.6	0.760[1]
Proximal Anatomical Axis (°±SD)	9.6±3.0	9.5±3.2	9.9±2.5	0.380[1]
p-value	0.001[2]	0.001[2]	0.001[2]	

Abbreviations, SD: Standard Deviation, [1] Mann-Whitney U test, [2] Friedman's test

Table 4 Correlation between demographic characteristics and the PTS measurements

Correlations		FSA	ACL	PCL	PAA
Age	rho	-0.198	-0.172	-0.138	-0.143
	p-value	0.101	0.155	0.256	0.238
Weight	rho	-0.044	-0.046	-0.010	-0.031
	p-value	0.719	0.703	0.936	0.796
Height	rho	0.018	0.001	-0.059	-0.050
	p-value	0.882	0.994	0.629	0.683
BMI	rho	-0.054	-0.045	0.031	0.001
	p-value	0.656	0.711	0.800	0.995

Abbreviations: FSA: Fibular Shaft Axis, ACL: Anterior Cortical Line, PCL: Posterior Cortical Line, PAA: Proximal Anatomical Axis, BMI: Body Mass Index

Discussion

We aimed to evaluate and compare the reliability and agreement of four commonly used radiographic methods for measuring the PTS on standard lateral knee radiographs. All four methods-fibular shaft axis, anterior cortical line, posterior cortical line, and proximal anatomical axis-exhibited excellent intra-observer and good-to-excellent inter-observer reliability (ICC > 0.800), confirming their reproducibility across independent raters. Despite the high reliability of each method, we observed substantial variation in the absolute PTS values across anatomical reference lines, indicating that different approaches can yield significantly divergent slope measurements. However, strong, statistically significant positive correlations across all pairs of measurement techniques suggest that these methods are directionally consistent and comparably valid, though not interchangeable. Notably, the PTS measurements did not significantly differ between male and female patients, and no significant correlations were found between PTS values and the demographic variables of age, height, weight, or BMI. These findings suggest that PTS values are independent of patient-specific anthropometric characteristics and that consistent, reliable measurements can be obtained regardless of demographic differences, provided standardized imaging protocols and clearly defined anatomical landmarks are used.

The observed reliability data are broadly consistent with, and in many cases exceed, those reported in the existing literature. For instance, Lee et al. (21) reported moderate to good interobserver reliability depending on the method used, with ICC values ranging from

0.61 to 0.89. Similarly, Abdul Wahid et al. (17) observed inter-rater agreement ranging between 0.68 and 0.85. In a detailed comparative study of multiple radiographic techniques, Fletcher et al. (22) reported a wider ICC range from 0.529 to 0.926, highlighting the variability in reliability across methods. In their analysis, techniques based on the posterior tibial cortex and mechanical axis yielded higher reliability, whereas those referencing the fibular shaft or anterior cortex demonstrated lower reproducibility. The consistently high ICC values observed in our study across all four methods may be attributed to several methodological strengths. These include the use of standardized true lateral radiographs with adequate tibial length (≥15 cm distal to the plateau), a clearly defined measurement protocol, and evaluations conducted by experienced observers. Taken together, our results underscore the importance of technical rigor in imaging and measurement procedures. They also suggest that when appropriately applied, all four methods can yield highly reliable inter-observer assessments of the PTS.

The accuracy of PTS measurements is highly dependent on the choice of anatomical reference axis and the imaging modality used. In our study, although all four radiographic techniques demonstrated excellent reliability, the mean PTS values varied substantially depending on the chosen reference line, ranging from 7.2° (posterior cortical line) to 12.4° (anterior cortical line). Yoo et al. (5) emphasized that different reference axes yield significantly different PTS values, with posterior cortex-based measurements being more consistent and reproducible, whereas anterior cortex- or anatomical-axis-based approaches may be affected by tibial bowing or malalignment. Hashemi et al. (8) similarly showed that PTS values can shift significantly depending on the axis used, and such differences can alter biomechanical interpretations, particularly in anterior cruciate ligament injury risk assessments. Fletcher et al. (22) later noted that short lateral knee radiographs may introduce projection errors and underrepresent the tibial axis, and recommended full-length CT scans for more accurate tibial alignment and slope assessment. These findings collectively support the critical need for standardization in both reference axis selection and imaging modality to ensure clinically meaningful and reproducible PTS measurements.

