CORONAL PLANE ALIGNMENT OF THE KNEE (CPAK) CLASSIFICATION AND PHENOTYPING - A PERSONALIZED APPROACH TO IMPROVING FUNCTIONAL OUTCOMES IN TOTAL KNEE ARTHROPLASTY

Biser Bonchev[1,2], Tsvetoslav Yordanov (✉)[1,2], Teodor Ivanov[1,2], Plamen Petkov[1], Teodor Teofilov[1], Simeon Bogdanov[1]

[1]University Hospital Sofiamed, Sofia, Bulgaria
[2] Sofia University, Faculty of Medicine, Department of Surgery, Obstetrics and Gynecology, Sofia, Bulgaria

yordanov.tsvetoslav@gmail.com

DOI: 10.58542/jbota.v63i1.207

Abstract — The CPAK (Coronal Plane Alignment of the Knee) classification is an innovative system for phenotyping coronal-plane knee alignment, introduced by MacDessi and colleagues in 2021. It extends the traditional radiographic description by mathematically reconstructing the patient's prearthritic anatomy using the arithmetic HKA (aHKA) and joint line obliquity (JLO). The system stratifies patients into nine phenotypes, with only 15-20% of the population exhibiting a truly neutral phenotype (Type V). This article is the first in the Bulgarian medical literature to present the CPAK classification and its clinical application. Based on our clinical experience and the international literature, we outline the advantages of kinematic alignment compared with conventional mechanical alignment in patients with different phenotypes[6].
Keywords— CPAK classification, kinematic alignment, total knee arthroplasty, phenotyping, arithmetic HKA, joint line obliquity.

1 Introduction

Total knee arthroplasty (TKA) is a highly effective treatment for advanced knee osteoarthritis, and a large proportion of patients achieve good to excellent functional outcomes. However, up to 20% of patients remain dissatisfied with the result, prompting surgeons to continually pursue improved techniques and approaches.

For decades, mechanical alignment (MA) has been considered the gold standard in TKA. This technique aims to restore a neutral lower-limb mechanical axis by achieving a hip-knee-ankle angle (HKA) of 180° through standardized bone resections. Although MA delivers predictable long-term results, with implant survivorship exceeding 90%

at 15 to 20 years, rising rates of patient dissatisfaction have driven the development of alternative approaches.

Kinematic alignment (KA), popularized by Howell in the early 21st century, is a philosophy that seeks to restore each patient's individual prearthritic anatomy rather than imposing a standardized neutral alignment. This approach has shown promising results in terms of patient satisfaction and functional recovery.

As noted in the monograph "Balancing in Knee Arthroplasty": "With advances in biomechanical research over the past two decades, the concept of kinematic alignment has emerged. It is based on restoring the patient's prearthritic anatomy and individual axes of motion, with the aim of achieving function as close as possible to that of the patient's healthy knee before the onset of disease."[16]

At the Clinic of Arthroplasty and Orthopaedic Traumatology at SofiaMed University Multi-Specialty Hospital, we have gradually become convinced of the advantages of kinematic alignment in appropriately selected patients. This prompted us to become more thoroughly acquainted with the CPAK classification and to adopt a personalized approach for each patient. The present article, for the first time in the Bulgarian medical literature, presents this innovative classification and its clinical application.

2. CPAK CLASSIFICATION – CONCEPT AND FUNDAMENTAL PRINCIPLES

Historical Background and Development

The CPAK classification was developed by MacDessi and al. and published in the prestigious Bone & Joint Journal in February 2021. The authors analyzed 500 healthy and 500 arthritic knees, demonstrating substantial variability in native knee anatomy. Their key finding was that only about 15% to 20% of the population has a truly neutral phenotype.[1]

Key Parameters of the Classification

The CPAK classification is based on two key parameters that together define each patient's anatomic phenotype: **(Fig. 1)**

1. Arithmetic HKA (aHKA)

Arithmetic HKA is a mathematical reconstruction of constitutional lower-limb alignment prior to the onset of degenerative changes. It is calculated using the formula aHKA = MPTA − LDFA, where MPTA is the medial proximal tibial angle and LDFA is the lateral distal femoral angle. In the CPAK classification, neutral aHKA is defined as 0° ± 2°.[1]

Based on aHKA, knees are classified into three categories:

Varus (aHKA < −2°);

Neutral aHKA =0±2°;

Valgus (aHKA > +2°).

