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Research Article

Accuracy of Preoperative Radiographic Templating Across Four Widely Used Total Knee Arthroplasty Systems

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ABSTRACT

Objective: This study aimed to evaluate the accuracy of standardized preoperative radiographic templating in predicting femoral and tibial component sizes across four different total knee arthroplasty (TKA) systems in patients undergoing primary TKA for osteoarthritis.

Methods: This retrospective, single-center observational study included 160 knees from 141 patients (mean age of 67.3 ± 7.9 years) who underwent primary TKA for osteoarthritis between March 2011 and March 2020. Of the 141 patients, 122 underwent unilateral and 19 underwent bilateral TKA. Four different TKA systems were evaluated, with 40 knees assigned to each implant group. Standardized weight-bearing anteroposterior and lateral knee radiographs were used to measure femoral and tibial dimensions using a picture archiving and communication system (PACS). The primary outcome was the agreement between radiographically predicted and intraoperatively implanted femoral and tibial component sizes. Agreement was assessed using weighted Cohen's kappa (κ), and interobserver reliability was evaluated using the intraclass correlation coefficient (ICC).

Results: For femoral components, the exact size was predicted in 76.9% of knees, and 96.8% of predictions were within ±1 implant size. For tibial components, the exact size was predicted in 64.4% of knees, and 92.5% were within ±1 implant size. Agreement between predicted and implanted sizes was substantial for femoral components (κ=0.70, 95% CI, 0.62–0.78) and moderate for tibial components (κ=0.54, 95% CI, 0.45–0.63). Size discrepancies differed significantly among the four implant systems for both tibial (P=0.001) and femoral components (P=0.010). Overall, 94.4% (302/320) of all component size predictions were within ±1 implant size.

Conclusion: Standardized preoperative radiographic templating reliably predicted component size across four different TKA systems, with greater accuracy for femoral than for tibial components. When standardized radiographic acquisition, calibration, and measurement protocols are applied, conventional two-dimensional templating can provide clinically acceptable component-size predictions across different implant designs. These findings support its clinical utility as an accessible and cost-effective method for preoperative planning in primary TKA.

Level of Evidence: Level III, Diagnostic study.

Introduction

Total knee arthroplasty (TKA) is a cornerstone surgical intervention for end-stage osteoarthritis, effectively alleviating pain and restoring knee function, as established by long-term outcome studies.[1] Although the success of TKA is fundamentally linked to implant design and surgical precision, a growing body of evidence underscores that accurate preoperative planning and precise component size selection are equally critical determinants of long-term clinical success and implant survivorship. Inappropriate sizing is not merely a technical oversight but a significant clinical concern, predisposing patients to a spectrum of complications including anterior knee pain, instability, patellofemoral maltracking, stiffness, and premature aseptic loosening—all of which detrimentally impact functional recovery and implant longevity.[2]

Preoperative templating serves as a strategic blueprint for surgery, aiming to pre-determine optimal implant size, alignment, and bone resection levels. This proactive planning enhances operative efficiency, reduces intraoperative decision-making uncertainty, and streamlines surgical workflow.[3] Among available planning modalities, 2-dimensional (2D) radiographic templating remains the most widely used and cost-effective method in clinical practice. It has consistently demonstrated reliability, allowing surgeons to estimate prosthesis dimensions using standard anteroposterior (AP) and lateral radiographs, thereby minimizing reliance on excessive intraoperative trialing and potentially reducing operative time.[4,5]

Two-dimensional digital templating remains the most accessible and widely utilized method for preoperative planning in TKA, despite inherent limitations including magnification errors and the inability to assess rotational alignment. Emerging 3-dimensional (3D) computed tomography (CT)-based planning techniques offer improved accuracy in predicting component sizes, particularly for the femoral implant. However, factors such as increased radiation exposure, higher costs, and the requirement for specialized software limit the widespread adoption of CT-based templating. Consequently, optimizing standardized

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2D templating protocols remains a clinically important objective, particularly in settings where advanced imaging modalities are not readily available.[6] The present study aims to evaluate whether a rigorously standardized 2D templating approach can reliably predict implant sizes across multiple implant designs.

