Mechanical Alignment in Knee Replacement Homogenizes Postoperative Coronal Hip–Knee–Ankle Angle in Varus Knees: A Navigation-Based Study

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Abstract

After knee replacement, postoperative lower limb alignment is influenced by the geometry of the prosthesis position and surrounding soft tissue that contributes to the hip–knee–ankle (HKA) angle. The purpose of this study is to determine the dynamic coronal HKA angle after mechanical alignment in total knee replacement using computer navigation. We conducted a pre–post design study of 71 patients with varus osteoarthritic knees on which total knee arthroplasty was performed. The HKA was measured before and at the end of the surgical procedure with the patient in the supine position using a navigation system at 30, 60, and 90 degrees of knee flexion. Postoperative implant position and flexion and extension gaps were assessed. HKA was clustered in three preoperative dynamic patterns (PDPs; Varus-Neutral, Varus-Valgus, and Varus-Varus). There were statistically significant differences in the dynamic coronal HKA between the preoperative and postoperative statuses after mechanically aligned knee replacement (with $p < 0.0001$) Before the surgical procedure, statistically significant differences were found between patterns at any angle of flexion confirming a well-differentiated preoperative dynamic behavior between the three groups. Postoperatively, 98.6% (71 out of 72) of the knees were within ± 3 degrees of the HKA at full extension. Fifty-eight knees (80.6%) were assessed to a "within-range" postoperative dynamic alignment at any grade of flexion considered. There are differences between the preoperative and postoperative status of the dynamic coronal HKA angle after mechanically aligned knee replacement. We proposed that an excellent dynamic HKA alignment is achieved not only at full extension within the range of 0 ± 3 degrees but also when this alignment is maintained at 30, 60, and 90 degrees.

Keywords
- computer assisted
- arthroplasty
- replacement
- knee
- femorotibial mechanical angle
- dynamic alignment

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After total knee arthroplasty (TKA), the postoperative lower limb alignment is influenced by the geometry of the prosthesis position[1] and surrounding soft tissue that contribute to the hip–knee–ankle (HKA) angle.[2–4] It is not clearly established what the optimal TKA alignment is due to wide variations between individual patients, sexes, and races.[5–9]

The HKA angle within 3 degrees of neutral has been used as the essential outcome measure in TKA, and mechanical alignment (MA) has been associated with implant survival. However, the relationship between the survival of a primary TKA and mechanical axis alignment may be weaker than described in several previous reports. Parratte et al found that a postoperative mechanical axis of 0 ± 3 degrees did not improve the 15-year implant survival rate.[10–12]

Accordingly, kinematic alignment (KA) for TKA was introduced as an alternative alignment strategy. KA aims to coalign the flexion–extension axis of the femoral component to the natural kinematic axes of the patient's knee.

Recently, functional alignment has been proposed. This technique has elements of both measured resection and gap-balancing procedures. With functional alignment, the gaps are balanced before cutting the femur and tibia by changing the implant targets in all three planes individualized to the patient's knee.[13]

There are changes in the coronal mechanical axis from the extension to the flexion of the knee,[14] so the alignment of the knee cannot be considered fixed at full extension; in some manner, it could be considered "dynamic" from extension to full flexion. An understanding of the normal dynamics of the HKA angle can help the surgeon to achieve better alignment after TKA. The preoperative dynamic HKA angle has gained interest, especially in the osteoarthritic knee,[15] as this information may have clinical influence in the intraoperative decision-making process.[16]

Computer-assisted navigation provides surgeons with quantitative measurement tools for real-time assessment of lower limb alignment and kinematics.[17–20] It is a powerful instrument for intraoperatively supporting and guiding the surgeon in the adequate postoperative soft tissue balance of the knee.[17,21–24] Through this technology, the authors have published that there is well-defined preoperative dynamic alignment in osteoarthritic knees.[16]

The purpose of this study was to determine the dynamic coronal HKA angle after MA in total knee replacement using computer navigation. The hypothesis was that the dynamic HKA angle in the full range of motion would differ preoperatively and postoperatively after mechanically aligned knee replacement. We employed a pre–post study design[25] based on a consecutive case series focused on the null hypothesis (Ho) that the preoperative dynamic measurements of HKA angle at 0, 30, 60, and 90 degrees do not differ from the postoperative measurements in total knee replacement.

The main objective was to assess the preoperative and postoperative HKA angle distribution at 0, 30, 60, and 90 degrees of flexion and to assess "within-range" postoperative coronal dynamic alignment.

Materials and Methods

In total, 100 consecutive patients with 102 osteoarthritic knee joints on which TKA was performed in our institution from 2009 to 2010 were enrolled in this study. The inclusion criteria were patients with primary osteoarthritic knee joints receiving a posterior stabilized total knee replacement (Columbus, B. Braun Aesculap, Tuttlingen, Germany) due to substantial pain and loss of functionality with any degree of deformity. Patients were excluded if they had prostheses revision surgery for any reason in the last 8 years, had a preoperative valgus knee (HKA angle >180 degrees), had undergone any previous knee or hip surgery, had any major lower limb trauma resulting in an abnormal limb alignment, or had flexion contracture of >10 degrees.

