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Original Research

The Restoration of the Prearthritic Joint Line Does Not Guarantee the Natural Knee Kinematics: A Gait Analysis Evaluation Following Primary Total Knee Arthroplasty

Andrea Giordano Salvi, MD[a, b], Pieralberto Valpiana, MD[a, c, d], Bernardo Innocenti, PhD[c, e], Stefano Ghirardelli, MD[a], Matteo Bernardi, BSc[a], Giuseppe Petralia, MD[f], Giuseppe Aloisi, MD[f], Karlos Zepeda, MS[g], Christian Schaller, MD[a], Pier Francesco Indelli, MD, PhD[a, c, d, h, i, *]

[a] *Südtiroler Sanitätsbetrieb, Department Orthopaedic Surgery, Brixen, Italy*
[b] *Hôpital Maisonneuve-Rosemont, Department Orthopaedic Surgery, Montréal, Quebec, Canada*
[c] *Personalized Arthroplasty Society (PAS), Atlanta, GA, USA*
[d] *Paracelsus Medical University (PMU), Institute of Biomechanics, Salzburg, Austria*
[e] *Université Libre de Bruxelles, BEAMS Department (Bio Electro and Mechanical Systems), Bruxelles, Belgium*
[f] *Dipartimento di Medicina Clinica, Sanita' Pubblica, Scienze della Vita e dell'Ambiente, Universita' degli Studi dell'Aquila, L'Aquila, Italy*
[g] *Touro College of Osteopathic Medicine, Department of Orthopaedics, New York, NY, USA*
[h] *The Breyer Center for Overseas Studies in Florence, Stanford University, Florence, Italy*
[i] *CESAT, Department of Orthopaedic Surgery, Azienda Sanitaria Toscana Centro, Fucecchio, Florence, Italy*

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ABSTRACT

Background: Unrestricted kinematic alignment (uKA) in total knee arthroplasty (TKA) has the theoretical advantage of reproducing patients' constitutional alignment and restoring the pre-arthritic joint line position and obliquity. However, modifications of the original uKA technique have been proposed due to the potential risk of mechanical failure and instability. Given the significant variability in soft tissue behavior within the same bony morphology group, uKA pure knee resurfacing could be occasionally detrimental. This study aimed to kinematically compare the outcomes of uKA TKA with those of a robotic-assisted KA TKA technique based on specific soft-tissue boundaries.
Methods: In this retrospective gait analysis study, 24 TKA patients and 12 healthy controls were recruited. Inclusion criteria were a 9-month minimum follow-up from successfully, primary medial-pivot or medially-congruent TKA performed for isolated degenerative joint disease. Preoperatively, patients were randomly assigned to two surgical groups: A) uKA (#12) and B) robot-assisted (#12), KA (hybrid-kinematic) with boundaries (±3° from hip-knee-ankle neutral axis) and a slight intercompartmental gap asymmetry (max 2 mm lateral-opening). The gait analysis was performed using instrumented treadmills equipped with 3D cameras.
Results: Sagittal knee kinematic data: during the early-stance phase of gait, the uKA group showed a less consistent weight-acceptance phase and a less efficient transition between the first knee-flexion peak and mid-stance-extension plateau with respect to the hybrid-kinematic alignment group. Spatiotemporal and overall gait quality data: no significant differences were found between the two TKA groups regarding walking speed ($P = .51$) and step length ($P = .8534$). Control group patients walked more efficiently compared to TKA groups, showing inferior trunk flexion and inferior variation in step length ($P < .0001$).
Conclusions: This study showed that restoring the pre-arthritic joint line, as advocated by surgeons following the uKA philosophy, does not guarantee a closer-to-normal knee kinematics.

