Cross-sectional Study

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Distribution of coronal plane alignment of the knee classification in Chinese osteoarthritic and healthy population: a retrospective cross-sectional observational study

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Background: Few studies have reported the coronal constitutional alignment of the lower limbs in mainland China. This study aimed to analyse the distribution of the coronal plane alignment of the knee (CPAK) classification in the osteoarthritic (OA) and healthy Chinese populations.

Materials and methods: The CPAK distributions of 246 patients (477 knees) with OA and 107 healthy individuals (214 knees) were retrospectively examined using long-leg radiographs. Radiological measurements and CPAK classification of different Kellgren–Lawrence grades in patients with unilateral total knee arthroplasty (TKA) were compared. The clinical outcomes of patients with CPAK type I who underwent mechanical alignment or restricted kinematic alignment during TKA were examined.

Results: The most common distributions in the OA and healthy groups were type I and type II, respectively. In patients who underwent unilateral TKA, the most common distribution of knees graded as Kellgren–Lawrence 3–4 was type I. However, the most common distributions of contralateral knees graded as Grade 0–2 were type I and II. For patients with CPAK type I, the mechanical alignment and restricted kinematic alignment groups did not differ significantly concerning postoperative clinical outcomes at 3 months.

Conclusion: The most common distributions in Chinese osteoarthritic and healthy populations were types I and II, respectively. In addition, OA progression may lead to changes in the CPAK classification.

Keywords: Constitutional alignment, coronal plane alignment of the knee, kinematic alignment, osteoarthritis, total knee arthroplasty

Introduction

The restoration of neutral coronal mechanical alignment (MA) is considered the cornerstone of successful and durable total knee arthroplasty (TKA). However, when "constitutional varus" knees have been acknowledged, restoring neutral alignment in these cases may, in fact, be abnormal and undesirable and would likely require some degree of medial soft-tissue release[1]. Therefore, restoring the constitutional alignment rather than the neutral alignment in TKA has gained interest among knee surgeons.

HIGHLIGHTS

- The most common coronal plane alignment of the knee classification was type I in Chinese osteoarthritis population, which is varus with the joint line apex distal. In normal individuals, the most common type was type II, which is neutral with the joint line apex distal.
- Osteoarthritis progression may lead to changes in coronal plane alignment of the knee classification.

Kinematic alignment (KA) aims to align the articular surfaces of the femoral and tibial components with the normal or pre-arthritic joint lines of the knee[2]. With the development of navigated or robotic-assisted systems, restricted KA, inversed KA, and functional KA have been derived from KA, compromising the restoring of constitutional alignment and the principle of the “safe zone” in MA philosophy[3]. The premise of applying these personalised alignment philosophies is to recognise the constitutional alignment in an arthritic knee.

The conventional system for classifying coronal alignment only differentiates three types of alignment (neutral, varus, and

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valgus). Lin and colleagues and Hirschmann and colleagues introduced new classification systems for non-osteoarthritic (OA) knees, both based on the mechanical hip-knee-ankle angle (mHKA), as well as the femoral and tibial joint lines[4,5]. Although constitutional varus does not affect the joint line orientation (JLO) in the coronal plane, once an arthritic deformity commences, the lower limb mechanical axis shifts, commonly accentuating the original alignment[6]. MacDessi and colleagues described the coronal plane alignment of the knee (CPAK) classification, which combines the anatomical joint line measures of the lateral distal femoral angle (LDFA) and medial proximal tibial angle (MPTA), resulting in only two critical variables: the arithmetic hip-knee-ankle angle (aHKA; constitutional limb alignment) and JLO. Thus, the CPAK classification simplified the categorisation into nine knee phenotypes. In addition, because CPAK incorporates an aHKA, it can be used for both patients with arthritis and healthy individuals[7]. A recent systematic review suggested that significant variations in the CPAK distribution exist among countries[8]. In contrast to the conclusion that there was a similar frequency distribution between healthy and arthritic groups across all CPAK types, CPAK distributions were significantly different between healthy individuals and patients with OA in India; the most common phenotype in OA knees was type I (58.8%), while this type only accounted for 21.2% of healthy knees[9]. This result is also consistent with the CPAK distribution in the OA population from Japan and healthy individuals from Taiwan[10,11].

However, few studies have investigated the distribution of CPAK in OA and healthy populations in mainland China. In addition, changes from the native phenotype would be drastic if the knee were mechanically aligned for the varus phenotype theoretically[12]. To the best of our knowledge, no study has compared clinical outcomes between applying the MA and rKA philosophy among patients with the most common varus phenotype (CPAK type I).

Therefore, this study aimed to (1) describe the CPAK distributions in both healthy and OA knees in Chinese patients, and (2) compare clinical outcomes between applying rKA and MA philosophy in patients classified as having CPAK type I.

Material and methods

Study groups and design

OA group

Data from consecutive patients with OA and knee pain who underwent primary TKA performed by a single senior surgeon between August 2021 and July 2023 at a single institution were analysed retrospectively. A total of 273 patients underwent long-leg radiography. The following 27 patients were excluded from this study: those who had prior total hip arthroplasty ($n=2$), those with obvious bony deficiency of the femur or tibia ($n=10$), and those with simultaneous knee flexion and leg rotation on radiographs[13,14] ($n=15$). The CPAK distribution in the remaining 246 cases (unilateral, 15; bilateral, 231; total, 477 knees) was examined.

