Joint Diseases and Related Surgery

Jt Dis Relat Surg
2024;35(1):194-201

ORIGINAL ARTICLE

Phenotyping of the Turkish population according to Coronal Plane Alignment of the Knee classification: A retrospective cross-sectional study

Ahmet Şenel, MD[1], Murat Eren, MD[1], Selman Sert, MD[1], Tahsin Gürpınar, MD[2], Engin Çarkçı, MD[1], Barış Polat, MD[3]

[1]Department of Orthopedics and Traumatology, Istanbul Training and Research Hospital, Istanbul, Türkiye
[2]Department of Orthopedics and Traumatology, Inmotion Orthopaedics, Canberra, Australia
[3]Department of Orthopedics and Traumatology, Dr. Burhan Nalbantoğlu State Hospital, Nicosia, Cyprus

Total knee arthroplasty is one of the widely performed orthopedic surgeries worldwide; achieving a pain-free and functional joint, along with high patient satisfaction, are among the goals of this surgery.[1] Patient, surgeon, and implant-related factors influence the outcomes. One of the patient-related factors is the morphological changes of the distal femur and proximal tibia, which contribute to the formation of the knee joint surface.[2] Implant malposition and malalignment are among the causes of revision knee arthroplasty.[3] Therefore, the impact of implant coronal plane position on outcomes has drawn the attention of researchers.[4]

Received: October 01, 2023
Accepted: November 20, 2023
Published online: November 30, 2023

Correspondence: Ahmet Şenel, MD. İstanbul Eğitim ve Araştırma Hastanesi Ortopedi ve Travmatoloji Kliniği, 34098 Fatih, İstanbul, Türkiye.

E-mail: ahmetsenel23@gmail.com

Doi: 10.52312/jdrs.2023.1464

Citation: Şenel A, Eren M, Sert S, Gürpınar T, Çarkçı E, Polat B. Phenotyping of the Turkish population according to Coronal Plane Alignment of the Knee classification: A retrospective cross-sectional study. Jt Dis Relat Surg 2024;35(1):194-201. doi: 10.52312/jdrs.2023.1464.

ABSTRACT

Objectives: This study aimed to phenotype healthy individuals and patients with arthritic knees in the Turkish population according to the Coronal Plane Alignment of the Knee (CPAK) classification.

Patients and methods: The retrospective cross-sectional study included 207 healthy individuals (109 males, 98 females; mean age: 32.9±8.4 years; range, 20 to 45 years) with a total of 414 knees (Group 1) and 296 patients (155 females, 141 males; mean age: 54.5±7.9 years; range, 43 to 80 years) with a total of 408 arthritic knees (Group 2) who met the inclusion criteria and underwent evaluation using digital long-leg radiographs between January 2019 and July 2023. Mechanical lateral distal femoral angle and medial proximal tibial angle were measured. Subsequently, the arithmetic hip-knee-ankle angle (aHKA) and joint line obliquity (JLO) were calculated. Based on the results obtained, participants in both groups were categorized according to the CPAK classification.

Results: In Group 1, the mean aHKA was 0.3°±2.5°, and the mean JLO was 175.2°±3.5°. In Group 2, the mean aHKA was -1.4°±3.9°, and the mean JLO was 174.6°±3.7°. The most common CPAK type in healthy individuals (Group 1) was type 2 (41.5%), followed by type 3 (14.7%) and type 1 (14.5%). In arthritis patients (Group 2), the most common CPAK type was type 2 (31.6%), followed by type 1 (28.2%) and type 3 (13.5%).

Conclusion: The CPAK classification serves as an important guide for categorizing lower extremity alignment. In the Turkish population, healthy individuals most commonly exhibited CPAK type 2, 3, and 1 alignments, respectively, while osteoarthritic patients predominantly displayed CPAK type 2, 1, and 3 alignments.

Keywords: Coronal Plane Alignment of the Knee classification, knee alignment, knee arthroplasty, Turkish population.