However, the predictive accuracy of this established technique is moderated by several variables. Technical factors, such as patient positioning during radiography, inherent radiographic magnification, and—importantly—geometric and scaling variations intrinsic to different implant manufacturers, can significantly influence templating precision.[7] Recent evidence confirms that design-specific characteristics—including femoral component geometry, mediolateral width options, and sizing increments—directly impact templating outcomes and intraoperative sizing decisions.[8] The inherent variations in design philosophy and sizing scales between different manufacturers present a considerable obstacle to establishing universal templating standards. Consequently, although the utility of preoperative templating within a single implant system is well-documented, the existing literature reveals a notable gap: robust comparative data assessing the reliability of standardized radiographic measurements across multiple distinct prosthesis brands remains limited. Many prior investigations have been constrained to evaluations of single-implant systems or relatively small, homogeneous patient cohorts, limiting the generalizability of their findings.[3,9]

This study was designed to address this specific evidence gap. The authors conducted a retrospective analysis with a dual primary aim. First, to evaluate the accuracy and agreement between preoperatively predicted and intraoperatively used implant sizes for both femoral and tibial components; and second, to perform this assessment across 4 different, commercially prevalent TKA systems. By involving a substantial patient cohort and incorporating multiple implant designs, this investigation seeks to provide a more comprehensive and clinically generalizable assessment. The authors hypothesized that a standardized preoperative radiographic measurement protocol could reliably predict final implant size within a clinically acceptable margin of error, irrespective of the specific prosthesis brand utilized.

Materials and methods

Study design and patient selection

This retrospective, single-center, observational study included patients who underwent primary TKA for primary knee osteoarthritis between March 2011 and March 2020 at a tertiary referral center. The study initially included 499 patients and 625 knee radiographs. After applying the exclusion criteria, a total of 160 knees from 141 patients were selected and subsequently divided into 4 groups of 40 patients each. The number of patients per prosthesis brand group (n=40) was determined through computer-generated simple random sampling from the surgical database to ensure equal group sizes and reduce selection bias, facilitating a balanced comparative analysis. Regarding the sex distribution, although there was an overall imbalance favoring female patients, this distribution was statistically comparable across all 4 implant groups (P=.345). Although the authors did not perform a sex-specific subgroup analysis of templating accuracy, the consistent sex distribution across groups suggests that sex differences are unlikely to have biased the comparative results. Future studies could explore potential sex-related effects on implant sizing accuracy.

HIGHLIGHTS

- Standardized radiographic templating reliably predicted implant size across 4 different total knee arthroplasty systems (TKA), with 94.4% of all predictions within the clinically acceptable ± 1 size range.
- Femoral component sizing demonstrated higher accuracy (·=0.70; 96.8% within ± 1 size) compared with tibial sizing (·=0.54; 92.5% within ± 1 size).
- Conventional radiographic templating remains a reliable, reproducible, and cost-effective cornerstone for preoperative planning in primary TKA.

The inclusion criteria were as follows: patients diagnosed with primary osteoarthritis who underwent primary TKA and had complete, standardized preoperative AP and lateral knee radiographs suitable for radiographic templating. Only cases with fully documented intraoperative implant size data were eligible for analysis.

Patients were excluded if they had undergone revision arthroplasty, post-traumatic or inflammatory arthritis, severe deformities preventing standardized radiographic acquisition, or incomplete clinical, radiographic, or surgical records.

The dataset included 141 distinct patients, of whom 19 underwent bilateral TKA and 122 underwent unilateral procedures. Each knee was analyzed independently, consistent with the methodology outlined in the Methods section. The outcomes for bilateral cases were evaluated on a per-knee basis to maintain consistency in the analysis of templating accuracy. Although no separate subgroup comparison between unilateral and bilateral cases was performed, including bilateral knees as independent observations aligns with established practices in radiographic templating studies. Future investigations may consider stratified analyses to explore whether bilateral cases differentially affect templating accuracy or clinical outcomes.

Demographic and clinical data were retrieved from the institutional electronic medical record system. All data were anonymized prior to analysis.

This retrospective study was approved by the Institutional Review Board of Çukurova University (Approval No 2020/13; Date: April 10, 2020). The requirement for written informed consent was waived owing to the retrospective nature of the study, in accordance with institutional guidelines and the principles of the Declaration of Helsinki. This study was conducted and reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology guidelines.

Prosthesis groups

To evaluate consistency across varied implant morphologies, 4 commercially prevalent posterior-stabilized TKA systems from different manufacturers were included. The 4 prosthesis brands included in this study were selected because they represent the most commonly utilized TKA implant systems within the hospital and the broader national context. This deliberate selection was intended to ensure that the study findings are directly relevant and generalizable to local clinical practice and the patient population served. By focusing on these widely adopted implant systems, the analysis captures the implant design variability most frequently encountered in routine surgical settings, thereby enhancing the external validity and practical applicability of the results. These systems, designated as Brands A through D to maintain objectivity and comply with institutional legal guidelines (as manufacturer approval for this academic investigation was not obtained), were selected based on their distinct design philosophies regarding femoral component geometry, tibial baseplate coverage, and sizing increments—factors known to potentially

influence templating accuracy. Despite anonymization, the distinct design characteristics of each system—such as femoral geometry, tibial coverage, and sizing increments—are described in detail to ensure scientific transparency.