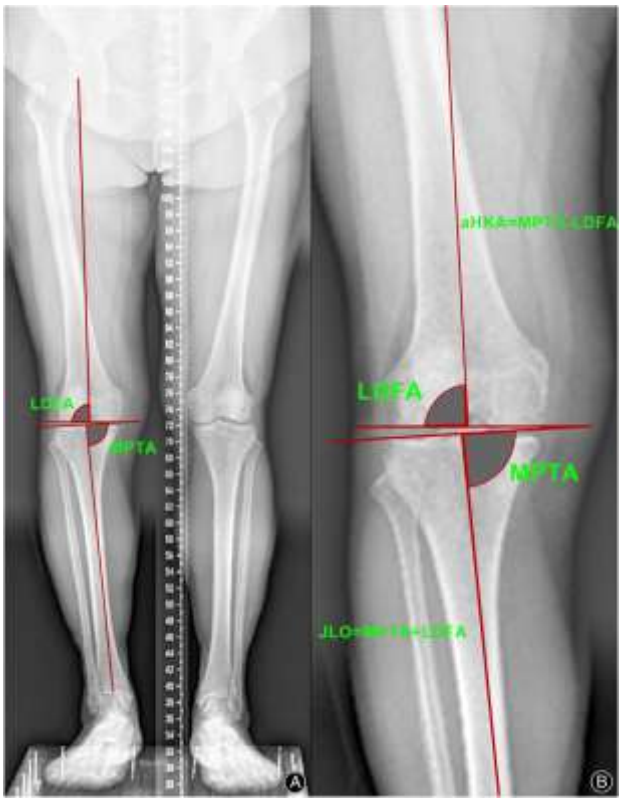


Fig. 1 Measurement of LDFA and MPTA

2. Joint Line Obliquity (JLO)

Joint line obliquity (JLO) measures the inclination of the knee joint line relative to the horizontal plane. This parameter is important for soft-tissue balance and proprioception. JLO is calculated as JLO = MPTA + LDFA, with neutral JLO defined as 180° ± 3°.^{0}±3^{0}. [1]

The CPAK classification divides JLO into three categories:

Apex distal (JLO < 177°);

Neutral (177° ≤ JLO ≤ 183°);

Apex proximal (JLO > 183°).

3. Nine Phenotypes

The combination of aHKA and JLO forms a 3×3 matrix of nine phenotypes (Types I through IX). (Fig. 2)

Varus phenotypes:

Type I (varus + apex distal): Constitutional varus with distal distal jointline obliquity.

Type IV (varus + neutral JLO): Constitutional varus with a horizontal joint line.

Type VII (varus + apex proximal): Constitutional varus with proximal joint line obliquity.

Neutral phenotypes:

Type II (neutral + apex distal): Straight axis with distal joint line obliquity.

Type V (neutral + neutral JLO): The "classic" neutral phenotype, present in only 15% to 20% of the population.

Type VIII (neutral + apex proximal): Straight axis with proximal joint line obliquity.

Valgus phenotypes:

Type III (valgus + apex distal): Constitutional valgus with distal joint line obliquity.

Type VI (valgus + neutral JLO): Valgus with a horizontal joint line

Type IX (valgus + apex proximal): Constitutional valgus with proximal joint line obliquity.

