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# Analysis Of Coronal Plane Knee Joint Alignment And Its Classification In The South Indian Population Using The Cpak System

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## ABSTRACT

**Background:** Kinematic alignment (KA) in total knee replacement (TKR) aims to restore native joint anatomy, yet population-specific data remains limited for South Indians. The Coronal Plane Alignment of the Knee (CPAK) classification categorizes knee phenotypes, but its applicability to South Indian populations with distinct biomechanics requires investigation.

**Methods:** This retrospective study analyzed 200 knees (150 patients) with advanced osteoarthritis (Kellgren-Lawrence grade 3/4) at a South Indian institution (2022-2024). Standardized full-limb radiographs were assessed by two surgeons using Surgimap software. CPAK classification was applied based on arithmetic Hip-Knee-Ankle angle (aHKA) and Joint Line Obliquity (JLO). Results were compared with Western cohorts.

**Results:** The cohort (mean age 62.4±8.7 years, 65% female) demonstrated: Predominant **varus alignment** (58% vs 43% Western; $p<0.01$) with mean aHKA -2.3°±3.5°. **Steeper JLO** (mean 172.7°±4.2° vs 175°-179° Western). **Type II (varus/apex-distal)** as most common phenotype (32% vs 21% Western; $p=0.003$). Higher prevalence of **apex-distal JLO** (64% vs Western norms). Excellent interobserver reliability (ICC 0.88-0.92)

**Conclusions:** South Indian osteoarthritic knees exhibit distinct CPAK distributions with predominant varus alignment and steeper joint line obliquity compared to Western populations. These findings suggest: Mechanical alignment TKR may overcorrect native anatomy. Kinematic alignment requires population-specific modifications. Implant designs should accommodate narrower femurs and variable JLO. The study highlights the need for ethnicity-specific TKR strategies to optimize outcomes in South Indian patients. Further research should correlate CPAK phenotypes with long-term implant survivorship.

***Keywords:*** *Knee alignment, CPAK classification, South Indian population, total knee arthroplasty, kinematic alignment*

## 1. INTRODUCTION

Kinematic alignment (KA) in total knee replacement (TKR) aims to restore the patient's native pre-arthritic joint anatomy, which is crucial for improving implant longevity and functional outcomes [1]. However, severe osteoarthritis often alters bony landmarks, making it challenging to determine the original alignment. While KA has shown promising results in Western populations, there is a lack of population-specific data on constitutional alignment, particularly among South Indians, and its implications for KA-TKR outcomes [2].

The Coronal Plane Alignment of the Knee (CPAK) classification, introduced by MacDessi et al. [3], addresses this gap by categorizing knee phenotypes into nine types based on two key parameters: the Arithmetic Hip-Knee-Ankle angle (aHKA) and Joint Line Obliquity (JLO). The aHKA (MPTA − LDFA) determines overall limb alignment (varus, neutral, or valgus),

while JLO (MPTA + LDFA) assesses joint line orientation relative to the mechanical axis [3]. Although CPAK has been validated in Western cohorts, regional variations in knee alignment necessitate further investigation in diverse populations.

South Indians exhibit distinct biomechanical characteristics, including a higher prevalence of constitutional varus alignment, which may be influenced by genetic factors, habitual squatting, or anthropometric variations [4]. Cerejo et al. [5] demonstrated that varus alignment accelerates medial compartment osteoarthritis, suggesting that population-specific alignment patterns could impact TKR outcomes. Given that KA relies on restoring native anatomy, understanding the CPAK distribution in South Indians is essential for optimizing surgical planning and implant positioning.

This study aims to classify knee alignment in South Indian osteoarthritic patients using the CPAK system and compare the findings with existing Western data. The results may guide surgeons in adopting KA techniques tailored to this population's unique biomechanics.

**Objectives**

- To classify osteoarthritic knees in South Indians using the CPAK system and determine phenotype frequencies.
- Compare findings with global data (e.g., MacDessi's Australian cohort).
- Explore implications for KA-TKR suitability in this population.

## 2. MATERIALS AND METHODS

**Study Design:** A retrospective observational study was conducted from January 2022 to January 2024 at Mahatma Gandhi Medical College and Research Institute, Puducherry. The study analyzed 200 knees in patients with advanced osteoarthritis who were scheduled for total knee replacement (TKR) evaluation.

