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ORIGINAL ARTICLE

Radiological Evaluation of the Phenotype of Indian Osteoarthritic Knees based on the Coronal Plane Alignment of the Knee Classification (CPAK)

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Abstract

Background Understanding constitutional alignment of the lower limb is essential to optimize alignment strategies during total knee arthroplasty. The coronal plane alignment of knee (CPAK) classification system was proposed as a comprehensive assessment tool based on coronal alignment and variations in joint line obliquity (JLO). This prospective observational cross-sectional study aimed to evaluate the phenotype of knees in the Indian population based on the CPAK system.

Methods Two cohorts of individuals (250 young healthy volunteers and 250 elderly patients with knee osteoarthritis) underwent radiological assessment with long-leg radiographs and were classified based on the CPAK system. Measurements included the mechanical and arithmetic hip–knee–ankle angles (mHKA, aHKA), joint line obliquity (JLO), lateral distal femoral angle (mLDFA) and medial proximal tibial angle (mMPTA). Knees were grouped into 9 CPAK phenotypes based on aHKA and JLO.

Results A total of 1000 knees were evaluated. In cohort-1 of healthy young adults, most knees were distributed in the CPAK class II phenotype (128 knees, 25.6%) followed by CPAK Type I (106 knees, 21.2%). In cohort-2 of elderly arthritic adults, most knees were distributed in Type I (294 knees, 58.8%) with constitutional varus and apex-distal joint line orientation.

Conclusion The majority of the study population was found to have constitutional varus alignment. In addition, a high proportion of patients in both categories, especially arthritic patients undergoing TKA, were found to have varus alignment with an apex-distal oblique joint line. This classification may help optimize component positioning to restore constitutional alignment and joint line orientation during TKA.

Keywords Total knee arthroplasty · Alignment · Classification · Constitutional varus · Radiology

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Introduction

Alignment strategies during total knee arthroplasty (TKA) have varied significantly across the world based on surgeon preference and philosophy [1]. There has been a long-standing debate on the optimal coronal alignment target in patients undergoing TKA, with mechanical alignment (MA) being the most used alignment strategy. MA has shown excellent long-term survivorship. Mechanical alignment was developed to reduce contact pressures on the polyethylene insert, in an attempt to equalize pressure distribution over the medial and lateral compartments of the knee [2–4]. This alignment strategy was developed only based on biomechanical forces and to improve the longevity of the prosthesis [2, 4–8].

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Mechanical alignment does not consider the patient's native or constitutional alignment, and the alignment target remains the same for all patients operated with such TKA instrumentation. Coronal plane alignment of the knee after TKA was hypothesized to influence patient satisfaction and joint perception after surgery. Bellemans et al. [9] introduced the concept of "constitutional varus", referring to the native varus alignment of the knee observed in non-arthritic and arthritic populations. It is reported that restoring constitutional varus reduces the requirement of soft-tissue releases and improves quantitative balance after TKA [10].

Kinematic alignment (KA), inverse kinematic alignment (iKA) and restricted kinematic alignment (rKA) belong to the other school of alignment strategies in which the three femoral kinematic axes are restored during TKA, with restoration of the native joint line and kinematics [1, 8, 10–12]. However, there has always been some concern about the degree of coronal alignment of components which are acceptable and debate regarding the long-term survival.

MacDessi et al. published the coronal plane alignment of the knee (CPAK) classification to improve the nomenclature of coronal deformity of the knee [13]. This classification quantifies and defines the coronal alignment combined with the joint line obliquity (JLO). The JLO can vary significantly irrespective of the coronal deformity (neutral, varus or valgus hip–knee–ankle (HKA) angle-based definitions). This combined classification proposed nine phenotypical variations of knee alignment and JLO. Understanding the phenotype is important, as with the advent of robotic-assisted TKA, it is now possible to offer "Personalized arthroplasty" to patients to restore the joint line, joint line obliquity and constitutional varus or valgus.

There have only been a few reports of the CPAK phenotype distribution in Asian populations [14, 15]. There is no report on CPAK classification and characterization of coronal alignment in the Indian population. This study aimed to evaluate the CPAK distribution of healthy and arthritic Indian knees and compare the findings with published reports from the European or Japanese populations.

Methods

This study was a prospective cross-sectional observational study conducted between January 2022 and June 2022, at a single high-volume arthroplasty centre, with an evaluation of coronal plane alignment (based on the CPAK classification) in two cohorts of patients. Cohort-1 included 250 young, healthy non-arthritic adult volunteers, between the ages of 20 and 35 years. Cohort-2 included 250 consecutive elderly patients with osteoarthritis of the knee, who presented with bilateral knee pain to the outpatient department. Radiological evaluation was done for both knees in the study population which was recruited by convenience sampling from both healthy subjects and patients presenting with bilateral knee pain in the outpatient department (500 subjects, 1000 knees). This study was approved by the Institutional Ethics Committee (SIEC/2022/477).

