ACTA ORTHOPAEDICA et TRAUMATOLOGICA TURCICA
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Research Article

Knee phenotypes distribution according to CPAK classification in Turkish population

Vahit Emre Özden[1,2], Göksel Dikmen[1,2], Kayahan Karaytuğ[1,2], Arda Mavi[3], Yılmaz Onat Köylüoğlu[3], İsmail Remzi Tözün[1,2]

[1]*Department of Orthopedics and Traumatology, Acibadem Mehmet Ali Aydinlar University Faculty of Medicine, Istanbul, Türkiye*
[2]*Department of Orthopedics and Traumatology, International Joint Centre (IJC), Acibadem Maslak Hospital, Istanbul, Türkiye*
[3]*Undergraduate, Acibadem Mehmet Ali Aydınlar University Faculty of Medicine, Istanbul, Türkiye*

ARTICLE INFO

Article history:
Submitted April 4, 2024
Received in revised form August 5, 2024
Last revision received form September 14, 2024
Accepted October 1, 2024
Publication Date December 31, 2024

Keywords:
Knee
Alignment
Phenotypes
CPAK
Turkish population
Total knee arthroplasty

ORCID iDs of the authors:
V.E.O. 0000-0003-1082-4882;
G.D. 0000-0001-6892-3488;
K.K. **0000-0002-8138-8232**;
A.M. 0000-0001-6371-6549;
Y.O.K. 0000-0002-2776-6650;
İ.R.T. 0000-0003-4234-6555.

Corresponding author:
Göksel Dikmen
goksel.dikmen@acibadem.edu.tr

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ABSTRACT

Objective: This study aimed to investigate the distribution of knee phenotypes based on the CPAK classification in healthy nonarthritic subjects and osteoarthritic patients in Türkiye.

Methods: Radiological EOS analysis of nonarthritic 1172 knees and osteoarthritic 571 knees was evaluated to clarify the distribution of CPAK classification. The knees were categorized into 9 subgroups according to the arithmetic hip-knee-ankle (aHKA) angle and joint-line obliquity (JLO). The medial proximal tibial angle (MPTA) and lateral distal femoral angle (LDFA) were used to calculate aHKA and JLO. The Sectra workstation program was used for all radiological measurements.

Results: In the nonarthritic group, CPAK distribution was 20.9% type I (n=245), 2.5% type II (n=30), 0.08% type III (n=1), 46.67% type IV (n=545), 7.7% type V (n=91), 0.7% type VI (n=9), 18% type VII (n=211), 2.9% type VIII (n=35), 0.2% type IX (n=3). The mean JLO was 173.7 ± 4.38, and the mean aHKA was 0.15 ± 3.81 in nonarthritic group. Arthritic group CPAK type distribution was 20.7% type I (n=118), 3.1% type II (n=18), 0.17% type III (n=1), 57.1% type IV (n=326), 8.4% type V (n=48), 0.17% type VI (n=1), 7.8% type VII (n=45), 1.4% type VIII (n=8), and 0.8% type IX (n=5). The mean JLO was 174.2 ± 3.78, and the mean aHKA was −2.21 ± 4.48 in the osteoarthritic group.

Conclusion: CPAK type IV and CPAK type I were the most common subgroups in the nonarthritic and arthritic groups. CPAK type 5, which is the target of the mechanical alignment strategy, is only 7.8% in the nonarthritic group and 8.4% in the osteoarthritic group in the Turkish population.

Level of Evidence: Level III, Diagnostic Study.