Healthy group

Data of consecutive visitors at the outpatient clinic who underwent long-leg radiography without any sign of cartilage degeneration or medical history of the lower extremity between January 2023 and July 2023 at the same institution were analysed retrospectively. In total, 136 visitors were recruited for this study. The following 29 visitors were excluded from this study: those with extra-articular deformity of the femur or tibia ($n=15$), those with simultaneous flexion of the knee and rotation of the leg on radiographs ($n=13$), and those having a poor-quality image ($n=1$). The CPAK distribution in the remaining 107 patients (214 knees) was examined.

The study protocol (diagram of the study design is in the supplementary file) was approved by the institutional review board of the author's institution, and all patients provided informed consent before undergoing long-leg radiography, in line with the STROCSS criteria[15]. Supplemental Digital Content 1, http://links.lww.com/JS9/B901.

Radiological measurements

All the participants underwent standard digital long-leg radiography (the protocol is provided in the supplementary file, Supplemental Digital Content 2, http://links.lww.com/JS9/B902). The mechanical axis of the femur was marked from the centre of the femoral head to the centre of the knee. The centre of the head was marked using the concentric circular method to identify the centre. The centre of the ankle was marked as the point on the talar dome at mid-width. The mHKA angle is the angle subtended by the mechanical axes of the femur and tibia. The LDFA was defined as the lateral angle between the femoral mechanical axis and the joint line of the distal femur. MPTA was defined as the medial angle formed between the tibial mechanical axis and the joint line of the proximal tibia. Joint line convergence angle (JLCA) was the angle formed between joint orientation lines on opposite sides of the same joint[16]. All measurements were performed by an orthopaedic fellow. A senior author performed a subgroup analysis of 60 knees in the OA group and repeated the analysis at 1-week intervals to assess inter- and intra-observer agreement.

CPAK classification of OA and healthy group

aHKA was calculated using the following formula: aHKA = MPTA - LDFA. The JLO was calculated using the following formula: JLO = MPTA + LDFA. Using aHKA and JLO measurements, patients were matched to nine possible CPAK alignment groups (Figure S1 in the supplementary file, Supplemental Digital Content 2, http://links.lww.com/JS9/B902). The mean aHKA and JLO of the two groups were rounded to the nearest whole number for final allocation to the CPAK class. The CPAK limit for the definition of neutral knees was an aHKA of $0\pm2°$. CPAK boundaries for a neutral JLO were defined as $180\pm3°$, varus aHKA less than -2° and a valgus aHKA more than +2°. The apex distal JLO was less than 177°, whereas the apex proximal JLO was greater than 183°[9]. The OA and healthy groups were categorised according to the CPAK classification, and their distribution was investigated.

Radiological measurements and CPAK classification on different Kellgren–Lawrence Grade in patients with unilateral TKA

In the OA group, patients with grade 3 or 4 Kellgren–Lawrence (K–L) tibiofemoral OA in the arthritic knee undergoing TKA and Grade 0, 1, or 2 OA in the contralateral knee were selected.

A total of 162 patients were included in this study. The distribution of CPAK classification was examined on each side.

Symmetrical distribution in coronal alignment in the healthy group

In the healthy group, left-to-right symmetry was evaluated using MPTA, LDFA, mHKA, and JLCA. Pearson's correlation coefficients (r) were also calculated.

Clinical outcomes of patients undergoing CPAK type I by different coronal alignment strategies during TKA

A total of 90 cases were categorised as CPAK type I among 162 patients who underwent TKA between August 2021 and July 2023. The surgical approach and perioperative treatment followed the protocol published in a previous study[17]. Gap balancing and stepwise release strategies were applied as described in a previous study[18] (the protocol is in the supplementary file, Supplemental Digital Content 2, http://links.lww.com/JS9/B902). For coronal alignment, femoral and tibial cuts were performed to place the implants perpendicular to the mechanical axis of the bone in primary TKA before January 2023, and 56 of the 90 TKA were performed between August 2021 and December 2022. From January 2023, a new seven-axis robot-assisted system (Jianjia, Hangzhou Jianjia Robot Co., Ltd.)[19,20] was applied in primary TKA, and the remaining 34 TKA used the robot-assisted rKA philosophy (protocol is in the supplementary file, Supplemental Digital Content 2, http://links.lww.com/JS9/B902) between January and July 2023. Preoperative planning for K–L 3–4 arthritic knee was based on the CPAK classification of the contralateral knee. All procedures used the Vanguard fixed posterior-stabilised knee system (Zimmer Biomet) without patellar replacement. The 34 cases who used the rKA technique were defined as the rKA group. The other 56 ones were included as candidates for an age-matched (± 5 years) and sex-matched MA control group. The preoperative Oxford knee score (OKS), intraoperative stepwise release strategy, and postoperative OKS at three months were compared between the rKA and MA groups.