All patients provided written informed consent, and the Hospital Committee for Medical and Health Research Ethics approved the study (Hospital General Universitario Gregorio Marañón, Madrid, Spain, Protocol 1–04. V-02). All procedures were performed following the 1964 Declaration of Helsinki and its later amendments.

After evaluating their eligibility, $n = 72$ knees (71 patients) were included in the final analysis. There were several reasons to exclude patients. Twenty-three of them had a valgus osteoarthritic knee. Three were excluded because an ultracongruent liner was used. Two patients had received a hip prosthesis before, one had previous knee surgery, and one had 20 degrees of knee flexion contracture (►**Fig. 1**).

Demographic data collected on the cohort included age, sex, body mass index (BMI), and follow-up period.

The baseline characteristics of the study population are reported in ►**Table 1**. Due to the presence of missing values, summary statistics for BMI was calculated with $n = 60$.

Intraoperative HKA Angle Acquisition

After the registration process and through a standard anterior knee approach, optical infrared (IR) trackers were screwed into the femur and tibia.

To allow the system to determine the coronal HKA angle, the rotational centers of the hip, knee, and ankle were needed. The centers of the hip and knee were obtained using a kinematic method, whereby the hip is rotated and the knee was extended and flexed to allow the navigation system to determine the centers of movement. The center of the ankle was calculated anatomically using the most prominent zone of the lateral and medial malleoli and the anterior joint line. The HKA angle was assessed at this moment of the surgical procedure, before any soft tissue release or bone cutting. The HKA angle was measured with the patient supine with the maximum knee extension possible (considering that value as 0) and with 30, 60, and 90 degrees of flexion.

Once obtained, the surgical procedure was performed following a navigated gap-balancing technique (Orthopilot version 4.2; Braun Aesculap, Tuttlingen, Germany). A distal femoral cut was aimed to be done at a 90-degree sagittal and coronal plane with respect to the hip center. The tibial cut was intended to be done at 90-degree coronal and 2-degree posterior slope sagittal to the ankle center. Gaps at 0 and

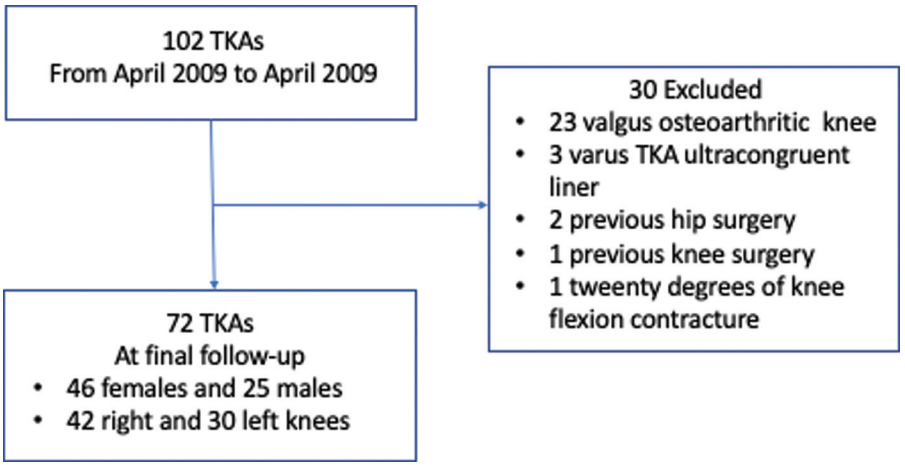

Fig. 1 Patient flow diagram. TKA, total knee arthroplasty.

Table 1 Study population baseline

Patients characteristics	Values
Female *n* (%)	46 (64.79)
Male *n* (%)	25 (35.21)
Right knee *n* (%)	42 (58.33)
Left knee *n* (%)	30 (41.67)
Age (y)	
Mean ± SD	74.42 ± 6.49
Median (Q1, Q3)	75.5 (71, 78.25)
BMI (kg/m^2)	
Mean ± SD	33.03 ± 5.44
Median (Q1, Q3)	32.60 (29.29, 36.15)
Follow-up (y)	
Mean ± SD	8.15 ± 2.03
Median (Q1, Q3)	8.77 (7.88, 9.34)

Abbreviations: BMI, body mass index; SD, standard deviation.

90 degrees were assessed after all bone cuts, and the final femoral rotation was measured by the navigation system referenced to the preoperative posterior condyle axis.

The HKA angle was reevaluated at the end of the surgical procedure once the cementation process was completed, and the tourniquet was deflated. The navigation system calculated the final gaps in full extension and 90 degrees of flexion. The HKA angle was measured in the same manner as was done preoperatively, and the range of movement from extension to full flexion was recorded.