* Corresponding author. Südtiroler Sanitätsbetrieb, Dantestraße 51, 39042, Brixen, Italy. Tel.: +1 408 706 6288.
E-mail address: pindelli@stanford.edu

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Introduction

Total knee arthroplasty (TKA) represents a surgical intervention whose outcomes are still unsatisfactory in a significant percentage of patients [1]. Recently, a few authors criticized the classical surgical technique adopted by most arthroplasty surgeons (mechanical alignment with the recreation of symmetric and rectangular flexion and extension gaps) [2,3] as the major reason for patient dissatisfaction. Even though the mechanical alignment (MA) principles implementation led to an excellent long-term survival rate, less than 1% of patients preoperatively showed a neutral knee axis [4]. Because of the constant change of the native knee joint anatomy typical of MA and to improve knee arthroplasty patient functional outcomes, a paradigm shift from MA to a more personalized alignment approach has been adopted during the last decades [5]. The first and innovative customized approach, the unrestricted kinematic alignment (uKA) technique, was proposed by Howell et al. [6]: this technique aimed to restore native knee kinematics by simply resurfacing the knee joint to restore the native tibial-femoral articular surface restoring and, at the same time, the pre-arthritic joint line. Following the same principles, variations of this technique (ie, modern personalized TKA techniques) have introduced safe boundaries to cope with extreme patho-anatomies, when a pure resurfacing could have raised doubts because of the risk of a mechanical failure [7–11].

Moreover, recent studies have shown that uKA surgical approach could result in a high rate of unbalanced knee joints [12,13]. Although there is still no consensus on personalized TKA soft tissue balancing, it is evident that the medial tibiofemoral compartment should remain as stable as possible throughout the entire range of knee flexion [14,15]. Notably, given the significant variability in soft tissue behavior within the same bony morphology group, pure knee resurfacing could be detrimental in certain cases [16]. Implementing robotic-assisted surgery in the workflow of personalized TKA could provide valuable insights into the soft tissue envelope and help prevent this potential complication.

The study goal was to kinematically compare two different personalized TKA workflows: the classical uKA with pure resurfacing of the joint and restoration of the pre-arthritic joint line as described by Howell et al. [6] and a robot-assisted hybrid KA (hybrid kinematic alignment [hKA]) technique designed to achieve an intercompartmental asymmetric gap within safe alignment boundaries. The study's hypothesis posited that there would be no discernible gait analysis distinctions between the two distinct workflows in accurately replicating a close-to-normal knee kinematic during level walking.

Material and methods

This was a retrospective cohort gait analysis study of a consecutive series of patients who underwent unilateral TKA intervention. All surgeries were performed at the same institution by the same surgeons (P.V. and P.F.I.) between January 2022 and March 2023. The inclusion criteria were a minimum follow-up of 9 months from primary medial pivot or medially congruent TKA for a primary terminal knee osteoarthritis (Kellgren Lawrence III-IV), a high satisfaction rate as shown by a minimum score of 70 points according to the Knee Injury and Osteoarthritis Outcome Score [17] and an interest in study participation. Patients were excluded if they had a preoperative hip-knee-ankle (HKA) angle >180° (valgus morphotype), a postoperative complication requiring a secondary surgical procedure, a lower limb neuro-muscular impairment before surgery, or if they were unable to sustain the kinematic assessment analysis. Preoperatively, the patients were randomly assigned into two groups according to the surgical technique: A) unrestricted kinematic alignment technique (uKA) and B) robot-assisted, hybrid kinematic alignment (named hKA) with intraoperative determination of alignment boundaries (±3° from HKA neutral axis) and a slight intercompartmental gap asymmetry (max 2 mm lateral-opening).

The two TKA groups were compared to 12 healthy individuals as the control group. The controls were volunteers recruited among the physical therapy students at our institution; none had previous neuro-muscular issues. Ethical approval was obtained from the Institutional Research and Ethical Committee (IRB: SABES 71/2023 and 17/2024). All patients signed an informed consent prior entering the study.