Eligibility for imaging in cohort-1 included—healthy young adult volunteers without previous history of knee trauma, no previous history of knee surgeries, no history of developmental conditions affecting the lower extremities or metabolic bone disease treated in childhood or history suggestive of poly-arthralgia or inflammatory arthritis. Eligibility for imaging in cohort-2 included adult patients who presented to our outpatient department with complaints of bilateral knee pain, with radiological evidence of advanced osteoarthritis of the knees (Kellgren–Lawrence Grade 3 and 4 arthritis) [16, 17]. A total of 250 consecutive patients were analysed, irrespective of the type of deformity (varus or valgus). Known cases of inflammatory arthropathy, previous knee surgeries like high-tibial osteotomy (HTO) and post-traumatic arthritis of the knee were excluded from the imaging protocol.

Radiological Assessment

All patients underwent digital full-length or long-leg scanograms based on an established protocol by Paley [18]. Radiological parameters were measured on the DICOM (Digital Imaging and Communications in Medicine) images using validated software (SurgiMap, Nemaris, NY, USA). Measurements of radiological parameters were made in both groups by two observers, and further evaluation to rule out intra- and inter-observer variability. Patients were positioned in front of the long-leg scanogram frame or Bucky with bipedal stance and asked to stand with the patellae facing forwards. The radiographs were obtained using three 17″ × 17″ digital cassettes and exposure with a fixed 80 kV and 15 mA source. The distance between the X-ray source and scanogram frame was set to 180 cm. Radio-opaque markers are placed directly on the scanogram frame, to align sequential X-rays. All 3 X-rays were stitched using the Truview-ART software (BPL Medical Technologies). The measurements taken are as follows:

(1) Coronal alignment of the lower limb based on measurement of the mechanical hip–knee–angle (mHKA) is the angle between the mechanical axes of the femur and tibia (Fig. 1).
(2) The mechanical lateral distal femoral angle (LDFA) is the lateral angle between the mechanical axis of the femur and the distal femoral joint line tangent (Fig. 2).
(3) The mechanical medial proximal tibial angle (MPTA) is the medial angle between the mechanical axis of the tibia and the proximal tibial joint line tangent (Fig. 3).

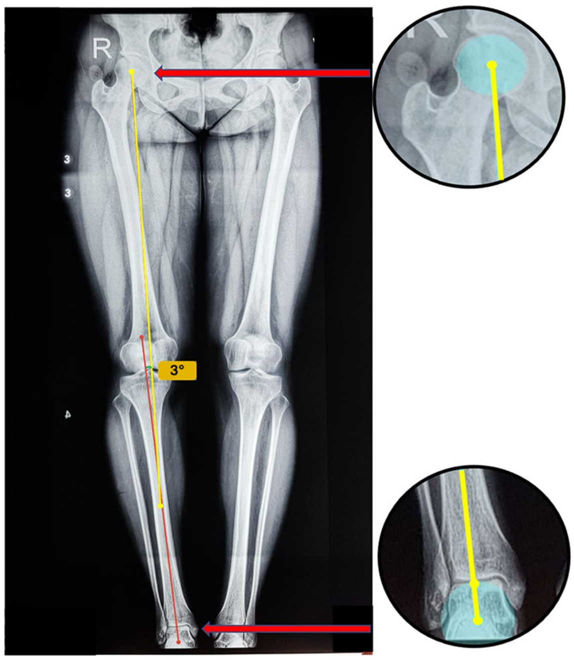

Fig. 1 Full-length or long-leg digital scanogram with the femoral mechanical axis (yellow line) and tibial mechanical axis (red line) marked, with the HKA angle measurement; the femoral head centre is marked using the concentric circle method and the centre of the ankle is the mid-point of the talar dome width

Fig. 2 Measurement of the lateral distal femoral angle (mLDFA) on the long-leg films; this is the angle between the femoral mechanical axis and the joint line

A schematic diagram of radiological measurements of LDFA and MPTA is illustrated in Fig. 4.

The mechanical axis of the femur is marked from the centre of the femoral head to the centre of the knee. The centre of the head is marked using the concentric-circle method to identify the centre. The centre of the ankle is marked as the point on the talar dome at mid-width. As proposed in the reference study, the constitutional varus of the patient is calculated based on the "*arithmetic HKA angle measurement (aHKA)"*. This parameter is calculated based on the following formula: $aHKA = MPTA - LDFA$. This formula has been validated in previous reports. A negative aHKA indicates varus and a positive aHKA indicates valgus alignment. aHKA is a measurement unaffected by joint space narrowing, and tibiofemoral subluxation and is valid to assess coronal plane alignment in healthy and arthritic subjects [9, 13].

Assessment of joint line obliquity (JLO) is calculated by the formula: $JLO = MPTA + LDFA$ [13]. The obliquity is measured based on relation to the horizontal or floor, with the patient in a stable double-leg stance. If JLO = 180 degrees, the joint line is neutral or parallel to the ground. If the JLO > 180 degrees, this is an apex-proximal joint line; if the JLO < 180 degrees, the JLO is defined as apex distal.