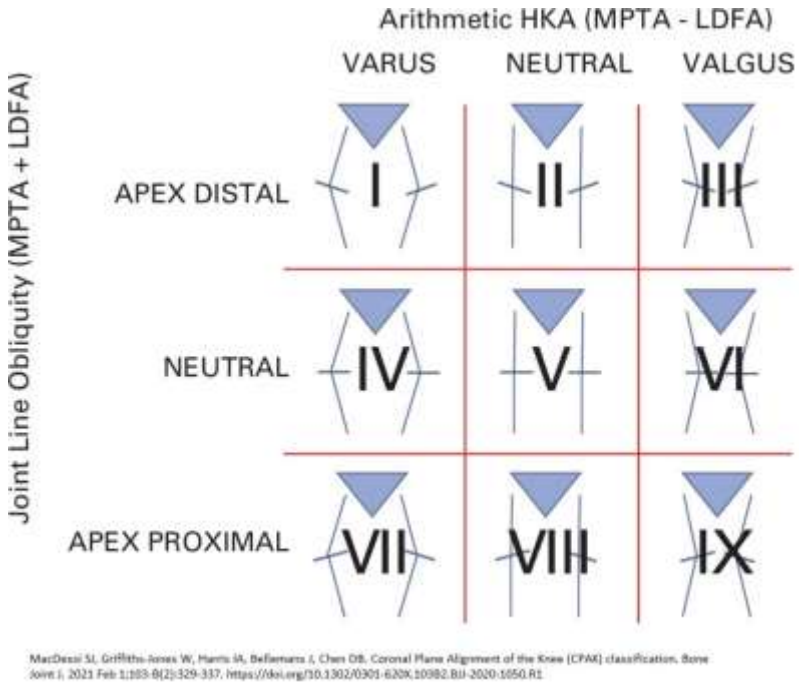


Fig. 2 Nine phenotypes defined in the CPAK classification, aHKA and JLO. [1]

3. LITERATURE REVIEW

Demographic Prevalence of CPAK Phenotypes

Large-scale studies from different geographic regions confirm substantial variability in the prevalence of CPAK phenotypes. Toyooka and al. (2024) analyzed 8,739 Japanese knees and found that only 4.7% were classified as Type V. In an Austrian study,

Huber et al. (2023) reported sex-related differences, with women showing a higher prevalence of valgus phenotypes.[10]

In a systematic review, Pagan et al. (2023) assessed geographic variation and found that Type II is the most common phenotype in most populations (35% to 40%), followed by Type I. These findings underscore the need for a personalized approach.[3]

Comparison of Functional Outcomes: KA versus MA

Numerous randomized controlled trials (RCTs) in recent years have compared kinematic alignment with mechanical alignment. The meta-analysis by Liu et al. (2024) included six RCTs with 444 patients and demonstrated a statistically significant advantage of kinematic alignment (KA) in terms of the Knee Society Score (KSS) and WOMAC.[4]

Sarzaeem et al. (2024) performed simultaneous bilateral TKA, using KA on one knee and MA on the contralateral knee in the same patient. Their results showed that KA was associated with shorter operative time, faster functional recovery, and higher satisfaction at two-year follow-up.[5]

Kafelov et al. (2023) analyzed the Forgotten Joint Score (FJS), a key measure of how "native" the joint feels to the patient. At one-year follow-up, functional positioning achieved a significantly higher FJS.[7]

CPAK-Specific Outcomes

In their original study, MacDessi et al. (2021) showed that different CPAK phenotypes respond differently to the two alignment strategies. In Type I, 100% of patients in the KA group achieved optimal balance, compared with only 15% in the MA group ($p < 0.001$). In Type II, the corresponding rates were 78% versus 46% ($p = 0.018$), and in Type IV, 89% versus 0% ($p < 0.001$).[1]

Van de Graaf et al. (2024) analyzed 2,116 robot-assisted TKAs and found that functional alignment minimizes changes in joint-line obliquity (JLO). Corban et al. (2024) reported that in 75% to 80% of patients, mechanical alignment (MA) alters the native CPAK phenotype.[9]

Long-Term Outcomes and Implant Survivorship

Dossett et al. (2023) reported 13-year outcomes and found no statistically significant difference in reoperation rates between the two methods. Young et al. (2020) published five-year results showing no differences in clinical or radiographic outcomes between KA and MA.[11]

Howell et al. showed that alignment outside the neutral range does not compromise implant survivorship, provided that defined safety boundaries are respected.[12]

4. CLINICAL APPLICATION AND AUTHOR EXPERIENCE

Preoperative Planning

Despite certain objective limitations and challenges over the past three years, at the Clinic of Arthroplasty and Orthopaedic Traumatology at SofiaMed University Multi-Specialty Hospital we have been phenotyping patients scheduled for TKA. Preoperative planning includes obtaining an appropriate weight-bearing radiograph; measuring MPTA and LDFA; calculating aHKA and JLO; determining the CPAK phenotype; and selecting the optimal alignment strategy.

Indications for the Different Techniques

Mechanical alignment (MA): We reserve this approach for Type V patients (neutral aHKA and neutral JLO), in whom the goals of MA coincide with native anatomy.