Surgical technique

A standard medial parapatellar approach was used in all cases: the anterior and posterior cruciate ligaments were removed in all cases. In the uKA group, an unrestricted caliper-verified KA TKA was performed following the original surgical principles and utilizing the implant design proposed by the same authors (GMK Sphere, Medacta International, Lugano, Switzerland) [18]. In the hKA group, a robotic-assisted kinematic technique was deployed as previously described [14]: in this group, a medially-congruent implant design (Persona MC, Zimmer Biomet, Warsaw, IN) was deployed under robotic assistance (ROSA, Zimmer Biomet, Warsaw, IN). The goal of this hKA technique was to resurface the tibiofemoral joint, following the algorithm proposed by Vendittoli et al. [7] to stay within a safe alignment zone (medial proximal tibial angle and lateral distal femoral angle 0° ± 5° from neutral, HKA 180 ± 3°), and to balance the soft tissue envelope to achieve an intercompartmental asymmetric gap with a maximum 2 mm of mediolateral difference. The robotic system used in this cohort of patients allowed for personalization of the gaps before bone-cut execution, both in flexion and in extension.

Gait analysis set up and physical examination

The gait analysis was carried out utilizing a modern marker-less instrumented treadmill (WalkerView—WV—by TecnoBody, Bergamo, Italy) equipped with an instrumented belt enriched with 8 load cells, a 48" wide liquid crystal display screen providing continuous virtual reality/biofeedback, a 3D camera for motion picture (Kinect v2, Microsoft, USA), and a control, 15" touchscreen connected to a personal computer. The WV-integrated software utilized for the gait analysis (TecnoBody MS, Bergamo, Italy) evaluated, in real-time, multiple spatiotemporal parameters (cadence, stance/swing times, step time, and step length) and sagittal kinematic variables (trunk, hips, and knees range of motion [ROM]) [19].

A physical examination was performed for every patient, and data regarding passive and active hips, knees, and ankles' ROM were collected. A formal evaluation according to the Knee Injury and Osteoarthritis Outcome Score system was performed before gait analysis to confirm that the patient met the study inclusion criteria [17]. Before gait trials, healthy controls and patients were asked to familiarize themselves with the WV treadmill platform by undertaking a 10-minute walk at their comfortable speed (maximum 20 km/h). After the 10 minutes trial, all participants underwent a 3-minute gait test at their comfortable speed; in particular, the belt speed was increased to the comfortable one gradually (about 30 seconds), then 2 minutes of constant belt speed, where data were captured, and lastly, the belt speed was gradually reduced to a stop (about 30 seconds). The same physical therapist (M.B.), with experience in gait analysis, oversaw the correct execution of the test and acquired all data. The knee kinematic and the spatiotemporal data throughout the gait cycle were then recorded by the system.

Sagittal knee kinematic data analysis

The knee flexion-extension kinematic curves were evaluated to permit a quantitative comparison between groups. The two main gait phases, stance, and swing, were further divided into their functional periods, based on the normal key events occurring throughout the stride [20] (Fig. 1): heel strike, 1st knee flexion peak, knee extension peak, and 2nd knee flexion peak.

Stance phase

The stance phase was split into four subphases: load response, early-stance, mid-stance, and terminal stance phase [20]. During normal gait, after the heel strike, the gait cycle is characterized by a 1st knee flexion peak, where the knee acts as a shock absorber to permit a body weight smooth passage from the opposite limb; this double-stance period is routinely called the “load response” phase. Afterward, the knee rapidly extends to reach its position of maximum stability to permit the single support period. This progressive knee extension phase is called “early-stance” [20] and it is followed by the “mid-stance phase,” where the knee reaches its maximum extension. As the contralateral swing limb advances, the contralateral foot moves forward with respect to the ipsilateral hip, starting the “terminal-stance phase” [20]. In the normal knee sagittal kinematic curve, the “terminal-stance” merges with the mid-stance into an extension plateau (Fig. 1): the longer this extension plateau persists, the longer the stride is since the contralateral swinging limb could touch the ground further. The “stance phase” ends with the “preswing phase”; this represents the second double support period during which the knee needs to flex quickly to permit the toe-off [20].

Swing phase

In this study, the swing phase was further divided into three subphases: early, middle, and terminal swing phase (Fig. 1), which were represented by the bell curve, which characterizes the second knee peak flexion [19,20].