Introduction

There are many approaches for surgical planning of total knee arthroplasty. The traditional technique is mechanical alignment (MA), but alternative, patient-friendly techniques, such as the kinematic alignment (KA) technique, have also been developed.[1] The goal of MA of the knee is a 0° neutral Hip-Knee-Ankle Angle (aHKA), with both femur and tibial components perpendicular to the mechanical axes. In contrast, the KA approach to total knee arthroplasty aims to restore the normal, constitutional joint line by restoring the natural level of joint lines and angles, while aiming to set the femoral component on kinematic axes. The goal of KA is to align the articular knee surfaces according to each individual's pre-arthritic aHKA and pre-arthritic joint line obliquity (JLO), which is highly personalized.[2]

CPAK classification aims to analyze the constitutional, pre-arthritic alignment of each patient using their arthritic coronal plane graphics. Using LDFA and MPTA to calculate aHKA and JLO, aHKA values are classified into 3 subgroups varus, valgus, and neutral, and JLO values are classified as apex distal, neutral, and apex proximal. The combination of these 2 subgroupings creates 9 types of CPAK.[3] MacDessi et al. also used their proposed CPAK classification to analyze which CPAK types are the best fits to benefit from constitutional alignment restoration. Kinematic alignment has a more accurate fit with patient anatomy and better optimization of soft tissue balance than mechanical Alignment.[4]

Many countries defined their populations' knee phenotype distributions with CPAK populational cohort studies.[5] More patient's friendly alignment strategies can be used with a better understanding of the population distributions of knee phenotypes for TKA. This study aims to reveal the distribution of knee phenotypes that vary in the coronal plane according to the CPAK classification in the Turkish population.

Material and methods

After obtaining institutional review board approval from Acıbadem University (Approval No:2023-09/306 Date: May, 20232013-09/306), a retrospective case-control study was planned to investigate the distribution of CPAK types among the Turkish arthritic and nonarthritic population, using the EOS radiography

Cite this article as: *Özden VE, Dikmen G, Karaytuğ K, Mavi A, Köylüoğlu YO, Tözün İR. Knee phenotypes distribution according to CPAK classification in Turkish population. Acta Orthop Traumatol Turc., 2024;58(6):341-345.*

DOI: 10.5152/j.aott.2024.24053

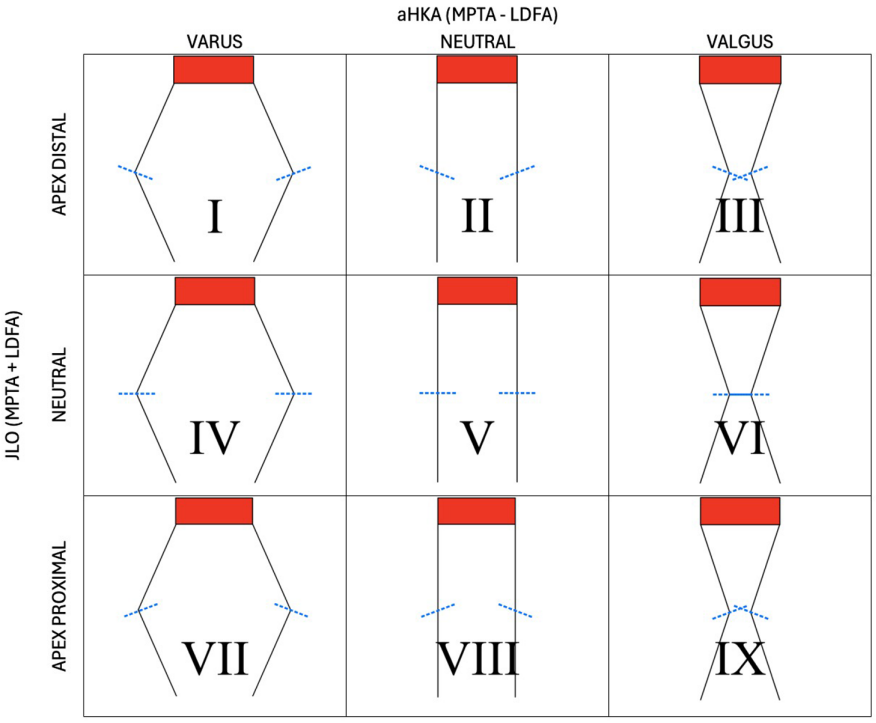

Figure 1. In CPAK classification, aHKA is calculated using the formula aHKA=MPTA − LDFA. After the calculation of aHKA, it is classified into 3 groups. JLO is calculated as JLO=MPTA+LDFA, and results are classified into 3 groups.

database of the radiology department. Each EOS radiography was measured by 2 researchers to maximize the inter- and intra-observer reliability with a minimum of 2 independent measurements. The interobserver r was 0.96 ($P < .001$) for measures between 2 observers, and the intraobserver r was 0.97 ($P < .001$) for measures among observers at 10-day interval.