Preoperative and Postoperative HKA Angle Data Analysis at 0, 30, 60, and 90 Degrees

The authors previously described the preoperative varus osteoarthritic dynamic behavior through a clustering method in five segments (expected, severe, varus–valgus, concave, and structured) and three patterns (Varus-Neutral, Varus-Valgus, and Varus-Varus).[16] The segmentation and patterns obtained were named empirically by the authors at that moment.

In the present study, we distinguish among three preoperative dynamic behaviors corresponding to the three abovementioned patterns:

- Varus-Neutral: (grouping together expected and severe segments) when the HKA angle trends to neutral as the knee flexes.
- Varus-Valgus: representing a starting varus alignment at 0 degrees and valgus alignment as the knee flexes.
- Varus-Varus: (grouping together concave and structured segments) if the HKA angle stays approximately constant and does not reach 0 degrees at any degree of flexion.

Postoperative Static Coronal Alignment

We believed that an optimal static alignment was achieved when the HKA angle value measured at 0 degrees was in the range of 0 ± 3 degrees of varus/valgus.

Postoperative Dynamic Coronal Alignment

We defined a "within-range" dynamic alignment as when there was no more than ± 3 degrees of deviation from 0 degree in any of the HKA angle values measured at 0, 30, 60, and 90 degrees.

Statistical Analysis

For a coverage probability of at least 95%, a minimum sample size of 71 knees was required to estimate the likelihood of being dynamically within range after surgery with a sampling error of ± 11%.

Continuous data were assessed for normality using the Shapiro–Wilk test. In the case of normality, analysis of variance (ANOVA) was used to compare the three preoperative dynamic patterns (PDPs; Varus-Neutral, Varus-Valgus, and Varus-Varus). Otherwise, the Kruskal–Wallis test was used. The three PDPs were comparable in terms of BMI, age, and follow-up period.

For each PDP and knee flexion angle (KFA), the Wilcoxon test was used to detect differences between pre- and postsurgery HKA angle values.

For each phase (pre- and postsurgery) and PDP, the Friedman's test was used to detect differences in HKA angle values across the four KFAs considered. In the case of a significant

result, post hoc pairwise comparisons between KFAs were performed based on the Wilcoxon test (with Bonferroni's correction to keep the global type-I error at an α level of 5%).

For each phase and PDP, the Cochran Q-test was used to detect differences in the proportions of patients whose HKA angle values deviated ± 3 degrees from 0 degrees across the four KFA considered. In the case of a significant result, post hoc pairwise comparisons were performed based on the McNemar test with Bonferroni's correction.

For each phase and KFA, an extension of Fisher's exact test (the Freeman–Halton test) was used to detect differences in the proportions of patients who were out of range across the three groups defined by PDPs.

Statistical analysis was performed using R software. A result of $p < 0.05$ was considered statistically significant.

Results

Preoperative and Postoperative HKA Angle

►**Fig. 2A** graphically shows the distribution of the HKA angle values for each PDP in each of the four measured knee angulations before knee replacement. The black line between the boxplot represents the trend in the distribution of HKA angle values throughout the measured range of motion. It should be noted that between the Varus-Valgus and the Varus-Neutral, the slopes of the lines are practically similar; they differ only in the starting point.

Before the surgical procedure, statistically significant differences were found between patterns at any angle of flexion (with $p < 0.0001$ for Varus-Neutral vs. Varus-Valgus at 0, 30, 60, and 90 degrees; Varus-Neutral vs. Varus-Varus at 0 and 30 degrees; and Varus-Valgus vs. Varus-Varus at 60 and 90 degrees, and with $p < 0.05$ for Varus-Valgus vs. Varus-Varus at 30 degrees). These results confirm well-differentiated preoperative dynamic behavior among the three groups.

►**Fig. 2B** shows the distribution of the HKA angle values for each PDP in any of the four measured knee angulations after knee replacement. Again, the black line between the boxes represents the trend in the HKA angle distribution throughout the measured range of motion. The three PDPs have very similar postoperative dynamic behavior, maintaining a constant HKA angle value, close to neutral, as the knee bends and within the ± 3-degree zone represented in the graph by the dotted lines. Based on the post hoc Wilcoxon test (with Bonferroni's correction), there were statistically significant differences only when comparing the HKA angle values between 0 and 30 degrees in the Varus-Varus group.

Graphically, it can be seen that the behavior of the knee is totally different before and after surgery and that the HKA angle shows more homogeneous and consistent values once the prosthesis has been implanted.

The gray zone in the middle of ►**Fig. 2** shows the statistical analysis using the Wilcoxon test comparing each PDP and KFA and the HKA angle distribution pre- and postsurgery. For a better understanding, the analysis relates, for instance, the blue boxplot (representing the HKA angle measurements at 0 degrees of flexion) against itself before and after surgery. This analysis was done for each of the colored boxplots, representing the four angles at which the HKA angle has been measured (blue = 0 degrees, yellow = 30 degrees, gray = 60degrees, and red = 90 degrees). Statistically significant differences are detected in all the comparisons (except for the Varus–Valgus behavior pre- versus postsurgery at 90 degrees of flexion), thus supporting the alternative hypothesis considered in the study.