Spatiotemporal data and overall gait quality assessment

Speed, cadence, and stride length were collected for every patient according to a previously published protocol [19]. An overall gait assessment was performed, collecting trunk flexion, center of gravity (CoG) vertebral displacement, and stride length variation. Excessive trunk flexion during gait was regarded as a compensatory mechanism aimed at mitigating quadriceps engagement to counteract the external unbalancing forces [21]. It has been shown that leaning forward during the stance phase of gait reduces the external knee flexion moment by approaching the ground reaching force to the knee joint center of rotation [21]. CoG vertical displacement is routinely considered a good indicator of an efficient gait since it has been demonstrated that any variation of its natural sinusoidal path of low amplitude could lead to an increase in energy expenditure to maintain the gait speed and step length [22]. Lastly, in this study, particular attention was paid to the stride length variation, since a consistent variation has been correlated with cognitive decline, functional impairment, and risk of falling [23].

Demographic and radiographic data

Multiple demographic data including sex, age, height, weight, and body mass index (BMI) were recorded. Radiographic measurements were performed on coronal, full-length weight-bearing radiographs by a single investigator (A.G.S.) before and after the surgery.

Preoperative and postoperative measurements included the HKA angle, the medial proximal tibial angle, and the distal lateral femoral angle.

Sample size and statistical analysis

The normal continuous variables were described in mean and standard deviation values, whereas the non-normally distributed continuous variables were described in the median and interquartile range. The normality of the continuous variable was assessed by a Shapiro-Wilk test. Comparisons of radiographic and demographic data were performed between the uKA and hKA groups using the unpaired Student’s *T*-test. The kinematic curves of uKA, hKA, and control groups were compared at each key event

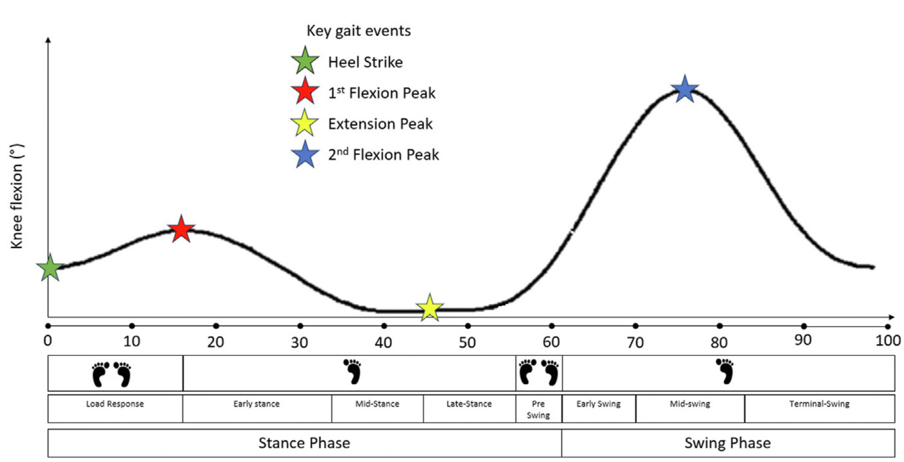

Figure 1. Physiological flexion-extension knee kinematic curve during level walking. The main gait phases (stance and swing) and their respective subphases are represented. The key gait events are depicted by colored stars. Lastly, double- and single-stance periods are highlighted, respectively, by 1 or 2 footprints.

Table 1
Demographic and radiographic data.

	hKA group (n = 12)	uKA group (n = 12)	Control group (n = 10)	Control vs hKA	Control vs uKA	hKA vs uKA
				P value	*P* value	*P* value
Age (y)	73 ± 8	78 ± 8	36 ± 13	<.001	<.001	n.s.
Gender (F/M)	0.33	0.23	0.63	<.001	<.001	n.s.
Height (m)	1.72 ± 0.12	1.74 ± 0.06	173 ± 0.11	n.s.	n.s.	n.s.
Weight (kg)	78 ± 11	83 ± 14	69 ± 19	n.s.	n.s.	n.s.
BMI (kg/m^2)	26 ± 2.56	27 ± 3.78	23 ± 3.33	n.s.	n.s.	n.s.
Radiographic measures						
Pre-HKA	173.0 ± 5.0	176.0 ± 4.0				n.s.
Pre-LDFA	89.0 ± 2.0	89.0 ± 4.0				n.s.
Pre-MPTA	87.0 ± 3.0	87 ± 3.0				n.s.
Post-HKA	178 ± 2.0	178 ± 3.0				n.s.
Post-LDFA	88.0 ± 3.0	88.0 ± 2.5				n.s.
Post-MPTA	88.0 ± 2.5	87.0 ± 3.0				n.s.