Statistical analysis

Scatterplots for each population were created to demonstrate the alignment distributions according to the CPAK classification for the OA and healthy groups. Normality of data distribution was assessed for continuous variables using the Shapiro–Wilk test. The reliability of the measurements was validated by calculating intraclass correlation coefficients to assess inter- and intra-observer agreement using a two-way mixed-effects model with absolute agreement. Paired sample *t*-tests were used to analyse paired normally distributed data. Independent-sample *t*-tests were used to compare differences between non-paired normally distributed data. The Pearson χ^2 test was used to compare the observed frequencies of categorical data. Two-tailed values of P less than 0.01 were considered statistically significant. All statistical analyses were performed using SPSS version 19 (IBM Corporation).

Results

Interobserver and intraobserver agreement for measurements

Intraobserver agreement between measures 1 week apart was high, with an intraclass correlation coefficient greater than 0.9 for both observers. Similarly, interobserver agreement at both weeks one and two was high, with an intraclass correlation coefficient greater than 0.9 (Table 1).

Radiological measurements and CPAK classification in OA and healthy groups

Age, sex, radiological measurements, and CPAK classifications of the two groups are shown in Table 2. Type I was the most common type in the OA group (Fig. 1). Type II was the most common type in the healthy group (Fig. 2).

Comparison of radiological measurements and CPAK classification between different K–L Grades

Radiological measurements and CPAK classifications of the different K–L Grades are shown in Table 3. The mHKA, MPTA, and aHKA of knees graded as K–L 3–4 were significantly smaller than those of K–L 0–2. However, LDFA and JLCA were significantly higher than those of K–L 0–2. The distribution of the CPAK classification was statistically different between the different K–L Grades. The most common distribution of knees graded as K–L 3–4 was type I knees (Fig. 3). The most common distribution of knees graded as K–L 0–2 were type I and II (Fig. 4).

Comparisons and correlations of radiological measurements between left and right limb in the healthy group

Except for the LDFA and aHKA, no statistically significant difference was observed between the angle measurements of the left and right limbs, and the differences in both the mean and standard deviation values were less than 1°. Correlation analyses revealed moderate-to-high correlations between the measurements, ranging from r = 0.718 (JLCA) to r = 0.861 (MPTA). The distribution of the

Table 1

Intra-rater and inter-rater variability assessment[a]

	Intraclass correlation coefficient			
	Intraobserver		Interobserver	
	Observer 1	Observer 2	Week 1	Week 2
mHKA	0.996 $P<0.001$ 95% CI (0.993–0.998)	0.996 $P<0.001$ 95% CI (0.994–0.998)	0.997 $P<0.001$ 95% CI (0.995–0.998)	0.997 $P<0.001$ 95% CI (0.995–0.998)
MPTA	0.946 $P<0.001$ 95% CI (0.896–0.97)	0.947 $P<0.001$ 95% CI (0.911–0.968)	0.972 $P<0.001$ 95% CI (0.953–0.983)	0.972 $P<0.001$ 95% CI (0.953–0.983)
LDFA	0.962 $P<0.001$ 95% CI (0.938–0.977)	0.969 $P<0.001$ 95% CI (0.948–0.981)	0.963 $P<0.001$ 95% CI (0.938–0.977)	0.967 $P<0.001$ 95% CI (0.937–0.982)
JLCA	0.925 $P<0.001$ 95% CI (0.838–0.961)	0.902 $P<0.001$ 95% CI (0.841–0.941)	0.943 $P<0.001$ 95% CI (0.907–0.966)	0.963 $P<0.001$ 95% CI (0.937–0.978)

JLCA, joint line convergence angle; LDFA, lateral distal femur angle; mHKA, mechanical hip-knee-ankle; MPTA, medial proximal tibial angle.
[a]Two-way mixed-effects model with absolute agreement.

Table 2

Comparison of baseline demographic characteristics, radiological measurements and CPAK classification between OA and healthy group.

Parameter	OA group (477 knees)	Healthy group (214 knees)
Mean age in years (SD)	65.3 (7.3)	48.8 (14.4)
Sex		
Male	65	41
Female	181	66
Mean mHKA angle in degrees (SD)	173.6 (6.7)	177.7 (3.6)
Mean MPTA in degrees (SD)	85.0 (3.8)	86.3 (2.7)
Mean LDFA in degrees (SD)	88.6 (3.6)	86.2 (2.4)
Mean JLCA in degrees (SD)	3.0 (2.4)	2.4 (1.5)
Mean aHKA angle in degrees (SD)	– 3.6 (5.8)	0.2 (3.7)
Mean JLO angle in degrees (SD)	173.6 (4.6)	172.5 (3.6)
Distribution of CPAK classification (%)		
Type I	43.6	22.9
Type II	21.6	44.9
Type III	10.5	23.8
Type IV	11.5	1.4
Type V	7.5	5.6
Type VI	3.8	1.4
Type VII	1.1	0
Type VIII	0	0
Type IX	0.4	0

aHKA, arithmetic hip-knee-ankle; CPAK, coronal plane alignment of the knee; JLCA, joint line convergence angle; JLO, joint line obliquity; LDFA, lateral distal femoral angle; mHKA, mechanical hip-knee-ankle; MPTA, medial proximal tibial angle; OA, osteoarthritis.

CPAK classification between the left and right limbs was not significantly different (Table 4).

