

Coronal Knee Alignment is Directly Related to Knee Medial-to-Lateral Bone Density Ratio

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INTRODUCTION: Prior research found an association between coronal knee alignment and femoral condyle bone mineral density (BMD).¹ The primary study aim was to assess the association between knee alignment and bone mineral density (BMD) for both the entire distal femoral and proximal tibial epiphyseal regions using CT Hounsfield Units (HU) and compare medial-to-lateral ratio (MLR) between knee alignment groups. The secondary aim was to assess the association between sex and other demographics on regional BMD in relation to coronal knee alignment.

METHODS: After Institutional Review Board, 312 individuals were included (mean age 66.5, SD 9.3; 50.6% females). A search was conducted from 2008–2025 for patients with non-contrast knee-CT and anteroposterior standing long-leg radiographs. Individuals with femur or tibia fracture or surgery history or known metabolic bone disease other than osteopenia and osteoporosis were excluded. Mean trabecular bone CT-HU were measured for six regions for calculation of MLR: medial femoral condyle (MFC), lateral femoral condyle (LFC), entire distal femur epiphysis (DFE), medial tibial plateau (MTP), lateral tibial plateau (LTP), and entire proximal tibial epiphysis (PTE). HU measurements excluded the subchondral plate, visible sclerotic bone margins or bone cysts; (Fig. 1). Combined-MLR was also calculated (MFC+MTP to LFC+LTP ratio). Knee alignment was measured and cases categorized: (1) major varus ($\leq 170^\circ$), (2) varus ($>170^\circ, <178^\circ$), (3) neutral ($178-182^\circ$), (4) valgus ($>182^\circ, <190^\circ$), and (5) major valgus ($\geq 190^\circ$). Statistical analysis was performed using SPSS (v29.0.2.0; IBM, Armonk, NY). Data were tested for normal distribution (Shapiro-Wilk test). Correlation coefficients were calculated to assess association between variables. An independent Samples T-test or ANOVA test was used to analyze normally distributed continuous variables and a Mann-Whitney U test or Kruskal-Wallis test for nonparametric data. A p-value of <0.05 was considered statistically significant.

RESULTS: Overall, 18.3% had neutral alignment, 53.5% varus, 17.0% major varus, 10.6% valgus, and 0.6% major valgus (Table 1). Overall, in 88.5%, LFC had higher BMD than MFC ($p<0.001$), and in 92.9% MTP higher BMD than LTP ($p<0.001$). In neutral knees, BMD was 20.4% lower for MFC vs, LFC ($p=0.002$), and 23.5% lower for LTP vs. MTP ($p=0.002$). Increasing valgus alignment correlated with decreasing MLR based on HKAA and MLR correlations (DFE: Pearson $r=-0.459, p<0.001$; PTE: $r=-0.322, p<0.001$). Overall, DFE was found to have 28.4% higher mean BMD than PTE (mean HU: 191.4 vs. 137.1; $p<0.001$). Moderate positive correlations were found between bodyweight and HU for all medial and lateral regions (MFC: $r=0.280, LFC: r=0.314, MTP: r=0.238, LTP: r=0.313; p<0.001$). Median HKAA for females was 176.9° ($173.1-180.6^\circ$) vs. for males 173.1° ($170.6-176.2^\circ$), with males having more overall varus deformity ($p<0.001$). Significant MLR differences were found between alignment groups ($p<0.05$; Table 2), and especially for females when stratified by sex. More statistically significant differences were observed for females vs. males between alignment groups for the DFE-MLR, PTE-MLR and combined-MLR (MFC+MTP to LFC+LTP).

DISCUSSION: Increasing valgus was associated with decreasing distal femur and proximal tibia MLR. The correlation between HKAA and combined-MLR were stronger for females than males and more statistically significant differences were observed for females between alignment groups and MLR.

SIGNIFICANCE/CLINICAL RELEVANCE: These findings may suggest medial-to-lateral BMD is more susceptible to alignment variation in females compared to males. Overall, higher BMD was found for DFE than PTE. Regional deficits were common and may have surgical implications.

REFERENCES:

1. Rougreau G, Villard A, Langlais T, et al. Femoral condyle bone mineral density in osteoarthritis differs significantly between knees with valgus vs. varus deformity. Orthop Traumatol Surg Res. 2023;103584.

