

ORIGINAL PAPER

Is the coronal plane alignment of the knee (CPAK) classification useful to plan individualized total knee arthroplasty surgery for the Spanish population? A critical analysis of the CPAK classification



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KEYWORDS

Coronal plane alignment knee classification (CPAK); Robotics; Total knee arthroplasty (TKA); Total knee replacement (TKR); Phenotype; Alignment

Abstract

Introduction: The CPAK classification aims to categorize knee phenotypes. The original study was based on Australian and Belgian population, but significant variation in CPAK distribution exists between different geographic areas. The primary objective is to evaluate knee phenotypes of osteoarthritic Spanish population based on the CPAK system. The secondary objective is to compare the Spanish CPAK distribution with that observed in the original study to analyse if proposing modifications is necessary when applying the classification to our population. Finally, we aim to critically analyse the utility of this classification to plan individualized TKA.

Methods: It is a cross-sectional observational study analysing radiological datasets from 121 patients with knee osteoarthritis treated with a Mako assisted TKA in three Spanish institutions. The preoperative lower limb CT-scan was used to measure the MPTA and LDFA of each patient. Then, the aHKA (MPTA – LDFA) and JLO (MPTA + LDFA) were calculated to categorize patients into the nine CPAK phenotypes.

Results: The commonest knee phenotypes of osteoarthritic Spanish population were the distal apex JLO CPAK types (74%: II (28%), I (23%) and III (23%)). No patient presented a proximal apex type (VII, VIII and IX). The 30% of the patients had a varus alignment and 26% a valgus. No relevant differences were found between the Spanish CPAK distribution and that observed in the original study.

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PALABRAS CLAVE

Coronal plane alignment knee classification (CPAK);
Robótica;
Artroplastia total de rodilla;
Prótesis total de rodilla;
Fenotipo;
Alineación

Conclusions: No modifications to the CPAK classification should be necessary for the Spanish population. The CPAK classification can be useful to describe and categorize osteoarthritic patients. However, relevant limitations have been found to the classification, questioning its utility to plan and guide individualized TKA surgery.

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¿Es útil la clasificación CPAK (*Coronal Plane Alignment of the Knee*) para planificar la cirugía individualizada de artroplastia total de rodilla en la población española? Un análisis crítico de la clasificación CPAK

Resumen

Introducción: La clasificación CPAK tiene como objetivo categorizar los fenotipos de rodilla. El estudio original se basó en población australiana y belga, pero existe una variación significativa en la distribución CPAK entre diferentes áreas geográficas. El objetivo principal es evaluar los fenotipos de rodilla en población española con artrosis utilizando el sistema CPAK. El objetivo secundario es comparar la distribución CPAK española con la observada en el estudio original para analizar si es necesario proponer modificaciones al aplicar la clasificación a nuestra población. Finalmente, se analizará críticamente la utilidad de esta clasificación al planificar una ATR individualizada.

Métodos: Estudio observacional transversal que analiza datos radiológicos de 121 pacientes con artrosis de rodilla tratados mediante ATR asistida por Mako en tres instituciones españolas. Se utilizó la tomografía computarizada preoperatoria de la extremidad inferior para medir el MPTA y el LDFA de cada paciente. Posteriormente, se calcularon el aHKA (MPTA-LDFA) y JLO (MPTA+LDFA) para categorizar a los pacientes en los nueve fenotipos CPAK.

Resultados: Los fenotipos de rodilla más comunes en la población española con artrosis fueron los tipos CPAK de ápex distal (74%: II (28%), I (23%) y III (23%). Ningún paciente presentó un fenotipo con ápex proximal (VII, VIII y IX). El 30% de los pacientes tenían una alineación en varo y el 26%, en valgo. No se encontraron diferencias relevantes entre la distribución CPAK española y la observada en el estudio original.

Conclusiones: No deberían ser necesarias modificaciones a la clasificación CPAK para la población española. La clasificación CPAK puede ser útil para describir y categorizar a los pacientes con artrosis. Sin embargo, se han encontrado limitaciones relevantes en la clasificación, cuestionando su utilidad para planificar y guiar la cirugía de ATR individualizada.