For each prosthesis brand, a computer-generated simple random sampling method was used to select 40 patients from the respective surgical database, ensuring temporal distribution across the entire study period. This resulted in a total study population of 160 patients with equal group sizes (n=40 per brand). This balanced allocation minimized selection bias and facilitated a robust comparison of templating performance across different implant systems.

Radiographic technique and measurements

Preoperative knee radiographs were systematically acquired according to a standardized institutional protocol. Standardized weight-bearing AP and lateral views were obtained with the patients in an upright position to ensure physiological joint alignment and loading. A radio-opaque spherical marker with a known diameter of 25 mm was routinely positioned at the knee joint level during image acquisition to serve as an external calibration reference. Radiographic measurements were conducted using well-defined anatomical landmarks to ensure consistency and reproducibility across various implant designs. Femoral dimensions were measured on lateral radiographs from the anterior femoral cortex to the posterior femoral condyle, parallel to the femoral shaft axis. Tibial measurements included the mediolateral width at the proposed resection plane, measured from the medial to lateral cortical margins on AP views, and the AP length on lateral views from the anterior tibial cortex to the posterior margin of the tibial plateau. These standardized reference points, combined with calibration using the spherical marker, minimized magnification errors and enhanced the accuracy and reliability of templating across the 4 prosthesis brands studied.

Technical parameters were standardized as follows: tube-to-film distance of 180 cm, 40 kV, 2.5 mAs, and 44 ms exposure time. Radiographs that did not meet these predefined technical criteria were excluded from the subsequent analysis.

Digital radiographs were analyzed using the institutional PACS (Carestream Vue PACS, version 12.1; Carestream Health, Rochester, NY, USA). Prior to measurement, all images were calibrated within the PACS software using an embedded spherical marker to eliminate magnification error. Femoral and tibial dimensions were measured on both AP and lateral views according to each manufacturer's specific templating guidelines and subsequently compared with the actual implant sizes documented during surgery (Figures 1-3).

All radiographic measurements were performed independently by 2 orthopedic specialists with expertise in arthroplasty planning, and each measurement was repeated twice to ensure reliability. Inter-observer reliability was quantified using intraclass correlation coefficients (ICCs), demonstrating excellent agreement (ICC=0.92, 95% CI: 0.88-0.95). Given that radiographic templating accuracy varies with image magnification and implant design characteristics, a rigorous calibration and standardization protocol was implemented to ensure consistency across all measurements and implant systems.

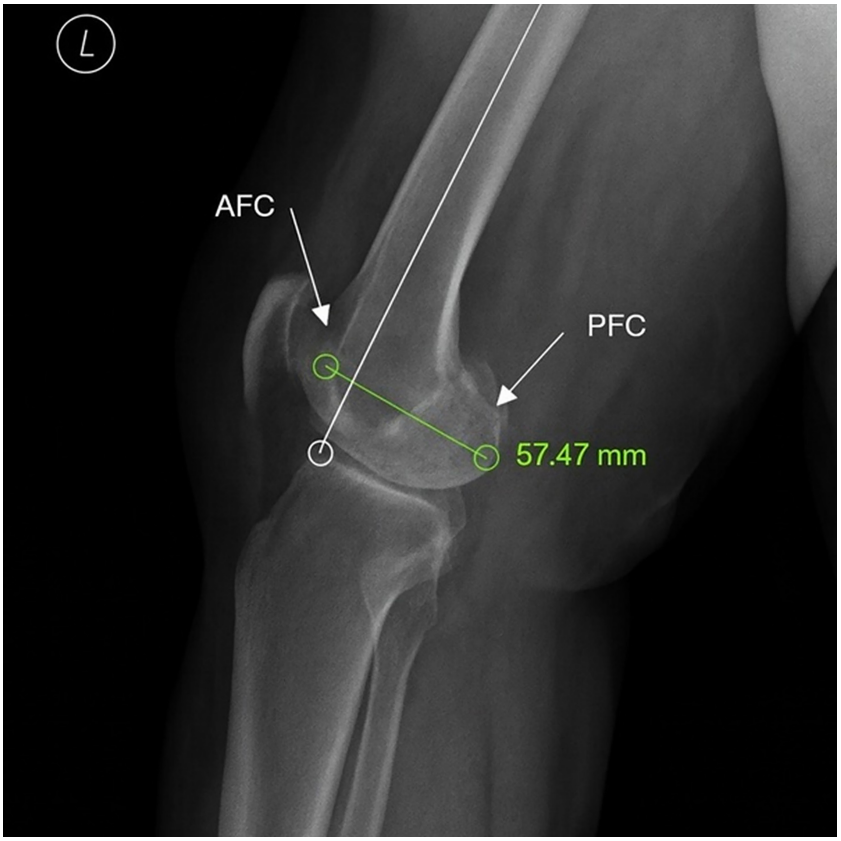


Figure 1 . Preoperative lateral knee radiograph demonstrating the measurement of the femoral lateral dimension (circular markers) used for femoral component sizing. The measurement is obtained from the anterior femoral cortex (AFC) to the posterior femoral condyle (PFC), parallel to the femoral shaft axis, in accordance with the implant manufacturer's templating guidelines.