Comparison of baseline characteristics, preoperative radiological measurements, intraoperative stepwise release strategy, and postoperative clinical outcomes of patients undergoing CPAK type I between rKA and MA group during TKA

The baseline characteristics, preoperative radiological measurements, intraoperative stepwise release strategy, and postoperative OKS at three months in patients classified as type I between the rKA and MA groups are shown in Table 5. Baseline characteristics and preoperative radiological measurements were comparable between the two groups. In the rKA group, 12 TKA with contralateral knees classified as type I, 12 TKA with contralateral knees classified as type II, one TKA with contralateral knees classified as type IV, and four TKA with contralateral knees classified as type V were performed according to the same CPAK-type alignment. Three TKA with contralateral knees classified as type III were performed for the CPAK type II alignment, one TKA with a contralateral knee classified as type VI, and one TKA with a contralateral knee classified as type IX were performed for the CPAK type V alignment. Compared with that in the MA group, the rKA group tended to consist of fewer patients who required stripping off the capsule from the posteromedial distal femur and release of the medial collateral ligament, but the difference was not statistically significant. The two groups did not differ significantly concerning the postoperative clinical outcomes at three months.

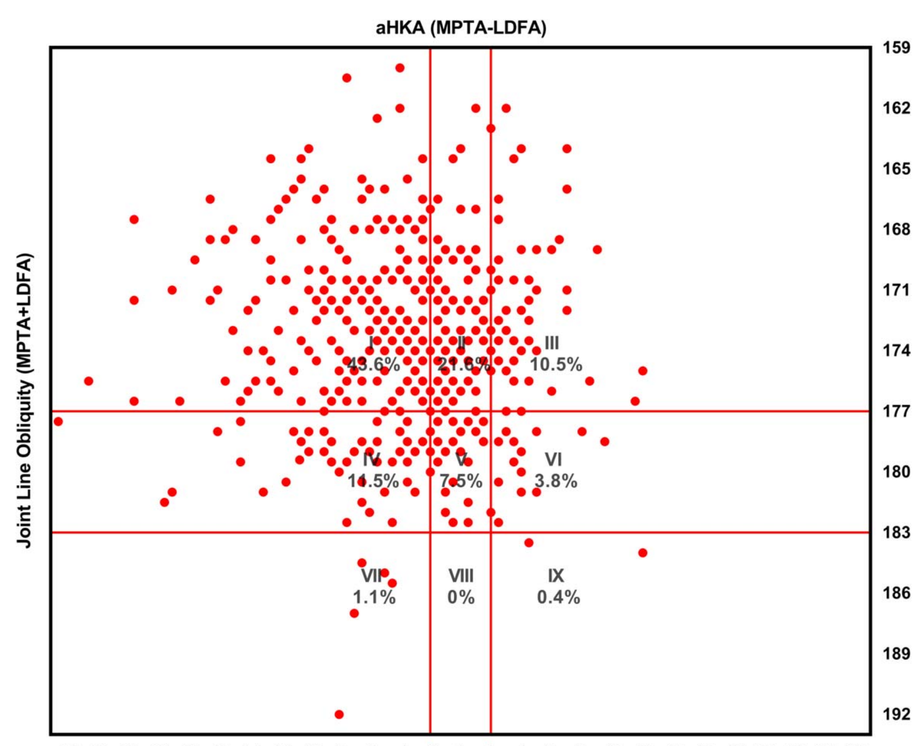

Figure 1. Plot of arithmetic hip-knee-ankle angle (aHKA) against joint line obliquity for an arthritic population, showing the distribution by percentage in the nine coronal plane alignments of the knee types. LDFA, lateral distal femoral angle; MPTA, medial proximal tibial angle.