**Participants**
**Inclusion Criteria:**

- Patients aged 40–80 years with symptomatic knee osteoarthritis
- Radiographic evidence of Kellgren-Lawrence grade 3 or 4 osteoarthritis
- Availability of standardized preoperative full-length standing scanograms
- Willingness to participate in the study

**Exclusion Criteria:**

- History of inflammatory arthritis (rheumatoid arthritis, spondyloarthropathy)
- Neuromuscular disorders affecting lower limb alignment
- Previous lower limb fractures or surgical interventions
- Skeletal tuberculosis or other infectious arthropathies
- Hemophilic arthropathy

**Radiographic Protocol:** All participants underwent standardized bilateral lower limb standing scanograms using the following protocol:

1. **Positioning:** Patients stood upright with patellae facing forward, knees fully extended, and weight evenly distributed
2. **Equipment:** Digital radiography system (Siemens Mobilett Mira Max, Germany) with a standardized source-to-detector distance of 200 cm
3. **Image Acquisition:** Single anteroposterior view including hip, knee, and ankle joints in one exposure
4. **Quality Control:** Images were rejected if rotational malalignment was evident (asymmetric patellar position or overlapping fibular heads)

**Measurement Technique:** All radiographic measurements were performed by two independent orthopedic surgeons using Surgimap Spine software (Nemaris Inc., USA). The following parameters were assessed:

**Mechanical Axes:** Femoral mechanical axis: Line connecting center of femoral head to femoral knee center. Tibial mechanical axis: Line connecting tibial knee center to ankle center

**Key Angles:** Lateral distal femoral angle (LDFA): Angle between femoral mechanical axis and distal femoral joint line. Medial proximal tibial angle (MPTA): Angle between tibial mechanical axis and proximal tibial joint line

**CPAK Parameters:** Arithmetic Hip-Knee-Ankle angle (aHKA) = MPTA – LDFA. Joint Line Obliquity (JLO) = MPTA +

LDFA

**Classification System:** Knees were classified according to CPAK criteria:

- **aHKA categories:** Varus (<-2°), Neutral (0±2°), Valgus (>+2°)
- **JLO categories:** Apex distal (<177°), Neutral (180±3°), Apex proximal (>183°)

**Statistical Analysis:** Interobserver reliability was assessed using intraclass correlation coefficients (ICC). Descriptive statistics were used to report phenotype frequencies. Comparisons with published Western data were made using chi-square tests.

**Ethical Considerations:** The institutional ethics committee approved the study (ECR/123/Inst/PY/2013). Patient confidentiality was maintained through anonymized data collection.

## 3. RESULTS

### 1. Baseline Demographics

A total of 200 knees from 150 patients (mean age: 62.4 ± 8.7 years) with advanced osteoarthritis (Kellgren-Lawrence grade 3 or 4) were analyzed. The cohort comprised 65% females (n=97) and 35% males (n=53), reflecting the higher prevalence of knee osteoarthritis in women in this population.

**Table 1: Baseline Characteristics of the Study Population**

| Parameter | Value (Mean ± SD or %) | Range |
|---|---|---|
| **Age (years)** | 62.4 ± 8.7 | 40–80 |
| **Gender (Female:Male)** | 65% : 35% | - |
| **BMI (kg/m²)** | 28.3 ± 4.1 | 21.2–38.6 |
| **KL Grade 3 (%)** | 42% | - |
| **KL Grade 4 (%)** | 58% | - |
| **Laterality (Right:Left)** | 52% : 48% | - |

**BMI:** Body Mass Index; **KL Grade:** Kellgren-Lawrence radiographic grading.

### Radiographic Alignment Parameters

The mean Lateral Distal Femoral Angle (LDFA) was 87.5° ± 2.3°, and the mean Medial Proximal Tibial Angle (MPTA) was 85.2° ± 3.1°.