LDFA, lateral distal femoral angle; MPTA, medial proximal tibial angle; n.s., not statistically significant.

using a three-level one-way analysis of variance, followed by a Bonferroni post hoc test in case of normal distributed data. For not normally distributed continuous variable, the Kruskal-Wallis test substituted the analysis of variance test. In the case of dichotomous variables, data were represented as percentages, and a Fisher's exact test was used to assess the difference between the groups. Significance was set at an alpha value of 0.05. All statistical analyses were undertaken with SPSS 26 (IBM Corp., Armonk, NY). A power analysis was performed using data from our control group, where the maximum knee flexion in the swing phase was 57.2° (standard deviation 3.7). Using a power of 80% and alpha <0.05, and since a change of 5° was deemed to be clinically significant, a minimum of 10 patients were required in each group.

Results

Thirty-six subjects met the inclusion criteria and were accepted to enter the study protocol: 12 patients in the hKA group, 12 in the uKA group, and 12 controls. The gait assessment was performed at a minimum of 9 months from the index procedure in both experimental groups. No significant differences were found between the uKA and hKA groups in terms of patients' age, weight, height, and BMI. Statistically significant differences were found between the two TKA groups and the control group for age, weight, and BMI ($P <$ .001): in fact, subjects in the control group were younger and with a lower BMI. The gender distribution was also different among the TKA and control groups; namely, 63% of controls were women, whereas only 23% and 33% in the uKA and rKA, respectively ($P <$ .05) (Table 1).

Sagittal knee kinematic data

Stance phase

The load response data analysis had to cope with skewed data, namely due to the inconsistency of the 1st knee flexion peak in both experimental groups. Hence, to compare the load response phase, the weight acceptance (WA) physiological behavior was described by a dichotomous variable determined by the presence (WA) or absence (no WA) of the 1st knee flexion peak (Fig. 2); the statistically significant difference between these two variables was determined according to the Fisher's exact test. Patients in the control group showed a consistent presence of the 1st knee flexion peak when compared to the uKA TKA group ($P <$ .001). Namely, the physiologic WA behavior was more consistently represented in the controls (54.5%) and in the hKA TKA group (36.4%) than in the uKA TKA group (9.1%). In particular, uKA TKA patients were more likely to lose the natural knee flexion pattern compared to the control group, whereas no statistically significant difference was depicted between the control group and the hKA TKA group [Fig. 3]. However, the differences between the two TKA groups were considered trends, since no statistically significant differences were reached.

In addition to a less consistent WA behavior, the uKA group showed a less efficient transition between the double support and the single stance period during the early stance phase: in fact, the average slope of this section of the gait curve, as depicted by the early stance speed variable, was flatter compared to control [$P <$ .009] and hKA groups [$P =$ .009]. Interestingly, the hKA group curve showed a closer-to-normal early stance slope during the transition to the knee extension peak [$P >$ .05]. No significant differences were

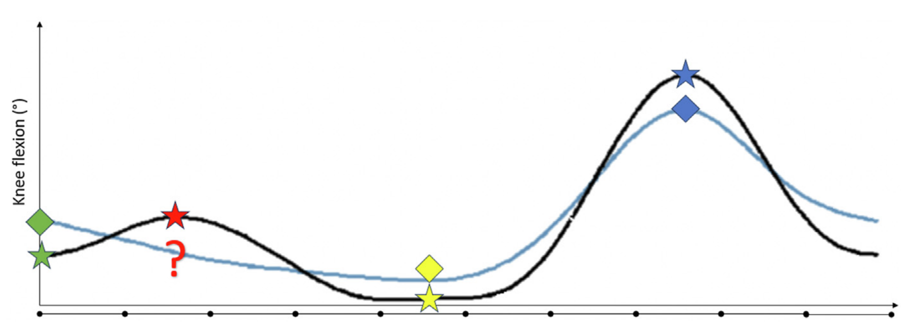

Figure 2. Comparison between a physiological (black one) and pathological (blue one) post-TKA flexion-extension knee kinematic curve during level walking. The gait key events are depicted by colored stars on physiological curve and by colored diamond on pathological one. The missing 1st flexion peak on the pathological curve points out a quadriceps avoidance gait, which leads to poor functional outcomes.