With aHKA and JLO measured, patients can be matched to 9 possible CPAK alignment groups (Fig. 5). The mean aHKA and JLO of the two cohorts were rounded to the nearest whole number for final allocation to a CPAK Class. CPAK limits for the definition of neutral knees was an aHKA of 0 ± 2 degrees. Varus aHKA less than − 2 degrees and a valgus aHKA more than + 2 degrees. An apex distal JLO is less than 177°, while an apex proximal JLO is greater than 183°.

Statistical Analysis

Data normality was assessed with the Shapiro–Wilk test. Continuous variables are presented as means with standard deviations and were compared using the independent samples t test. Scatter-plot data visualization was used to represent the proportions of knees classified according to the CPAK classification. The measurements' reliability was validated by calculating the Pearson correlation to evaluate intra-observer and inter-observer correlation coefficients in an initial group of patients. In addition, inter-observer

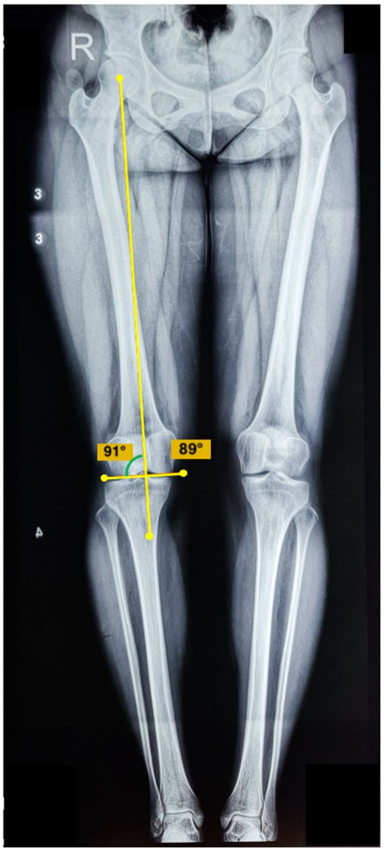

Fig. 3 Measurement of the medial proximal tibial angle (mMPTA) is the medial angle between mechanical axis of the tibia and the proximal tibial joint line tangent

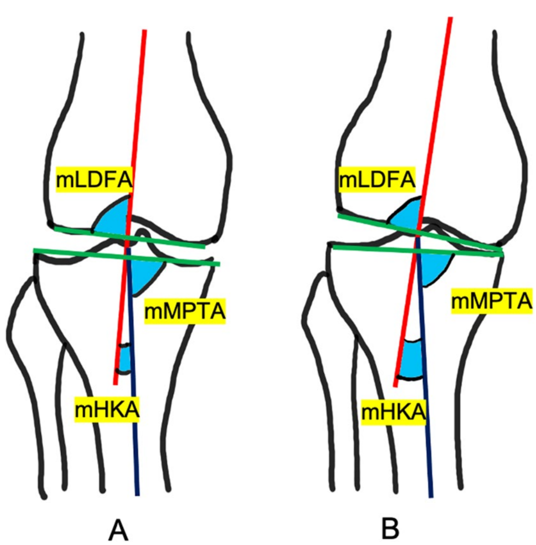

Fig. 4 **a** Schematic representation of the measurement of lateral distal femoral angle (LDFA), medial proximal tibial angle (MPTA), and mechanical hip–knee–ankle angle (mHKA) in a knee with preserved joint space and mild constitutional varus alignment. **b** The same knee following degenerative loss of medial joint space, showing a change in mHKA

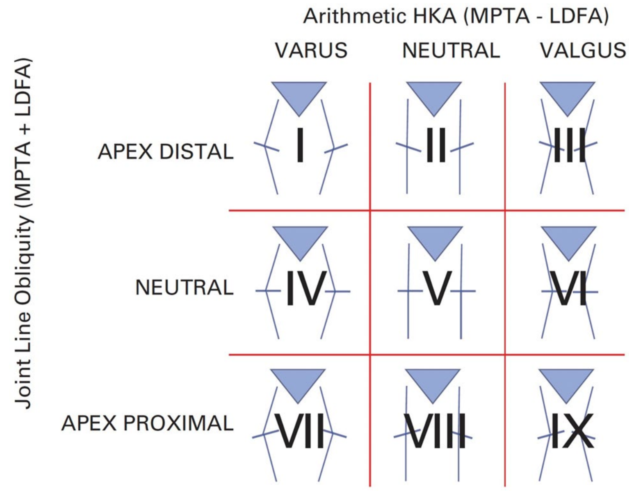

Fig. 5 Schematic representation of the knee phenotypes based on the CPAK classification system, based on the joint line obliquity and aHKA measurements. Image reproduced from original work with permission from Dr. Samuel MacDessi [13]

measurement reliability was assessed for the entire study group. Data compilation was done using Excel (2016, Microsoft, USA) and data analysis was done using SPSS Ver.22 (Armonk, NY, USA).