Kinematic alignment (KA): We apply this approach in all other phenotypes, with particularly favorable results in Types I, II, III, IV, and VI. In these groups, KA provides better soft-tissue balance without the need for extensive soft-tissue releases.

Intraoperative Findings

With the implementation of KA guided by CPAK phenotyping, we observed a substantially reduced need for soft-tissue releases, particularly in Types I and II; easier achievement of balanced extension and flexion gaps; better preservation of native joint-line obliquity; and a more physiologic load distribution.

Early Postoperative Outcomes

When we compared patients treated with CPAK-based KA (n = 45) with historical controls treated with conventional MA (n = 38) over an 18-month period, we observed higher functional scores at 6 and 12 months, greater satisfaction (88% vs 76%), faster functional recovery, and no early complications.

5. DISCUSSION

The CPAK classification represents a paradigm shift in total knee arthroplasty. Instead of imposing a standardized neutral alignment on every patient, it allows us to identify and restore each individual's native anatomy.

As MacDessi and colleagues, emphasize in their seminal work: "CPAK is a pragmatic, comprehensive classification for coronal knee alignment, based on constitutional alignment and joint line obliquity, which can be used in healthy and arthritic

knees. CPAK identifies which knee phenotypes may benefit most from kinematic alignment when optimization of soft tissue balance is prioritized".[1]

MacDessi and colleagues' most striking finding is that only 15% to 20% of the population has a truly neutral phenotype (Type V). This means that in the remaining 80% of patients, conventional mechanical alignment effectively alters native anatomy. This likely helps explain why a substantial proportion of patients remain dissatisfied after TKA performed with mechanical alignment.[1]

A particularly important element of CPAK is joint-line obliquity (JLO). When JLO exceeds 3°, mechanical alignment often necessitates aggressive soft-tissue releases to achieve balance. These releases not only prolong operative time but can also disrupt native proprioceptive mechanisms. In contrast, kinematic alignment preserves native JLO and largely eliminates the need for such releases.

Geographic variability in phenotype prevalence is another important consideration. In Asian populations, the proportion of patients with a neutral phenotype is even lower (4% to 7%), whereas in European populations it is approximately 15% to 20%. This further underscores the need for a personalized approach.

From a technical standpoint, the CPAK classification provides a clear framework for preoperative planning. Using straightforward radiographic measurements and simple arithmetic calculations, we can determine each patient's phenotype and select the most appropriate alignment strategy.

Long-term implant survivorship remains a key concern. To date, studies with follow-up of up to 13 years have not shown an increased risk of revision with kinematic alignment compared with mechanical alignment. Nevertheless, longer-term data is still needed.

In Bulgarian orthopaedic practice, the CPAK classification is presented for the first time in this publication. We hope this article will stimulate interest in a more personalized approach to TKA.

6. DISCUSSION

The CPAK classification represents an important advance in personalized total knee arthroplasty. By enabling systematic phenotyping and restoration of each patient's prearthritic anatomy, this approach offers a potential solution to persistent patient dissatisfaction after TKA.

The main conclusions are as follows: Only 15% to 20% of the population has a truly neutral phenotype. Kinematic alignment provides better functional outcomes and higher satisfaction. Different CPAK phenotypes respond differently to the two approaches. Long-term implant survivorship with KA appears comparable to that with MA. CPAK is a practical system that should become a standard component of preoperative planning.

At the Clinic of Arthroplasty and Orthopaedic Traumatology at SofiaMed University Multi-Specialty Hospital, we have become convinced of the benefits of this personalized approach and recommend its wider adoption in Bulgarian orthopaedic practice.

The CPAK classification does not replace surgical experience or clinical judgment; rather, it is an additional tool that helps surgeons make informed decisions for each individual patient. The future of TKA lies in personalization, and CPAK is a meaningful step in that direction.

7. References

1. MacDessi SJ, Griffiths-Jones W, Harris IA, Bellemans J, Chen DB. Coronal Plane Alignment of the Knee (CPAK) classification: a new system for describing knee phenotypes. Bone Joint J. 2021;103-B(2):329-337. doi: 10.1302/0301-620X.103B2.BJJ-2020-1050.R1.