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Introduction

There is a growing interest in individualized alignment techniques for total knee arthroplasty (TKA) surgery.^{1–3} These philosophies consider that patient constitutional (prearthritic) anatomy should be taken into account when performing a knee replacement to achieve more natural knee kinematics and to improve soft tissue balance.^{2–4} However, uncertainty still exists in estimating patient native anatomy, understanding knee phenotypes and determining which alignment strategy is best suited for each patient.

In 2021, MacDessi et al. proposed the coronal plane alignment of knee (CPAK) classification.⁵ It aims to be a simple system for predicting prearthritic knee alignment and categorizing knee phenotype in the coronal plane. Knees are classified into nine phenotypes based on two critical variables: the arithmetic hip-knee-ankle angle (aHKA) and joint line obliquity (JLO), which can be obtained through a mathematical formula after measuring the radiological medial

proximal tibial angle (MPTA) and lateral distal femoral angle (LDFA). The JLO is defined as (MPTA + LDFA); values >183 indicate a proximal apex JLO, while <177 indicate a distal apex JLO. The aHKA, which theoretically predicts the prearthritic alignment,^{6–8} is defined as (MPTA – LDFA). The boundaries of neutral alignment were set as 0 ± 2 .

The original CPAK study from MacDessi was based on osteoarthritic Australian patients and healthy Belgian volunteers.⁵ However, a significant variation in CPAK distribution among different geographic areas has been observed.⁹ Understanding the specific population distribution in knee phenotypes is important to plan for more personalized TKA procedure. The CPAK classification can be adapted to the specific distribution and characteristics of a population. Hsu et al.¹⁰ observed that Asian population has more varus and wider alignment distribution and, therefore, they proposed to enlarge the boundaries of neutral aHKA. To our knowledge, CPAK distribution in the Spanish population has not been explored yet.

The primary objective of this study is to evaluate the phenotype of patients with osteoarthritic knees in a sample of Spanish population based on the CPAK system. The secondary objective is to compare the Spanish CPAK distribution with the distribution observed in the original study to analyse if modifications should be done to the classification for the Spanish. Finally, we aim to discuss and critically analyse the utility of the CPAK classification to plan individualized TKA.

Methods

Study design

After obtaining the local Ethical Committee approval (24/043), a multicentric cross-sectional observational study was performed in three medical institutions from Spain (iMove Traumatología - Clínica Tres Torres, Hospital del Mar de Barcelona, Hospital Sant Joan de Déu de Manresa). Radiological datasets from patients with knee osteoarthritis treated with a TKA between 2022 and 2024 were analysed. Inclusion criteria were: (a) patients with primary knee osteoarthritis who underwent a TKA, (b) surgery performed using the Mako robotic system (Stryker Corporation, Kalamazoo, USA) and with preoperative lower limb CT-scan available and (c) operated on between 2022 and 2024 in one of the Spanish institutions participating in the study. Exclusion criteria were: (a) TKA secondary to infection, fracture, osteotomy or malignancy, (b) revision surgery or (c) severe bone loss. Only the limb undergoing surgery was analysed in this study.

Outcomes variables

Demographic data

Age, gender and diagnosis to indicate a TKA.

Radiological data

Mako assisted TKA systematically requires a preoperative CT-scan to create a 3D model that guides the preoperative planning and intraoperative steps. The CT-based scanning protocol (PN 200004) focuses on minimizing radiation dose and involves a spiral continuous scan of the hip, knee and ankle.¹¹ The scan is processed by a Mako segmentation specialist and a Mako product specialist to perform the segmentation, anatomical landmarks identification and measurements (protocol 214928). The knee scan is segmented using 1 mm slices. Anatomical bone landmarks (including hip centre, femur/tibia knee centre, ankle centre, distal femur medial/lateral and proximal tibia medial/lateral) were identified in the scan. The joint centres were imputed based on three-dimensional analysis of the images. Distal femoral landmarks were set at the most distal surface of each condyle. For the proximal tibia, the sagittal landmark was located at a point two-thirds posterior from the anterior cortex of each plateau, which represents the area with more contact stress.¹² Using these anatomical landmarks, the MPTA (medial angle formed between the tibial mechanical axis and the joint line of the proximal tibia) and LDFA (lateral angle formed between the femoral mechanical axis and the joint line of the distal femur) of

each patient were measured. CT-derived values for coronal alignment were obtained within the robotic system software. By their nature and methodology, the procedure is identical each time, so independent measurements by separate observers were not necessary.¹² However, all the cases were reviewed by a specialist knee orthopaedic surgeon.