The sample size was calculated based on previously published studies in which the estimated medial proximal tibial angle measurement (MPTA = 87° ± 3°) for a required level of statistical significance of 0.05, and a power of 0.9, a minimum of 48 lower limb radiology pairs (96 knees) would be required in each group to detect > 2° differences in measurements [19–21]. With a mean MPTA difference of 3.79 and standard deviation of 3.1 (based on the first 30 radiology pairs evaluated in this study), 91 patients are required in each group (young healthy adults and arthritic group) for 0.9 power at 5% significance. This study is sufficiently powered.

Results

The baseline characteristics of the study population are summarized in Table 1. There were a total of 250 subjects in each group (500 knees). The mean age of cohort-1 (young healthy population) was 26.7 years (SD = 4.51) and of cohort-2 (arthritic population) was 62.2 years (SD = 8.19).

The mean arithmetic HKA (aHKA) of the healthy subjects was -1.74 degrees (SD = 3.52) indicating a variation of native alignment between neutral (0 ± 2 degrees) and constitutional varus (aHKA < – 2 degrees). The mean aHKA of the arthritic cohort was – 6.85 degrees (SD = 4.95), indicating a varus alignment profile in the majority of the patients studied.

Table 1 Baseline demographic characteristics of study population;

Parameter	Normal group ($n=250$; total = 500 knees)	Osteoarthritic group ($n=250$; total = 500 knees)	*P* value
Mean age in years (SD)	26.77 (4.51)	62.25 (8.19)	< 0.001*
Gender			
Male	109 (43.6%)	76 (30.4%)	< 0.001**
Female	141 (56.4%)	174 (69.6%)	
Mean height in cm (SD)	163.73 (9.14)	160.47 (7.13)	< 0.001*
Mean weight in Kg (SD)	69.49 (14.48)	72.64 (10.46)	0.001*
Mean BMI (SD)	25.77 (4.77)	28.24 (4.04)	< 0.001*
Mean aHKA in degrees (SD)	−1.746 (3.52)	−6.852 (4.95)	< 0.001*
Mean JLO in degrees (SD)	176.02 (4.49)	173.552 (4.96)	< 0.001*
mLDFA	88.88 (2.95)	90.20 (3.56)	< 0.001*
mMPTA	87.14 (2.76)	83.35 (3.44)	< 0.001*

cm centimetres, *BMI* body mass index, *SD* standard deviation, *aHKA* arithmetic hip–knee–ankle angle, *JLO* joint line obliquity, *Kg* kilogram, mMPTA mechanical medial proximal tibial angle, mLDFA mechanical lateral distal femoral angle.

*Independent *t* test, **Chi-square test

The joint line obliquity (JLO) was similar in both cohorts. However, the mean JLO of cohort-1 was 176 degrees (SD = 4.49) and of cohort-2 was 173.5 degrees (SD = 4.96), indicating that the joint line apex is distal in the overall study population.

CPAK Classification of the Study Population

The CPAK classification system limits and interpretation are summarized in Table 2. Based on the limits defined by the CPAK classification, the study population was grouped into the nine possible phenotypes.

In cohort-1 of healthy young adults, most knees were distributed in the CPAK class II phenotype (128 knees, 25.6%) followed by CPAK Type I (106 knees, 21.2%). The order of distribution based on frequency was—Type II, Type I, Type V (98 knees, 19.6%), Type IV (84 knees, 16.8%), Type III, Type VI, Type VIII and finally Type IX, with the latter groups only having a minority of cases. (Table 3) This indicates that in the young healthy population, most subjects (234 knees, 46.8%) had neutral or varus alignment with an apex-distal joint line (Types I and II). A total of 182 knees (36.4%) had a neutral or varus alignment with a neutral joint line (Types IV and V). The overall distribution of cohort-1 knees based on CPAK classification is depicted in Fig. 6.

In cohort-2 of elderly arthritic adults, most knees were distributed in Type I (294 knees, 58.8%) with a constitutional varus alignment and apex-distal joint line orientation. The findings are summarized in Table 4. The remainder of cases were distributed mainly in Type IV (91 knees, 18.2%) and Type II (69 knees, 13.8%). This indicates that most arthritic knees in the study group had varus constitutional alignment with apex-distal joint lines. The overall distribution of cohort-2 knees based on CPAK classification is depicted in Fig. 7. Comparison of the distribution of constitutional alignment (aHKA) of both cohorts is shown in Fig. 8.

The reliability of measurements was assessed using Pearson correlation. Intra-observer and inter-observer correlation was high in measurements assessed in both groups (LDFA, MPTA) with a coefficient of correlation > 0.9 in all measurements Table 5.