Figure 2 . Standardized lateral knee radiograph illustrating measurement of the tibial lateral dimension. The distance is measured from the anterior tibial cortex to the posterior margin of the tibial plateau, perpendicular to the longitudinal tibial axis, as part of the preoperative radiographic templating protocol.

Statistical analysis

Statistical analyses were performed using IBM Statistical Package for the Social Sciences Statistics for Windows, version 25.0 (IBM Corp., Armonk, NY, USA). Continuous variables are presented as the mean ± SD, whereas categorical variables are expressed as frequencies and percentages. Normality of data distribution was assessed using the Shapiro–Wilk test.

Comparisons among the 4 prosthesis brands were conducted using 1-way analysis of variance with Tukey post hoc tests for normally distributed variables and the Kruskal–Wallis test with Dunn's correction for non-normally distributed variables. Categorical variables were compared using the chi-squared test or Fisher's exact test, as appropriate.

The primary outcome—agreement between radiographically predicted and intraoperatively implanted femoral and tibial component sizes—was assessed using Cohen's weighted kappa coefficient (κ) with 95% CI. Kappa values were interpreted according to the criteria proposed by Landis and Koch.[10] Cronbach's α was used as a complementary measure of internal consistency rather than the primary agreement metric; the ICC was retained as the principal measure of reliability.

Agreement between predicted and actual implant sizes was further analyzed using Bland–Altman plots, with calculation of mean bias and 95% limits of agreement.[11] Proportional bias was assessed by linear regression analysis of the differences against the means.

For clinical interpretation, a prediction within 1 adjacent implant size (1 size smaller or larger than the implanted component) was predefined as the acceptable tolerance.[18] Because sizing increments differed among implant systems, this tolerance was defined according to each manufacturer's sequential component sizes rather than as a fixed numerical difference. Accordingly, 1 adjacent size corresponded to ± 0.5 for Brand A and ± 1.0 for Brands B, C, and D.

All statistical tests were 2-tailed, and statistical significance was set at $P < .05$.

Results

A total of 160 knees from 141 patients (31 males, 110 females; mean age 67.3 ± 7.9 years) undergoing primary TKA were included, with an equal distribution across the 4 prosthesis brands (n=40 each). The patients' demographic and surgical characteristics are presented in Table 1. Although the sex distribution and operated side were comparable across the groups ($P > .05$), a statistically significant difference in mean age was observed ($P=.003$); however, all means fell within a narrow clinical range (65.2-69.1 years).

Preoperative digital templating demonstrated high clinical utility in predicting TKA component sizes. The overall agreement between the templated and implanted components was substantial, with 94.4% (302/320) of all predictions falling within the clinically acceptable range of ± 1 implant size.

The agreement between radiographically predicted and intraoperatively implanted tibial component sizes was moderate, with a weighted Cohen's κ of 0.54 (95% CI: 0.45-0.63). Radiographic templating predicted the final tibial size exactly in 64.4% (103/160) of cases, and within ± 1 size in 92.5% (148/160) of cases. Bland–Altman analysis showed minimal bias (mean difference, −0.3 ± 1.1 sizes), with 95% limits of agreement from −2.5 to +1.9 sizes. Internal consistency for tibial sizing measurements was excellent. Cronbach's α was 0.87 (95% CI: 0.82-0.91) between preoperative radiographic and intraoperative mediolateral (ML) measurements, and 0.89 (95% CI: 0.85-0.92) between radiographically predicted and intraoperative ML measurements. For AP measurements, the corresponding α values were 0.86 (95% CI: 0.81-0.90) and 0.93 (95% CI: 0.89-0.94), respectively (Table 2).

When analyzed by implant brand, tibial component agreement was highest for A implants (κ=0.64). Lower agreement levels were observed for B (κ=0.46), C (κ=0.48), and D (κ=0.43) systems. Comparison of size discrepancies revealed statistically significant differences among brands ($P=.001$), with the smallest mean absolute difference observed in the A group (Table 3).

Femoral component sizing showed a higher level of agreement, with a weighted κ of 0.70 (95% CI=0.62-0.78). Exact size matching was achieved in 76.9% (123/160) of cases, and 96.8% (155/160) of predictions were within ± 1 size of the implanted component. Bland–Altman analysis revealed a mean bias of −0.2 ± 0.9 sizes, with 95% limits of agreement between −2.0 and +1.6 sizes. The internal consistency for femoral measurements was also high. Agreement between preoperative radiographic and intraoperative ML measurements yielded a Cronbach's alpha of 0.85 (95% CI=0.79-0.89), which increased to 0.92 (95% CI=0.89-0.94) for radiographically predicted vs. intraoperative measurements. For AP measurements, the values were 0.77 (95% CI=0.68-0.83) and 0.92 (95% CI=0.89-0.94), respectively (Table 4).