The use of CT-scan to measure MPTA and LDFA has demonstrated to be more precise, reproducible and to have a good correlation with long leg radiographs.¹³ CT overcomes difficulties with positioning, rotation, habitus and contractures when assessing the coronal alignment.¹²

CPAK analysis

Using the measured MPTA and LDFA of each patient, the aHKA (MPTA – LDFA) and JLO (MPTA + LDFA) were calculated. These two arithmetic variables allow to categorize patients into nine knee phenotypes (I–IX) according to the CAPK classification.⁵ For JLO, values >183 indicate a proximal apex obliquity, 177–183 a neutral apex and <177 a distal apex. While for aHKA, values >182 indicates a valgus alignment, 178–182 a neutral alignment and <178 a varus alignment.

All the patients included in the study were categorized into nine knee phenotypes according to the CPAK classification. The CPAK distribution of our study population was analysed. Finally, the CPAK distribution observed in our study based on Spanish osteoarthritic patients was compared with the distribution reported in the original article with an Australian osteoarthritic cohort.⁵ The Belgian cohort was not considered for the comparison because it was based on healthy population.

Statistical analysis

Categorical variables were summarized as frequencies and percentages. Mean and standard deviation were calculated for continuous variables. Groups were compared using the Student *T*-test and Mann–Whitney *U* test, according to normality. The Pearson test was used to perform the correlation analysis. All *p*-values were two-tailed and <0.05 was considered as statistically significant. The analysis was performed using Stata® v. 14 software (StataCorp, College Station, USA).

Results

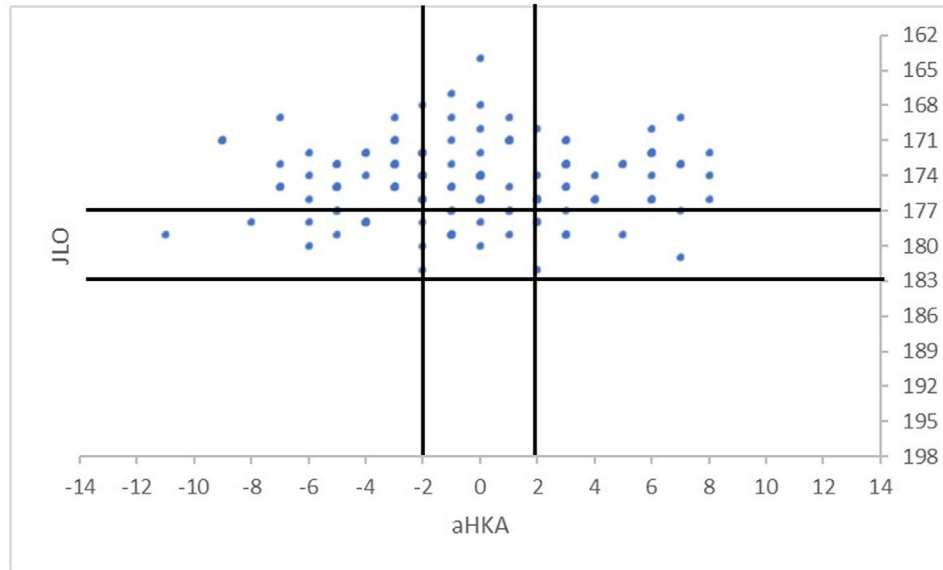
One hundred twenty-one patients were included in the study. Mean age was 71.7 ± 7.5 years and there were 73 women (60%) and 48 men (40%). Mean measured MPTA was $87.1 \pm 2.6^\circ$ and LDFA was $87.4 \pm 2.7^\circ$. An inverse correlation between MPTA and LDFA, $r = -0.24$ ($p = 0.012$) was observed.