Table 2 Classification of knee phenotypes based on the CPAK classification system

CPAK phenotype class	aHKA (MPTA-LDFA) (in degrees)	JLO (MPTA + LDFA) (in degrees)	Knee phenotype
Type I	Less than − 2	Less than 177	Varus aHKA with apex distal JLO
Type II	0 ± 2	Less than 177	Neutral aHKA with apex distal JLO
Type III	More than 2	Less than 177	Valgus aHKA with apex distal JLO
Type IV	Less than − 2	180 ± 3	Varus aHKA with neutral JLO
Type V	0 ± 2	180 ± 3	Neutral aHKA with neutral JLO
Type VI	More than 2	180 ± 3	Valgus aHKA with neutral JLO
Type VII	Less than − 2	More than 183	Varus aHKA with apex proximal JLO
Type VIII	0 ± 2	More than 183	Neutral aHKA with apex proximal JLO
Type IX	More than 2	More than 183	Valgus aHKA with apex proximal JLO

CPAK Coronal plane alignment of knee, *aHKA* arithmetic hip–knee–ankle angle, *MPTA* medial proximal tibial angle, *LDFA* lateral distal femur angle, *JLO* joint line obliquity

Table 3 Alignment classification of healthy young adult population based on the CPAK classification system

Side	Varus aHKA ($n=202$)		Neutral aHKA ($n=235$)		Valgus aHKA ($n=63$)	
	Right	Left	Right	Left	Right	Left
Number	92	110	117	118	41	22
mHKA	−4.04 (2.71)	−4 (2.76)	−0.71 (1.78)	−0.80 (1.79)	2.70 (1.50)	2.59 (1.70)
mLDFA	90.56 (2.01)	91.02 (2.61)	87.76 (2.33)	87.77 (2.53)	85.58 (2.50)	86.68 (3.07)
mMPTA	85.54 (2.04)	85.82 (2.50)	87.21 (2.17)	88.06 (2.37)	89.65 (2.91)	90.31 (2.98)
aHKA	−5.02 (1.75)	−5.2 (2.34)	−0.54 (1.29)	−0.18 (1.33)	4.07 (1.60)	3.63 (1.21)
JLO	176.10 (3.66)	176.85 (4.54)	175.24 (5.19)	176.32 (4.51)	175.24 (5.19)	177 (5.93)
CPAK phenotype assessment						
CPAK 1						106 (21.2%)
CPAK 2						128 (25.6%)
CPAK 3						30 (6%)
CPAK 4						84 (16.8%)
CPAK 5						98 (19.6%)
CPAK 6						29 (5.8%)
CPAK 7						12 (2.4%)
CPAK 8						9 (1.8%)
CPAK 9						4 (0.8%)

mLDFA mechanical lateral distal femoral angle, *mMPTA* mechanical medial proximal tibial angle, *aHKA* arithmetic HKA

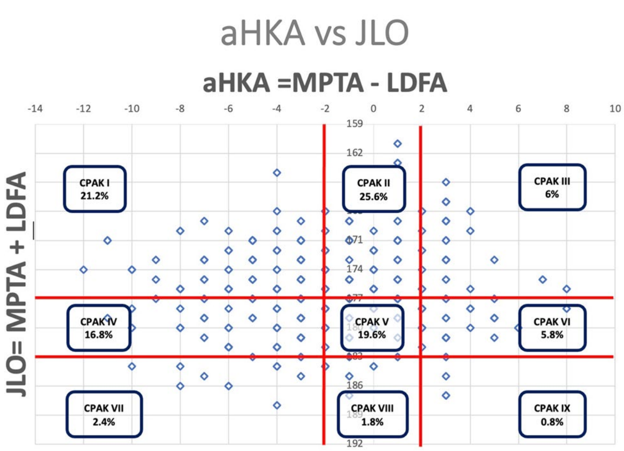

Fig. 6 CPAK phenotype distribution of healthy young adults with a high proportion of individuals in Types II and I

Discussion

This study evaluated the knee phenotype of healthy and arthritic Indian subjects based on the coronal alignment of the knee (CPAK) classification system. The analysis established that young non-arthritic and elderly arthritic Indian subjects are likely to have a neutral or varus constitutional alignment. The arthritic population showed a high prevalence of Type I CPAK phenotype, with varus constitutional alignment with an apex-distal joint line obliquity (JLO).

To our knowledge, only two studies evaluated constitutional coronal plane alignment with the CPAK classification. MacDessi et al. first reported the classification system based on two study populations, one Australian and the other European [13]. Toyooka et al. assessed arthritic knee phenotypes in the Japanese population [15]. The findings of our study showed similar CPAK phenotype distribution compared to the Japanese arthritic population and were very different from the European/Australian study findings. The comparison of radiological parameters and CPAK knee phenotypes in our study are compared to other ethnicities and summarized in Table 6.

Most arthritic patients in the Japanese population (53.8%) were type I (varus aHKA and apex distal JLO). In the report on the European-Australian population, Type I accounted for only 19.4%, whereas this type accounted for a much larger percentage in the Japanese study. Most Indian arthritic patients also presented with Type I knee phenotype (294 knees, 58.8%) with a constitutional varus alignment and apex-distal joint line orientation. This was similar to the CPAK alignment distribution of the Japanese population. Another study of the Korean population also revealed a high proportion of constitutional varus [22].