►**Table 2** summarizes postoperative femoral, tibial position, and flexion–extension gaps. Statistically nonsignificant differences were detected across the PDPs in terms of the data collected.

►**Table 2**: femoral rotation was obtained with respect to the posterior condyle line. The joint orientation angles in the frontal and sagittal planes were assessed according to Paley's recommendation.[26] The surgical navigator determined the calculation of the spaces in millimeters on the medial and lateral compartment.

Preoperative and Postoperative Static Coronal HKA Angle Analysis

Before surgery, only 15.3% of the knees (11 out of 72) were preoperatively within range at full extension (see top panel of ►**Fig. 2**).

After the surgical procedure, 98.6% of the knees (71 out of 72) were within ± 3 degrees of the HKA angle at full extension according to computer measurement. This outlier knee was preoperatively clustered in the Varus-Neutral dynamic behavior.

Preoperative and Postoperative Dynamic Coronal HKA Angle Analysis

►**Table 3** shows the percentage of knees that were within range after knee arthroplasty for any KFA assessed, considering the whole sample (fourth column) and distinguishing by PDP (the first three columns). Fifty-eight knees (80.6%) exhibited a "within-range" postoperative dynamic alignment at any KFA. Of the remaining 14 knees, 85.7% (12 out of 14) presented a similar behavior in the sense that they remained within range up to a certain grade of flexion and, from there, remained out of range.

As the knee bends, the rate of being out of range increases. According to Cochran's Q-test, this result is statistically significant when the entire sample of knees is considered. Post hoc pairwise comparison based on the McNemar test with Bonferroni's correction finds a significant difference when comparing the percentage of knees within range at 90 degrees (83.3%) with the percentage at 0 (98.6%) and 30 degrees (97.6%).

Despite the fact that the percentage of patients within range at 90 degrees and at any KFA seems to be higher in the Varus-Varus group, the different PDPs do not show a statistically significant difference based on the Freeman–Halton extension of Fisher's exact test. This absence of statistical significance may correspond with the relatively low number of patients in each PDP.

Discussion

The most important finding of the present study is that there are differences in the dynamic coronal HKA angle between

