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Original Research

Coronal alignment in Indian osteoarthritic knees: Predominance of varus apex-distal phenotypes highlights population-specific alignment patterns

Madan Mohan Reddy, Senior Consultant Orthopaedic Surgeon [a], J. Praveen, Associate Consultant [a], Karthik Reddy Pammi, Consultant Orthopaedic Surgeon [a,*], D. Prasad, Senior Registrar [b], Adithya Kumar Jilmudi, Orthopaedic Surgeon [c], Ravi Teja Rudraraju, Orthopaedic Surgeon [c,d]

[a] *Department of Orthopaedics, Apollo Hospital, Greams Road, Chennai, Tamil Nadu, India*
[b] *Department of Orthopaedics, Apollo Hospital, Greams Road, Chennai, Tamil Nadu, India*
[c] *Department of Orthopaedics, Apollo Hospitals, Hyderabad, Telangana, India*
[d] *Department of Orthopaedics, SVS Medical College, Mahbubnagar, Telangana, India*

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ABSTRACT

Introduction/objectives: The coronal plane alignment of the knee (CPAK) classification, derived from the arithmetic hip–knee–ankle angle (aHKA) and joint line obliquity (JLO), is scarcely studied in Indian populations. This study evaluated CPAK phenotype distribution in Indian osteoarthritic (OA) knees and its association with demographics and early outcomes following robotic-assisted total knee arthroplasty (RATKA) using a functional alignment (FA) approach.

Methods: All RATKA done consecutively between January 2022 and September 2023 were included for this retrospective study. Patient's preoperative long-leg radiographs were analyzed to measure the medial proximal tibial angle (MPTA), lateral distal femoral angle (LDFA), aHKA, and JLO. Knees were classified into nine CPAK phenotypes (Types I–IX) according to alignment category (varus $\leq -3°$, neutral $-3°$–$3°$, and valgus $\geq 3°$) and JLO orientation (apex-distal [AD], neutral, and apex-proximal [AP]). Chi-square/Fisher's exact tests assessed associations with age, gender, and operative side. Postoperative alignment restoration and early functional outcomes were evaluated at six months.

Results: Finally, the sample was based on 947 end-stage OA (Kellgren–Lawrence Grade 4) knees from 604 Indian patients with a mean age of 61.7 ± 9.7 years; 65% were women. Varus alignment: 88.2% of knees, valgus: 11.8%, and none were neutral. CPAK Type I (varus with AD joint line) predominated (78.7%), followed by Types III (9.5%), VII (6.8%), and IX (5.0%). No statistically significant differences were found between genders ($p = 0.088$) or sides. Postoperatively, 60% of Type I knees retained their native alignment with correction with ±3° aHKA, while 18% were moderated toward Type II alignment. After 6 months, Knee injury and Osteoarthritis Outcome Score (KOOS) increased from 50.7±2.1 to 89.1±1.2, KOOS- Activities of Daily Living subscale increased from 41.6 ± 3.2 to 85.9 ± 1.3, and Forgotten Joint Score increased from 29.8±1.2 to 77.9±1.3 (all $p < 0.05$).

Conclusion: In this large-scale radiographic study of Indian OA knees, varus alignment with an AD joint line (CPAK Type I) was the most prevalent phenotype. Postoperative radiographic assessment showed alignment restoration within a physiologic range in most cases, accompanied by marked improvement in early functional outcomes.

Level of Evidence: Level IV – Retrospective observational study.

* Corresponding author. Apollo Hospital, Greams Road, Chennai 600006, India. Tel.: +91 91 9985146226.
E-mail addresses: drmadanmohan.ortho@gmail.com (M.M. Reddy), karthik616@gmail.com (K.R. Pammi), drprasadortho15@gmail.com (D. Prasad), drravitejar@gmail.com (R.T. Rudraraju).

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What are the new findings?

- Most Indian osteoarthritic knees demonstrate a varus alignment with an apex-distal joint line, most frequently corresponding to coronal plane alignment of the knee Type I phenotype.
- Neutral alignment phenotypes are absent in advanced Indian knee osteoarthritis, underscoring population-specific anatomical characteristics.
- Following robotic-assisted total knee arthroplasty using a functional alignment technique, native alignment was maintained within 0±3 degrees, accompanied by significant improvement in patient-reported functional outcomes.

INTRODUCTION

Coronal plane alignment is a critical determinant of outcomes in total knee arthroplasty (TKA). Historically, the mechanical alignment (MA) philosophy aimed to restore a neutral hip–knee–ankle axis (HKA: 180°) in the coronal plane [1], a "gold standard" yielding excellent long-term implant survivorship [2]. Achieving a straight limb with a horizontal joint line was thought to optimize load distribution and longevity [2]. However, neutral MA is not "normal" for all patients; alignment varies widely among individuals [3]. Bellemans et al. reported constitutional varus (≥3°) in 32% of men and 17% of women in a young adult population [3], suggesting that forcing such knees to neutral may require extensive ligament releases and compromise soft-tissue function.

Patient-specific alignment strategies emerged in response. Kinematic alignment (KA) restores prearthritic alignment and joint line orientation, aiming to match the patient's native anatomy and reduce ligament releases, potentially improving satisfaction and function [4,5]. Functional alignment (FA) bridges MA and KA by combining individualized bony alignment with precise soft-tissue balancing [6]. It respects native joint line obliquity (JLO) and limb axis within safe limits while ensuring symmetric, well-balanced gaps.