The long-term functional outcomes and satisfaction of total knee arthroplasty performed based on mechanical alignment have been well-documented for many years.[5,6] In mechanical alignment, bone

cuts are made perpendicular to the mechanical axis to bring the lower extremity alignment into a neutral position. This is argued to prevent patellar instability, equalize load distribution in the mediolateral direction, and prevent polyethylene wear and early prosthesis loosening.[7] Subsequently, Bellemans et al.[8] reported that a natural varus alignment of >3°, defined as constitutional varus, generally occurs in 32% of males and 17% of females. Therefore, it has been suggested that total knee arthroplasty performed in neutral (mechanical) alignment could result in overcorrection in some patients. It has been emphasized that less correction may yield better functional results compared to neutral alignment.[9] Hence, applying arthroplasty in mechanical alignment for everyone, disregarding soft tissue balance, may not provide the same functional and satisfactory results for all patients. This has led to the definition of alternative alignments, including anatomical, adjusted mechanical, kinematic, and restricted kinematic alignment techniques.[10,11]

Recently, the Coronal Plane Alignment of the Knee (CPAK) classification was introduced to the literature by MacDessi et al.[12] In this classification, lower extremity alignment is divided into nine groups based on the arithmetic hip-knee-ankle angle (aHKA) and joint line obliquity (JLO). Subsequently, through CPAK studies conducted in different countries, it has been reported that lower extremity alignment varies across populations.[13]

This study aimed to phenotype young, healthy individuals and patients with arthritic knees in the Turkish population according to the CPAK classification. The study primarily assessed whether there was a difference in CPAK classification between young, healthy individuals and individuals with arthritic knees in the Turkish population. The study also determined whether there was a difference in coronal plane lower extremity alignment between the Turkish population and other populations.

PATIENTS AND METHODS

This retrospective cross-sectional cohort study was conducted at the Istanbul Training and Research Hospital, Department of Orthopedics and Traumatology. The study included healthy individuals (Group 1) and patients with arthritic knees (Group 2) who presented to our high patient volume institution between January 2019 and July 2023. Standard long-leg radiographs (LLRs) of all participants were evaluated from the digital radiology system (PACS; picture archiving communication systems). Inclusion criteria for Group 1 were individuals aged between 20 and 45 years with no knee joint complaints who sought medical examination for employment purposes. In Group 2, individuals with knee joint pain symptoms and radiological evidence of Kellgren-Lawrence grade 3-4 osteoarthritis with primary gonarthrosis were included. Individuals with congenital anomalies, sequelae of poliomyelitis, traumatic arthritis, limb length discrepancy, a history of lower extremity fractures, orthopedic surgical history with implantation due to fractures, a history of hip or knee arthroplasty, lower extremity deformities, and amputation history were excluded from the study. Of a total of 2,437 radiological evaluations, 414 knees of 207 patients (109 males, 98 females; mean age: 32.9±8.4 years; range, 20 to 45 years) in Group 1 and 408 knees of 296 patients (155 females, 141 males; mean age: 54.5±7.9 years; range, 43 to 80 years) in Group 2 met the criteria.

The PACS of the hospital information management system (PROBEL, Izmir, Türkiye) was used for radiological measurements. All measurements were made by two senior surgeons who blinded to the demographic and group information of participants. In case of disagreement among the examiners, remeasurements were made until consensus was reached. For standard LLR imaging, patient is placed in front of the long-leg scanogram frame in a bipedal stance with the patella facing forward. Digital cassette

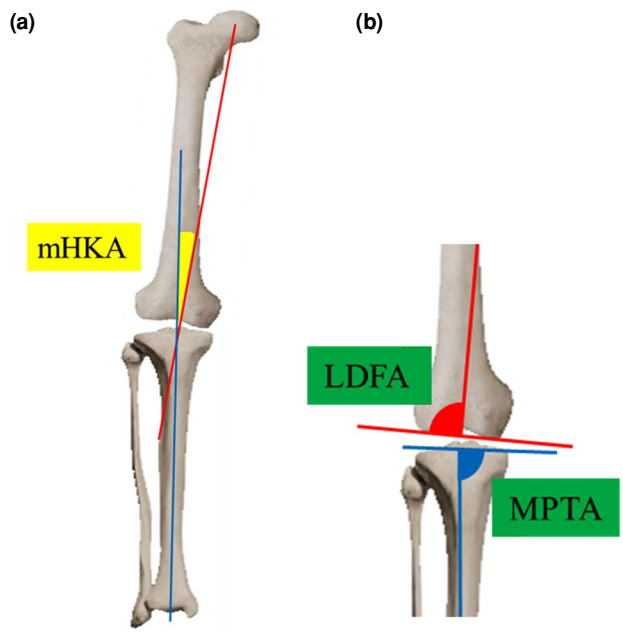

FIGURE 1. (a) Mechanical Hip-Knee-Angle (mHKA) measurement. **(b)** Mechanical Lateral Distal Femoral Angle (LDFA) and Mechanical Medial Proximal Tibial Angle (MPTA) measurement.

