Correlation Between Tibial Cortical Thickness and Volumetric Bone Mineral Density to Inform Cementless Total Knee Arthroplasty Implantation

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INTRODUCTION: Cementless total knee arthroplasty (TKA) has gained exponential interest due to modern porous implants promising durable fixation, reduced operative time, and simplified revisions, yet early aseptic loosening of tibial components persists as a postoperative complication. We previously demonstrated that volumetric bone-mineral density (BMD) derived from computed tomography (CT) can be useful to identify patients with appropriate bone strength for cementless TKA. Compared to plain radiographs, however, CT-scans have increased cost and availability. Alternatively, previous investigations suggest that cortical thickness measured on plane radiographs correlates with bone strength and could predict suitability for cementless fixation. Similarly, the Dorr Classification has been used successfully for decades in hip replacement. No study has rigorously quantified this correlation specifically within the planned tibial resection zone in TKA. This study aimed to determine whether tibial cortical-thickness ratios from standard radiographs correlate with volumetric CT-derived BMD at the critical implant interface region, potentially informing patient selection for cementless TKA.

METHODS: We conducted a single-center, retrospective cohort analysis of 80 consecutive adult patients (≥18 years old) undergoing robotic-assisted primary TKA between 15 January 2017 and 1 December 2024. Inclusion criteria comprised the presence of preoperative low-dose CT scans (obtained for MAKO® surgical planning) with a BMD reference phantom and weight-bearing anteroposterior (AP) and lateral tibial radiographs within three months preoperatively. Exclusion criteria included hardware on ipsilateral or contralateral knee surgery, major tibial deformity, revision cases, incomplete imaging datasets, and known metabolic bone disorders. Tibial cortical thickness measurements were performed digitally (PACS) at 10 cm and 15 cm distal to the tibial spines on both AP and lateral views. Cortical thickness ratios were calculated as (medial + lateral cortex thickness)/outer cortical diameter. Volumetric BMD was quantified at the planned tibial cut.3 Cross-sectional trapezoidal area was calculated using the average of the cortical thickness multiplied by the distance between the measurements, (Cortical thickness at 10cm + Cortical thickness at 15cm)/2)*10cm, on AP and lateral radiographs. The total area (cm²) was correlated with quadrant-specific volumetric BMD. The primary outcome assessed was the correlation between cortical thickness ratios and volumetric BMD. Secondary analyses stratified patients into cortical thickness categories (High, Intermediate, Low). Reliability of radiographic measurements was confirmed via intra- and inter-rater intraclass correlation coefficients (ICC).

RESULTS: Mean volumetric BMD was highest in the posterior-medial quadrant (255 ± 73 mg/cm³) and lowest in the anterior-lateral quadrant (152 ± 59 mg/cm³). Radiographic cortical-thickness ratios measured at 15 cm distal to the tibial spines on lateral radiographs demonstrated the strongest correlation with volumetric BMD (Spearman r = 0.40, 95% CI: 0.20–0.57). Measurements taken 10 cm distal on lateral radiographs (r = 0.26, 95% CI: 0.05–0.46) and AP views at 10 cm (r = 0.22, 95% CI: 0.00–0.42) showed weaker correlations. The cortical ratio at 15 cm on AP radiographs did not correlate with BMD (r = 0.21, 95% CI: –0.01–0.41). Cross-sectional trapezoidal area measurements on AP radiographs of the medial tibia displayed a strong correlation with volumetric BMD (r = 0.63, 95% CI: 0.47–0.75). Intra- and inter-rater reliability for cortical-thickness measurements were excellent (ICC > 0.80 for all measurement points).

DISCUSSION AND CONCLUSION: Radiographic cortical-thickness, particularly at 15 cm distal to the tibial spines on lateral radiographs, correlates moderately with CT-derived BMD beneath the tibial resection, highlighting their potential as reproducible preoperative screening tools for cementless TKA candidates. Medial tibial trapezoidal area on AP radiographs demonstrated a strong correlation, offering an additional predictor for BMD. Although radiographic metrics cannot fully replace CT-based BMD assessments, these findings support their integration into future clinical practice to inform implant selection, potentially reducing the incidence of early aseptic loosening associated with cementless tibial fixation and increasing operative efficiency.

Figure 1. Axial CT-based bone mineral density (BMD) maps demonstrating regional BMD distribution beneath the tibial resection plane. Density is categorized and color-coded as low (blue), intermediate (green), and high (red).
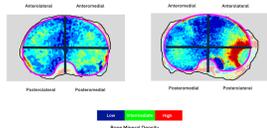

Figure 2. Standard anteroposterior (AP) radiographs of the right knee illustrating quantitative cortical-thickness assessment. Medial (B) and lateral (A) (D) cortical widths were digitally measured 10 cm and 15 cm distal to the tibial spines in each projection (blue calipers). Trapezoidal area is denoted by the green and yellow boxes (right).

Figure 3. Standard lateral radiographs of the right knee illustrating quantitative cortical-thickness assessment. Anterior (A) (D) and posterior (B) (E) cortical widths were digitally measured 10 cm and 15 cm distal to the tibial spines in each projection (blue calipers). Trapezoidal area is denoted by the green and yellow boxes (right).

Table 1. Spearman correlations between volumetric bone mineral density (BMD) in proximal-tibial quadrants and trapezoid areas measured on anteroposterior (AP) and lateral radiographs.

Bone Mineral Density	Area of a Trapezoid	Spearman r	Lower 95% CI	Upper 95% CI
Anterior-Medial Quadrant	AP Medial	0.41	0.21	0.58
	AP Lateral	0.15	-0.07	0.36
	Lateral Anterior	0.22	0	0.42
	Lateral Posterior	0.02	-0.2	0.24
Anterior-Lateral Quadrant	AP Medial	0.05	-0.17	0.27
	AP Lateral	0.09	-0.13	0.31
	Lateral Anterior	0.26	0.05	0.46
	Lateral Posterior	0.24	0.02	0.44
Posterior-Lateral Quadrant	AP Medial	0.07	-0.15	0.28
	AP Lateral	0.13	-0.1	0.34
	Lateral Anterior	0.37	0.16	0.54
	Lateral Posterior	0.48	0.5	0.64
Posterior-Medial Quadrant	AP Medial	0.63	0.47	0.75
	AP Lateral	0.25	0.03	0.45
	Lateral Anterior	0.41	0.21	0.59
	Lateral Posterior	0.25	0.03	0.45