The mean of aHKA was -0.4 ± 4.2 , indicating a mean native alignment between neutral and constitutional varus. Mean calculated JLO was 174.5 ± 3.3 ; joint line apex was distal in the overall study population. The distribution of aHKA and JLO is shown in Table 1.

The distribution of knee phenotypes according to the CPAK classification is shown in Fig. 1. The commonest knee phenotypes were those with a distal apex JLO (74%): types II (28%), I (23%) and III (23%). On the other hand, no patient presented a proximal apex JLO: types VII, VIII and IX (0%).

Table 1 Distribution of aHKA and JLO according to the CPAK classification of the Spanish population with knee osteoarthritis.

aHKA		
<−2 (varus)	−2 to 2 (neutral)	>2 (valgus)
36 (29.8%)	54 (44.6%)	31 (25.6%)
JLO		
<177 (distal apex)	177–183 (neutral apex)	>183 (proximal apex)
89 (73.6%)	32 (26.4%)	0 (0%)

**Figure 1** Distribution of knee phenotypes of the Spanish population sample with knee osteoarthritis analysed in this study according to the CPAK classification.

The 30% of the patients showed a varus lower limb alignment (aHKA <−2) and the 26% a valgus (aHKA >2).

No statistically significant differences were found when comparing the CPAK distribution in Spanish patients with knee osteoarthritis and the CPAK distribution reported in the original article with osteoarthritic Australian population⁵ ($p > 0.05$). Additionally, the CPAK distribution of osteoarthritic population from different countries is shown in Table 2.

No differences between women and men were found for MPTA, LDFA, aHKA, JLO nor CPAK distribution ($p > 0.05$).

Discussion

The most important finding of the study is that the commonest knee phenotypes of osteoarthritic Spanish population were the distal apex JLO CPAK types (74%: type II (28%), I (23%) and III (23%)), while no patient presented a proximal apex JLO (types VII, VIII and IX). The 30% of the patients showed a varus lower limb alignment and the 26% a valgus. The CPAK distribution found in osteoarthritic patients from Spain was equivalent to the distribution reported in Australia.

The original CPAK study analysed knee phenotypes of the Australian and Belgian population.⁵ Later, Pagan et al.⁹ observed relevant variations in CPAK distributions between

different geographic areas. Among arthritic knees, there was a significant difference in the prevalence of CPAK types I and II between samples from Australia (I – 19.4% and II – 32.2%), France (I – 33.4% and II – 19.5%), Japan (I – 53.8% and II – 25.4%) and India (I – 58.8% and II – 13.8%). Other studies have also observed that the Asian population presents a varus alignment and cases with severe varus more usually than Westerns.^{10,14–16} Liu et al. stated that the CPAK distribution is too concentrated when used in Chinese population.¹⁵ For this reason, Hsu et al. proposed to modify the CPAK classification for this specific population, enlarging the boundaries of neutral aHKA ($0 \pm 3^\circ$).¹⁰ However, phenotypes distributions are more homogeneous regarding JLO. All the studied osteoarthritic populations present a very high predominance of distal apex JLO (Japan 87.4%,¹⁶ China 80.2%,¹⁵ Austria 76.3%,¹⁷ China 75.7%,¹⁴ India 74%,¹⁸ Turkey 73.3%,¹⁹ Australia 67%,⁵ France 63.5%²⁰ and Germany 61.8%²¹), while the proximal apex obliquity is extremely rare (<5%) (Table 2).

Due to the high heterogeneity in CPAK distributions, it is important to study the specific Spanish distribution in knee phenotypes. It may help surgeons to plan for more personalized TKA procedure, optimizing component positioning considering constitutional alignment and joint line orientation. Our osteoarthritic Spanish sample also presented a high prevalence (74%) of distal apex JLO CPAK types (II –

Table 2 Knee phenotypes distribution according to the CPAK classification in osteoarthritic population of different countries.