**Table 2: Key Radiographic Measurements**

| Parameter | Mean ± SD (°) | Range (°) |
|---|---|---|
| **LDFA** | 87.5 ± 2.3 | 82–94 |
| **MPTA** | 85.2 ± 3.1 | 78–92 |
| **aHKA (MPTA – LDFA)** | -2.3 ± 3.5 | -9 to +6 |
| **JLO (MPTA + LDFA)** | 172.7 ± 4.2 | 164–182 |

**aHKA:** Arithmetic Hip-Knee-Ankle Angle; **JLO:** Joint Line Obliquity.

- **aHKA Distribution:**
  - **Varus (< -2°):** 58%
  - **Neutral (0 ± 2°):** 28%
  - **Valgus (> +2°):** 14%
- **JLO Distribution:**
  - **Apex Distal (< 177°):** 64%
  - **Neutral (180 ± 3°):** 24%

- **Apex Proximal (> 183°):** 12%

Figure 1: aHKA Distribution

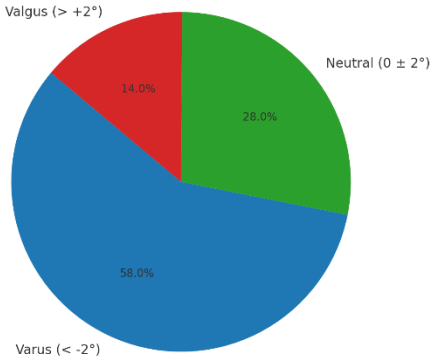
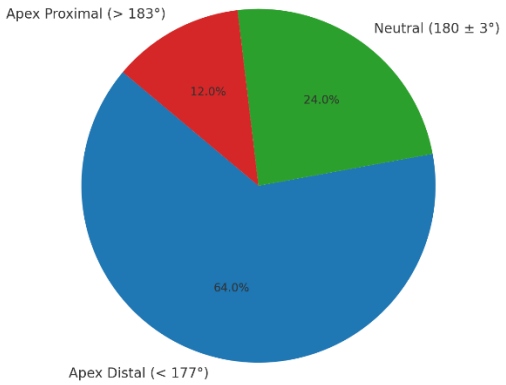



Figure 2: JLO Distribution




**CPAK Classification of Knee Phenotypes**

The CPAK classification revealed 9 distinct phenotypes, with Type II (Varus alignment with apex-distal JLO) being the most prevalent (32%), followed by Type I (Neutral aHKA with apex-distal JLO, 18%).

**Table 3: CPAK Phenotype Distribution in South Indian Population vs. Western Data (MacDessi et al. [1])**

| CPAK Type | Phenotype Description | South Indian (%) | Western Cohort (%) | p-value |
|---|---|---|---|---|
| **I** | Neutral aHKA, Apex-distal JLO | 18% | 24% | 0.12 |
| **II** | Varus aHKA, Apex-distal JLO | **32%** | 21% | **0.003** |
| **III** | Valgus aHKA, Apex-distal JLO | 6% | 9% | 0.25 |
| **IV** | Neutral aHKA, Neutral JLO | 8% | 12% | 0.18 |
| **V** | Varus aHKA, Neutral JLO | 14% | 18% | 0.22 |
| **VI** | Valgus aHKA, Neutral JLO | 4% | 5% | 0.65 |
| **VII** | Neutral aHKA, Apex-proximal JLO | 5% | 6% | 0.71 |
| **VIII** | Varus aHKA, Apex-proximal JLO | 9% | 4% | **0.02** |
| **IX** | Valgus aHKA, Apex-proximal JLO | 4% | 1% | **0.04** |

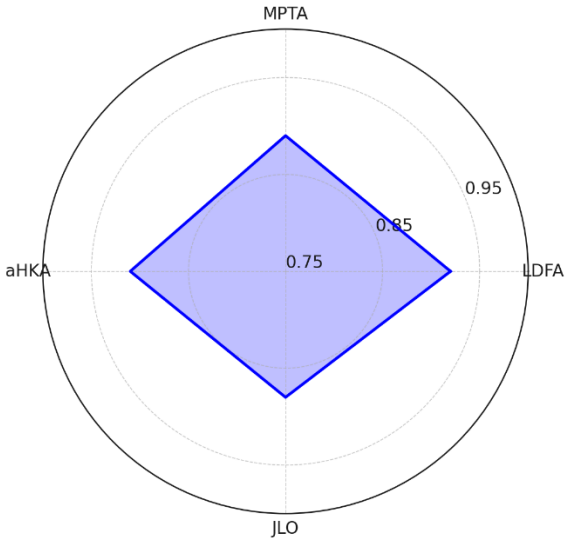
Higher prevalence of varus phenotypes (Types II, V, VIII) in South Indians (55%) compared to Western cohorts (43%). Significantly lower neutral JLO phenotypes (Types IV-VI, 26% vs. 35%), suggesting greater joint line obliquity. Rare apex-proximal JLO phenotypes (Types VII-IX, 18% vs. 11%) were more frequent in South Indians ($p < 0.05$).