is used to take the radiographs, with the X-ray source positioned at a fixed distance of 180 cm from the scanogram frame. The following measurements, as described by Paley[14] in standard LLRs, were performed (Figure 1): mechanical hip-knee-angle, the angle between the mechanical axes of the femur and tibia; mechanical lateral distal femoral angle (LDFA), the angle between the mechanical axis of the femur and the distal femoral joint line; mechanical medial proximal tibial angle (MPTA), the angle between the mechanical axis of the tibia and the proximal tibial joint line.

Subsequently, the aHKA and JLO used in the CPAK classification were calculated (Figure 2).[12] The aHKA is calculated as aHKA=MPTA-LDFA. A negative aHKA indicates varus alignment, while a positive aHKA indicates valgus alignment. The JLO is calculated using the formula JLO=MPTA+LDFA, describing the horizontal relationship between the joint line and the ground. Joint line obliquity is labeled as "parallel" or "neutral" when it equals 180°, "apex proximal" when >180°, and "apex distal" when <180°. The CPAK classification consists of nine groups determined based on aHKA and JLO. In the CPAK classification, neutral alignment is defined as aHKA between +2° and –2°, varus alignment as aHKA <–2°, and valgus alignment as aHKA >+2°. The orientation of the joint line is defined as "neutral" when JLO is between 177° and 183°, "apex distal" when JLO is <177°, and "apex proximal" when JLO is >183°.

Statistical analysis

Data were analyzed using IBM SPSS version 25.0 software (IBM Corp., New York, NY, USA). Descriptive statistics were expressed as mean, standard deviation, median, minimum, and maximum values for numerical variables and with numbers and percentages for categorical variables. Comparisons of the numerical variables in two independent groups were made using Student's t-test

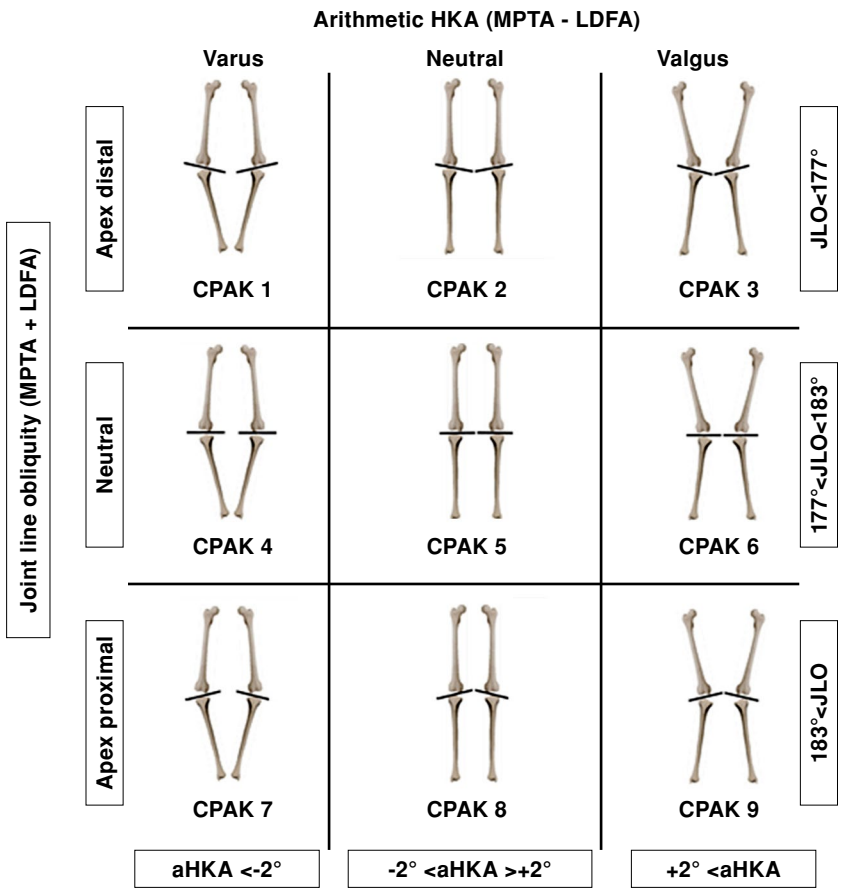

FIGURE 2. Coronal plane alignment of the Knee classification.

