Automated Coronal Plane Alignment of the Knee Classification Using Artificial Intelligence for Pre- and Postoperative Radiographs

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INTRODUCTION: Coronal Plane Alignment of the Knee (CPAK) has redefined how limb alignment is evaluated on long-leg radiographs classifying phenotypes based on femoral, tibial, and joint line orientation. This approach offers a more comprehensive framework than traditional varus/valgus classification, with growing relevance in both preoperative planning and postoperative assessment of total knee arthroplasty (TKA). However, CPAK classification requires multiple precise measurements and is subject to interobserver variability. This study presents the first use of artificial intelligence (AI) to automate CPAK classification on both preoperative and postoperative radiographs.

METHODS: An AI model was developed to measure lateral distal femoral angle (LDFA), medial proximal tibial angle (MPTA), arithmetic hip-knee-ankle angle (aHKA), and joint line obliquity (JLO) on long-leg radiographs. CPAK types were assigned using the nine-arithmetic scheme described by MacDessi et al., with thresholds for neutral alignment (aHKA = 0 ± 2°, JLO = 180 ± 3°). The dataset included 200 patients (122 female, 78 male). AI-generated measurements were compared with expert-labeled radiographs. Agreement between AI and labeled radiographs was assessed using intraclass correlation coefficients (ICC) for categorical classification and Pearson correlation for continuous angle measurements. Error was reported as mean, median, and interquartile range (IQR). Institutional Review Board approval was obtained with a waiver of informed consent.

RESULTS SECTION: The model was evaluated on 200 patients**.** AI-based classification demonstrated excellent agreement for aHKA class (ICC = 0.93, 95% CI: 0.90–0.94) and good agreement for both JLO (ICC = 0.83) and CPAK classification (ICC = 0.86). For raw angles, MPTA showed very strong correlation (r = 0.93) with a mean error of 0.92° and median of 0.67° (IQR: 0.31–1.15). The aHKA had moderate correlation (r = 0.66) with a mean error of 1.45° and median of 0.81° (IQR: 0.38–1.32). The JLO showed weak correlation (r = 0.45) with a mean error of 1.55° and median of 0.79° (IQR: 0.39–1.55). The LDFA showed the weakest correlation (r = 0.38) but had a mean error of 0.99° and median of 0.50° (IQR: 0.22–0.86). All correlations were statistically significant ($p < 0.001$).

DISCUSSION: CPAK classification has transformed radiographic evaluation of coronal alignment in both native and post-arthroplasty knees. This study applies AI for automated CPAK classification across the surgical timeline. The model demonstrated strong performance across multiple angle metrics and CPAK classification, with the highest accuracy in MPTA and aHKA. Despite lower correlations for LDFA and JLO, absolute errors remained within clinically acceptable ranges and are likely superior to interobserver variability. This study is limited by its single-center dataset and retrospective design, which may affect generalizability. These findings support the integration of AI as a scalable, objective tool for alignment analysis and orthopedic practice and research.

SIGNIFICANCE/CLINICAL RELEVANCE: Automating CPAK classification with AI addresses a major barrier in limb-alignment analysis by reducing measurement burden and interobserver variability. This approach has the potential to improve pre- and postoperative decision-making, standardize research methodology, and enhance clinical efficiency in total knee arthroplasty.

IMAGES AND TABLES:

Table 1. Comparison of CPAK Classification Based on Derived Angle Measurements

CPAK Measurement	ICC	95% CI
aHKA	0.93	0.90, 0.94
JLO	0.83	0.78, 0.87
CPAK	0.86	0.81, 0.89

CPAK, coronal plane alignment of the knee. ICC, intraclass correlation coefficient. CI, confidence interval. aHKA, arithmetic hip/knee/ankle angle. JLO, joint line obliquity.

Table 2. Comparison of Raw Angle Measurements

Angle	Pearson's Correlation Coefficient	Mean Error (degrees)	Median Error (degrees)	IQR (degrees)
LDFA	0.38	0.99	0.50	0.22-0.86
MPTA	0.93	0.92	0.67	0.31-1.15
aHKA	0.66	1.45	0.81	0.38-1.32
JLO	0.45	1.55	0.79	0.39-1.55

IQR, interquartile range. LDFA, lateral distal femoral angle. MPTA, medial proximal tibial angle. aHKA, arithmetic hip/knee/ankle angle. JLO, joint line obliquity.