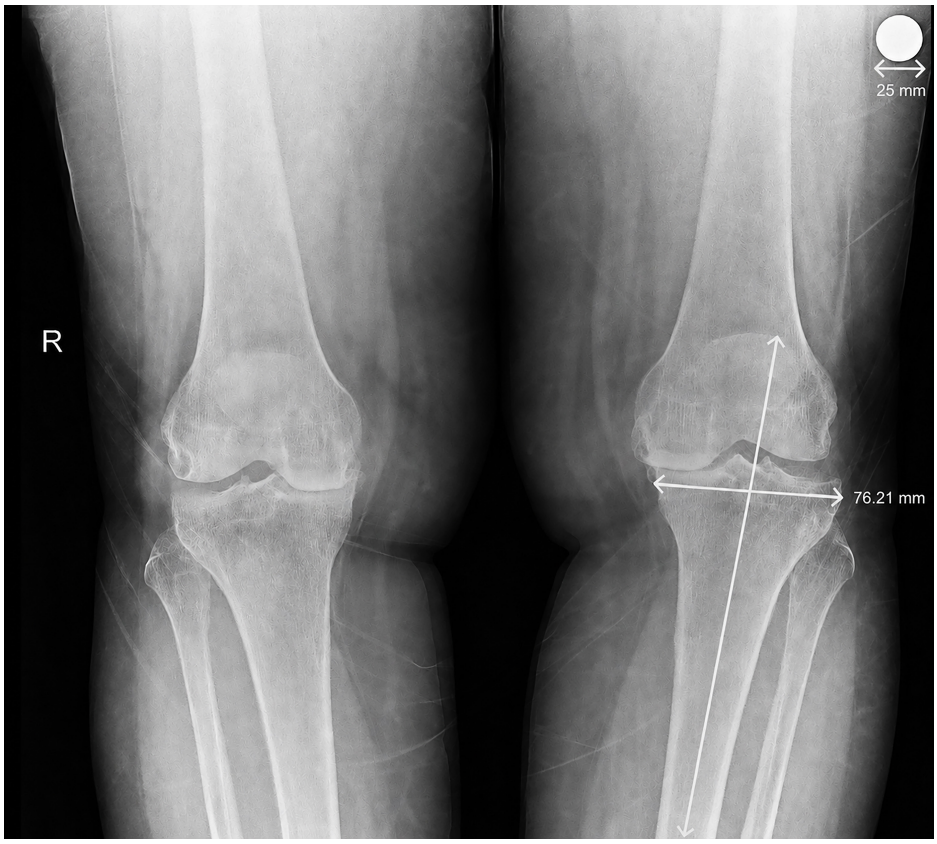


Figure 3 . Calibrated weight-bearing anteroposterior knee radiograph showing measurement of the tibial mediolateral (ML) dimension. The width is measured at the level of the proposed tibial resection plane, from the medial to the lateral cortical margins, to select an appropriately sized tibial baseplate ensuring optimal coverage without component overhang. The 25-mm radiopaque spherical marker is visible in the upper right corner of the radiograph.

The highest femoral component agreement was observed for A (κ=0.72) and C (κ=0.71) brands, followed by D (κ=0.69) and B (κ=0.64). Inter-brand differences in size discrepancies were statistically significant (*P*=.010), with A and C showing the smallest mean absolute differences (Table 5).

A direct comparison of all predicted vs. implanted sizes confirmed that digital templating performance was clinically robust across all 4 implant systems. The mean absolute difference between predicted and implanted sizes was less than half a component size for both the femur (0.42 ± 0.38) and the tibia (0.58 ± 0.52). Although statistically significant differences were detected ($P < .05$), their clinical magnitude was minimal. Notably, when the standard surgical tolerance of ± 1 implant size was applied, the aggregate accuracy across both components and all brands was 94.4%.

Post hoc power analysis (G*Power) using observed effect sizes (tibial: w=0.28; femoral: w=0.24; α=0.05; n=40/group) showed achieved powers of 86% (tibial) and 79% (femoral), meeting or approaching the 80% benchmark and confirming adequate sample size to detect clinically meaningful differences.

Table 1. Demographic characteristics of patients according to prosthesis brands

Variable	Brand A (n=40)	Brand B (n=40)	Brand C (n=40)	Brand D (n=40)	*P*
Age (years)	65.9 ± 6.2	64.2 ± 8.2	70.3 ± 7.5	68.5 ± 8.7	.003
Gender					.345
Male	4 (10.0)	10 (25.0)	9 (22.5)	8 (20.0)	
Female	36 (90.0)	30 (75.0)	31 (77.5)	32 (80.0)	
Surgical side					.878
Right TKA	20 (50.0)	17 (42.5%)	18 (45.0)	20 (50.0)	
Left TKA	20 (50.0)	23 (57.5)	22 (55.0)	20 (50.0)	

Values are given as mean ± SD or number (%).
TKA, total knee arthroplasty.