In the original description of the CPAK classification [13] (study based on European and Australian populations), the most common knee phenotypes were Type II (neutral alignment based on aHKA and an apex distal joint line), with 39.2% in a healthy population and 32.2% in the arthritic population. This was followed by patients mainly in Type

Table 4 Alignment classification of arthritic adult population based on the CPAK classification system

Side	Varus ($n=400$)		Neutral ($n=88$)		Valgus ($n=12$)	
	Right	Left	Right	Left	Right	Left
Number	196	204	48	40	6	6
mHKA	−11.92 (4.60)	−12.55 (4.71)	−2.37 (4.26)	−5.12 (5.18)	8.66 (6.74)	8.83 (5.34)
aHKA	−8.41(3.70)	−8.80 (3.72)	−0.22 (1.30)	−0.8 (1.15)	6 (3.16)	4.5(1.22)
JLO	172.74 (4.68)	174.45 (4.92)	172.81 (4.94)	174.05 (4.54)	167 (8)	178.5 (4.18)
mLDFA	90.58 (2.89)	91.62 (3.19)	86.52 (2.55)	93 (0)	80.5 (3.39)	87 (2.52)
mMPTA	82.16 (3.07)	82.82 (2.97)	86.29 (2.55)	86.62 (2.36)	86.5 (5.04)	91.5 (1.76)
CPAK Classification-based phenotypes						
CPAK 1						294 (58.8%)
CPAK 2						69 (13.8%)
CPAK 3						7 (1.4%)
CPAK 4						91 (18.2%)
CPAK 5						17 (3.4%)
CPAK 6						5 (1%)
CPAK 7						14 (2.8%)
CPAK 8						3 (0.6%)
CPAK 9						0 (0%)

mLDFA mechanical lateral distal femoral angle, *mMPTA* mechanical medial proximal tibial angle, *aHKA* arithmetic HKA

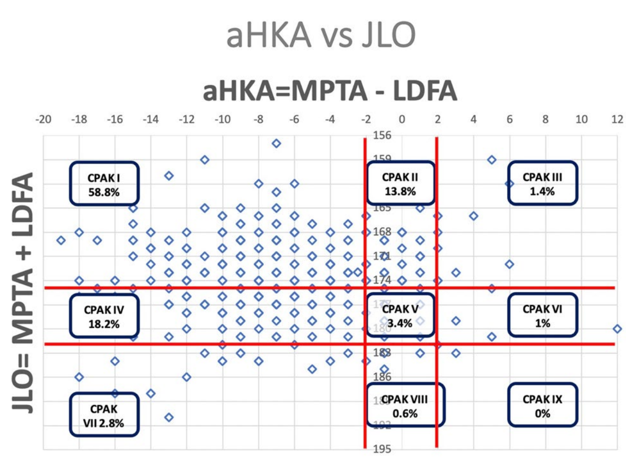

Fig. 7 CPAK phenotype distribution of elderly arthritic adults with a high proportion of individuals in Type I phenotype

I or Type V. MacDessi et al. evaluated differences in joint balancing between mechanical alignment (MA) versus restricted kinematic alignment (rKA) which restored native LDFA, MPTA, aHKA and JLO in patients undergoing navigated TKA. They reported a higher proportion of optimal knee balance (based on sensor technology) with patient-specific rKA alignment compared to MA.

It is interesting to note that young healthy adults in our study had either neutral or varus constitutional alignment. The mean arithmetic HKA (aHKA) of the healthy subjects was – 1.74 degrees (SD = 3.52), with a majority of patients with a varus constitutional alignment (Fig. 5). However, a large majority of patients in the arthritic group were classified under Type I, with varus constitutional alignment. Arithmetic and mechanical HKA measurements may change with time and as age progresses tending towards an increasing varus alignment. Long-term follow-up of the healthy subjects is required to understand age-related changes in lower limb alignment and the influence of severity of arthritis on the changes in radiological parameters assessed in this study.

Nayak et al. [23] studied the alignment variations in 966 Indian patients based on the grade of osteoarthritis. This study evaluated the mechanical HKA measurement, with 65.8% of patients with varus deformity (HKA < 177 degrees). They also evaluated the association between condylar plateau angle and grade of osteoarthritis, femoral and tibial bowing in the study population.

Bellemans et al. introduced the concept of constitutional varus in their study population in which they reported a high 49.2% constitutional varus with aHKA less than or equal to – 3 degrees [9]. Of the total 500 normal knees in our study, 202 (40.4%) had varus constitutional alignment, with minor variations in joint line obliquity. In the arthritic cohort, 400 (80%) patients had a varus alignment, with sub-classification in the CPAK system based only on the joint line obliquity.