Study groups' whole-body anterior-posterior (AP) EOS radiographs were selected according to exclusion criteria from the database of the radiology department. All EOS views were performed between May 2015 and May 2023. Exclusion criteria were determined as follows: having a leg length difference of more than 2 cm, having undergone lower extremity surgery (plate, screw, intramedullary nail repair, and high tibial osteotomy), scoliosis which causes a pelvic tilt in the coronal plane of more than 2 degrees, poor image quality or imaging-related artifacts, and patients with bilateral total or partial knee arthroplasty or bilateral total or partial hip arthroplasty. Informed consent was obtained from the patients who agreed to take part in the study.

HIGHLIGHTS

- Total knee arthroplasty (TKA) has evolved from traditional mechanical alignment techniques to more personalized approaches like kinematic alignment, which aim to restore each patient's pre-arthritic joint anatomy. This study aims to analyze the distribution of knee phenotypes in the Turkish population using the CPAK classification to inform patient-specific alignment strategies for TKA.
- The results showed that CPAK type IV was the most common phenotype, accounting for 46.67% (n=545) in the nonarthritic group and 57.1% (n=326) in the arthritic group, followed by type I with 20.9% (n=245) and 20.7% (n=118), respectively. The mean JLO was 173.7 ± 4.38 and the mean aHKA was 0.15 ± 3.81 in the nonarthritic group, while in the arthritic group, the mean JLO was 174.2 ± 3.78 and the mean aHKA was −2.21 ± 4.48.
- Better understanding of national population distributions of knee phenotypes with CPAK is important for Turkish surgeons to optimize alignment strategies and improve patient-specific outcomes in total knee arthroplasty.

After the elimination, images were divided into 2 age groups: 18-44 years of age and 44+ years of age. Each image was staged using the Kellgren-Lawrence[6] knee osteoarthritis staging. For the patient group between the ages of 18 and 44, patients with Kellgren-Lawrence stage 0 were selected to create the *nonarthritic* group; in the group consisting of patients over 44 years of age, patients with Kellgren-Lawrence stages 3 and 4 were selected to create the *arthritic* group. The arthritic group included 571 knee radiographies from 338 patients, 51% were male (n=172) and 49% were female (n=166). The nonarthritic group included 1172 knee radiographs from 586 patients, 50% were male (n=293) and 50% were female (n=293).

Radiological measurements

The mechanical axis line of the femur is created by drawing a line between the center point of the femoral head and the midpoint of the distal femur within the knee joint. A second line is created by connecting the distal endpoints of the lateral and medial condyles located within the joint of the distal femur. The lateral angle created by these lines is called LDFA. Similarly, by working on the tibia, the mechanical axis of the tibia is created between the midpoint of the proximal tibia within the knee joint and the center of the distal tibial plafond. A second line is drawn between the centers of the medial and lateral contours of the tibia located on the most distal surface of the knee joint. The medial angle formed by these lines drawn on the tibial surface of the knee joint is called MPTA. classification uses JLO and aHKA variables to classify. These variables are calculated by using LDFA and MPTA measurements (Figure 1). In CPAK classification, aHKA is calculated using the formula aHKA=MPTA − LDFA. After the calculation of aHKA, it is classified into 3 groups: neutral aHKA is 0° ± 2°, inclusive; a varus aHKA is <-2°, a valgus aHKA is >2°. Similarly, in CPAK classification, JLO is calculated as JLO=MPTA+LDFA, and results are classified into 3 groups: 180° ± 3° is neutral JLO, apex proximal JLO is >183°, and apex distal JLO is <177°. Nine classes of the CPAK classification are obtained by using