HKA: Hip-knee-ankle; LDFA: Lateral distal femoral angle; CPAK: Coronal Plane Alignment of the Knee; MPTA: Mechanical medial proximal tibial angle; JLO: Joint line obliquity; aHKA: Arithmetic hip-knee-ankle angle.

for data with normal distribution. The difference of categorical variables in independent groups was examined with the chi-square test. The intraclass correlation coefficient (ICC) was employed to assess interobserver agreement pertaining to the LDFA and MPTA angle measurements. Two-way random mode was used to calculate the ICC with a 95% confidence interval. The ICC was interpreted as follows: below 0.50, poor; between 0.50 and 0.75, moderate; between 0.75 and 0.90, good; above 0.90, excellent. A p-value <0.05 was considered statistically significant.

RESULTS

The demographic characteristics and radiological evaluation results of the study groups are presented in Table I. According to the results obtained in Group 1, healthy individuals had neutral or constitutional varus alignment of the lower extremity with the apex-distal joint line. However, while the mean aHKA was 1.0°±2.6° and JLO was 176.4°±3.5° in healthy females, they were -0.4°±2.1° and 174.0°±3.1° in healthy males, respectively. It was determined by these findings that females had valgus alignment, and males had varus alignment. Nevertheless, the joint line was similar in both groups, with an apex distal.

In Group 2, the results showed that patients with arthritic knees had varus alignment with the apex-distal joint line. Among female patients, the mean aHKA was –1.1°±3.8°, and the mean JLO was 174.7°±4.1°. In male patients, these values were –2.2°±4.1° and 174.2°±3.4°, respectively. According to these findings, male patients had more varus alignment than female patients, and the joint line was apex distal in both sexes.

TABLE I
Demographic characteristics of the groups

	Group 1 (n=207)				Group 2 (n=296)				
Parameters	n	%	Mean±SD	Min-Max	n	%	Mean±SD	Min-Max	*p*
Age (year)			32.9±8.4	20-45			54.5±7.9	43-80	<0.001*
Sex									0.235**
Female	98	47.3			155	52.4			
Male	109	52.7			141	47.6			
LDFA			88.0°±2.3°				88.0°±2.9°		0.874 *
MPTA			87.2°±1.9°				86.6°±2.6°		<0.001 *
aHKA			0.3°±2.5°				-1.4°±3.9°		<0.001 *
JLO			175.2°±3.5°				174.6°±3.7°'		0.012*

SD: Standard deviation; LDFA: Lateral distal femoral angle; MPTA: Mechanical medial proximal tibial angle; aHKA: Arithmetic hip-knee-ankle angle; JLO: Joint line obliquity; * Student's t test; ** Chi-squared test.

TABLE II
Distribution of groups according to the CPAK classification

	Group 1 (n=414)		Group 2 (n=408)		
CPAK groups	n	%	n	%	*p*
1	60	14.5	115	28.2	<0.001
2	172	41.5	129	31.6	0.004
3	61	14.7	55	13.5	0.618
4	21	5.1	42	10.3	0.006
5	49	11.8	50	12.3	0.915
6	45	10.9	10	2.5	<0.001
7	0	0.0	4	1.0	0.060
8	2	0.5	0	0.0	0.499
9	4	1.0	3	0.7	>0.999

CPAK: Coronal Plane Alignment of the Knee; * Fisher's Exact test.

Both the LDFA and MPTA measurements demonstrated significant interobserver correlations, with coefficients of 0.939 and 0.931, respectively, as well as significant intraobserver correlations, with coefficients of 0.939 and 0.928, respectively.

In Group 1, it was found that the most common CPAK alignment was type 2 (41.5%), followed by type 3 (14.7%) and type 1 (14.5%; Table II). The scatter graph for Group 1 is shown in Figure 3. Coronal Plane Alignment of the Knee type 2 was found to be the most common type in both males and females in Group 1 (33.0% and 50.0%, respectively). However, the second most frequently observed alignment was type 1 CPAK (21.2%) in males, while it was type 6 CPAK (19.4%) in females.