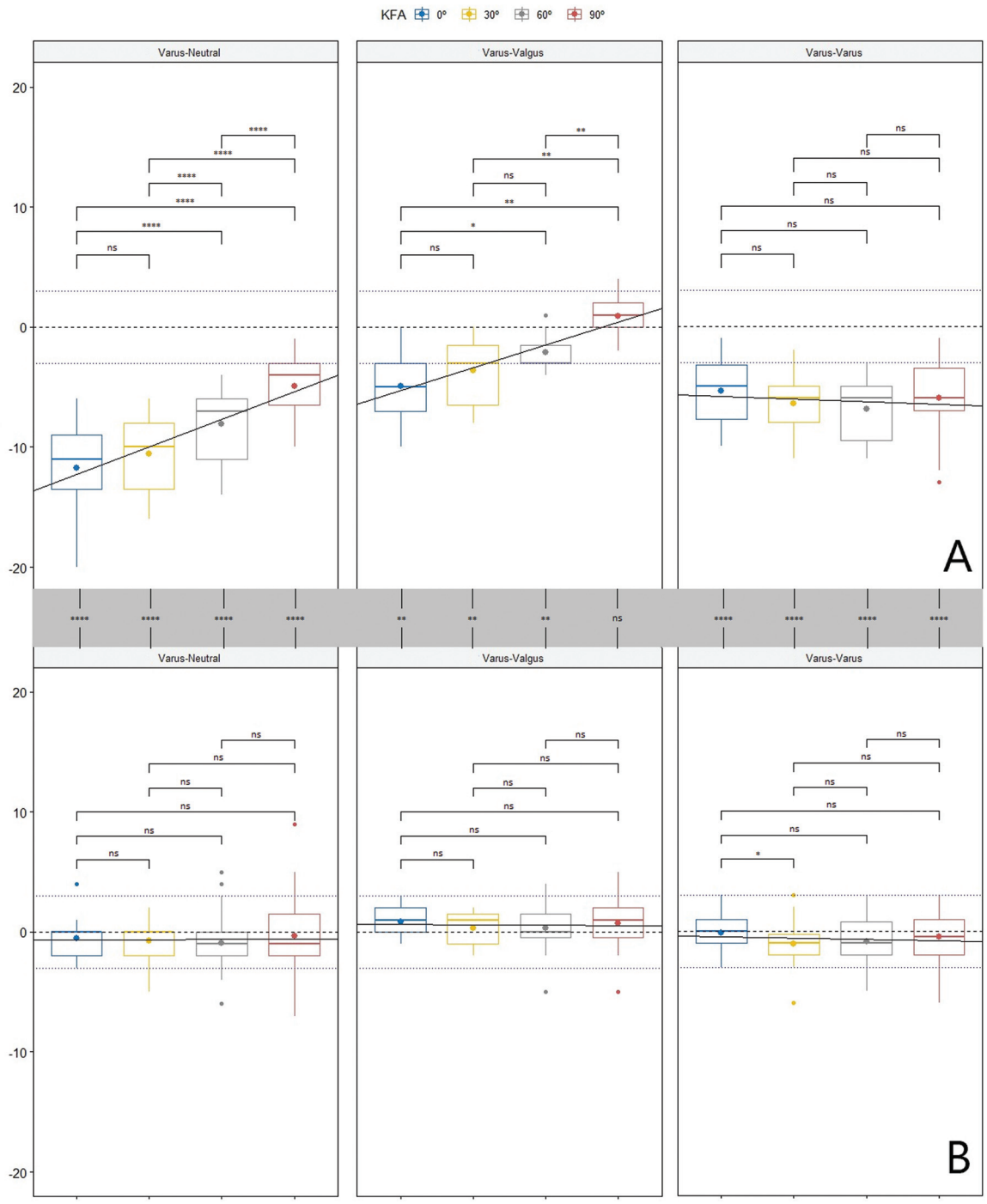

Fig. 2 The difference in dynamic behavior between the three groups proposed by the authors can be seen graphically through colored boxplots corresponding to each KFA (blue = 0, yellow = 30, gray = 60, and red = 90 degrees). The spot in the middle of the box represents the mean value. The horizontal line in the box represents the median value. The height of the box is the interquartile range, Q1–Q3, representing that central 50% of the most representative values. The vertical outbox lines represent the minimum and maximum of the nonoutlier values; when a value deviated from the top or bottom of the box more than 1.5 times the interquartile range, it was identified as an outlier and expressed as a dot. Horizontal black lines across the four colored boxplots of each panel are regression lines that represent how HKA angle changes as the knee is bent. (**A**) Preoperative: in the so-called Varus-Neutral behavior, the HKA angle tends to reach a neutral value, despite having pronounced varus initial values. The Varus-Valgus pattern presents an initial HKA angle value slightly in varus, and it reaches valgus values as it bends. The Varus-Varus cluster always maintains an HKA angle value in varus throughout the full range of movement. (**B**) Postoperative: in the three PDPs, the postoperative HKA angle is homogeneous and well established in ± three degrees from 0. Only the "Varus-Varus" PDP shows statistically significant differences between 0 and 30 degrees. It should be noted that all patients in the Varus-Valgus group showed valgus HKA angle mean values throughout the entire range of knee motion, and only a few individual patients ranged in varus or valgus values. Gray zone: for each PDP and any KFA, there are statistically significant differences when comparing HKA angle measurements between phases (pre- versus postsurgery), except in the case of Varus-Valgus at 90 degrees of flexion. HKA, hip–knee-ankle; KFA, knee flexion angle; ns, nonsignificant; PDP, preoperative dynamic pattern; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$; $^{****}p < 0.0001$. Statistically significant pairwise comparisons based on post hoc Wilcoxon's tests with Bonferroni's correction (for each panel, i.e., for each PDP and phase) or based on Wilcoxon tests (gray zone, i.e., for each PDP and KFA).