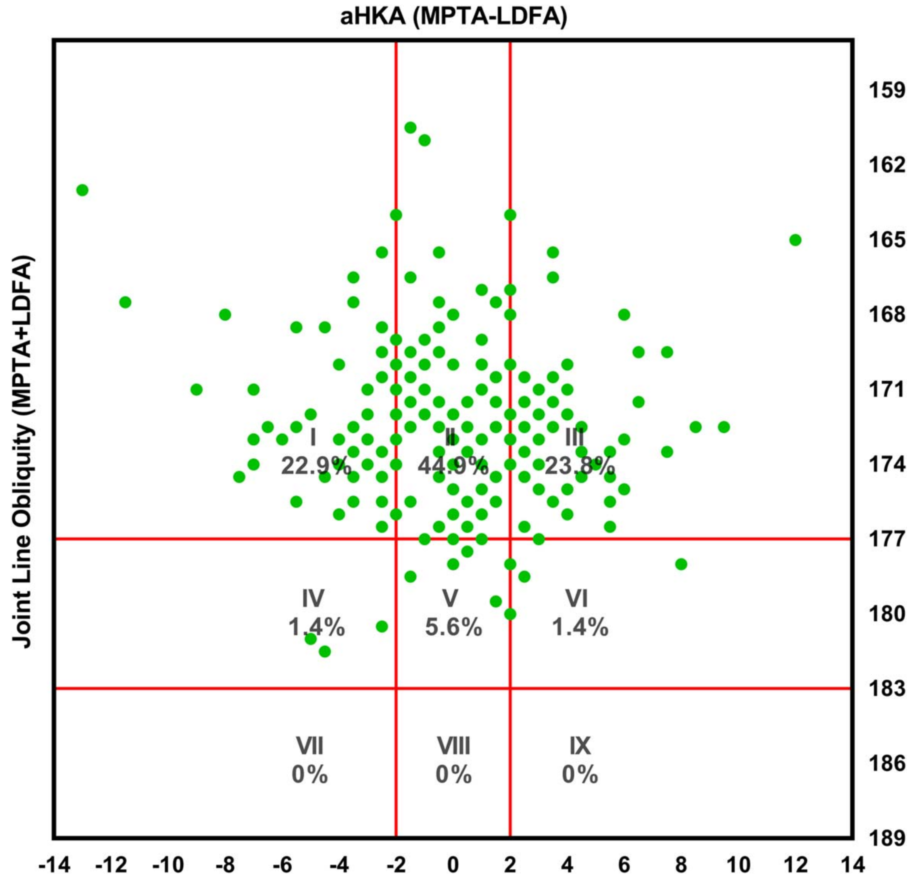

Figure 2. Plot of the arithmetic hip-knee-ankle angle (aHKA) against joint line obliquity for a healthy population, showing the distribution by percentage in the nine coronal plane alignments of the knee types. LDFA, lateral distal femoral angle; MPTA, medial proximal tibial angle.

Table 3

Comparison of radiological measurements and CPAK classification between Grade 3-4 K-L tibiofemoral OA in an arthritic knee undergoing TKA and Grade 0-2 OA in the contralateral knee.

Parameter	K–L 3–4 (162 knees)	K–L 0–2 (162 knees)	*P*
Mean mHKA angle in degrees (SD)	171.6 (6.9)	177.0 (4.1)	< 0.001[a]
Mean MPTA in degrees (SD)	84.2 (3.8)	86.4 (3.1)	< 0.001[a]
Mean LDFA in degrees (SD)	88.9 (3.7)	87.6 (3.1)	0.001[a]
Mean JLCA in degrees (SD)	3.9 (2.4)	2.2 (1.6)	< 0.001[a]
Mean aHKA angle in degrees (SD)	– 4.7 (6.0)	– 1.2 (4.2)	< 0.001[a]
Mean JLO angle in degrees (SD)	173.1 (4.5)	174.0 (4.6)	0.052[a]
Distribution of CPAK classification (%)			< 0.001[b]
Type I	55.6	27.8	
Type II	17.3	27.8	
Type III	7.4	17.9	
Type IV	11.1	6.8	
Type V	4.3	14.2	
Type VI	3.1	4.3	
Type VII	1.2	0.6	
Type VIII	0	0	
Type IX	0	0.6	

aHKA, arithmetic hip-knee-ankle; CPAK, coronal plane alignment of the knee; JLCA, joint line convergence angle; JLO, joint line obliquity; K–L, Kellgren–Lawrence; LDFA, lateral distal femoral angle; mHKA, mechanical hip-knee-ankle; MPTA, medial proximal tibial angle; OA, osteoarthritis; TKA, total knee arthroplasty.

[a]Paired-samples *t*-test.

[b]Pearson χ^2 test.

Discussion

The first study, which focused on constitutional alignment in normal patients, initially divided it into varus, neutral, and valgus using mHKA[1]. However, with the progression of OA, cartilage wear can impact mHKA[21]. For example, when a knee with a neutral constitutional alignment experiences wear of the cartilage in the medial compartment, the mHKA will exhibit a varus deformity. Therefore, constitutional alignment cannot be determined using the mHKA in patients with OA. MacDessi and colleagues found that MPTA and LDFA, which are based on bony landmarks, were unaffected by cartilage wear in patients with OA; therefore, aHKA and JLO which were calculated using MPTA and LDFA, were unchanged with the progression of OA[22,23]. Subsequently, they proposed that the aHKA and JLO can represent constitutional alignment in normal and OA populations and established the CPAK classification[7]. Recently, Nomoto *et al.*[24] reported the follow-up of a group of cases graded as K–L 0–2 and found that when they progressed to grade K–L 3–4, the CPAK classification did not change. The most common CPAK classification in this group of cases, when graded as K–L 0–2, was type I, which was consistent with the distribution of K–L 3–4. In other Asian countries, the most common classification of the normal population is type II. Therefore, it can be concluded that the distribution of CPAK classification does not change as knee OA progresses and may not be applicable to