While the coronal plane alignment of the knee (CPAK) classification proposed by MacDessi et al. [2] provides a structured, phenotype-based description of coronal alignment using the arithmetic HKA (aHKA) and JLO [7], most available data originate from Western populations. Ethnic and anthropometric differences strongly influence lower-limb morphology; however, large-scale data on coronal alignment phenotypes in Indian osteoarthritic (OA) knees remain scarce. Given the limited data on coronal alignment patterns in Indian patients, we believe that identifying the most prevalent phenotype and describing population-specific alignment characteristics distinct from those reported in western cohorts would help fill the existing knowledge gap.

Therefore, the present study aimed to determine the distribution of coronal alignment phenotypes in Indian OA knees using the CPAK classification and to describe postoperative alignment characteristics and early (6 months follow-up) functional outcomes following robotic-assisted total knee arthroplasty (RATKA) performed with an FA philosophy. We hypothesized that Indian OA knees would demonstrate distinct coronal alignment patterns when evaluated using the CPAK classification and that RATKA performed using an FA approach would achieve postoperative alignment close to each patient's native coronal pattern while supporting early functional recovery.

METHODS

Study design and ethics

This single-center retrospective radiographic study included consecutive patients who underwent RATKA for end-stage primary OA (Kellgren–Lawrence Grade 4) between January 2022 and September 2023. All assessments were based on preoperative long-leg standing and postoperative short-leg radiographs, with functional outcomes obtained from routinely collected medical records; no additional clinical examinations were performed. Patients with secondary arthritis, inflammatory arthropathy, prior osteotomy, extra-articular deformity, or patients undergoing unicompartmental knee arthroplasty were excluded from the study, and all remaining patients meeting clinical and radiographic criteria were included. In line with institutional ethics policy, analyses involving anonymized radiographic data without patient identifiers do not require prior institutional review board approval; however, written informed consent was routinely obtained from all patients prior to undergoing RATKA. The study adhered to institutional ethical standards and the principles of the Declaration of Helsinki.

Radiographic measurements and CPAK classification

All patients underwent standardized standing long-leg radiograph (LLR) in the anteroposterior plane, obtained with the patella facing forward and both lower limbs fully extended to visualize the mechanical axes of the femur and tibia evaluated by two independent orthopaedic surgeons. Lateral knee radiographs were also acquired for all patients as part of the standard preoperative imaging protocol; however, only the long-leg anteroposterior views were analyzed in this study as the objective was limited to evaluating coronal plane alignment. Preoperative radiographs were acquired using a uniform digital protocol with consistent source-to-image distance and calibration markers to ensure measurement reproducibility across cases. Representative radiographs and schematic illustrations are included to demonstrate how the coronal alignment parameters—medial proximal tibial angle (MPTA), lateral distal femoral angle (LDFA), arithmetic HKA (aHKA) angle, and JLO—were measured and how the CPAK classification was applied.

The parameters measured included in the following

- **MPTA –** medial angle between tibial mechanical axis and tibial plateau.
- **LDFA –** lateral angle between femoral mechanical axis and distal femoral joint line.
- **aHKA –** MPTA − LDFA; varus ≤ −3°, neutral −3° to 3°, and valgus ≥3°. Negative values indicate varus and positive valgus.

JLO is categorized as apex-distal (AD), neutral, or apex-proximal (AP) using MPTA + LDFA thresholds from prior literature [2]. Based on established thresholds [2], JLO was classified as AD when MPTA + LDFA <176°, neutral when 176°–184°, and AP when >184°. For example, a knee with an MPTA of 82° and an LDFA of 92° (total 174°) was categorized as apex-distal; an MPTA of 86° and LDFA of 94° (180°) as neutral; and an MPTA of 90° and LDFA of 96° (186°) as apex-proximal.

Each knee was assigned a CPAK Type I–IX based on aHKA and JLO. For example, varus + AD = Type I; valgus + AP = Type IX.

The radiographic measurements of MPTA, LDFA, aHKA angle, and JLO obtained from preoperative LLRs were used to classify each knee according to the CPAK system. The distribution of CPAK phenotypes was analyzed to determine the predominant alignment pattern in Indian OA knees and to assess its association with demographic factors such as age and gender. Postoperative radiographic assessment was performed using standardized AP and lateral short-knee radiographs to confirm component positioning and joint line consistency following RATKA. Quantitative assessment of postoperative alignment restoration within functional alignment targets was obtained from intraoperative robotic system outputs. Functional outcome scores including Knee injury and Osteoarthritis Outcome Score (KOOS), KOOS scores involving activities of daily living (ADL) subscale, and Forgotten Joint Score (FJS) were reviewed to document early recovery (at six months).

Surgical procedure

RATKA was performed using either the fully automated Cuvis Joint Robot (Curexo, South Korea) with the Opulent total knee system (Meril Healthcare Pvt. Ltd., India) or the semi-active Mako system (Stryker, USA) with the Triathlon implant (Stryker, USA), selected based on patient preference and implant availability. Implant selection was independent of preoperative radiographic measurements. The cruciate-retaining design was used in the majority of cases across both systems, while posterior-stabilized (PS) implants were reserved for patients with obesity, severe coronal deformity (varus or valgus >20°), or tibial bone defects requiring additional stability. Both robotic platforms enabled real-time intraoperative planning, intraoperative bone resections, and assessment of alignment.

All RATKA procedures in this study were performed using an FA strategy. The surgical plan aimed to restore each patient's native limb alignment and joint line orientation within ±3° of the preoperative aHKA angle.