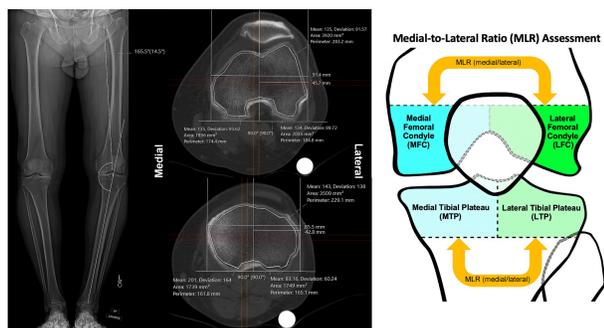


Fig. 1. Image illustrating HKAA measurements on a left knee on standing AP LLXR of a major varus case (left), example HU measurements of the same case including distal femur epiphysis, and medial and lateral compartments (center images), and diagram of medial-to-lateral ratio of HU for bone density comparison of both epiphyseal regions for the distal femur and proximal tibia (right).

Table 1. MLR BMD measurements by knee alignment group.

HKAA Group	N (%)	Median (IQR)
Distal Femur Epiphysis MLR (N=312)		
Overall	312 (100%)	0.83 (0.76-0.93)
Major Varus	53 (17.0%)	0.88 (0.80-0.99)
Varus	167 (53.5%)	0.87 (0.78-0.96)
Neutral	57 (18.3%)	0.80 (0.70-0.88)
Valgus	33 (10.6%)	0.71 (0.62-0.77)
Major Valgus	2 (0.6%)	0.54 (0.51-0.57)
Proximal Tibia Epiphysis MLR (N=312)		
Overall	312 (100%)	1.29 (1.13-1.55)
Major Varus	53 (17.0%)	1.45 (1.21-1.90)
Varus	167 (53.5%)	1.33 (1.17-1.56)
Neutral	57 (18.3%)	1.24 (1.14-1.41)
Valgus	33 (10.6%)	1.07 (0.92-1.24)
Major Valgus	2 (0.6%)	0.80 (0.72-0.88)
Combined-MLR (N=312)		
Overall	312 (100%)	1.00 (0.92-1.10)
Major Varus	53 (17.0%)	1.09 (0.97-1.20)
Varus	167 (53.5%)	1.04 (0.96-1.12)
Neutral	57 (18.3%)	0.96 (0.89-1.02)
Valgus	33 (10.6%)	0.84 (0.76-0.93)
Major Valgus	2 (0.6%)	0.63 (0.59-0.67)

MLR=medial-to-lateral ratio, BMD=bone mineral density, Combined-MLR=MFC+MTP to LFC+LTP ratio.

Table 2. Medial-to-lateral ratio pairwise comparisons by alignment group.

Sample 1-Sample 2	DFE-MLR		PTE-MLR		C-MLR	
	p-value	Adj. p-value	p-value	Adj. p-value	p-value	Adj. p-value
Major Valgus-Valgus	0.384	>0.999	0.348	>0.999	0.485	>0.999
Major Valgus-Neutral	0.080	0.803	0.039	0.386	0.070	0.700
Major Valgus-Varus	0.009	0.086	0.015	0.146	0.009	0.090
Major Valgus-Major Varus	0.006	0.057	0.004	0.042	0.003	0.029
Valgus-Neutral	0.004	0.043	<.001	<.001	<.001	0.003
Valgus-Varus	<.001	<.001	<.001	<.001	<.001	<.001
Valgus-Major Varus	<.001	<.001	<.001	<.001	<.001	<.001
Neutral-Varus	<.001	0.001	0.104	>0.999	<.001	0.003
Neutral-Major Varus	<.001	0.001	0.003	0.027	<.001	<.001
Varus-Major Varus	0.439	>0.999	0.040	0.397	0.067	0.670

Independent-Samples Kruskal-Wallis Test.

DFE=distal femur epiphysis, PTE=proximal tibia epiphysis, MLR=medial-to-lateral ratio, C-MLR=Combined MLR, Adj. p-value=adjusted p-value, by Bonferroni correction.