Table 2 Femoral rotation was obtained with respect to the posterior condyle line

Variable	Varus-Neutral	Varus-Varus	Varus-Valgus	Global
Preoperative dynamic behavior *n* (%)	31 (43.06)	26 (26.11)	15 (20.83)	72 (100)
Femoral coronal position (degree)				
Mean ± SD	90.26 ± 0.77	90.35 ± 0.89	90.20 ± 1.21	90.28 ± 0.91
95% CI	89.99–90.53	90.00–90.69	89.59–90.81	90.07–90.49
Median (Q1, Q3)	90 (90, 91)	90 (90, 91)	91 (89.5, 91)	90 (90, 91)
Femoral slope (degree)				
Mean ± SD	90.29 ± 1.10	90.31 ± 0.88	89.93 ± 0.59	90.22 ± 0.94
95% CI	89.90–90.68	89.97–90.65	89.63–90.23	90.01–90.44
Median (Q1, Q3)	90 (90, 91)	90 (90, 91)	90 (90, 90)	90 (90, 91)
Femoral rotation (degree)				
Mean ± SD	1.55 ± 1.46	1.96 ± 1.31	1.80 ± 1.15	1.75 ± 1.34
95% CI	1.04–2.06	1.46–2.47	1.22–2.38	1.44–2.06
Median (Q1, Q3)	2 (1, 2.5)	2 (1, 3)	2 (1, 3)	2 (1, 3)
Femoral rotation 0–3 *n* (%)	28 (90.32)	23 (88.46)	15 (100)	66 (91.67)
Femoral rotation >3 *n* (%)	1 (3.23)	3 (11.54)	0	4 (5.56)
Femoral rotation internal *n* (%)	2 (6.45)	0	0	2 (2.78)
Tibial coronal position (degree)				
Mean ± SD	90.42 ± 0.62	90.35 ± 0.74	90.20 ± 0.68	90.35 ± 0.68
95% CI	90.20–90.64	90.06–90.63	89.86–90.54	90.19–90.50
Median (Q1, Q3)	90 (90, 91)	90 (90, 91)	90 (90, 91)	90 (90, 91)
Tibial slope position (degree)				
Mean ± SD	92.45 ± 1.43	92.46 ± 1.48	92.53 ± 1.41	92.47 ± 1.42
95% CI	91.95–92.96	91.89–93.03	91.82–93.25	92.14–92.80
Median (Q1, Q3)	92 (92, 93.5)	93 (91.25, 94)	93 (92, 93)	93 (92, 94)
Medial extension gap (mm)				
Mean ± SD	1.55 ± 1.91	1.50 ± 1.39	1.40 ± 2.06	1.50 ± 1.75
95% CI	0.88, 2.22	0.96–2.04	0.36–2.44	1.10–1.90
Median (Q1, Q3)	1 (0.50, 2.50)	1 (0.25, 2)	1 (0.5, 2)	1 (0, 2)
Lateral extension gap (mm)				
Mean ± SD	2 ± 2.21	2.12 ± 1.77	2.07 ± 1.94	2.06 ± 1.98
95% CI	1.22–2.78	1.43–2.80	1.08–3.05	1.60–2.51
Median (Q1, Q3)	2 (0.5, 3)	2 (1, 2)	2 (0.5, 3)	2 (1, 3)
Medial flexion gap (mm)				
Mean ± SD	3.19 ± 1.68	2.69 ± 2.00	2.60 ± 1.72	2.89 ± 1.80
95% CI	2.60–3.79	1.93–3.46	1.73–3.47	2.47–3.31
Median (Q1, Q3)	3 (2, 4)	3 (2, 4)	3 (2, 4)	3 (2, 4)
Lateral flexion gap (mm)				
Mean ± SD	3.03 ± 1.83	2.65 ± 1.62	2.13 ± 2.36	2.71 ± 1.89
95% CI	2.39–3.68	2.03–3.28	0.94–3.33	2.27–3.14
Median (Q1, Q3)	3 (2, 4)	3 (2, 3.75)	3 (1, 4)	3 (1, 4)

Abbreviations: CI, confidence interval; SD, standard deviation.
Note: The joint orientation angles in the frontal and sagittal planes were assessed according to Paley's recommendation.[26] The surgical navigator determined the calculation of the spaces in millimeters on the medial and lateral compartment.

Table 3 "Within range" = 0 ± 3 degrees of the hip–knee–ankle angle

Variable	Preoperative Varus-Neutral $n = 31$	Preoperative Varus-Valgus $n = 15$	Preoperative Varus-Varus $n = 26$	Global $n = 72$
PO knees within range at 0 degrees % (*n*) 95% CI	96.8 (30)	100 (15)	100 (26)	98.6 (71) 88.2–99.2
PO knees within range at 30 degrees % (*n*) 95% CI	96.8 (30)	100 (15)	96.2 (25)	97.2 (70) 86.9–97.9
PO knees within range at 60 degrees % (*n*) 95% CI	87.1 (27)	86.7 (13)	88.5 (23)	87.5 (63) 78.2–89.2
PO knees within range at 90 degrees % (*n*) 95% CI	80.6 (25)	80 (12)	88.5 (23)	83.3 (60)[a] 74.5–85.5
PO knees within range at any KFA % (*n*) 95% CI	74.2 (23)	80 (12)	88.5 (23)	80.6 (58) 72.0–83.0

Abbreviations: CI, confidence interval; KFA, knee flexion angle; PO, postoperatively.
[a] $p < 0.05$. Statistically significant pairwise comparisons based on the McNemar test with Bonferroni's correction: 90 versus 0 degrees with 83.3 versus 98.6% and 90 versus 30 degrees with 83.3 versus 97.2%.

the preoperative and postoperative status after mechanically aligned knee replacement. It is remarkable that there are also different behaviors in the four measurement flexion values analyzed. Except for the Varus-Varus pattern, it has been proven that, preoperatively, the HKA angle values at 0 and 30 degrees are alike but differ from those at 60 or 90 degrees of flexion. Postoperatively, these differences are strongly attenuated.

This finding suggests that, preoperatively, the geometry of the articular surface and the static and dynamic stabilizers play a crucial role in the dynamic HKA angle. Once the surgery is complete, everything relies on the prosthetic design, position, and, to a lesser extent, the soft tissue envelope.

Among knee surgeons, the concept of KA has gained interest. This approach assumes that the aim of knee arthroplasty must be the natural alignment of the knee, rather than the restoration of alignment to neutral. This philosophy is supported by the fact that a slight varus alignment may be physiological,[27] based on the current knowledge and kinematics of the normal knee.[28–32] In a certain way, it is true, as when standing or walking, the load transmission is close to the medial side of the knee, and the muscles of the hip must act as a stabilizer. It is unclear how this compensatory muscle system is affected in a patient with osteoarthritic knees.