Data analysis

Analyses were performed using IBM SPSS Statistics v28.0 (IBM Corp). Continuous variables were tested for normality (Shapiro–Wilk) and reported as mean ± standard deviation (SD) or median (interquartile range [IQR]). Categorical variables, including CPAK frequencies, were presented as counts and percentages. CPAK distributions were assessed overall and stratified by age, gender, and operative side. Group comparisons used Chi-square or Fisher's exact tests ($p < 0.05$). Scatter plots illustrated aHKA–JLO clustering by subgroup. No data were missing. Discrepancies between observers were resolved by consensus or senior review.

RESULTS

Study participants

A total of 604 patients (947 OA knees) were analyzed, with a mean patient age of 61.7 ± 9.7 years (range: 24–85 years). The cohort included 183 men (30.3%) and 421 women (69.7%), indicating a female predominance (Table 1).

Radiographic parameters

On average, the MPTA was 82.03° ± 4.9° (range 74.5°–99.3°), LDFA averaged 90.6° ± 4.1° (range 83.2°–97.6°). The median aHKA (overall limb alignment) was −8.1° (IQR –12.1° to −4.3°). In fact, 88.2% of the knees had a varus alignment (aHKA ≤ −3°), while only 11.8% showed valgus alignment (aHKA ≥3°), and effectively none of patients were of the neutral alignment range (−3°–3°). The JLO demonstrated considerable variability across patients, with a mean of 162.4° ± 40.9° and an extreme range from 153.4° to 194.9°. Some knees had very low JLO angles (~153°), whereas others had very high angles (~195°), indicating a pronounced AD tilt (joint line sloping downward laterally) (Figs. 1 and 2).

Table 1
Demographic characteristics of the study population.

Variables	Details
Total number of patients, n	604
Age (in years)	
Mean ± SD	61.7 ± 9.7
Range	24 to 85
Gender, n (%)	
Male	183 (30.3)
Female	421 (69.7)

SD = standard deviation.

CPAK phenotype distribution

The vast majority of knees fell into just four of the nine possible phenotype categories. CPAK Type I – characterized by varus alignment with an AD joint line – was by far the most common, accounting for 78.7% of all knees. The next most frequent was Type III (approximately 9.5% of knees), which corresponds to valgus alignment with an AD joint line. This was followed by Type VII (around 6.8%), representing varus alignment with an AP joint line, and Type IX (about 5.0%), representing valgus alignment with an AP joint line. No knees in our series were classified as Types II, V, or VIII (neutral aHKA combined with AD, neutral, or AP JLO, respectively) (Table 2). We observed a dense cloud of data points concentrated in the varus and AD quadrant of the plot, corresponding to Type I knees (Fig. 3). By contrast, very few points lie in the opposite quadrants (especially the AP side), underscoring how rare those phenotypes (Types VII–IX) are in our sample.

Association of CPAK phenotypes with age, gender and operative side

There was no statistically significant association between CPAK distribution and gender ($p = 0.088$). Both men and women were predominantly classified as Type I, with only minor variations in the less common valgus or AP phenotypes (Fig. 4A and B). No significant differences were observed across age groups ($p = 0.143$), and Type I remained the most frequent phenotype in all categories, with slightly more pronounced varus patterns in older patients (Fig. 5A–C).

Similarly, no significant differences were found in CPAK distribution between left and right knees ($p > 0.20$). Both sides demonstrated a similar predominance of Type I phenotypes, with only small and non-significant variations in other CPAK groups (Fig. 6A and B).

Postoperative correction

Among patients classified as preoperative CPAK Type I (78.7% of the cohort), approximately 60% were still retained to Type I with correction of aHKA to ±3°. An additional 18% were realigned to a Type II phenotype, guided by the principles of FA. All patients initially presenting with a Type IX phenotype (5%) were adjusted to the Type VI alignment. Notably, 18% of patients with an average preoperative aHKA of −3.6° ± 5.6° were corrected to a postoperative alignment within ±4°, while those with a baseline aHKA of 5.1° ± 1.5° were adjusted to within ±3° of neutral. No cases of early revision surgery were reported in any patient.

Functional recovery

The total KOOS increased from a baseline of 50.7 ± 2.1 to 89.1 ± 1.2 at six months postoperatively ($p < 0.01$). Functional benefits, particularly the KOOS-ADL subscale, improved from 41.6 ± 3.2 to 85.9 ± 1.3 ($p < 0.05$). Additionally, the FJS rose from 29.8 ± 1.2 at the baseline to 77.9 ± 1.3 at six months ($p < 0.05$), underscoring statistically significant gains in joint awareness and overall functional recovery.