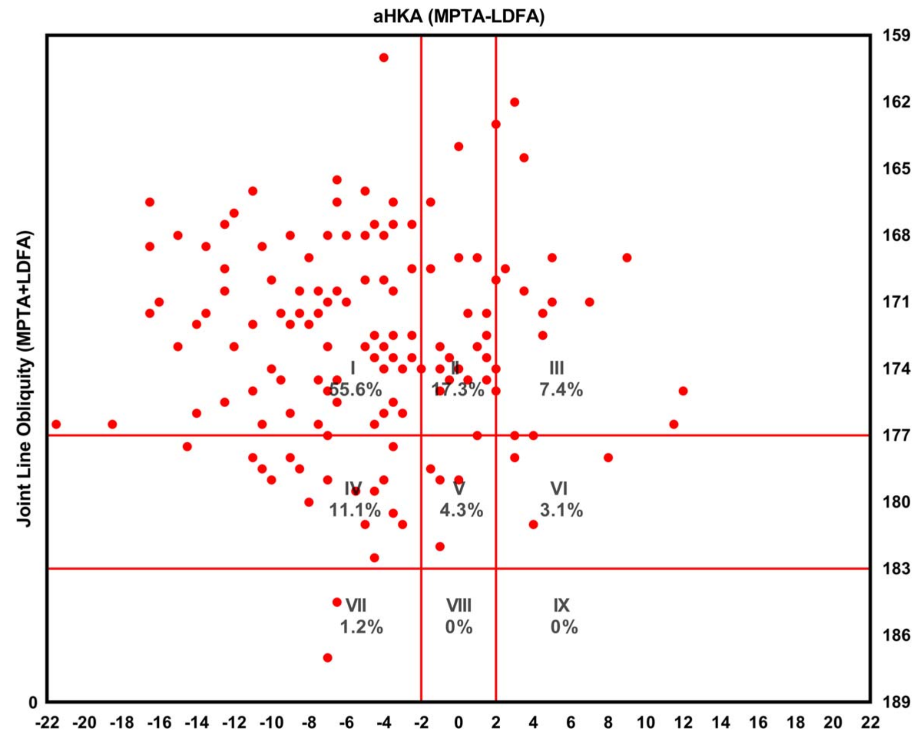

Figure 3. Plot of the arithmetic hip-knee-ankle angle (aHKA) against joint line obliquity for knees with Kellgren–Lawrence 3–4 in patients undergoing unilateral TKA, showing the distribution by percentage in the nine coronal plane alignment of the knee types. LDFA, lateral distal femoral angle; MPTA, medial proximal tibial angle.

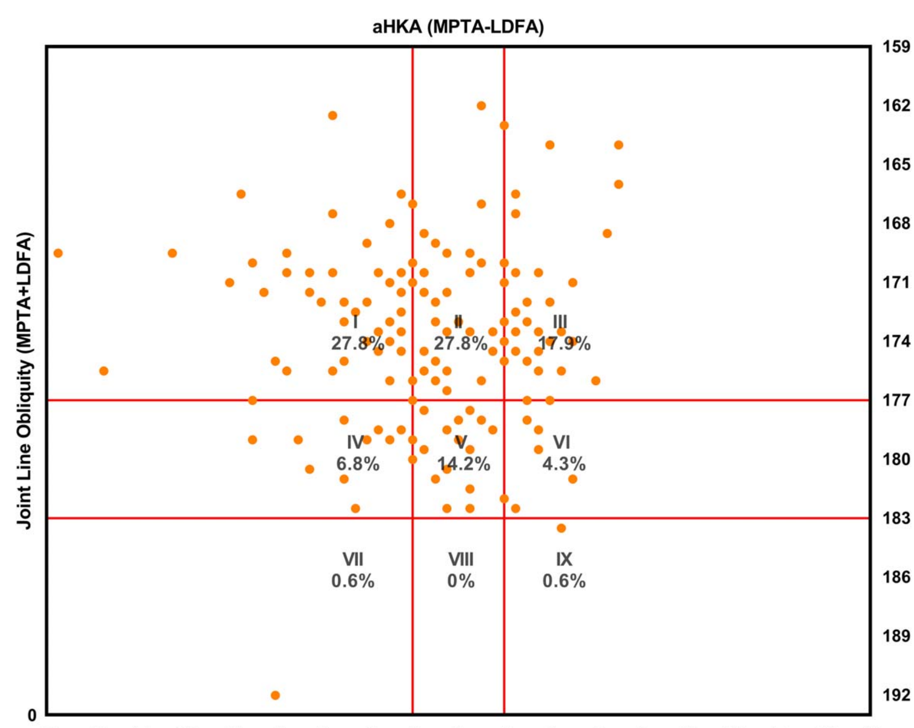

Figure 4. Plot of the arithmetic hip-knee-ankle angle (aHKA) against joint line obliquity for contralateral knees with Kellgren–Lawrence 0–2 in patients undergoing unilateral TKA, showing the distribution by percentage in the nine coronal plane alignment of the knee types. LDFA, lateral distal femoral angle; MPTA, medial proximal tibial angle.

Table 4

Comparisons and correlations of radiological measurements between left and right limb in healthy group.

				Right-left correlation	
Parameter	Left limb ($n=107$)	Right limb ($n=107$)	*P*	*r*	*P*
Mean mHKA in degrees (SD)	177.5 (3.5)	178.0 (3.7)	0.098[a]	0.764	< 0.001[c]
Mean MPTA in degrees (SD)	86.2 (2.7)	86.5 (2.7)	0.043[a]	0.861	< 0.001[c]
Mean LDFA in degrees (SD)	86.4 (2.5)	86.0 (2.4)	0.006[a]	0.731	< 0.001[c]
Mean JLCA in degrees (SD)	2.3 (1.5)	2.5 (1.6)	0.017[a]	0.718	< 0.001[c]
Mean aHKA in degrees (SD)	-0.2 (3.6)	0.5 (3.7)	0.001[a]	0.792	< 0.001[c]
Mean JLO in degrees (SD)	172.6 (3.7)	172.4 (3.5)	0.369[a]	0.796	< 0.001[c]
Distribution of CPAK classification (%) 0.518[b]					
Type I	24.2	21.4			
Type II	48.5	41.4			
Type III	18.6	28.9			
Type IV	0.9	1.8			
Type V	6.5	4.6			
Type VI	0.9	1.8			
Type VII	—	—			
Type VIII	—	—			
Type IX	—	—			

aHKA, arithmetic hip-knee-ankle angle; CPAK, coronal plane alignment of the knee; JLCA, joint line convergence angle; JLO, joint line obliquity; LDFA, lateral distal femoral angle; mHKA, mechanical hip-knee-ankle angle; MPTA, medial proximal tibial angle.
[a]Paired-samples *t*-test.
[b]Pearson χ^2 test.
[c]Pearson correlation coefficient.