Analysis of polyethylene insert thickness revealed significant differences among the 4 prosthesis brands (Kruskal–Wallis test, $P < .0001$). Brand A predominantly utilized 8-mm inserts (72.5%), whereas Brand D most frequently employed 10-mm inserts (70.0%). Brand C showed a tendency toward thicker inserts, with 55.0% of cases requiring 11 mm or greater polyethylene thickness, whereas Brand B demonstrated an intermediate profile, with 52.5% of cases using 9-mm inserts. The predominance of 8-10 mm-inserts across the entire cohort (83.8%) suggests that adequate soft tissue balance was achieved in the vast majority of cases. Importantly, insert thickness is determined by intraoperative soft-tissue balance and flexion-extension gap measurements rather than by prosthesis design or component size.

Discussion

This comparative study confirms that standardized preoperative radiographic templating reliably predicts implant size in TKA, especially for femoral components (κ=0.70; most predictions within ± 1 size). When acquired and calibrated under strict protocols, conventional 2D radiographs retain significant clinical utility in contemporary arthroplasty, consistent with previous reports.[4,5]

The observed disparity between femoral and tibial prediction accuracy warrants specific consideration. While femoral sizing achieved

Table 2. Radiographic and operative tibial measurements

Variable	Total	Brand A	Brand B	Brand C	Brand D
Tibia medio-lateral measurement	74.0 ± 4.6	73.9 ± 4.1	74.9 ± 5.2	73.5 ± 4.2	73.9 ± 4.8
Tibia recommended medio-lateral	71.5 ± 4.7	72.1 ± 4.4	73.5 ± 4.5	71.7 ± 3.9	68.7 ± 4.8
Medio-lateral measurement of tibia in operation	71.0 ± 4.3	71.3 ± 3.9	72.7 ± 3.9	70.8 ± 4.0	69.3 ± 4.6
Medio-lateral measurement Cronbach's · (95% CI)	0.87 (0.82-0.91)	0.86 (0.73-0.92)	0.93 (0.86-0.96)	0.82 (0.65-0.90)	0.89 (0.79-0.94)
Tibia antero-posterior	49.1 ± 4.9	49.2 ± 3.9	52.9 ± 4.9	49.2 ± 4.3	45.1 ± 3.2
Tibia recommended antero-posterior	48.1 ± 3.9	48.1 ± 2.9	51.7 ± 2.9	47.7 ± 3.7	45.1 ± 3.4
Antero-posterior measurement of tibia in operation	47.7 ± 3.6	47.6 ± 2.7	51.1 ± 2.5	46.9 ± 3.5	45.3 ± 3.1
Antero-posterior Cronbach's alpha (95% CI)	0.86 (0.81-0.90)	0.87 (0.75-0.93)	0.68 (0.40-0.83)	0.85 (0.72-0.92)	0.85 (0.72-0.92)

Values are given as mean ± SD unless otherwise indicated.
AP, anteroposterior; ML, mediolateral.

substantial agreement, tibial component prediction demonstrated more moderate reliability (κ=0.54). This differential performance may reflect the distinct anatomical and technical challenges inherent to tibial sizing. The proximal tibia exhibits greater geometric variability and is more susceptible to the influence of soft-tissue coverage and radiographic projection.[12] In addition, tibial baseplate designs vary considerably among manufacturers in terms of coverage philosophy and sizing increments, which may further contribute to measurement variability. These findings corroborate earlier reports identifying tibial sizing as a persistent challenge in radiographic templating.[13,14]

A key contribution of the present study lies in its multi-brand comparative design. By evaluating 4 distinct implant systems, this analysis extends beyond the single-system focus that characterizes much of the existing literature.[9] The consistent templating performance observed across all brands—despite inherent differences in implant geometry—suggests that a standardized, protocol-driven radiographic templating approach can be effectively applied across different prosthesis systems. This observation aligns with the findings of Peek et al[15] who demonstrated that the consistent use of a standardized technique improves templating accuracy. Variations observed between implant brands may be attributed to differences in design philosophies, size increments, and ML/AP ratios, which influence component fit and selection. These factors can affect templating accuracy and surgical outcomes, underscoring the need for brand-specific considerations during preoperative planning. Although this study applied a standardized templating protocol across multiple prosthesis systems, further investigation into how these design variables impact templating reliability is warranted.