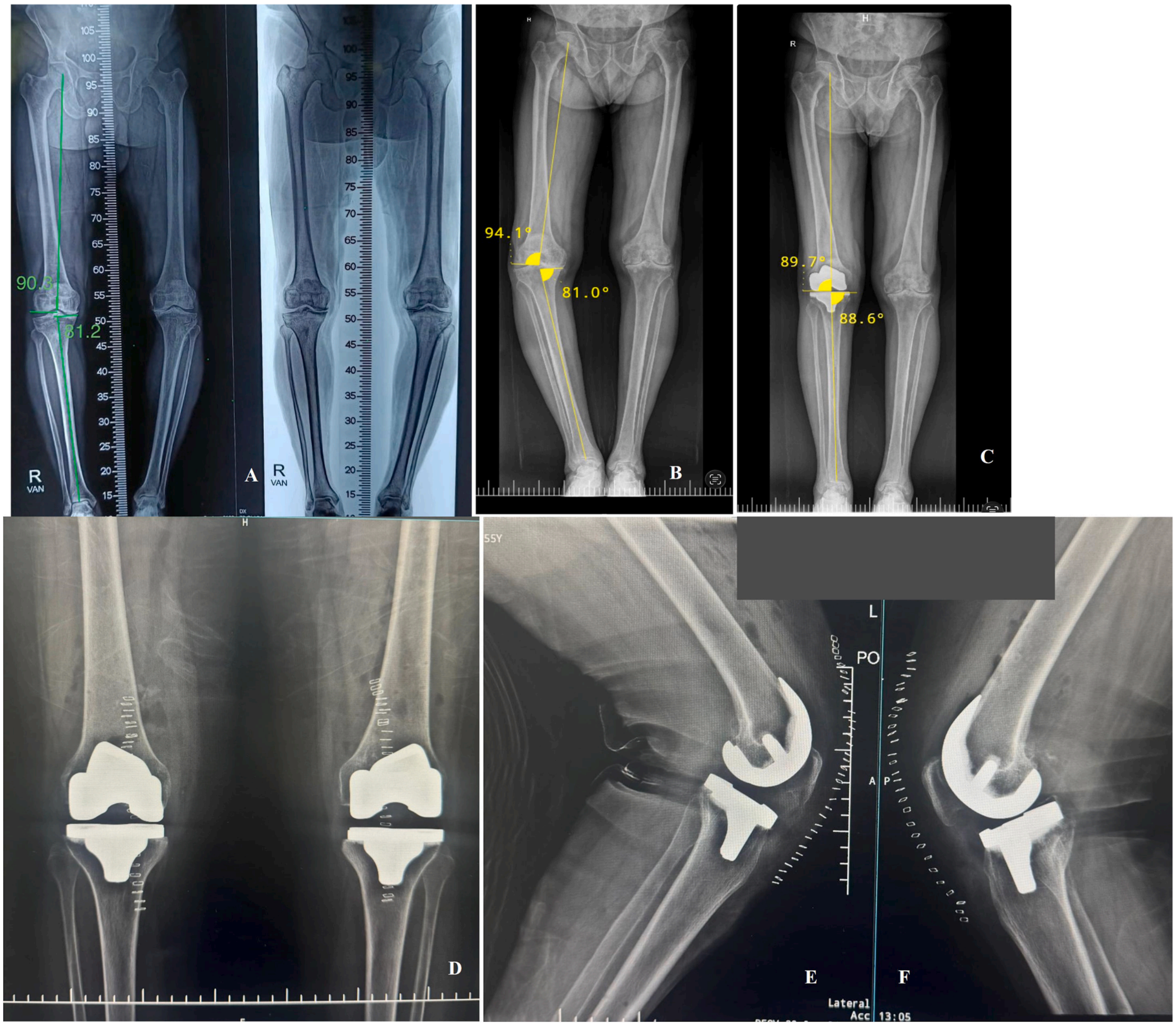

Fig. 1. Representative cases showing Panel A: Preoperative standing long-leg radiograph (LLR) demonstrating varus limb alignment; Panel B: Preoperative standing LLR illustrating coronal alignment measurements, including arithmetic hip–knee–ankle angle and joint line orientation derived from the medial proximal tibial angle and the lateral distal femoral angle; Panel C: Postoperative standing LLR demonstrating global coronal alignment correction following robotic-assisted total knee arthroplasty (RATKA); Panel D: Postoperative anteroposterior knee radiograph confirming appropriate femoral and tibial component positioning; Panel E and F: Postoperative lateral knee radiographs demonstrating satisfactory sagittal plane component positioning.

DISCUSSION

In this large-scale radiographic analysis of Indian OA knees, we found that the majority of patients exhibited a varus alignment pattern with an AD joint line, corresponding predominantly to CPAK Type I. Neutral phenotypes were absent, and varus alignment was significantly more frequent in males. RATKA performed using FA strategy restored alignment close to the patient's native phenotype, with significant postoperative improvement in early functional outcome scores.

Similar to Mulpur et al. [8] who reported that nearly 79% of Indian OA knees were Type I with negligible neutral phenotypes, our findings reaffirm that the Indian population shows a highly varus-dominant pattern, distinct from the western cohorts where neutral or valgus types are more prevalent [8]. In China, OA knees are most often presented as Type I, whereas healthy knees were usually mild varus with a neutral joint line (Type II), suggesting disease progression shifts alignment toward more varus [9]. This parallels our age-stratified analysis, where older individuals displayed accentuated varus and distal joint line orientation, implying progressive deformity with degeneration. These findings, consistent with reports from Indian [8,10], Chinese [9], and Turkish [7] populations (predominance of Type I and scarcity of neutral knees), contrast with western data where neutral or valgus phenotypes predominate, highlighting regional morphometric variation, including narrower tibial plateaus, higher medial condylar offset, and differing femoral bowing patterns reported in Indian and East Asian morphometric analyses. Collectively, these observations emphasize that alignment targets derived from western populations may not be universally applicable, underscoring the need for region-specific reference values and alignment strategies tailored to native morphotypes.