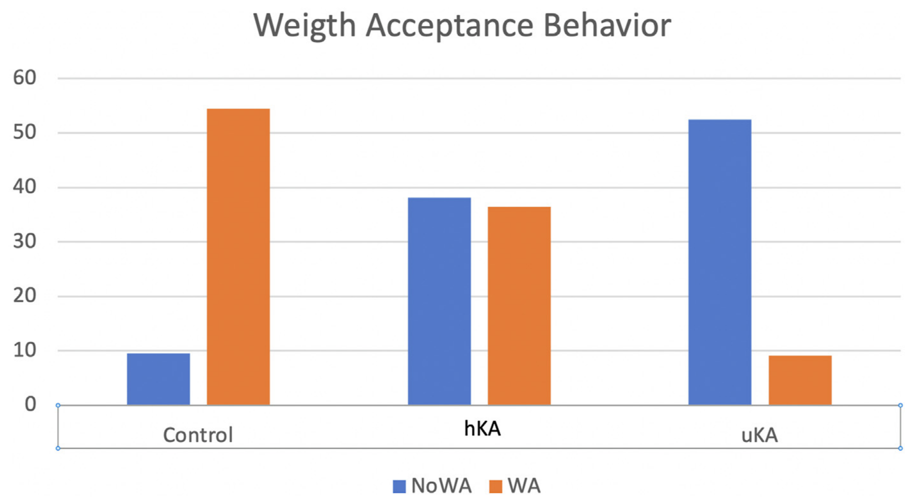

Figure 3. Column chart depicting the physiological weight acceptance (WA) behavior (ie, the presence of 1st knee flexion peak) distribution among the group. Patients from uKA group were more likely to lose a WA behavior compared to control group [$P < .001$].

found between the two TKA groups regarding the knee flexion at heel strike, the knee extension peak, and the knee ROM during the stance phase [Table 2]. Moreover, the control group showed a longer extension knee plateau compared to both TKA groups ($P < .001$).

Swing phase

Significant differences were also found between the control group and both TKA groups [Table 2] during the analysis of the data acquired in this gait phase. In particular, the control group showed a higher knee swing peak ($P < .0001$), a more efficient transition from stance to swing phase, as well as a more performing warm-up for the next gait cycle due to a quicker terminal swing extension ($P < .0001$). Interestingly, no statistical differences were found between the two TKA groups concerning the kinematic data during the swing phase of gait [Fig. 4].

Spatiotemporal and overall gait quality data

The control group walked faster with longer steps compared to both TKA groups ($P < .0001$), but without significant differences during the evaluation of the cadence parameter ($P = .066$). On the other hand, no significant differences were found between the two TKA groups regarding walking speed ($P = .5143$) and step length ($P = .8534$) [Table 3]. Not surprisingly, the control group walked more efficiently compared to both TKA groups; in fact, subjects in the control group walked with an inferior trunk flexion ($P < .0001$) and showed an inferior variation in step length ($P < .0001$). Finally, the analysis of CoG showed an increased CoG vertical displacement in controls with respect to the two TKA groups; this finding was considered a consequence of faster walking speed and longer step length ($P < .0001$) [24]. No differences were found between the two TKA groups regarding trunk flexion ($P = .1327$), variation in step length ($P = .6848$), and CoG variation ($P = .5560$).