From a clinical perspective, accurate preoperative templating enhances surgical efficiency and implant inventory management while reducing intraoperative trialing. Accurate component sizing and positioning are critical not only for optimal function but also for preventing postoperative complications; as Song et al[16] demonstrated, component malposition and flexion/extension gap mismatch are among the leading causes of instability requiring revision TKA. In resource-conscious healthcare environments, the cost-effectiveness and accessibility of conventional radiographic templating represent substantial advantages.

Table 3. Tibial difference across prosthesis brands

Tibia difference	Brand A	Brand B	Brand C	Brand D	Total
−2.0	1 (2.5)	0 (0.0)	1 (2.5)	2 (5.0)	4 (2.5)
−1.0	3 (7.5)	13 (32.5)	12 (30.0)	5 (12.5)	33 (20.6)
−0.5	3 (7.5)	0 (0.0)	0 (0.0)	0 (0.0)	3 (1.9)
0	32 (80.0)	24 (60.0)	25 (62.5)	22 (55.0)	103 (64.4)
1.0	0 (0.0)	3 (7.5)	2 (5.0)	7 (17.5)	12 (7.5)
2.0	1 (2.5)	0 (0.0)	0 (0.0)	4 (10.0)	5 (3.1)

Values are expressed as number (%). Tolerance defined as 1 adjacent size (± 0.5 for Brand A; ± 1.0 for Brands B-D).

The differences in templating accuracy observed among different implant brands in the study are consistent with broader findings in the literature. As noted by Lee et al,[17] patient-specific knee arthroplasty demonstrates promising biomechanical and clinical advantages over conventional implants by offering improved implant fit, alignment accuracy, and restoration of native knee kinematics; however, challenges remain, including imperfect preservation of tibial plateau anatomy and the need for long-term studies to validate sustained clinical benefits and implant survivorship.

Two-dimensional templating is cost-effective and common for preoperative planning in TKA but has limitations in accurately assessing component alignment and rotation. These issues may cause suboptimal implant sizing and placement. Recent evidence shows that 3D CT-based templating, especially with robot assistance, improves implant size prediction accuracy for femoral and tibial components. This precision is crucial in complex cases that require accurate rotational alignment. Despite higher initial costs, 3D planning can enhance surgical efficiency and outcomes. Future studies should identify clinical scenarios where 3D templating offers the greatest benefit, balancing accuracy and cost.[18]

The 94.4% accuracy rate within ± 1 size achieved in the study is consistent with the 96% (95% CI: 0.94-0.98) overall accuracy rate reported by Lee et al,[19] in their systematic review and meta-analysis. The authors also emphasized that this level of accuracy economically justifies the use of template-directed instrumentation.

Pichler et al[20] demonstrated that image quality measured by knee rotation and knee abduction/adduction on lateral knee radiographs does not significantly affect the accuracy of implant size prediction using digital templating. Although no differences in correlation coefficients were found between optimal and suboptimal radiographs (P=.39), the exact match rate for femoral components was only 45% even in the best-quality group, highlighting the limitations of current 2D methods and the need for advanced techniques, such as 3D planning.

In this study, tibial component templating demonstrated lower accuracy compared to femoral components (exact match: 64.4%; within ± 1 size: 92.5%), consistent with literature highlighting the limitations of 2D templating in tibial sizing. Notably, Klag et al[21] reported that 3D models generated from 2D radiographs achieved a 93.1% exact match rate for tibial component sizing, whereas attending surgeons using conventional 2D digital templating on the same patients achieved only 53% exact match. This stark contrast underscores the

Table 4. Radiographic and operative femoral measurements

Variable	Total	Brand A	Brand B	Brand C	Brand D
Femur medio-lateral measurement	70.5 ± 4.6	69.9 ± 4.6	71.2 ± 5.3	70.4 ± 4.3	70.5 ± 4.5
Femur recommended medio-lateral	67.6 ± 3.7	66.4 ± 3.6	68.3 ± 3.9	68.3 ± 3.6	67.5 ± 3.2
Medio-lateral measurement of femur in operation	67.4 ± 3.6	66.0 ± 3.8	68.6 ± 3.8	67.8 ± 3.5	67.2 ± 2.9
Medio-lateral measurement Cronbach's alpha (95% CI)	0.85 (0.79-0.89)	0.85 (0.72-0.92)	0.87 (0.75-0.93)	0.89 (0.79-0.94)	0.77 (0.57-0.88)
Femur antero-posterior	62.4 ± 5.1	62.3 ± 4.2	62.5 ± 6.5	62.5 ± 4.7	62.3 ± 4.9
Femur recommended antero-posterior	60.9 ± 3.8	61.6 ± 3.4	60.6 ± 3.9	62.3 ± 3.6	59.1 ± 3.5
Antero-posterior measurement of femur in operation	60.7 ± 3.6	61.3 ± 3.4	60.9 ± 3.8	61.8 ± 3.5	58.7 ± 3.1
Antero-posterior Cronbach's alpha (95% CI)	0.77 (0.68-0.83)	0.80 (0.78-0.94)	0.64 (0.32-0.81)	0.83 (0.68-0.91)	0.84 (0.69-0.91)

Values are given as mean ± SD unless otherwise indicated.

superiority of 3D technology in tibial sizing and suggests that the lower accuracy observed in the study may be attributable to inherent limitations of 2D methods.