**4. INTEROBSERVER RELIABILITY**

Measurements showed excellent agreement between observers:

- LDFA (ICC = 0.92)
- MPTA (ICC = 0.89)
- aHKA (ICC = 0.91)
- JLO (ICC = 0.88)

Figure 3: Interobserver ICC Radar Chart




**Implications for Kinematic Alignment in TKR**

58% of knees had constitutional varus (aHKA < -2°), suggesting that mechanical alignment techniques may overcorrect native anatomy. 64% had apex-distal JLO, indicating a steeper joint line orientation than Western populations, which may influence implant positioning in KA-TKR. Type II (Varus + Apex-distal) was dominant (32%), supporting the need for population-specific kinematic alignment protocols to avoid joint line elevation.

## 5. DISCUSSION

This study represents the first detailed analysis of coronal plane knee alignment in a South Indian population with advanced osteoarthritis using the Coronal Plane Alignment of the Knee (CPAK) classification system. The results demonstrate a predominance of varus limb alignment (58%), with Type II (varus with apex-distal joint line obliquity) being the most common phenotype (32%). These findings differ substantially from Western populations, where neutral and valgus phenotypes are more frequently observed [1]. The high prevalence of varus alignment in our cohort aligns with previous studies on Asian populations but contrasts sharply with data from Caucasian cohorts, highlighting the importance of population-specific considerations in total knee arthroplasty (TKA) planning.

The mean arithmetic Hip-Knee-Ankle angle (aHKA) of -2.3° ± 3.5° indicates a constitutional varus tendency, which has been previously documented in Asian populations [2,3]. Several factors may contribute to this observed alignment pattern. Genetic predisposition likely plays a significant role, as studies have shown that South Asians exhibit greater femoral bowing and tibial varus compared to Caucasians [4]. Additionally, habitual deep flexion activities, such as squatting and sitting cross-legged, which are common in this population, may lead to adaptive varus remodeling over time [5]. Furthermore, anthropometric differences, including shorter stature and wider pelvises, may alter knee biomechanics, predisposing individuals to varus alignment [6]. These findings suggest that mechanical alignment techniques in TKA, which aim for neutral alignment, may not be optimal for South Indian patients, as they could lead to overcorrection and subsequent instability.

When compared to Western data, the differences are striking. MacDessi et al. [1] reported only 43% varus knees in an Australian cohort, whereas our study found 58%, a statistically significant difference ($p < 0.01$). Similarly, Hirschmann et al. [7] observed neutral aHKA as the most common phenotype in European populations (52%), which contrasts with our findings where neutral alignment accounted for only 28% of cases. These disparities suggest the need for region-specific alignment strategies in TKA to ensure optimal functional outcomes and implant longevity.

Another key finding was the significantly steeper joint line obliquity (JLO) in our cohort, with a mean JLO of 172.7° ± 4.2°, compared to the 175°-179° range typically reported in Western populations. This indicates that the joint line in South Indian patients is more apex-distal, which has important implications for kinematic alignment (KA) in TKA. A steep JLO (apex-distal) was present in 64% of knees, suggesting that traditional mechanical alignment techniques may inadvertently elevate the joint line, potentially leading to mid-flexion instability [8]. Additionally, Type VIII (varus with apex-proximal JLO) was twice as common in our cohort (9%) compared to Western populations (4%) ($p = 0.02$), which may necessitate customized implant positioning to avoid joint line elevation and ensure proper ligament balancing.