2. Huber S, Mitterer JA, Vallant SM, et al. Gender-specific distribution of knee morphology according to CPAK classification. Knee Surg Sports Traumatol Arthrosc. 2023;31(10):4220-4230.

3. Pagan CA, Karasavvidis T, Lebrun DG, et al. Geographic variation in knee phenotypes based on CPAK classification: a systematic review. J Arthroplasty. 2023;38(9):1892-1899.

4. Liu B, Chen X, Wang Y, et al. Clinical outcomes of restricted kinematic alignment versus mechanical alignment: a meta-analysis. BMC Musculoskelet Disord. 2024;25:523.

5. Sarzaeem MM, Razzaghof M, Kazemian G, et al. Kinematic alignment technique outperforms mechanical alignment in simultaneous bilateral TKA. J Arthroplasty. 2024;39(9S2):S221-S228.

6. Grant S, Van de Graaf V, Chen D, et al. The CPAK Classification: How It Works and How It Affects Outcomes. JBJS Rev. 2024;12(10):e24.00062.

7. Kafelov M, Batailler C, Shatrov J, et al. Functional positioning principles achieved higher Forgotten Joint Score at 1 year. Knee Surg Sports Traumatol Arthrosc. 2023;31:5591-5602[7].

8. Van de Graaf VA, Clark GW, Collopy D, et al. Functional alignment minimizes changes to joint line obliquity. Bone Jt Open. 2024;5(12):1081-1091.

9. Corban LE, van de Graaf VA, Chen DB, et al. How often do we alter constitutional limb alignment with mechanically aligned TKA? Bone Jt Open. 2024;5(2):109-116.

10. Toyooka S, Osaki Y, Masuda H, et al. Distribution of CPAK classification in patients with knee OA in Japan. J Orthop Sci. 2024;29(1):272-277.

11. Young SW, Sullivan NP, Walker ML, et al. No difference in 5-year outcomes between kinematic and mechanical alignment. Clin Orthop Relat Res. 2020;478(6):1271-1279.

12. Howell SM, Papadopoulos S, Kuznik K, et al. Does varus alignment adversely affect implant survival six years after KA TKA? Int Orthop. 2015;39(11):2117-2124.

13. Parratte S, Van Overschelde P, Bandi M, et al. Anatomo-functional implant positioning with robotic assistance restores native alignment. Knee Surg Sports Traumatol Arthrosc. 2023;31:1334-1346.

14. MacDessi SJ, Oussedik S, Abdel MP, et al. The language of knee alignment: updated definitions. Bone Joint J. 2023;105-B(2):102-108.

15. Dossett HG, Estrada NA, Swartz GJ, et al. Kinematic versus mechanical alignment: two-year clinical results. Bone Joint J. 2014;96-B(7):907-913.

16. Бончев Б. Балансиране при колянно ендопротезиране. София: УМБАЛ Софиямед; 2026.

Authors

Ass. Prof. Biser Bonchev, PhD – Associate professor at Sofia University, Faculty of Medicine, Department of Surgery, Obstetrics and Gynecology. He is Chief of Department of Arthroplasty and Orthopedic Traumatology at University Hospital Sofiamed. Member of the Bulgarian Orthopedic and Traumatology Association (BOTA).

Dr. Tsvetoslav Yordanov – Teaching assistant at Sofia University, Faculty of Medicine, Department of Surgery, Obstetrics and Gynecology. He works as an orthopedic surgeon at University Hospital Sofiamed, Department of Arthroplasty and Orthopedic Traumatology.

Dr. Teodor Ivanov – Teaching assistant at Sofia University, Faculty of Medicine, Department of Surgery, Obstetrics and Gynecology. He works as an orthopaedic surgeon at University Hospital Sofiamed, Department of Arthroplasty and Orthopedic Traumatology.

Dr.Plamen Petkov – resident in Orthopedics and Traumatology at Department of Arthroplasty and Orthopedic Traumatology at University Hospital Sofiamed.

Dr. Teodor Teofilov – resident in Orthopedics and Traumatology at Department of Arthroplasty and Orthopedic Traumatology at University Hospital Sofiamed.

Dr. Simeon Bogdanov – Orthopedic surgeon at Department of Arthroplasty and Orthopedic Traumatology at University Hospital Sofiamed.