The authors have previously described that, regardless of varus or valgus in extension, the preoperative HKA angle at 90 degrees of flexion is close to neutral, and this situation can be considered normal in an osteoarthritic knee.[16] It is also known that knees that are in varus or up to 2.5 degrees of valgus in the supine position tend to become more varus upon standing.[33–35] This kinematic pattern suggests that the soft tissue constraints, rather than the underlying deformity, are more influential in the control of the alignment from lying to standing.[36] This trend is also observed in a flexed position when compared with hyperextension. Based on this knowledge, it is easily understood that the alignment of the knee cannot be considered as static but "dynamic."[37]

The importance of the dynamic behavior of knee prostheses is clear from the fact that dynamic models of finite element models on knee arthroplasty are described.[38,39]

The clinical relevance of our study resides in the fact that, focusing only on the full-extension HKA angle as a final objective, despite our philosophy of kinematic, mechanical, or functional strategy alignment, some critical data in the dynamic HKA angle that may affect the outcome of the surgical procedure are missed.[40] It is not clearly established what the optimal postoperative alignment is.[41] Traditionally, the gold standard has been considered a mechanical axis of 0 ± 3 degrees. Nevertheless, it has been described that this ideal mechanical axis does not ensure the optimal function and survival of the prosthesis.[10,42] This lack of certainty is due to wide variations between individual patients[6] and, as previously mentioned, because there are changes in the coronal mechanical axis from extension to flexion of the knee.[4,40,43–45] In our series, 98.6% of the patients were within 0 ± 3 degrees of the HKA angle at full extension after surgery, with an excellent result, minimizing the outliers. Nevertheless, we also have proven that there is postoperative kinematic variation in the coronal HKA angle plane between flexion and full extension, even though we achieved similar mean values in the flexion and extension gaps.[18] For this reason, we consider in our daily practice that an excellent dynamic alignment has been achieved not only when the HKA angle value at full extension is within the 0 ± 3 degrees of range but also when there are not more than 3 degrees of deviation from 0 in the HKA angle values measured at full extension and at 30, 60, and 90 degrees, as shown in ►**Fig. 3**.

As far as we know, nobody has previously proposed this definition of an optimal postoperative dynamic alignment,[46]