Table 5

Comparison of baseline characteristics, preoperative radiological measurements, stepwise release strategy and postoperative clinical outcomes of CPAK type I patients between rKA and MA group during TKA.

parameter	rKA group ($n=34$)	MA group ($n=34$)	*P*
Mean age in years (SD)	65.1 (7.5)	65.4 (6.8)	0.110[a]
Sex			—
Male	9	9	
Female	25	25	
Mean mHKA in degrees (SD)	168.9 (4.9)	167.9 (4.7)	0.423[a]
Mean MPTA in degrees (SD)	81.8 (2.9)	82.0 (2.5)	0.733[a]
Mean LDFA in degrees (SD)	89.5 (2.2)	89.6 (3.2)	0.875[a]
Mean JLCA in degrees (SD)	3.7 (1.9)	4.5 (1.9)	0.103[a]
Mean aHKA in degrees (SD)	– 7.7 (4.4)	– 7.6 (4.3)	0.915[a]
Mean JLO in degrees (SD)	171.3 (2.8)	171.6 (3.7)	0.703[a]
Distribution of CPAK classification (%)			0.797[b]
Type I	35.3	23.5	
Type II	35.3	41.1	
Type III	8.9	11.8	
Type IV	2.9	8.9	
Type V	11.8	11.8	
Type VI	2.9	2.9	
Type VII	—	—	
Type VIII	—	—	
Type IX	2.9	—	
Pre-OKS	25.7 (9.1)	26.7 (7.0)	0.601[a]
Pain scores	15.1 (5.9)	16.1 (4.4)	0.420[a]
Functional scores	10.6 (3.7)	10.7 (3.3)	0.926[a]
Stepwise release Number (%) of knees, *n* (%)			
Step 1	34 (100)	34 (100)	—
Step 2	17 (50)	24 (71)	0.083[b]
Step 3	7 (21)	12 (35)	0.177[b]
Post-OKS	55.7 (3.1)	56.0 (2.3)	0.594[a]
Pain scores	33.5 (1.7)	33.4 (1.2)	0.851[a]
Functional scores	22.2 (1.7)	22.6 (1.5)	0.284[a]

aHKA, arithmetic hip-knee-ankle angle; CPAK, coronal plane alignment of the knee; JLCA, joint line convergence angle; JLO, joint line obliquity; LDFA, lateral distal femoral angle; MA, mechanical alignment; mHKA, mechanical hip-knee-ankle angle; MPTA, medial proximal tibial angle; OKS, oxford knee score; rKA, restricted kinematic alignment; TKA, total knee arthroplasty.
[a]Independent-samples *t*-test.
[b]Pearson χ^2 test.

other populations with different distributions of the CPAK classification. Unlike the aforementioned results, this study found that in patients with OA with one knee graded as K–L 3–4 and the contralateral knee graded as K–L 0–2, the distribution of CPAK classifications was not consistent between the knees graded as K–L 3–4 and K–L 0–2. In addition, among the 162 knees graded as K–L 3–4, 90 were classified as type I, of which 52 (58%) were not classified as type I on the contralateral knee graded as K–L 0–2. These results may indicate that if TKA of these patients with OA classified as type I followed the KA philosophy referred to as aHKA and JLO to achieve a type I alignment postoperatively, it may lead to asymmetry of limb alignment on the left and right sides in more than half of the patients. Although there is still controversy regarding whether the contralateral side can be used as a reference to determine constitutional alignment in TKA[25,26], some rare situations may not be considered, such as in patients affected by a windswept deformity[27]. However, our results also showed that the consistency of MPTA, LDFA, mHKA, and JLCA between the left and right sides in healthy individuals tended to be higher than those in Becker's study, suggesting that the contralateral limb was not a reliable reference for restoring coronal alignment in TKA (in his study, the consistency of these measurements was <0.7)[25]. Furthermore, there was no significant difference in CPAK classification between the left and right knees, and the differences in the mean and standard deviation of each parameter were less than 1°. These results suggest that bilateral consistency may vary among populations. Referring to contralateral constitutional alignment for TKA may be feasible in populations with high consistency between the left and right sides.