Historically, coronal alignment in the knee has been quantified using angular parameters such as the mechanical HKA angle and the femorotibial angle, which describe the overall limb axis in the coronal plane [1,3,4]. While these conventional methods remain widely used, they offer a uniaxial representation of alignment and do not account for joint line orientation or the compensatory relationship between the femur and tibia that affects soft-tissue balance [3,4]. Using the CPAK system which provides a more comprehensive, phenotypic framework for evaluating population-specific variations and guiding individualized alignment strategies, particularly in FA or KA approaches by combining limb axis and joint line orientation [2,5,7,9,11], we could describe

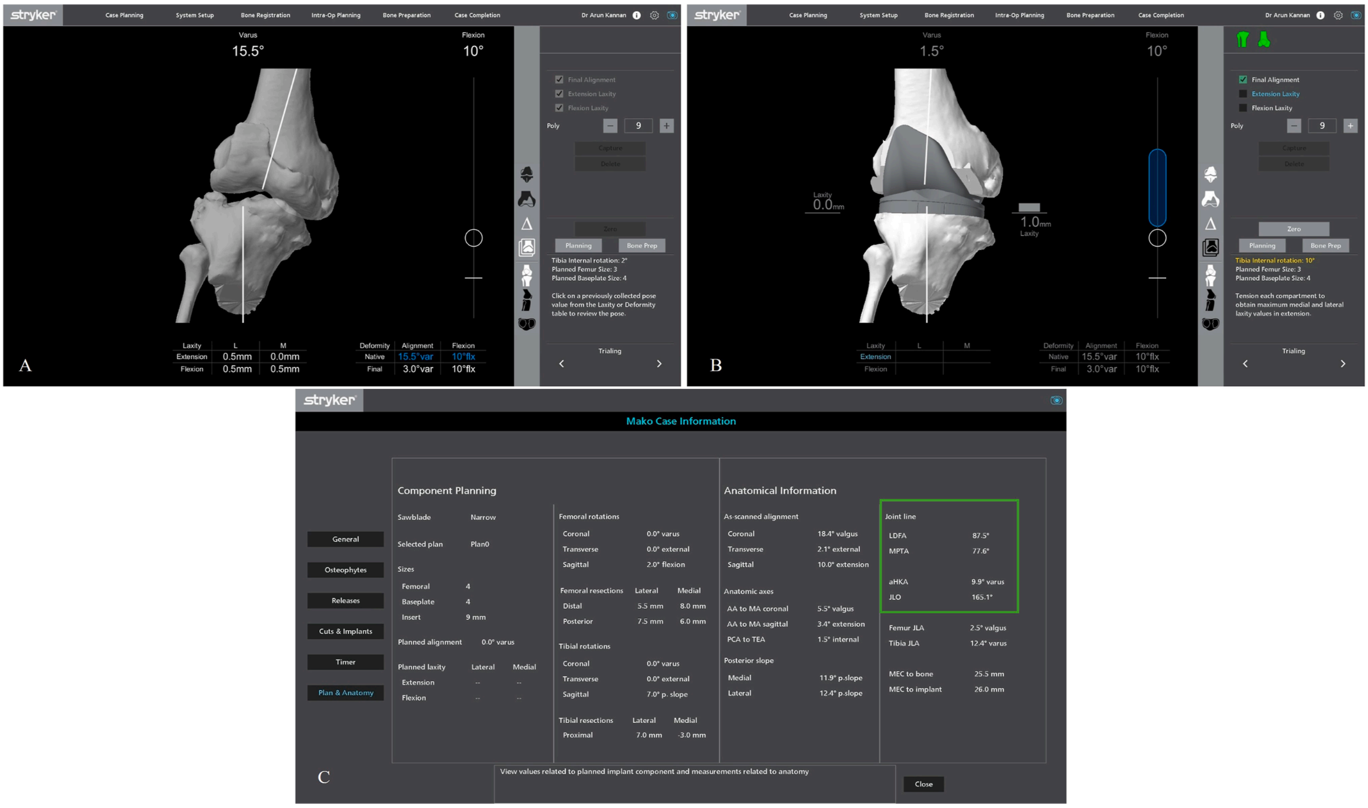

Fig. 2. Intraoperative robotic planning and alignment correction in robotic-assisted total knee arthroplasty (RATKA). Panel A: Intraoperative robotic planning view demonstrating native varus coronal alignment and joint line orientation prior to bone resection; Panel B: Robotic planning screen showing planned correction of coronal alignment within functional alignment targets, with preservation of joint line orientation and balanced extension and flexion gaps; Panel C: Robotic system case information panel illustrating quantitative intraoperative measurements of coronal alignment and joint line parameters, including arithmetic hip–knee–ankle angle, medial proximal tibial angle, lateral distal femoral angle, and joint line orientation as recorded following component planning and implantation.

Table 2
Clinical factors of the study population, including radiographic parameters used to assess coronal knee alignment.

Parameters, (n = 947)	Details	Range (degrees)
MPTA, (mean ± SD), degrees	82.03 ± 4.9	74.54 to 99.3
LDFA, (mean ± SD), degrees	90.6 ± 4.1	83.21 to 97.6
aHKA		
Median (IQR), degrees	−8.1	−12.1 to −4.3
Varus, n (%)	835 (88.2)	
Valgus, n (%)	112 (11.8)	
JLO		
Mean ± SD (degrees)	162.4 ± 40.9	153.4 to 194.9
Grade, n (%)		
I	745 (78.7)	
III	90 (9.5)	
VII	65 (6.8)	
IX	47 (5)	

MPTA = medial proximal tibial angle; LDFA = lateral distal femoral angle; aHKA = arithmetic hip–knee–ankle axis; JLO = joint line obliquity; AD = anterodistal (AD); AP = anteroproximal; IQR = interquartile range.

alignment phenotypes more precisely than with conventional parameters.