CAPK type	Spain Pujol et al. (current study)	Australia MacDessi et al.	Australia Tarassoli et al.	Japan Toyooka et al.	France Sappey-Mariniér et al.	India Mulpur et al.	China Gao et al.	China Liu et al.	Turkey Senel et al.	Germany Graichen et al.	Austria Huber et al.
I	23.1%	19.4%	33%	53.8%	33.4%	58.8%	43.6%	53.9%	28.2%	20.5%	28.1%
II	28.1%	32.2%	27.3%	25.4%	19.5%	13.8%	21.6%	17.1%	31.6%	30.8%	27.3%
III	23.1%	15.4%	15.9%	8.2%	10.6%	1.4%	10.5%	9.2%	13.5%	10.5%	20.9%
IV	8.3%	9.8%	3.7%	7.2%	10.2%	18.2%	11.5%	12.7%	10.3%	12.6%	6.2%
V	11.6%	14.6%	5.7%	4.4%	18.9%	3.4%	7.5%	2.3%	12.3%	17.8%	7.5%
VI	5.8%	7.4%	12.5%	1.0%	6.3%	1.0%	3.8%	3.0%	2.5%	7.7%	8.6%
VII	0%	0.6%	0%	0%	0.4%	2.8%	1.1%	0.9%	1.0%	0%	0.3%
VIII	0%	1.6%	1.1%	0%	0.6%	0.6%	0%	0.2%	0%	0%	0.3%
IX	0%	0.4%	1.1%	0%	0.1%	0%	0.4%	0.7%	0.7%	0.5%	0.7%

28%, I – 23% and III – 23%), while no patient presented a proximal apex type (VII, VIII and IX). Our varus alignment prevalence was 30% (mean aHKA was -0.4 ± 4.2), making our CPAK phenotype distribution similar to other European/Australian populations and different from Asian studies findings. In fact, the frequencies of the different CPAK types were equivalent when comparing our Spanish population with the original CPAK study ($p > 0.05$).⁵ It is relevant because the boundaries of the CPAK matrix are not arbitrary, they were determined to be one standard deviation for the mean aHKA and JLO of their study population. Since the original CPAK boundaries categorize our Spanish patients similarly to the original distribution, no modifications to the classification should be necessary for the Spanish population.

The CPAK classification has become a popular guide for planning personalized TKA procedures.¹⁹ It aims to be a simple system for predicting prearthritic alignment and categorizing knee types.⁵ It informs of both lower limb alignment and joint obliquity. It is easy-to-use since only two radiological measurements (MPTA and LDFA) are necessary to classify a patient in the CPAK matrix. Due to its international spread, it can also be useful to analyse interpopulation differences in knee phenotypes.⁹ Although this classification can be helpful to understand the population distribution, it presents some relevant limitations:

First, some would argue that this classification is too simple. It only evaluates the coronal plane in extension, but the coronal-flexion, sagittal and rotational alignment is neglected. Furthermore, the weight-bearing effect and soft tissue laxity are neither considered. The classification uses a mathematical formula based solely on two arithmetic parameters (aHKA and JLO), describing only nine potential knee phenotypes. Therefore, the complexity and variability of knee alignment and anatomy may be oversimplified through the CPAK classification. Hirschmann et al.²² proposed another classification based on functional knee phenotypes that considers HKA and tibial/femoral joint lines. Therefore, the JLCA is incorporated into the analysis too. This classification leads to 125 potential combinations. They defend that it is able to describe the highly variable coronal alignment and presents all the important anatomical information, while each CPAK group should

not be viewed as a homogeneous unit since multiple phenotypes exist within each type.^{21,22} Jenny and Baldairon compared both classifications and concluded that they are not correlated; each provides different and potentially complementary information.²³

Second, the CPAK distribution is extremely heterogeneous. In our study of 121 osteoarthritic Spanish patients, the 74% of them showed a distal apex JLO phenotype (I, II and III) while none presented a proximal apex (VII, VIII and IX). This finding has been corroborated in multiple studies analysing the CPAK distribution among osteoarthritic population worldwide (Table 2).^{5,14,16,18–21} Since the majority of patients are concentrated in only a few phenotypes, the classification may be less effective for categorizing patients into distinct groups and guiding personalized treatment. In our analysis, we found a negative correlation between MPTA and LDFA ($r = -0.24$); when the value of one parameter increases, the other decreases. Therefore, it is difficult that the sum of both parameters reaches a high value (mean JLO was 174.5 ± 3.3). It can explain the rarity of proximal apex cases (MPTA + LDFA > 193).