The results of this study showed that the MPTA and LDFA of knees of different grades were inconsistent, suggesting that OA progression may cause changes in bony landmarks. This was different from MacDessi's results[22], as well as a very recently published study indicating that in the Turkish population, healthy individuals and patients with OA most commonly exhibited CPAK type II alignments[28]. A possible reason for this may be that the sample size of the previous study was small and it was conducted in a Western population. In MacDessi's study, the most common phenotype in both normal individuals and patients with OA was type II[7]; however, in Asian populations, the most common phenotype in the normal population was type II[9,10], whereas type I was the most common phenotype in the OA population[9,11]. This study recruited more cases and was conducted on an Asian population. Second, the average varus deformity was 3° in MacDessi's studies[7,22,23], whereas our patients had an average varus deformity of 6°, suggesting that our cases may be more severe. Colyn *et al.*[21] reported that the coronal alignment parameters may change with OA progression. Although patients with bone deficiency or flexion contractures combined with rotation that resulted in poor image quality were excluded during enrolment, cases with "bone on bone signs" were also included. Therefore, significant subchondral sclerosis and bone remodelling may also affect the bony landmarks which define MPTA and LDFA, resulting in changes in aHKA or JLO and ultimately altering the CPAK classification. In this study, we found that the aHKA of knees graded as K–L 3–4 was smaller than 2°, compared with that of K–L 0–2; this result may verify the aforementioned hypothesis. It is also worth mentioning that we found a mean JLCA of 2.4° in normal individuals, which is much larger than that reported in previous studies[1,29]. Further studies are required to evaluate the clinical significance of these findings.

We retrospectively analysed the clinical outcomes of TKA scheduled according to the rKA philosophy, which refers to contralateral constitutional alignment in patients classified as type I. Since no TKA was performed according to the MPTA and LDFA of the arthritic knee (this option may not be reasonable according to the results of this study), we compared the outcomes of these cases with those of TKA scheduled according to the MA philosophy. These results were consistent with those of a previous study[30] in that there was no difference in clinical outcomes between patients following the rKA and MA philosophy. In the rKA group with type I knees, two-thirds of the TKA, which referred to the contralateral constitutional alignment, were performed for types other than type I; the most common type was type II (44%). This result is consistent with that of a previous study, which found that type II was the most common type in normal individuals. Given the proximity of type II and type I in CPAK classification[7] and the JLO of the two types were both "apex distal," it was reasonable to speculate that when a knee of type II experienced degeneration of the medial compartment, aHKA may gradually evolve from neutral to varus, resulting in a knee of type II becoming type I. This has increased the proportion of knees with type I in OA knees. This hypothesis may be partially supported by the results of a recently published study on unicompartmental knee arthroplasty (UKA), a bone-resurfacing and soft issue-sparing procedure[31]. In this study, CPAK phenotype I had the highest prevalence (45.0%) preoperatively, whereas following medial UKA, CPAK phenotype II had the highest prevalence (53.3%). Ho *et al.*[32] recently indicated that in mechanically aligned TKA for varus knees, patients with constitutional varus had a higher incidence of medial soft-tissue release. These results are consistent with those of the present study. In addition, even in the rKA group, we still performed soft-tissue release because our group of patients had severe varus deformity and used PS prostheses. In addition, two-thirds of the cases were not classified as having type I alignment. Therefore, soft-tissue release is necessary to achieve balanced TKA. However, due to adjustments in bone cutting, there was still a tendency to reduce the degree of soft-tissue release compared with that in the MA group, and less soft-tissue release will reduce related complications[33]. Notably, Kim *et al.*[34] recently suggested that preserving native CPAK in UKA procedures achieved favourable clinical outcomes one year postoperatively. Therefore, the results of this study may provide practical information for orthopaedic surgeons when planning knee procedures, such as UKA and TKA.

The limitations of this study are as follows: First, this was a retrospective study that only analysed OA and normal individuals who underwent long-leg radiography. A larger prospective multicentre cohort study is needed to verify the CPAK classification in different regions of the Chinese population. In addition, a more balanced distribution and number of healthy knees and OA knees would enhance the persuasiveness of the findings. Second, when selecting unilateral cases, the contralateral side taken as controls was defined as K–L 0–2 and cannot be considered as a normal knee. However, previous literature has suggested that OA usually involves both sides over time[35]; therefore, it is relatively rare for one knee to progress to K–L 3–4 while the contralateral side is completely normal. However, even in the presence of K–L 2, degeneration only has the possibility of narrowing the joint space and mild subchondral bone sclerosis, so it may have little impact on measuring MPTA and LDFA. Third, predictive models have been reported in TKA, such as predicting patient-reported outcomes, 90 day readmission rate, and surgical time[36]. Recently, Steele *et al.*[37] used deep automatic learning algorithms to measure MPTA and LDFA on long-leg radiographs and classified nearly 2000 knees according to the CPAK classification. However, no machine learning algorithm has been utilised to predict constitutional phenotypes in OA knees. We would focus on this topic in future studies with more enroled cases.

Conclusion

In summary, this study found that the most common CPAK classification in the Chinese population with OA was type I, which is varus, with the joint line apex distal. In healthy individuals, the most common type was type II, which is neutral, with the joint line apex distal. OA progression may lead to changes in the CPAK classification.

Ethical approval

The Institutional Review Board of The First Hospital of Jilin University(IRB number IRB00008484) approved this study (2023-711).

Consent

All participants agreed to provide medical records for education or non-profit research. No names, initials, Images or hospital numbers have be used in the paper.

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Author contribution

Y.-H.G.: data interpretation, writing the paper. Y.-M.Q.: data analysis. P.-H.H.: data collection. X.-Y.Z.: data collection. X.Q.: study concept or design.

Conflicts of interest disclosure

There are no conflicts of interest.

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Data statement

The data are not publicly available, as participants in this study need their data for further analysis.

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This paper was not invited.

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