We found no significant differences in CPAK distribution between genders or sides, suggesting alignment is largely determined by constitutional factors. Other populations have shown minor gender variations [12] but in our cohort, both sexes were similarly prone to varus OA. Bellemans et al. (2012) [3] similarly described constitutional varus as a largely sex-independent anatomical feature, though slightly more frequent in men, supporting our findings. Age appeared related to severity, with older patients showing more pronounced varus, consistent with the view that chronic varus loading accelerates degeneration [9,12,13]. Matsumoto et al. (2015) [13] further demonstrated that progressive medial cartilage loss accentuates varus deformity with advancing age, reinforcing our observation that degenerative progression modifies alignment patterns.

The high prevalence of varus phenotypes has important implications for TKA in India. Correcting such knees to neutral under MA often requires substantial medial releases and asymmetric bone cuts, which may destabilize the knee [14]. Functional or KA approaches can preserve native JLO and avoid excessive ligament release [15]. Evidence supports this: varus knees, especially Type I, show better balance and outcomes with individualized alignment [16,17]. Young et al. (2025) demonstrated that FA led to higher patient-reported outcomes and fewer soft-tissue releases compared to MA [16]. Similarly, Clark et al. (2022) highlighted that robotic-assisted FA replicates patient-specific morphotypes with submillimeter precision, minimizing the need for soft-tissue balancing [17]. Most Type I knees retained alignment within ±3°, reflecting FA's ability to preserve native orientation while avoiding extremes [16]. This shift pattern aligns with Palanisamy et al. who found that mechanically aligned TKAs in varus knees required greater releases and yielded slower recovery, underscoring the clinical advantage of FA in Indian patients [10].

Another contemporary development influencing alignment strategies is the rise of RATKA. Robotic assistance enables precise, individualized bone resections and alignment correction that complement FA principles. In fact, the combination of CPAK phenotype recognition and enabling technology has been touted as a new paradigm in TKA [11]. Chen (2025) emphasized that robotic systems bridge morphologic diversity and surgical precision [11]; our findings support this paradigm

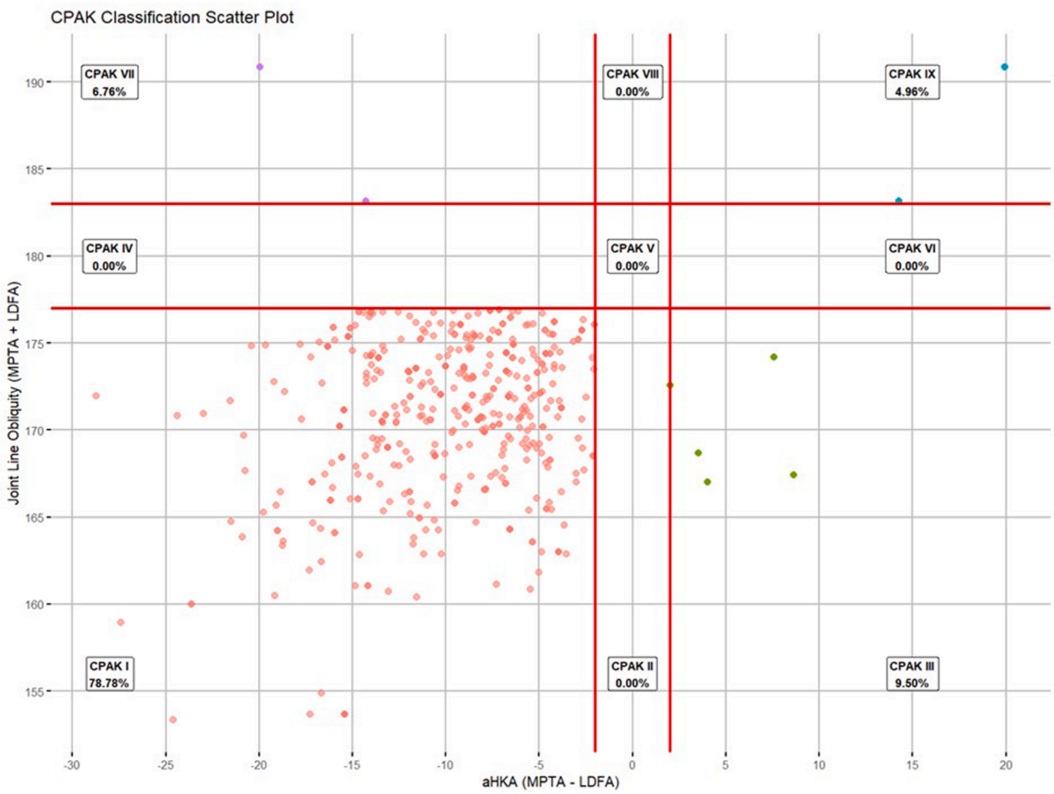

Fig. 3. CPAK classification scatter plot for all osteoarthritic knees in the study (n = 947). The horizontal axis is the arithmetic Hip–Knee–Ankle angle (aHKA, MPTA – LDFA) in degrees, with negative values indicating varus alignment and positive indicating valgus. aHKA = arithmetic hip–knee–ankle axis; CPAK = coronal plane alignment of the knee; LDFA = lateral distal femoral angle; MPTA = medial proximal tibial angle.