Mechanical alignment target of neutral alignment (the target is 0 degrees HKA, with an accepted variation of ± 3

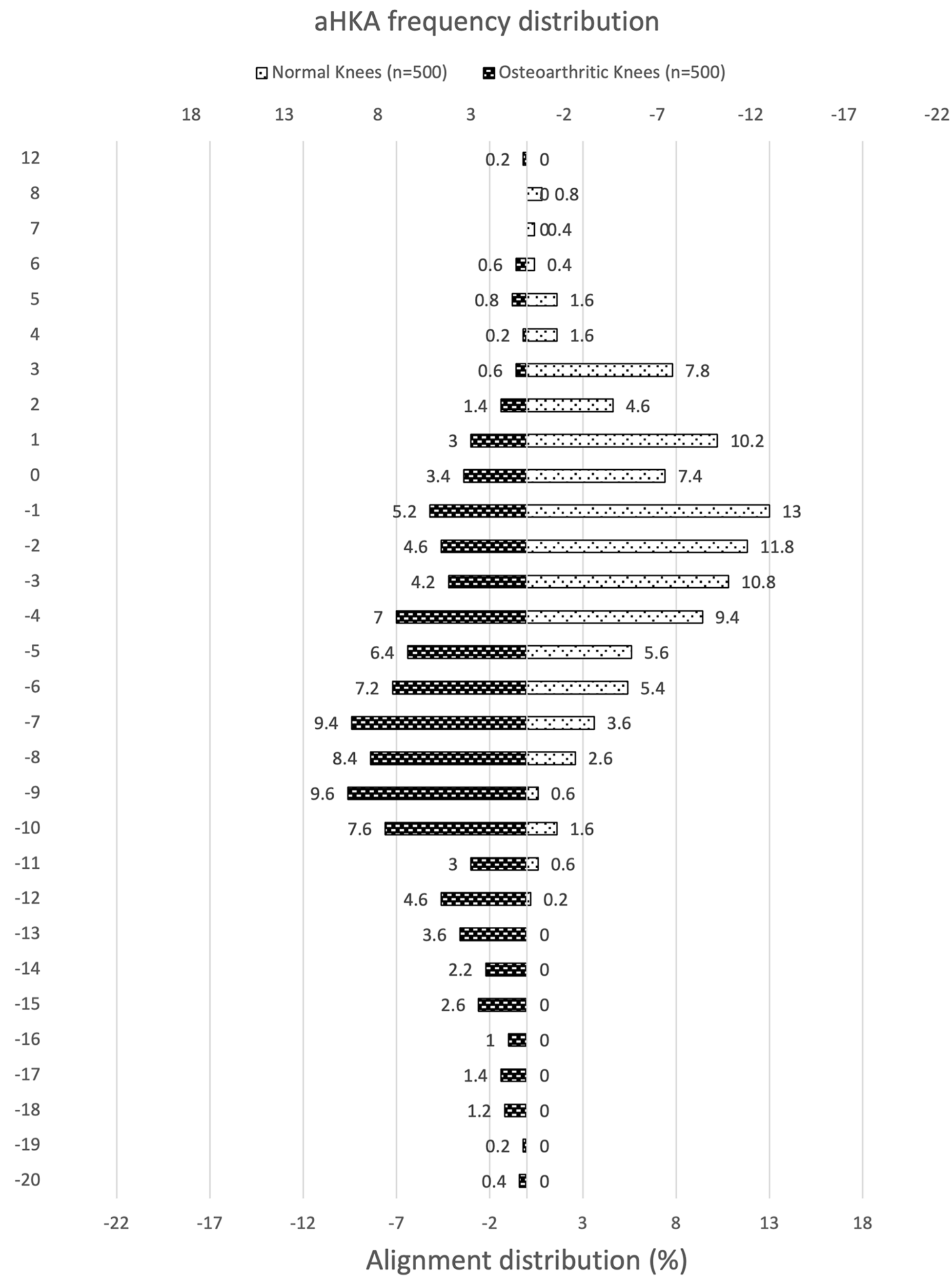

Fig. 8 Comparison of constitutional coronal alignment distribution of healthy and arthritic cohorts

degrees). With MA, the joint line is planned parallel to the ground in all cases. Mechanical alignment or neutral alignment was considered essential for long-term survivorship of the TKA prosthesis, with optimal joint forces across the medial and lateral joint compartments. Several studies have been published where this neutral alignment has been shown to have excellent survivorship [4–8, 24].

However, there are long-term studies on the excellent survivorship of kinematic alignment which restores the patients' native joint line and alignment to a greater extent. There was concern about the degree of varus applied and the subsequent medial compartment overload, with the potential or theoretical risk of early failure. Long-term studies have shown this is not the case [25, 26].

The adoption of robotic technology and navigation in total knee arthroplasty is increasing worldwide. The accuracy of robotics allows surgeons to use any alignment strategy with accurate positioning of components. Functional alignment refers to an adjusted mechanical alignment strategy specifically executed using robotics [27]. With functional alignment, femoral and tibial components can be positioned in varus or valgus, with strict limits (overall coronal alignment up to 5 degrees maximum) to quantitatively balance the knee.