In Group 2, it was observed that the most common CPAK alignment was type 2 (31.6%), followed by type 1 (28.2%) and type 3 (13.5%; Table II). The scatter graph for Group 2 is shown in Figure 4. When evaluated by sex in Group 2, CPAK type 2 was most frequently observed in females (31.8%), and type 1 was most frequent in males (36.7%). Additionally,

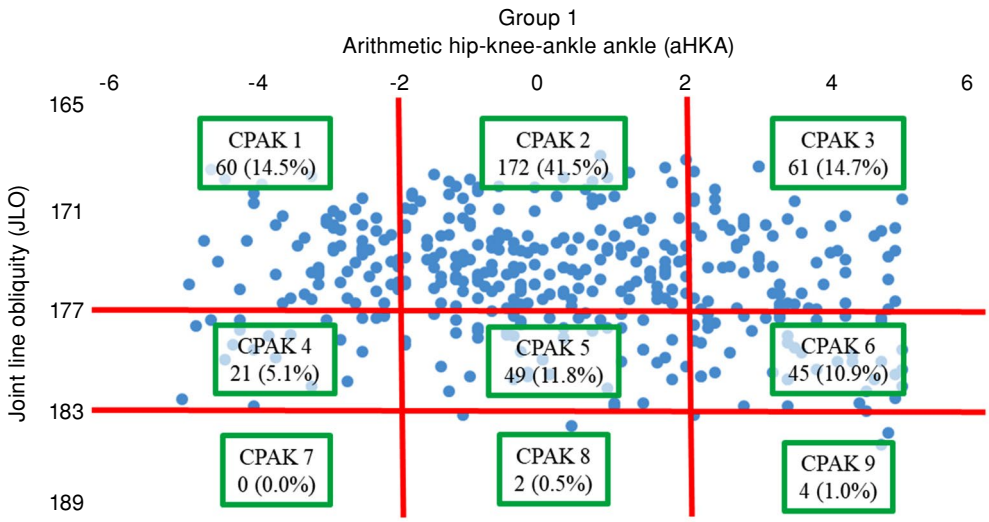

FIGURE 3. Scatter graph of CPAK classification in the healthy individual group (Group 1).
CPAK: Coronal Plane Alignment of the Knee.

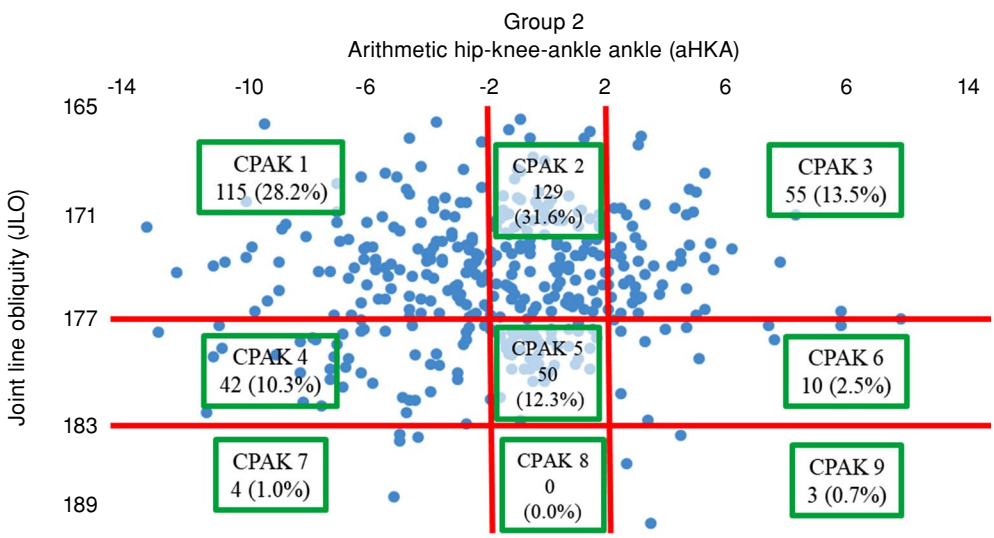

FIGURE 4. Scatter graph of CPAK classification in the arthritic patient group (Group 2).
CPAK: Coronal Plane Alignment of the Knee.

the second most common alignment in females was CPAK type 1 (24.3%), while in males it was type 2 (31.3%).