Third, concerns have risen questioning if the aHKA really predicts the native alignment and if the JLO indicates the real knee obliquity. The CPAK group defend that aHKA effectively estimates constitutional alignment. In a cross-sectional radiological analysis they compared 500 arthritic knees and 500 healthy knees⁶; no significant differences in aHKA nor CPAK distribution were found. In another matched-pairs study they included patients with asymmetric knee osteoarthritis. They found no differences when comparing the aHKA of the osteoarthritic knee with the HKA of the contralateral healthy knee.⁷ Nomoto et al.⁸ also defended that CPAK can predict native HKA. They followed 60 knees during eight years and found no modification in aHKA nor CPAK types. However, as pre-osteoarthritis imaging is only exceptionally available, this method is only an approximation, and the reality of native anatomy remains unknown.²³ The CPAK has also some limitations when assessing the knee JLO.²⁴ It only takes into account proximal tibia and distal femur bony anatomy, but soft tissue laxity, weight-bearing effect and other articulations are not considered. Furthermore, the CPAK-JLO value may be misleading; it does not express the real JLO but the relationship between MPTA and

LDFA. Therefore, Hsu et al.¹⁰ modified the CPAK-JLO formulae to reflect the actual JLO ($90^\circ - (\text{LDFA} + \text{MPTA})/2$). Şahbat et al.²⁵ compared two different methods to measure knee JLO and concluded that the CPAK classification detected the real knee apex position in less than half of the knees.

Fourth, the clinical relevance of maintaining the CPAK type has not been demonstrated yet.²³ Neither is clear if CPAK phenotype predicts knee behaviour during TKA surgery, guides treatment or prognosis. Lustig et al.²⁰ defend that a more personalized strategy should be followed to potentially improve TKA, however, they analysed 1078 knee replacements and found that changing the CPAK type did not influence clinical outcomes. Similarly, Streck et al.²⁶ analysed 158 knees with valgus osteoarthritis and concluded that the individual CPAK phenotype did not influence the outcome in this subgroup of patients. On the other hand, Franceschetti et al.,²⁷ studied 180 mechanically aligned TKA and observed that knees with a varus CPAK phenotype showed significantly inferior functional results.

This study is not without limitations: (1) The sample size may be relatively small, although it is similar to previous articles. Furthermore, all the patients were recruited from the same Spanish region. These factors may limit the capacity of the study to exactly represent the CPAK distribution of the Spanish population. However, patients from three different centres were included, increasing the representability of our analysis. (2) The CPAK distribution of Spanish healthy population was not analysed. We decided to include only osteoarthritic patients because in this group the CPAK classification may have a clinical repercussion (e.g. planning personalized TKA). (3) The study was based on bone morphology and radiological data; soft tissue behaviour and clinical implications of the CPAK distribution were not analysed. However, a strength of the study is that radiological parameters were measured using the routine preoperative CT-scan. Although the system can have some degree of error, it has demonstrated to be more precise and reproducible, overcoming the difficulties with positioning, rotation, habitus and contractures.

Conclusions

The commonest knee phenotypes of osteoarthritic Spanish population were the distal apex JLO CPAK types (74%: II (28%), I (23%) and III (23%)). No patient presented a proximal apex type (VII, VIII and IX). The 30% of the patients had a varus alignment and the 26% a valgus. No relevant differences were found between the Spanish CPAK distribution and the original study; therefore, no modifications to the classification should be necessary for the Spanish population.

The CPAK classification can be useful to describe and categorize our Spanish population. However, relevant limitations have to be taken into account for this classification, questioning its utility to plan and guide individualized TKA surgery.

Level of evidence

Level of evidence III.

CRedit authorship contribution statement

All authors contributed equally to this work. All authors contributed to the study conception and design, material preparation, data collection and analysis. The first draft of the manuscript was written by OP, and all authors commented on the versions of the manuscript. All authors read and approved the final manuscript.

Consent to participate and publication

The study was granted exemption from requiring patients written consent by the Center Ethics Committee because it a retrospective study which only utilizes radiological datasets.

Ethical approval

The study was approved by the Center Ethics Committee of the three institutions. The study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki.

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Conflicts of interest

None declared.

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