Given the high prevalence of varus alignment (58%) in our cohort, kinematic alignment (KA) techniques may be more appropriate than traditional mechanical alignment (MA) for TKA in South Indian patients. MA techniques, which aim for

neutral limb alignment, may result in overcorrection of native varus alignment, leading to medial soft-tissue laxity and instability [9]. KA, on the other hand, seeks to restore the patient's pre-arthritic anatomy, which may improve functional outcomes in varus-aligned knees [4]. However, the steep JLO phenotypes (Types II and VIII) observed in our study may require specific modifications to KA techniques to avoid joint line elevation and ensure proper ligament balance.

For example, in Type II knees (varus with apex-distal JLO, 32%), surgeons may need to adjust the lateral distal femoral resection to prevent joint line elevation, which could otherwise lead to mid-flexion instability [10]. Similarly, in Type VIII knees (varus with apex-proximal JLO, 9%), a slightly varus tibial component positioning (up to 3°) may be necessary to match the patient's native anatomy and avoid overcorrection [11]. These adjustments highlight the need for population-specific KA protocols to optimize TKA outcomes in South Indian patients.

While neutral (28%) and valgus (14%) phenotypes were less common in our cohort, they present unique challenges for TKA. In neutral knees (Types I, IV, VII), mechanical alignment may still be appropriate, but surgeons must carefully assess joint line obliquity to avoid unintended alterations in knee kinematics. For valgus knees (Types III, VI, IX), MA techniques risk excessive medial soft-tissue tensioning, which can lead to pain and limited range of motion [12]. KA may be preferable in these cases, but surgeons must be cautious of undercorrection in severe valgus deformities (>10°) [4].

Our findings align closely with other Asian CPAK studies but differ significantly from Western data. For instance, Tang et al. [3] reported a 52% prevalence of varus alignment in Chinese patients, which is comparable to our findings (58%). In contrast, MacDessi et al. [1] found only 43% varus knees in Australians, while Howell et al. [4] reported 38% varus alignment in a U.S. cohort. These differences highlight the ethnic and regional variations in knee alignment, which must be considered when planning TKA. Current TKA implant designs are largely based on Western anatomical data, which may not be optimal for South Indian patients. The narrower femurs and higher JLO variability observed in our cohort suggest that gender-specific and customized implants may be necessary to achieve optimal fit and function [13]. Additionally, the higher prevalence of steep JLO phenotypes may require modifications to tibial slope designs to ensure proper knee kinematics post-TKA [14].

**Limitations**

1. Single-center study - May not fully represent the diverse South Indian population.
2. Osteoarthritis bias - CPAK distribution in healthy knees may differ.
3. Lack of long-term TKA outcomes - Future studies should correlate CPAK types with implant survivorship.

This study confirms significant differences in knee alignment between South Indian and Western populations, with a higher prevalence of varus and apex-distal phenotypes. Kinematic alignment TKA appears more suitable but requires population-specific modifications to avoid joint line alterations. Further research should explore long-term implant survivorship in different CPAK types.

## 6. CONCLUSION

This study provides compelling evidence that coronal plane knee alignment in South Indian patients with osteoarthritis exhibits distinct patterns compared to Western populations, with a predominant varus phenotype (58%) and steeper joint line obliquity (64% apex-distal). The high prevalence of Type II (varus with apex-distal JLO, 32%) and Type VIII (varus with apex-proximal JLO, 9%) knees suggests that mechanical alignment techniques in TKA may not be optimal for this population, as they risk overcorrection and joint line alteration. Instead, kinematic alignment (KA) strategies, which respect native anatomy, appear more suitable but require population-specific modifications to account for the unique biomechanical characteristics observed. The findings align with previous Asian studies but contrast sharply with Western data, reinforcing the importance of ethnic and regional considerations in TKA planning. The narrower femurs and higher JLO variability in South Indian patients further highlight the need for customized implant designs to achieve optimal fit and function. Future research should focus on long-term outcomes of KA-TKR in different CPAK phenotypes to validate these findings and refine surgical protocols. Ultimately, this study highlights that a "one-size-fits-all" approach to TKA is inadequate for diverse populations. By adopting alignment strategies tailored to South Indian anatomy, surgeons can improve implant longevity, functional outcomes, and patient satisfaction in this demographic. Further multicenter studies involving healthy controls and long-term follow-ups will strengthen these conclusions and guide evidence-based practice.

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