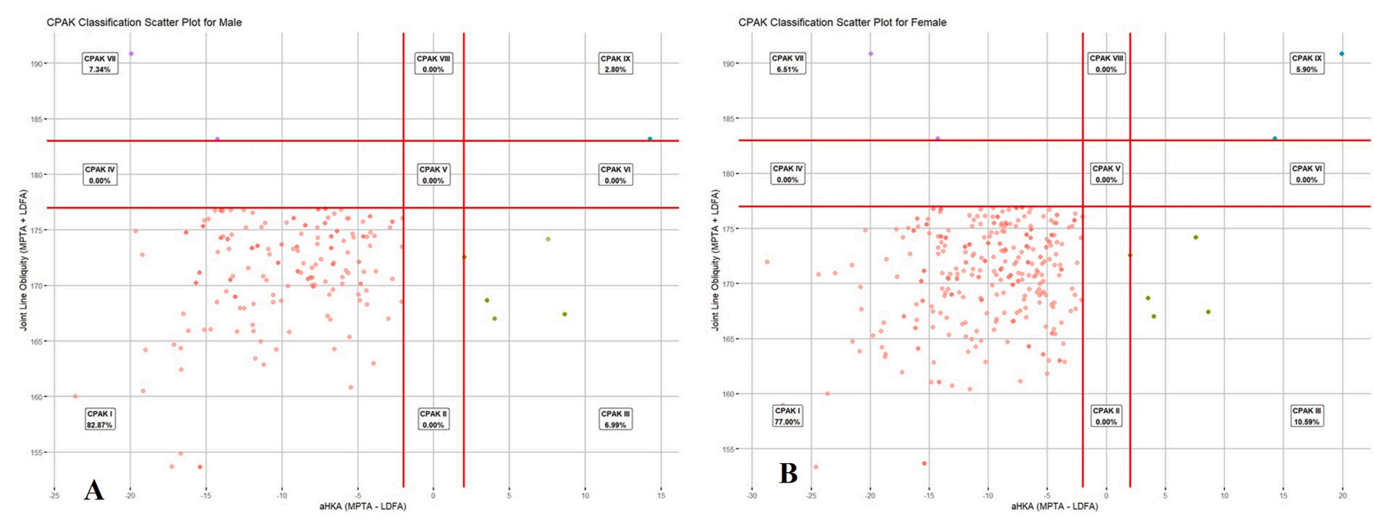

Fig. 4. CPAK classification scatter plots by Gender. Panel A— Male patients and panel B— Female patients. Each dot represents an individual knee plotted by aHKA and JLO, with red lines marking classification boundaries and percentages indicating the proportion in each CPAK type. aHKA = arithmetic hip–knee–ankle axis; CPAK = coronal plane alignment of the knee; JLO = joint line obliquity.

by demonstrating reproducible phenotype restoration with FA-guided RATKA. In a randomized RATKA trial, FA reduced releases and improved patient-reported scores in varus knees [16]. Our cohort demonstrated significant short-term functional improvement, consistent with prior FA studies, indicating rapid functional recovery and joint “forgettability.” These findings suggest that retaining mild varus in TKA may enhance satisfaction in Indian patients, although robotic accuracy in relation to functional outcomes was not measured in this particular study, hence interpretation is to be accordingly performed. Our observations also resonate with Karasavvidis et al. (2023) [15], who concluded that no single alignment philosophy is universally superior—our data show that FA may be especially suitable for varus-dominant Indian morphotypes.

Our study has several strengths including a large sample, standardized LLRs, intraoperative alignment evaluation and consistent CPAK-based assessment, providing robust Indian reference data. CPAK offers greater nuance than HKA alone by integrating joint line orientation, which is directly relevant to surgical planning.

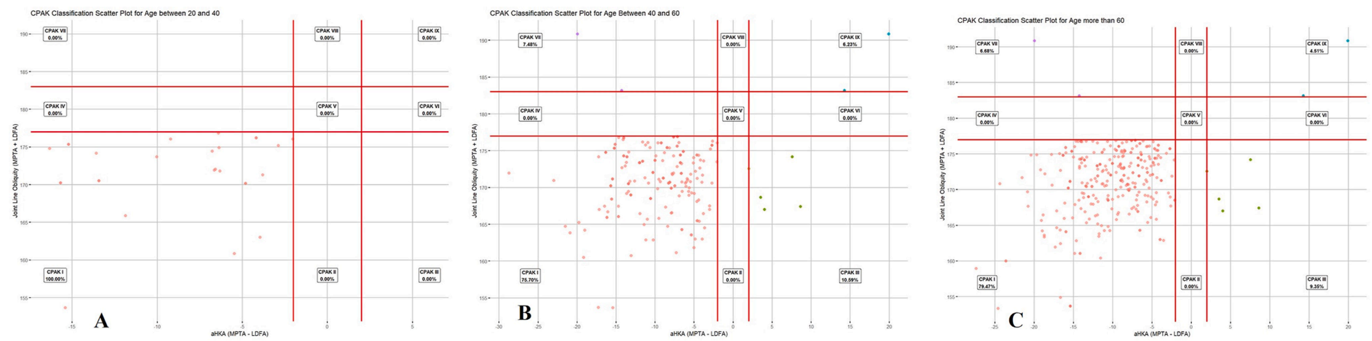

Fig. 5. CPAK classification scatter plots by age group Panel A—Age 20–40 years, panel B—Age 40–60 years, and panel C—Age >60 years. Each dot represents an individual knee plotted by aHKA and JLO, with red lines marking classification boundaries and percentages indicating the proportion in each CPAK type. aHKA = hip–knee–ankle angle; CPAK = coronal plane alignment of the knee; JLO = joint line obliquity.