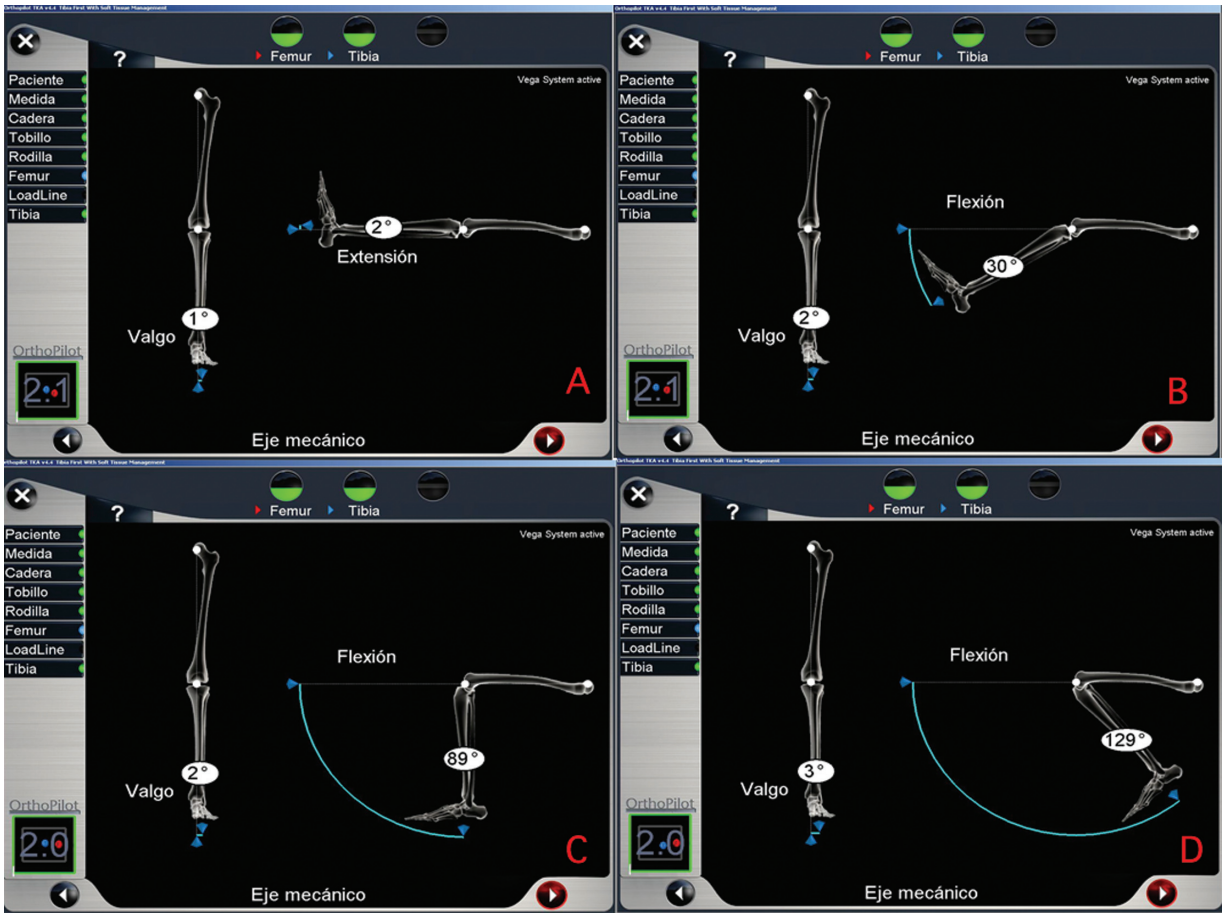

Fig. 3 shows a suitable dynamic postoperative alignment, as there are no more than three degrees of difference between the HKA angle in the full range of movement. (**A**) Full-extension, (**B**) midflexion, (**C**) 90 degrees of flexion, and (**D**) full flexion. HKA, hip–knee-ankle.

and it may be interesting for knee surgeons to consider it as an objective while performing knee replacement that is mainly assisted by computer. We want to emphasize that we still recommend establishing a postoperative HKA angle value within 0 ± 3 degrees of the HKA angle at full extension,[33] while paying attention to the dynamic HKA angle that provides the surgeon with important information regarding mid-flexion stability, especially when using a cruciate-retained prosthesis.[47]

This scheme is supported by the kinematic pattern described which suggests that when HKA angle is measured with the limb in full extension, the alignment depends more on the component's position than on the soft tissue envelope that stabilizes the prosthesis. The more the knee is bent, the more these structures are flexed, resulting in an expected coronal knee laxity in full flexion that the structural stability of the prosthetic design cannot adequately control. This behavior has also been observed in studies analyzing the effect of native laxities in various knee flexion angles[48] and their relationship with alignment, especially when following, as we did, a gap-balancing technique.[19,21]

After surgery, we could not find any statistically significant differences among the different PDPs. It is remarkable to mention that, despite the PDP, it is more difficult to achieve a postoperative "within-range" dynamic alignment as the knee bends.

The mixed Varus-Valgus pattern represents a challenging and highly demanding procedure that one may assume that after surgery will yield more out-of-range knees. Surprisingly, most of the patients exhibiting an out-of-range dynamic alignment corresponded to a reasonably natural preoperative dynamic behavior Varus-Neutral. The percentages of knees "within range" at any KFA was higher in the Varus-Varus group, may be because there is a tight medial side both with the knee flexed and in extension and any bone cutting or soft tissue release will cause a similar and simultaneous effect in the flexion and extension gaps. These results emphasize that the surgeon should aim to respect as much as possible the soft tissue envelope, especially in the presence of preoperative Varus-Neutral behavior to avoid unnecessary soft tissue or more massive bone cuts that may alter the HKA angle.

Limitations

We are aware that this study has several limitations to be considered. It is unknown if the postoperative dynamic HKA angle is related to the clinical outcome of TKA. All the findings of the present study are associated only with a posterior stabilized total knee replacement that is mechanically aligned. The dynamic alignments described cannot be reproduced in a posterior cruciate-retaining TKA. However, it is more than possible that both designs have similar postoperative dynamic

alignment.[49–51] Accordingly, a kinematical alignment strategy for knee replacement may have different postoperative dynamic HKA angle behavior. Further studies are necessary to determine this behavior.

It may also be argued that the dynamic measurement was assessed in a nonweight-bearing condition, but this does not in any way invalidate the different patterns described. However, the knee is stabilized not only by ligaments but also by muscles and tendons crossing the joint, making it impossible to intraoperatively simulate the weight-bearing condition.

Conclusion

We have developed a reproducible method increasing the relevance of the quantitative data provided by navigation systems and providing new considerations while performing mechanically aligned knee arthroplasty.

There are differences in the dynamic coronal HKA angle between the preoperative and postoperative status after mechanically aligned knee replacement. This finding suggests that, preoperatively, the geometry of the articular surface and the static and dynamic stabilizers play a crucial role in the dynamic HKA angle. Once the surgery is done, everything relies on the prosthetic design, position, and, to a lesser extent, soft tissue envelope. We proposed that an excellent dynamic alignment has been achieved not only when the HKA angle value at full extension is within the 0 ± 3 degrees of range but also when there are not more than 3 degrees of deviation from 0 degrees in the HKA angle values measured at full extension and 30, 60, and 90 degrees.

Further studies are necessary to determine if this dynamic approach to postoperative HKA angle has clinical utility in the surgeon's decision-making process.

Conflict of Interest
None declared.

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