DISCUSSION

This study is significant as the first study on CPAK classification in the Turkish population; based on the results, it was determined that in both healthy individuals and arthritic patients in the Turkish population, the most common CPAK alignment was type 2 (neutral alignment, apex distal joint line orientation), accounting for 41.5% and 31.6%, respectively.[15] The second most frequently observed alignment was type 3 (14.7%) in healthy individuals, while it was type 1 (28.2%) in the arthritic patient population.

Research aimed at improving both functional outcomes and patient satisfaction following total knee replacement continues to be popular. With the developments in implant designs, the effect of lower extremity coronal alignment on postarthroplasty results is of interest. Total knee arthroplasty performed with mechanical alignment causes an acute change in the lower extremity alignment of patients. This increases the effort required for patients to adapt to both their implants and the new alignment after arthroplasty. The individual alignment approach has come to the fore with "constitutional varus."[8,16] As a result, it was emphasized that kinematic alignment-based total knee arthroplasty can be an alternative to mechanical alignment-based procedures.[17]

Classifications are useful in creating a common language among healthcare professionals. In this regard, the CPAK classification has become a valuable guide for orthopedic surgeons in highlighting both interindividual and interpopulation differences in lower limb alignment. It plays a significant role in preoperative planning, demonstrating its impact on postoperative outcomes. The initial reference study that defined CPAK was conducted with participants from Australia (comprising the arthritic patient group) and Belgium (comprising the group of healthy individuals).[12] In both healthy and arthritic individuals, type 2 (neutral alignment with apex distal joint line orientation) was shown to be the most common (39.2% and 32.2%, respectively), followed by type 1 (varus alignment with apex distal joint line orientation; 26.4% and 19.4%, respectively).

Subsequent studies have reported lower limb alignments in different populations. In a study examining the Indian population, the most common types were type 2 (25.6%) and type 1 (21.2%) in healthy individuals, while the arthritic population had type 1 (58.8%) and type 4 (varus alignment and neutral joint orientation line; 18.2%), respectively.[18] Toyooka et al.[19] found that in the arthritic Japanese population, the most common CPAK alignments were type 1 (53.8%) and type 2 (25.4%).

In a recent study conducted in Taiwan, a healthy Asian population aged 20 to 70 years was evaluated, and it was found that the most common CPAK alignments were type 2 (39.3%) and type 1 (36.4%).[20] Additionally, in this study, due to a higher prevalence of varus alignment in the Asian population, they modified the original CPAK classification by accepting aHKA (anatomical hip-knee-ankle angle) as 0°±3° (the original CPAK classification specifies aHKA of 0°±2°). They also introduced the concept of actual JLO (aJLO; aJLO=90°–(LDFA+MPTA)/2) since they believed it better explained the relationship between the joint line and the ground. After modifying the CPAK measurements, the rate of neutral alignment in the Asian population increased from 4.7% (according to the original CPAK classification) to 25.7%.[20] The aJLO modification of the author can be supported by other studies in terms of showing the relationship between the joint line and the ground.

When the results of our study were compared with the literature, the coronal plane alignment of the healthy Turkish population was similar to the European, Indian, and Asian populations; on the other hand, while the pattern of the arthritic Turkish population is similar to the arthritic Australian and Asian populations, it is different from the Indian and Japanese populations.[15]

Huber et al.[21] examined the effect of sex on the knee alignment in an arthritic population by evaluating 8,739 cases. They emphasized that varus alignment was more prevalent in males, while neutral alignment and valgus alignment were more common in females. In males, the most frequent alignment types were type 1 (38.8%) and type 2 (27.3%), whereas in females, it was reported to be type 2 (27.3%) and type 3 (25.7%) in descending order. In our study, similarly, the most frequent alignment types in arthritic males were type 1 (36.7%) and type 2 (31.3%). However, in the female patient group, the most common types were type 2 (31.8%) and type 1 (24.3%).