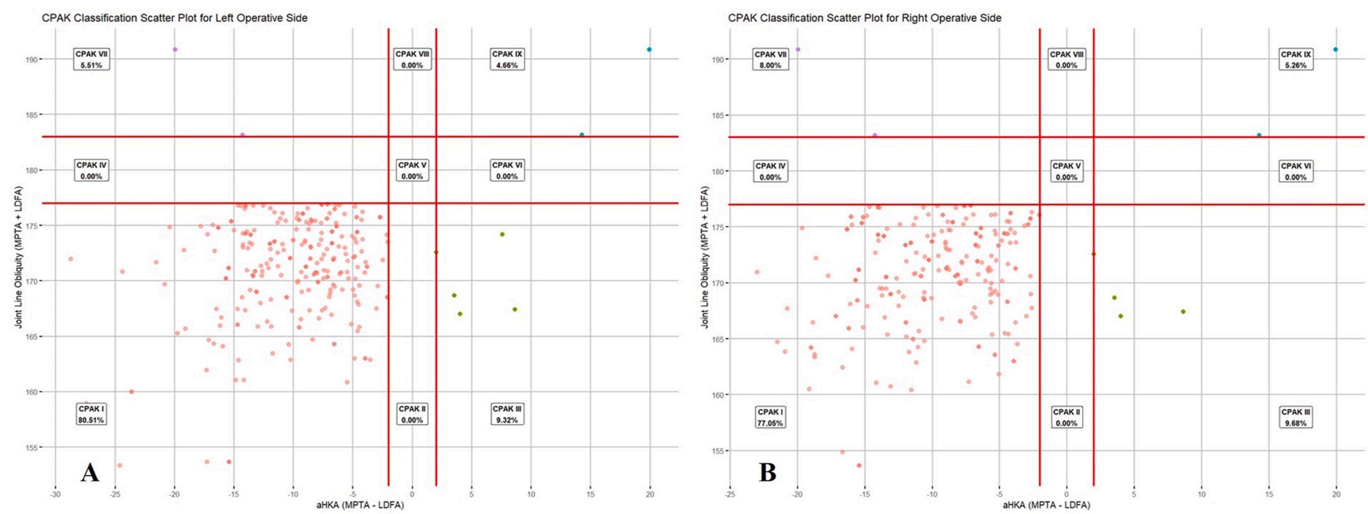

Fig. 6. CPAK classification scatter plots by operative side. Panel A—Left operative side and panel B—Right operative side. Each dot represents an individual knee plotted by aHKA and JLO, with red lines marking classification boundaries and percentages indicating the proportion in each CPAK type. aHKA = hip–knee–ankle angle; CPAK = coronal plane alignment of the knee; JLO = joint line obliquity.

Nonetheless, there are important limitations to acknowledge. First, this was a single-center, cross-sectional study, and the patient population—while large—may not be fully representative of all of India. Dietary, lifestyle, and genetic factors vary across the country and could influence alignment (for example, squatting habits or high tibial osteotomy prevalence could differ regionally). Second, our cohort consisted of patients with established knee OA and we did not include a control group of healthy, pre-arthritic knees. This means we are effectively describing the alignment at end-stage disease, which might differ from those individuals' native alignment before OA changes set in. Arthritic degeneration (especially medial compartment cartilage loss) can itself increase varus angulation over time. The lack of longitudinal or pre-OA data limits our ability to distinguish how much of the observed varus is "constitutional" versus acquired due to disease. An additional limitation relates to postoperative alignment assessment. Preoperative CPAK phenotyping was performed using standing LLRs, whereas postoperative radiographic evaluation relied on standard short-knee views for assessing component positioning. As short-knee radiographs do not reliably capture global mechanical axis parameters, postoperative alignment restoration was assessed using intraoperative robotic system outputs. This difference in imaging modalities should be considered when interpreting postoperative alignment findings. Finally, although the CPAK classification provides a comprehensive framework for describing coronal plane alignment, it simplifies a continuum of anatomical variation into discrete categories. Knees positioned near the boundaries between types may be reclassified due to minor differences in measurement, and small radiographic or landmark identification errors could shift a case from one phenotype to another. We attempted to minimize this limitation through standardized radiographic acquisition protocols and repeated measurements yet this remains an inherent consideration when using categorical alignment systems.

CONCLUSION

In summary, this CPAK-based radiographic analysis demonstrates that Indian knees with OA are predominantly varus-aligned, with Type I phenotypes being especially common. Our findings support the concept of FA in RATKA—using an individualized target rather than a uniform neutral alignment—as many Indian patients may benefit from retaining a slight varus alignment to achieve better ligament balance. Future research should build on these insights, for instance by examining outcomes of mechanically aligned versus functionally aligned TKAs in varus-prone populations or by investigating whether intermediate alignment targets (neither strict neutral nor full kinematic) yield optimal results in Indian patients.

Author contributions

Madan Mohan Reddy contributed to conceptualization; formal analysis; Funding acquisition; investigation; methodology; project administration; supervision; validation; visualization; roles/writing - review & editing.

Praveen J, Karthik Reddy Pammi, Prasad D, Adithya Kumar Jilmudi, and Ravi Teja Rudraraju contributed to data curation; formal analysis; Funding acquisition; investigation; methodology; project administration; resources; software; supervision; validation; visualization; roles/writing - original draft; and writing - review & editing.

Ethical considerations

The study was performed in accordance with the Declaration of Helsinki. Because we utilized only de-identified radiographic data and conducted no direct patient interventions, the institutional review board waiver was not required as per the guidelines of the Ethical committee board. Written informed consent was obtained from patients prior to each surgery.

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Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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