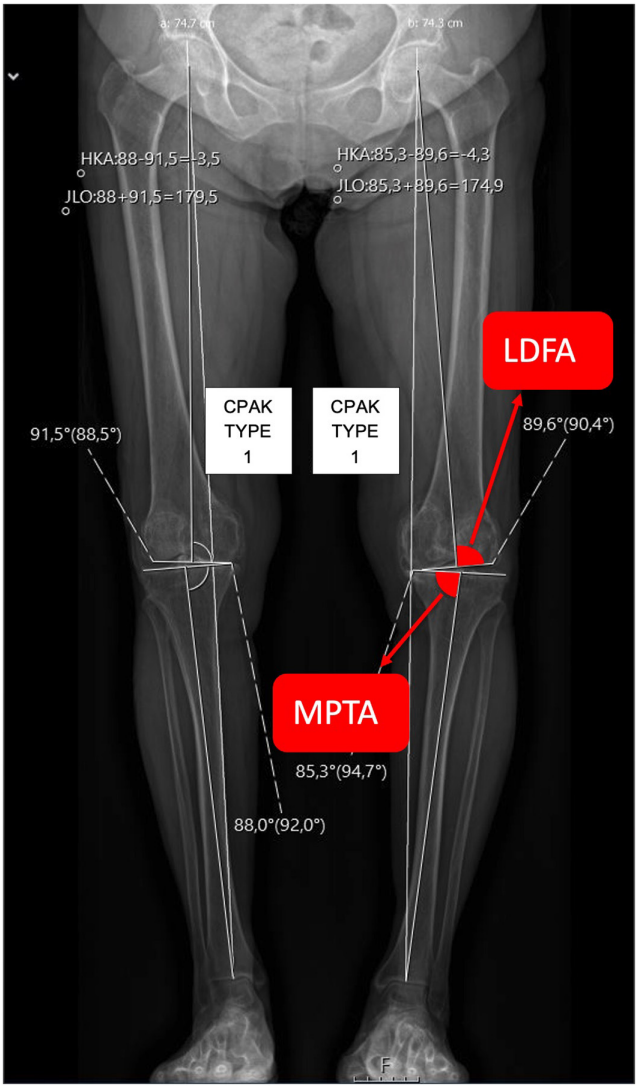

Figure 2. CPAK classification uses LDFA and MPTA to calculate aHKA and JLO, this patient has bilateral varus and apex distal deformity, creating CPAK type I.

the matrix of each of the 3 classes of these 2 variables. Mean aHKA, mHKA, LDFA, MPTA, JLO, and aJLO were calculated for each group (Figure 2).

Statistical analysis

Statistical analysis involved creating scatterplots to illustrate alignment distribution for both the original CPAK classification and the modified classification. The normality of data distribution for continuous variables was assessed using Q-Q plots and the Shapiro-Wilk test. Continuous variables were presented as mean (SD) and compared using independent-sample t-tests, with statistical significance set at a *P*-value ≤ .05. All analyses were conducted using the R statistical language (version 4.1.0, R Core Team, Austria), with a confidence level of 0.95 considered significant.

Results

Following the methodology of classifying and measuring each knee, the statistical analysis was performed to show phenotypic distribution. For the arthritic group, out of the studied 571 knees, the CPAK type distribution was 20.7% type I (n=118), 3.1% type II (n=18), 0.1% type III (n=1), 57.1% type IV (n=326), 8.4% type V (n=48), 0.1% type VI (n=1), 7.8% type VII (n=45), 1.4% type VIII (n=8), and 0.8% type IX (n=5). Also, the arthritic group's JLO and HKA analysis showed that the mean JLO was 174.2 ± 3.78 and the mean aHKA was −2.21 ± 4.48 (Figure 3).