Discussion

The main finding of this study was that hKA patients, when compared to uKA (having a pure resurfacing of the joint surface with reproduction of the prearthritic joint line obliquity), showed a closer to normal knee kinematic during load response and early stance gait phases. Because of these findings, the author's original hypothesis was not confirmed. In the author's opinion, these findings could be the consequence of the neglected soft tissue balancing part of the regular uKA workflow [18]: in fact, as suggested by Edelstein et al. [15] in a recent

Table 2
Kinematic knee parameters.

	hKA group (n = 12)	uKA group (n = 12)	Control group (n = 10)	Control vs hKA	Control vs uKA	hKA vs uKA
				P value	*P* value	*P* value
Stance phase						
Heel strike (°)	17.5 ± 8.0	15.0 ± 6.5	11.0 ± 5.5	n.s	n.s	n.s
Weight acceptance (%)	36.4 %	9.1 %	54.5 %	n.s	<.001	n.s
Early stance speed (°/s)	−47.4 ± 29.3	−19.3 ± 15.1	−72.4 ± 31.0	n.s	<.001	.009
Extension peak (°)	5.5 ± 4.5	6.5 ± 5.0	3.0 ± 3.5	n.s.	n.s.	n.s.
Mid-stance length (s)	0.37 ± 0.15	0.41 ± 0.17	0.20 ± 0.04	.002	.004	n.s
ROM stance (°)	15.0 ± 8.0	10.0 ± 6.5	16.5 ± 4.5	n.s	n.s	n.s
	hKA group (n = 12)	uKA group (n = 12)	Control group (n = 10)	Control vs hKA	Control vs uKA	hKA vs uKA
				P value	*P* value	*P* value
Swing phase						
Preswing speed (°/s)	121.5 ± 30.0	94.0 ± 25.0	176.0 ± 27.0	<.001	<.001	n.s.
Flexion peak (°)	45.0 ± 10.0	38.0 ± 6.0	57.0 ± 4.0	<.001	<.001	n.s.
Terminal swing speed (°/s)	−92.0 ± 32.5	−75.0 ± 23.0	−153.0 ± 26.0	<.001	<.001	n.s.

n.s., not statistically significant.

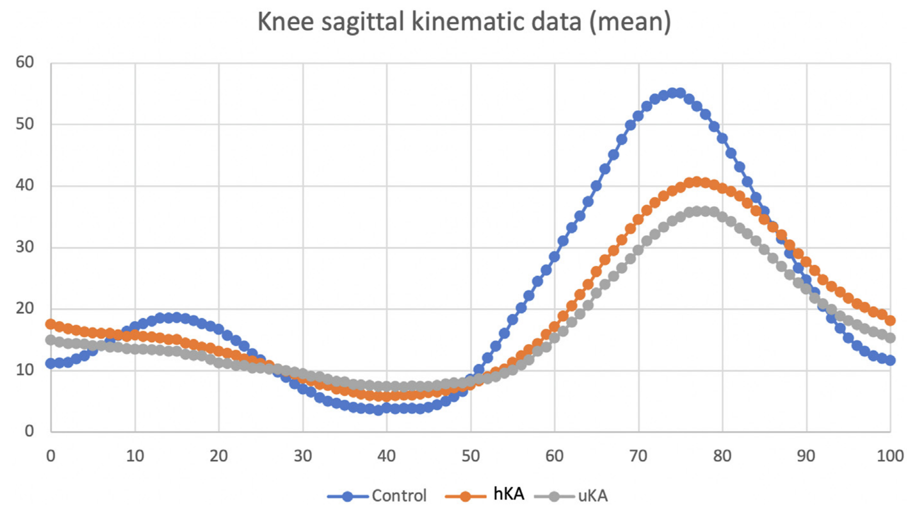

Figure 4. Comparison of flexion-extension knee kinematic curve among the 3 groups.

simulation study, the execution of a pure uKA surgical technique could lead up to 41% of unbalanced knees, with a medial flexion gap looser than the lateral flexion one [15]. Even if a consensus about soft balancing management is still lacking among modern personalized knee arthroplasty techniques, it is broadly accepted that, to reproduce the native knee kinematics, the tension in the medial compartment should be higher or at least equal to the lateral [25,26]. Consequently, even though the traditional unrestricted caliper-verified KA TKA technique is highly reproducible and accurate in terms of bone resections, this technique brings an intrinsic lack in recognizing and addressing an abnormal soft tissue envelope, leading to a post-operative instability issue [27].