Table 5 Intra-rater and inter-rater variability assessment with Pearson correlation

	Intra-class correlation coefficient	
	Intra-observer	Inter-observer
Cohort-1: Healthy		
mLDFA	0.934 (< 0.001)	0.928 (< 0.001)
mMPTA	0.969 (< 0.001)	0.951 (< 0.001)
Cohort-2: Arthritic		
mLDFA	0.978 (< 0.001)	0.966 (< 0.001)
mMPTA	0.970 (< 0.001)	0.961 (< 0.001)

Two-way random effects, single rater-measurement, absolute agreement

ICC Intra-class co-relation coefficient, *mLDFA* mechanical lateral distal femur angle, *mMPTA* mechanical medial proximal tibial angle

With the advent of technology, it is now possible to evaluate the knee phenotype of patients in the pre-operative evaluation phase, to understand radiological parameters contributing to the deformity. As discussed, the aHKA is independent of the arthritic wear and should be differentiated from the mHKA which is the static deformity at the time of TKA. Understanding the knee phenotype may aid surgeons in using robotics or navigation in restoring the native constitutional coronal alignment and joint line obliquity. Kinematic alignment and its variations—the restricted kinematic alignment (rKA) and inverse kinematic alignment (iKA)—seek to restore native constitutional varus and native kinematics. This has been studied in European patients, with iKA alignment strategy demonstrating improved satisfaction and outcomes compared to mechanical alignment. In a study by de Grave et al. [28], knees with preoperative varus deformity, achieved significantly ($p = 0.025$) better OKS using iKA (45.4 ± 2.0) compared to adjusted mechanical alignment (41.4 ± 6.8). Further studies will be needed to evaluate the influence of "personalized alignment" in arthroplasty on clinical outcomes and patient satisfaction after TKA [11].

One of the limitations of our study is the protocol for obtaining standing films. Although we followed strict protocol [18] to obtain the ideal anteroposterior view, there may be some rotational error. Our study used the validated methodology and had excellent intra-class correlation with high inter- and intra-observer reliability. Although computed tomography may be suggested as an alternative, this is associated with a significantly higher radiation dose, and can only be performed with the patient in the supine position. Studies have shown the variation of lower limb alignment

Table 6 Comparison of radiological measurements and CPAK knee phenotypes of this study population with previously published literature of other ethnicities

	MacDessi et al. (Europe + Australia)		Toyooka et al. (Japan)	C.E. Hsu et al. (Taiwan)	This study	
	$N = 500$ Knees Healthy subjects	$N = 500$ Arthritic group	$N = 500$ Knees Arthritic population	$N = 214$ Healthy subjects	Normal group ($n = 250$; total = 500 knees)	Osteoarthritic group ($n = 250$; total = 500 knees)
Mean age in years (SD)	(Range 20–27)	66 (44–88)	75.1 (8.0)	41.3 (18.6)	26.77 (4.51)	62.25 (8.19)
Gender						
Male	125 (50%)	190 (38%)	95 (19%)	111 (52%)	109 (43.6%)	76 (30.4%)
Female	125 (50%)	310 (62%)	405 (81%)	103 (48%)	141 (56.4%)	174 (69.6%)
Mean aHKA in degrees (SD)	−0.9 (2.5)	−0.8 (2.8)	−3.5 (4.8)	−1.5 (3.2)	−1.74 (3.52)	−6.85 (4.95)
Mean JLO in degrees (SD)	NA	NA	172.4 (3.8)	173.1 (3.3)	176.02 (4.49)	173.5 (4.96)
mLDFA	87.9 (1.74)	88.1 (2.1)	88.0 (2.9)	87.3 (2.4)	88.88 (2.95)	90.2 (3.56)
mMPTA	87.0 (2.07)	87.3 (2.1)	84.4 (3.3)	85.8 (2.2)	87.14 (2.76)	83.3 (3.44)
Type I	26.4%	19.4%	53.8%	36.4%	21.2%	58.8%
Type II	39.2%	32.2%	25.4%	39.3%	25.6%	13.8%
Type III	9.8%	15.4%	8.2%	13.6%	6%	1.4%
Type IV	5.4%	9.8%	7.2%	5.6%	16.8%	18.2%
Type V	15.4%	14.6%	4.4%	4.7%	19.6%	3.4%
Type VI	3.4%	7.4%	1.0%	0.5%	5.8%	1%
Type VII	0.2%	0.6%	0	0	2.4%	2.8%
Type VIII	0	1.6%	0	0	1.8%	0.6%
Type IX	0.2%	0.4%	0	0	0.8%	0

with postural changes with increased varus angle during weight bearing [29]. Therefore, a weight-bearing full-length film with HKA assessment is the ideal way to assess alignment before total knee arthroplasty [30].

Conclusion

The study population, including young healthy or elderly arthritic individuals, was found to have constitutional varus alignment. A high proportion of patients in both categories, especially arthritic patients undergoing TKA, were found to have varus alignment with an apex-distal oblique joint line. Understanding the phenotype of knee deformity may help optimize component positioning to restore constitutional alignment and joint line orientation in patients undergoing TKA.

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Declarations

Conflict of interest The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Authors do not have any financial conflicts or disclosures concerning this research work.

Institutional ethical committee approval This research was approved by the Institute Ethics Committee (SIEC/2022/477).

Informed consent For this type of study informed consent is not required.

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