For the nonarthritic group, out of the studied 1171 knees, CPAK type distribution was: 20.904% type I (n=245), 2.559% type II (n=30), 0.085% type III (n=1), 46.672% type IV (n=545), 7.764% type V (n=91), 0.767% type VI (n=9), 18.003% type VII (n=211), 2.986% type VIII (n=35), and 0.255% type IX (n=3). Nonarthritic group statistical analysis for JLO and HKA values has shown that mean JLO was 173.7 ± 4.38 and mean aHKA was 0.15 ± 3.81 in nonarthritic c group (Figure 4).

There was no statistically significant distribution ratio of CPAK classification between Kellgren-Lawrence-3 and Kellgren-Lawrence-4 patients in the arthritic group. Both HKA and JLO measurements of the right and left knees of the same patients are not significantly different from one another. HKA measures have means of −0.55 and −0.53, respectively, for right and left patients, with a *P*-value of .89. JLO measures have means of 173.8 and 173.9, respectively, for nonarthritic and arthritic patients, with a p-value of 0.68.

The most common CPAK Type for both groups was Type IV, and the second most common type was Type I. Also, incidences of CPAK Types III, VI, and IX for both groups were under 1%.

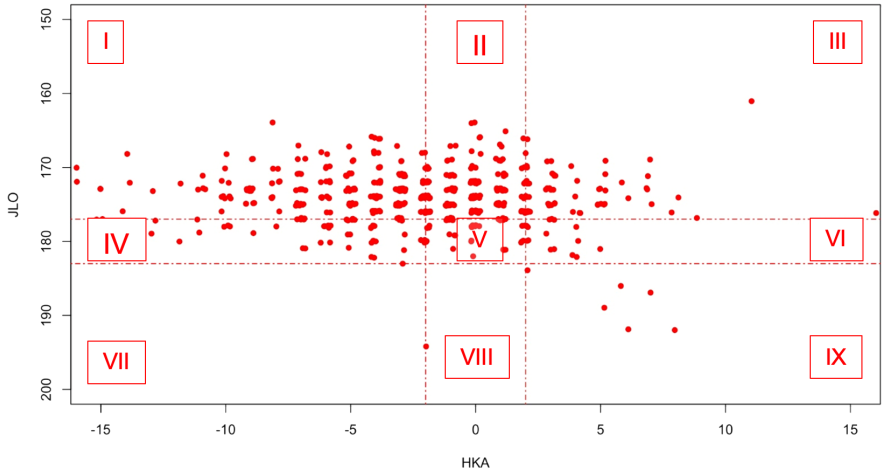

Figure 3. Arthritic group knee phenotype distribution according to CPAK classification.

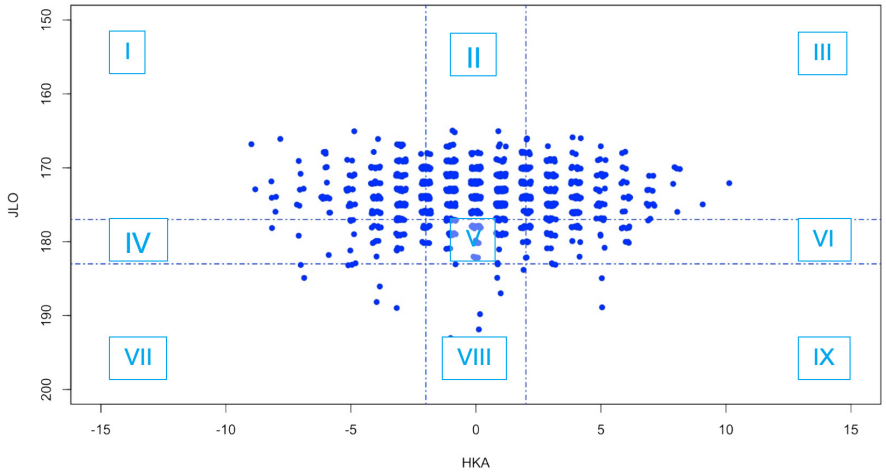

Figure 4. Nonarthritic group knee phenotype distribution according to CPAK classification.