Whether PTS differs between sexes remains debated in the literature. In our study, no statistically significant differences were observed between male and female patients across any of the four radiographic measurement techniques ($p > 0.05$). This finding aligns with the results of Clinger et al. (23), who reported no significant sex-based differences in medial, lateral, or global PTS in a cadaveric study of 250 specimens. Similarly, Pangaud et al. (24) found that men exhibited slightly higher global and lateral PTS values than women, but no difference was observed in the medial PTS. In contrast, Weinberg et al. (25), in a large osteological analysis, reported that women had significantly greater medial and lateral PTS values compared to men. These conflicting results may reflect differences in imaging modalities, anatomical reference axes, and the demographic composition of the study populations. In our study, we also found no significant correlations between PTS values and the demographic variables of age, height, weight, and BMI. This suggests that PTS may be largely independent of individual anthropometric characteristics.

This study has several notable strengths. First, it is one of the few studies to systematically compare four commonly used radiographic methods for measuring PTS on standardized lateral knee radiographs. Second, this study benefited from a standardized imaging protocol, predefined measurement definitions, and blinded, repeated readings by experienced specialists, yielding excellent intra- and inter-observer reliability. These features enhance the internal validity and reproducibility of the measurements within the study setting. Third, the strict inclusion criteria ensured high-quality radiographs with adequate tibial length, enhancing measurement consistency and validity. Finally, the use of digital DICOM-based measurements with calibration further strengthened the methodological rigor and reproducibility.

Several limitations must be acknowledged, however. The study was conducted in a single tertiary care center, which may limit the generalizability of the findings. Although the number of radiographs included ($n = 70$) was higher than the calculated minimum sample size, the cohort may still not reflect broader anatomical variability. Additionally, only lateral radiographs were used; the potential influence of patient positioning errors on slope measurements, despite stringent selection criteria, cannot be entirely ruled out. This evaluation was performed by a relatively small number of specialists, which may limit generalizability and could underestimate inter-observer variability in broader clinical practice. Although a standardized protocol and a washout period were used to enhance reproducibility, multi-center validation with larger and more diverse rater cohorts is warranted. Lastly, the study did not include a comparison with advanced imaging modalities, such as computed tomography (CT) or magnetic resonance imaging (MRI), which may provide a more precise assessment of the tibial slope.

This evaluation was performed by a relatively small number of specialists (two observers), which may underestimate inter-observer variability in wider practice. Although a standardized protocol and a washout period were used to enhance reproducibility, multi-center validation with larger, more diverse rater cohorts is warranted.

Conclusion

This study demonstrated that all four radiographic methods used to measure the PTS yielded high intra- and inter-observer reliability, confirming the reproducibility and consistency of these techniques when applied under standardized conditions. Despite strong correlations among the methods, absolute PTS values differed systematically by method, and the techniques are not interchangeable. This suggests that the choice of anatomical reference axis plays a more critical role in determining the measured slope than the measurement technique itself. Therefore, although each method offers internal consistency, caution must be exercised when comparing PTS values across studies because differences in reference axes may significantly influence the reported results. To ensure comparability and reproducibility, clinicians and researchers should pre-specify a single reference axis and use it consistently within a study or clinical pathway. Moreover, no significant associations were found between PTS values and patient demographics such as sex, age, height, and weight, indicating that these variables may not be major determinants of slope variation in radiographic assessments. Overall, our findings highlight the importance of clearly defining the measurement method in clinical evaluations and scientific reporting to ensure the accurate interpretation and meaningful comparison of PTS data.

Abbreviations

PTS - Posterior Tibial Slope; FSA-Fibular Shaft Axis; ACL - Anterior Cortical Line; PCL - Posterior Cortical Line; PAA – Proximal Anatomical Axis; ICC – Intraclass Correlation Coefficient; SD - Standard Deviation; CI - Confidence Interval; CT - Computed Tomography; MRI - Magnetic Resonance Imaging; DICOM - Digital Imaging and Communications in Medicine

Conflict of Interest Statement

The authors have no conflict of interest to declare.

Ethical Approval

Alaaddin Keykubat University Ethics Committee approved the study protocol. Date:11.06.2025 Issue:10-2. The study was conducted in line with the principles of the "Helsinki Declaration".

Consent to Participate and Publish

This retrospective observational study involved no human participation and was based solely on radiographic evaluations.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Availability of Data and Materials

Data available on request from the authors.

Artificial Intelligence Statement

The authors declare that they have not used any type of generative artificial intelligence for the writing of this manuscript, nor for the creation of images, graphics, tables, or their corresponding captions.

Authors Contributions

YY: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Validation; Visualization; Writing-original draft.

OK: Investigation; Validation; Writing-original draft; Data curation; Formal analysis; Writing- review & editing.

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