Wallace et al[22] demonstrated that a regression model based on patient-specific demographic data (gender, height, weight, age, and race) predicts femoral and tibial component sizes in TKA more accurately and precisely than traditional 2D digital radiographic templating. Although the study observed a significant difference in age between groups, the narrow clinical range of this difference and the comparable sex distribution across groups suggest that the findings underscore the importance of standardization independent of demographic variables.

Accuracy within ± 1 implant size is particularly critical in high-risk groups, including patients with bone loss, deformities, compromised bone stock, or revision cases. Because this study focused on primary TKA, future research should evaluate whether similar accuracy can be achieved in these more complex scenarios.

Lan et al[23] demonstrated that artificial intelligence (AI)-based preoperative 3D planning is superior to traditional 2D methods in prosthesis size prediction (femoral exact match: 90% vs. 66.7%; tibial: 86.7% vs. 60%) and axial alignment (significantly reduced femoral valgus correction angle and hip-knee-ankle angle outliers). These improvements translated into better functional outcomes (Western Ontario and McMaster University Osteoarthritis Index, American Knee Society Score) at 3, 6, and 12 months postoperatively. The study emphasizes the critical importance of accurate prosthesis sizing and alignment in reducing complications, such as pain, instability, and loosening. Although AI-based 3D planning requires advanced imaging, its enhanced precision supports its growing role in TKA preoperative workflows.

Park et al[24] reported that their AI-based automatic templating model developed from 2D radiographs achieved 88.9% accuracy within ± 1 size for both femoral and tibial components, compared to 95.1% and 100%, respectively, with manual templating by an experienced surgeon. The AI model was significantly faster than manual templating (48.7 seconds vs. 97.5 seconds; $P < .01$).

Table 5. Femoral difference across prosthesis brands

Femur difference	Brand A	Brand B	Brand C	Brand D	Total
−2.0	1 (2.5)	0 (0.0)	2 (5.0)	0 (0.0)	3 (1.9)
−1.0	0 (0.0)	4 (10.0)	4 (10.0)	7 (17.5)	15 (9.4)
−0.5	5 (12.5)	0 (0.0)	0 (0.0)	0 (0.0)	5 (3.1)
0	32 (80.0)	30 (75.0)	32 (80.0)	29 (72.5)	123 (76.9)
0.5	1 (2.5)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.6)
1.0	1 (2.5)	5 (12.5)	2 (5.0)	4 (10.0)	12 (7.5)
2.0	0 (0.0)	1 (2.5)	0 (0.0)	0 (0.0)	1 (0.6)

Values are expressed as number (%). Tolerance defined as 1 adjacent size (± 0.5 for Brand A; ± 1.0 for Brands B-D).

This study has several limitations. Its retrospective design carries a risk of selection bias, although systematic sampling helped mitigate this risk. The single-center nature ensured methodological consistency but may limit generalizability. The study evaluated only implant size prediction and did not assess alignment or rotational positioning. Although a statistically significant age difference was observed between groups ($P=.003$), all mean values fell within a narrow clinical range, and its potential impact on templating accuracy was not formally assessed. Future studies should investigate age-related factors, such as bone quality and degenerative changes, that may influence templating reliability. Minor implant design changes may have occurred during the 9-year study period; however, core design principles remained stable, and random sampling helped balance temporal distribution. Prospective, multicenter studies incorporating 3D analysis are needed to validate these findings.

This study confirms that a standardized preoperative radiographic templating protocol can reliably predict implant size in primary TKA. Femoral component prediction showed substantial agreement ($\kappa=0.70$), with 96.8% of cases within ± 1 size. This reliability was consistent across 4 distinct implant systems, with all brands achieving clinically acceptable accuracy for over 92% of tibial and 95% of femoral predictions. However, tibial component prediction was less accurate (64.4% exact match), reflecting the inherent anatomical and technical challenges of tibial sizing. While 92.5% of tibial predictions still fell within ± 1 size, surgeons should recognize that tibial templating is more prone to error and may require greater intraoperative adjustment. When rigorous calibration and measurement standards are applied, conventional radiographic templating remains a valid, reproducible, and cost-effective cornerstone of surgical planning, independent of specific prosthesis design.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Artificial Intelligence Usage Statement: The authors declared that this study used ChatGPT (OpenAI) to improve language and edit grammar during the preparation of the manuscript.

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