Discussion

Kinematic alignment is a trending approach to TKA, gaining popularity every day, with more surgeons using this method in daily practice. This trending topic has also caught the attention of researchers in this field, resulting in many studies showing long-term and short-term results of the approach and comparing it to the long-accepted traditional mechanical alignment. After the publication of the CPAK phenotype classification, the difference in outcomes of TKA with kinematic and mechanical alignments was shown for each CPAK type; this caught the attention of surgeons around the globe to modify the optimal approach during TKA operations on different populations. Research groups from various countries have shown their populations' CPAK type distributions, and the results indicate that there are geographic differences in knee phenotype.[1,7-12] With the help of outcome differences analysis between kinematically aligned TKA and mechanically aligned TKA for each CPAK type, determining the most common CPAK type of the population can be used as a helping tool during surgical planning while working with a specific population. This study presents the CPAK-type distribution of the Turkish population to aid TKA operation planning and to see where the Turkish population is situated within the geographic variances of knee phenotype.

Nonarthritic groups of the Turkish population had the highest incidence of CPAK type IV, with 46.67%. No other study showed their population's most prevalent CPAK type as type IV. Studies from various countries showed their "healthy/nonarthritic" populations' most prevalent CPAK types as follows: Belgium[1] type II (39.2%), Taiwan[10] type II (39.3%), India[12] Type II (25.6%), China[7] Type II (44.9%). The group with the second highest incidence among all populations was CPAK type I except China; the percentages can be listed as: the Turkish population had a CPAK type I ratio of 20.90%, Belgium population had a CPAK type I ratio of 26.4%, Taiwan population had a CPAK type I ratio of 36.4%, the Indian population had a CPAK type I ratio of 21.2% and finally China population had a CPAK type III as their second most common at 23.8%. In addition to that, our nonarthritic group consisted of 1172 knees from 586 patients, having the most number of knees and individuals out of all the studies mentioned that had a similar group of healthy individuals: the population of Belgium was studied with 500 knees of 250 individuals, the population of Taiwan was studied with 214 knees of 214 individuals, the population of India was studied with 500 knees of 250 individuals, and the population of China was studied with 214 knees of 107 individuals (Table 1).

Arthritic groups of the Turkish population also had the most prevalent CPAK type as type I (57.19%) and the second most prevalent as type II (20.70%) while studying the arthritic group's 571 arthritic knees from 338 individuals. Similarly, different groups of researchers showed their arthritic populations' CPAK type distributions from Australia, Japan, France, India, and China. CPAK distribution in Australia was studied 3 times in 2 different researches. In these studies, one study[1] had 2 arthritic groups: the first group examined 500 knees from 500 individuals and the second group examined 138 knees from 125 individuals. For both of the groups of this study and the most common CPAK type was type II with the ratios 32.2% for the first group, and 38% for the second. As for the second most common types, the first group's was type I with 19.4% and the second group's was type III with 20%. As for the second study of Australia[8] the most common CPAK type was type I with 33.0% and the second most common type was type II with 27.3%. Japanese[9] arthritic population's distribution results showed the most common CPAK type as type I (53.8%) and the second most common type as type II (25.4%) while studying 500 knees of 343 individuals. Study from France[11] included 1078 arthritic knees of 936 individuals and showed most common CPAK type as type I (33.4%) and the second most common type as type II (19.5%). Indian[12] arthritic population study showed

Table 1. Comparison of studied groups and CPAK distributions of nonarthritic groups from different populations

		(1)	(10)	(12)	(7)
	Turkey	**Belgium**	**Taiwan**	**India**	**China**
Number of patients	586	250	214	250	107
Number of knees	1172	500	214	500	214
Male/Female ratio	50/50	50/50	52/48	44/56	38/62
CPAK Types Distributions					
Type I	20.9%	26.4%	36.4%	21.2%	22.9%
Type II	2.5%	39.2%	39.3%	25.6%	44.9%
Type III	0.1%	9.8%	13.6%	6.0%	23.8%
Type IV	46.6%	5.4%	5.6%	16.8%	1.4%
Type V	7.7%	15.4%	4.7%	19.6%	5.6%
Type VI	0.7%	3.4%	0.5%	5.8%	1.4%
Type VII	18.0%	0.2%	0%	2.4%	0%
Type VIII	2.9%	0%	0%	1.8%	0%
Type IX	0.2%	0.2%	0%	0.8%	0%

CPAK, Coronal Plane Alignment of the Knee.

