

Association Between Mechanical Alignment of the Knee and Regional Bone Density Patterns in the Distal Femur and Proximal Tibia

Craig E. Klinger, BA, MPH, Douglas N. Mintz, MD, Robert E. Bilodeau, BS, William M. Ricci, MD, Kathryn A. Barth, MD, Elizabeth B. Gausden, MD, MPH, Ashley A. Weaver, PhD, Hollis G. Potter, MD, Peter K. Sculco, MD, Derek G. Hansen, MD

Purpose: Computed tomography (CT) Hounsfield Units (HU) are an established measure of bone mineral density (BMD). This study aimed to assess the association between knee alignment and both distal femoral and proximal tibial epiphyseal BMD using CT HU.

Methods: A records search was conducted from 1/1/2008 to 8/16/2025 for patients with both non-contrast knee-CT and standing long-leg radiographs. Individuals with femoral or tibial fractures or surgery or known metabolic bone pathology other than osteopenia and osteoporosis were excluded. Trabecular HU were measured on three consecutive axial CT images. Measured regions included medial femoral condyle (MFC), lateral femoral condyle (LFC), medial tibial plateau (MTP), and lateral tibial plateau (LTP). Knee alignment was measured on standing long-leg radiographs using hip-knee-ankle angles (HKAA). Medial-to-lateral ratio (MLR) was calculated using regional mean CT HU. MLR was calculated for five groups: major varus ($\leq 170^\circ$), varus ($>170^\circ < 178^\circ$), neutral ($178^\circ\text{--}182^\circ$), valgus ($>182^\circ < 190^\circ$), and major valgus ($\geq 190^\circ$).

Results: 312 cases were analyzed (mean age 66.5, SD 9.3; 158 females); 18.3% had neutral alignment, 53.5% varus, 17.0% major varus, 10.6% valgus, and 0.6% major valgus. In 88.5%, LFC had higher BMD than MFC ($P < .001$), and in 92.9% MTP had higher BMD than LTP ($P < .001$). HKAA was moderately negatively correlated with distal femur epiphysis MLR (Pearson $r = -0.459$, $P < .001$), and proximal tibia epiphysis MLR ($r = -0.322$, $P < .001$). With increasing varus, a gradient was found of increasing epiphyseal BMD medially, within the distal femur and proximal tibia. Significant MLR differences were found between alignment groups for the DFE (valgus vs. neutral $p = .043$, valgus vs. varus: $p < .001$, valgus vs. major varus: $p < .001$, neutral vs. varus: $p = .001$, neutral vs. major varus: $p = .001$), and for PTE (major valgus vs. major varus: $P = .042$, valgus vs. neutral: $p < .001$, valgus vs. varus: $p < .001$, valgus vs. major varus: $p < .001$, neutral vs. major varus: $p = .027$). In neutral knees, a 20.4% BMD deficit was found for medial femoral condyle vs. lateral femoral condyle, and 23.5% for lateral tibial plateau vs. medial tibial plateau.

Conclusion: Increased varus correlates with increased medial epiphyseal BMD along the distal femur and proximal tibia. Regional BMD deficits are common in the distal femur and proximal tibia epiphysis and may have implications for fracture risk and operative planning.