In total knee arthroplasty performed based on mechanical alignment, the goal is to achieve a CPAK type 5 alignment, which corresponds to a neutral alignment and a joint line parallel to the ground. As

previously mentioned, attempting to obtain the same alignment in every patient, disregarding individual lower limb alignment, may not necessarily lead to uniform postoperative outcomes. For instance, the transition from CPAK type 1 or type 2 in a patient to CPAK type 5 postoperatively and, similarly, from CPAK type 4 to type 5 in another patient may not yield equivalent satisfaction and functional results due to changes in soft tissue balance these individuals possess. In fact, it has been reported that altering lower limb alignment phenotypes excessively in patients can have negative consequences.[22] Furthermore, it should be noted that the number of individuals in the general population who physiologically possess a neutral alignment and joint line orientation (CPAK type 5) is a minority. In our study, CPAK type 5 alignment constitutes 11.8% of healthy individuals and 12.3% of the arthritic patient group. In the reference CPAK study, 15.6% of healthy individuals and 14.6% of patients had type 5 alignment.[12] Mulpur et al.[18] and Toyooka et al.[19] reported figures of 19.6% and 3.4%, respectively, in arthritic populations. Further studies should aim to share the impact of preoperative and postoperative CPAK alignment changes on functional outcomes and patient satisfaction in the literature.

Although our study reached an adequate number of participants, its limitation as a single-center study restricts the generalizability of the results to the entire population. Conducting studies with the participation of multiple centers from different geographic regions in our country can provide results that more comprehensively reflect the Turkish population. Furthermore, long-term follow-ups of healthy individuals can be conducted to identify changes in lower limb alignments over time.

In conclusion, individual lower extremity alignment should be considered in preoperative planning to increase functional results and patient satisfaction in total knee arthroplasty. The CPAK classification serves as an important guide for surgeons, providing a common language. In the Turkish population, healthy individuals predominantly exhibit CPAK type 2, 3, and 1 alignments, while arthritic patient populations predominantly exhibit CPAK type 2, 1, and 3 alignments, respectively.

Ethics Committee Approval: The study protocol was approved by the Istanbul Training and Research Hospital Clinical Research Ethics Committee (date: 15.09.2023, no: 229). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Idea/Concept: A.Ş., T.G.; Design: A.Ş., B.P.; Control/supervision: B.P., E.Ç.; Data collection: A.Ş., M.E., S.S.; Analysis: A.Ş., S.S.; Literature review: A.Ş., M.E., S.S.; Writing the article: A.Ş.; Critical review: B.P., T.G.

Conflict of Interest: The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding: The authors received no financial support for the research and/or authorship of this article.

REFERENCES

1. Stotter C, Reiter E, Schretter W, Reuter P, Nehrer S, Klestil T. Influence of the femoral entry point for intramedullary alignment in total knee arthroplasty: A computer-aided design approach. Jt Dis Relat Surg 2022;33:294-302. doi: 10.52312/jdrs.2022.645.
2. Dong XH, Huang XH, Chen M, Chang YH, Ling M, Yang B. Three-dimensional morphometric differences of resected distal femurs and proximal tibias in osteoarthritic and normal knees. BMC Musculoskelet Disord 2021;22:1013. doi: 10.1186/s12891-021-04889-z.
3. Dalury DF, Pomeroy DL, Gorab RS, Adams MJ. Why are total knee arthroplasties being revised? J Arthroplasty 2013;28(8 Suppl):120-1. doi: 10.1016/j.arth.2013.04.051.
4. Bilgin E, Bombacı H, Turgut A, Kalenderer Ö, Kılınç BE, Adıyeke L, et al. How are clinical outcomes related to the deviation severity of the tibiofemoral mechanical axis on coronal plane following knee arthroplasty? J Clin Orthop Trauma 2019;10:91-5. doi: 10.1016/j.jcot.2017.08.019.
5. Slevin O, Hirschmann A, Schiapparelli FF, Amsler F, Huegli RW, Hirschmann MT. Neutral alignment leads to higher knee society scores after total knee arthroplasty in preoperatively non-varus patients: A prospective clinical study using 3D-CT. Knee Surg Sports Traumatol Arthrosc 2018;26:1602-9. doi: 10.1007/s00167-017-4744-y.
6. Ritter MA, Faris PM, Keating EM, Meding JB. Postoperative alignment of total knee replacement. Its effect on survival. Clin Orthop Relat Res 1994;299:153-6.
7. Jeffery RS, Morris RW, Denham RA. Coronal alignment after total knee replacement. J Bone Joint Surg [Br] 1991;73:709-14. doi: 10.1302/0301-620X.73B5.1894655.
8. Bellemans J, Colyn W, Vandenneucker H, Victor J. The Chitranjan Ranawat award: Is neutral mechanical alignment normal for all patients? The concept of constitutional varus. Clin Orthop Relat Res 2012;470:45-53. doi: 10.1007/s11999-011-1936-5.
9. Vanlommel L, Vanlommel J, Claes S, Bellemans J. Slight undercorrection following total knee arthroplasty results in superior clinical outcomes in varus knees. Knee Surg Sports Traumatol Arthrosc 2013;21:2325-30. doi: 10.1007/s00167-013-2481-4.
10. Howell SM, Howell SJ, Kuznik KT, Cohen J, Hull ML. Does a kinematically aligned total knee arthroplasty restore function without failure regardless of alignment category? Clin Orthop Relat Res 2013;471:1000-7. doi: 10.1007/s11999-012-2613-z.