Table 2. Comparison of studied groups and CPAK distributions of arthritic groups from different populations

		(1)		(8)	(9)	(11)	(12)	(7)
	Turkey	Australia		Australia	Japan	France	India	China
Number of patients	338	500	125	76	343	936	250	246
Number of knees	571	500	138	88	500	1078	500	477
Male/Female ratio	51/49	38/62	41/59	54/46	19/81	83/17	30/70	26/73
CPAK Types Distributions								
Type I	20.7%	19.4%	16.0%	33.0%	53.8%	33.4%	58.8%	43.6%
Type II	3.1%	32.2%	38.0%	27.3%	25.4%	19.5%	13.8%	21.6%
Type III	0.1%	15.4%	20.0%	15.9%	8.2%	10.6%	1.4%	10.5%
Type IV	57.1%	9.8%	10.8%	3.4%	7.2%	10.2%	18.2%	11.5%
Type V	8.4%	14.6%	8.6%	5.7%	4.4%	18.9%	3.4%	7.5%
Type VI	0.1%	7.4%	5.0%	12.5%	1.0%	6.3%	1%	3.8%
Type VII	7.8%	0.6%	0%	0%	0%	0.4%	2.8%	1.1%
Type VIII	1.4%	1.6%	0%	1.1%	0%	0.6%	0.6%	0%
Type IX	0.8%	0.4%	0%	1.1%	0%	0.1%	0%	0.4%

CPAK, Coronal Plane Alignment of the Knee.

their most common CPAK type as type I (58.85%) and the second most common type as type IV (18.25%), while studying 500 arthritic knees of 250 individuals. Chinese[7] arthritic population was studied with 477 arthritic knees of 246 individuals, which had CPAK type I (43.6%) as their most common type and their second most common CPAK type was type II (21.6%) (Table 2). Overall, out of the studies mentioned above, our study had the highest number of knees classified according to CPAK classification with a combined total of 1743 knees from arthritic or healthy knees.

Limitations of this study were that the radiology database included many patients with spinal problems such as scoliosis. During the selection of images for the study, as a preventive measure, patients with scoliosis who had pelvic tilt were filtered out and not included in the study.

According to both arthritic and healthy groups' distributions of CPAK types, the Turkish population showed that their most prevalent CPAK type is CPAK type I and the second most prevalent type is CPAK type IV. The neutral alignment being CPAK type V, which is the target of mechanically aligned TKA, was detected as 7.8% in our nonarthritic group and 8.4% in our arthritic group.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Ethics Committee Approval: This study was approved by the Ethics Committee of Acıbadem University (Approval No: 2023-09/306, Date: May, 2023).

Informed Consent: Informed consent was obtained from the patients who agreed to take part in the study.

Peer-review: Externally peer reviewed.

Author Contributions: Concept – G.D., V.E.O.; Design – G.D., V.E.O.; Supervision – G.D., V.E.O.; Resources – K.K., Y.O.K., A.M.; Materials – V.E.O., R.T., G.D.; Data Collection and/or Processing– Y.O.K., A.M., G.D.; Analysis and/or Interpretation – K.K., Y.K.O., A.M.; Literature Search – A.M., G.D., V.E.O.; Writing – G.D., A.M., V.E.O.; Critical Review – İ.R.T.

Declaration of Interests: The authors have no conflict of interest to declare.

Funding: The authors declared that this study has received no financial support.

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