11. Rivière C, Iranpour F, Auvinet E, Howell S, Vendittoli PA, Cobb J, et al. Alignment options for total knee arthroplasty: A systematic review. Orthop Traumatol Surg Res 2017;103:1047-56. doi: 10.1016/j.otsr.2017.07.010.
12. MacDessi SJ, Griffiths-Jones W, Harris IA, Bellemans J, Chen DB. Coronal Plane Alignment of the Knee (CPAK) classification. Bone Joint J 2021;103-B:329-37. doi: 10.1302/0301-620X.103B2.BJJ-2020-1050.R1.
13. Pagan CA, Karasavvidis T, Lebrun DG, Jang SJ, MacDessi SJ, Vigdorchik JM. Geographic variation in knee phenotypes based on the coronal plane alignment of the knee classification: A systematic review. J Arthroplasty 2023;38:1892-9.e1. doi: 10.1016/j.arth.2023.03.047.
14. Paley D. Radiographic assessment of lower limb deformities. In: Paley D, editor. Principles of deformity correction. Chapter 3. 1st ed. Berlin: Springer, 200. p. 31-60.
15. Atik OŞ. Writing for Joint Diseases and Related Surgery (JDRS): There is something new and interesting in this article! Jt Dis Relat Surg 2023;34:533. doi: 10.52312/jdrs.2023.57916.
16. Lustig S, Sappey-Marinier E, Fary C, Servien E, Parratte S, Batailler C. Personalized alignment in total knee arthroplasty: Current concepts. SICOT J 2021;7:19. doi: 10.1051/sicotj/2021021.
17. Lee YS, Howell SM, Won YY, Lee OS, Lee SH, Vahedi H, et al. Kinematic alignment is a possible alternative to mechanical alignment in total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 2017;25:3467-79. doi: 10.1007/s00167-017-4558-y.
18. Mulpur P, Desai KB, Mahajan A, Masilamani ABS, Hippalgaonkar K, Reddy AVG. Radiological evaluation of the phenotype of Indian osteoarthritic knees based on the Coronal Plane Alignment of the Knee Classification (CPAK). Indian J Orthop 2022;56:2066-76. doi: 10.1007/s43465-022-00756-8.
19. Toyooka S, Osaki Y, Masuda H, Arai N, Miyamoto W, Ando S, et al. Distribution of Coronal Plane Alignment Of The Knee Classification in patients with knee osteoarthritis in Japan. J Knee Surg 2023;36:738-43. doi: 10.1055/s-0042-1742645.
20. Hsu CE, Chen CP, Wang SP, Huang JT, Tong KM, Huang KC. Validation and modification of the Coronal Plane Alignment of the Knee classification in the Asian population. Bone Jt Open 2022;3:211-7. doi: 10.1302/2633-1462.33.BJO-2022-0001.R1.
21. Huber S, Mitterer JA, Vallant SM, Simon S, Hanak-Hammerl F, Schwarz GM, et al. Gender-specific distribution of knee morphology according to CPAK and functional phenotype classification: Analysis of 8739 osteoarthritic knees prior to total knee arthroplasty using artificial intelligence. Knee Surg Sports Traumatol Arthrosc 2023;31:4220-30. doi: 10.1007/s00167-023-07459-z.
22. Rak D, Klann L, Heinz T, Anderson P, Stratos I, Nedopil AJ, et al. Influence of mechanical alignment on functional knee phenotypes and clinical outcomes in primary TKA: A 1-year prospective analysis. J Pers Med 2023;13:778. doi: 10.3390/jpm13050778.