Multiple authors reported instability as the third leading cause of TKA revision [28]. Because of this, leaving an “undetermined” asymmetry in the gap balancing has been historically considered a risk factor for a poor functional outcome [28,29]. The recent broad utilization of computer-assisted surgery devices has simplified the soft tissue balancing decision-making process [30]: nowadays, intraoperative sensors, navigation systems, and semi-active and passive robotic systems allow surgeons to intraoperatively balance the knee with a micrometric precision [31]. In the robotic-assisted cohort of this study (hKA), the authors were able to determine the desired intercompartmental gap asymmetry (<2 mm both in flexion as well as in extension), and, in our opinion, this accuracy has improved the kinematic of the knee, keeping the soft tissue envelope within a “safe limit.”

The use of a restricted KA approach in place of a uKA has also been widely advocated because concerns existed on the broad-spectrum application of the KA principles in extreme anatomies or in severe pathologic anatomies [7]. For this reason, Vendittoli et al. proposed an algorithm able to facilitate the application of kinematic alignment principles even in extreme cases, trading off minimal changes in joint line native orientation to respect the native morphotype of the patient, but within “safe bony limits.” However, one of the main principles of the original rKA surgical technique, as well as of uKA, is that the soft tissue knee envelope needs to have retained its competency, independently from the severity of the joint deformity [7]. The current authors believe that the soft tissue envelope may lose its native competency during the progression of the degenerative knee disease, and the combination of the rKA surgical technique with the robot-assisted soft tissue fine-tuning, which allows for a looser lateral compartment and a tighter medial compartment, could prevent a potential pitfall of an unstable KA TKA with a restored joint line orientation [32]. Moreover, although the restoration of the joint line obliquity is supposed to reproduce the “prearthritic” knee biomechanics, recent studies showed a weak correlation between postoperative outcome and joint line obliquity, likely due to soft tissue envelope variability within the same bony morphology group [33,34]. It has been shown that soft tissue fine-tuning was notably important when modern TKA designs, with more conforming bearings (as medial pivot) were deployed since kinematics relied completely on their competency [35–37].

The current study also showed, in particular in the uKA group, a reduced knee flexion excursion during the load response, a condition called “quadriceps avoidance gait” [38] [Fig. 2]. Specifically, TKA patients walked in a way to optimize the demand on

Table 3
Spatiotemporal and gait quality parameters.

	hKA group (n = 12)	uKA group (n = 12)	Control group (n = 10)	Control vs hKA	Control vs uKA	hKA vs uKA
				P value	*P* value	*P* value
Spatiotemporal parameters						
Speed (km/h)	1.95 ± 0.93	1.77 ± 0.39	4.08 ± 0.76	<.001	<.001	n.s.
Cadence (cycle/s)	0.77 ± 0.12	0.73 ± 0.18	0.88 ± 0.06	n.s.	n.s.	n.s.
Stride length (cm)	34.54 ± 15.27	35.50 ± 9.54	63.88 ± 11.04	<.001	<.001	n.s.
Quality gait parameters						
Trunk flex (°)	8.7 ± 3.9	11.2 ± 3.9	3.3 ± 1.9	<.001	<.001	n.s.
CoG (cm)	1.28 ± 0.57	1.19 ± 0.36	2.68 ± 0.81	<.001	<.001	n.s.
Stride variability (%)	9.07 ± 5.74	8.28 ± 3.64	3.36 ± 1.02	<.001	<.001	n.s.

n.s., not statistically significant.

quadriceps muscle to avoid the anterior pull on the tibia due to the patellar ligament action, which should be counterbalanced by the anterior cruciate ligament or, in its absence as in TKA, by the bearing conformity coupled with a proper soft tissue envelope tension [39]. It has been hypothesized that a reduction in quadriceps contraction could eliminate an abnormal anterior tibial translation that could be perceived as a sensation of joint instability by the patient; unfortunately, quadriceps avoidance gait in TKA patients had a substantial impact on the performance of the knee during important tasks of daily living, leading to poor functional outcomes [24]. This pathological gait pattern was less clear in hKA TKA patients compared to uKA TKA patients, possibly due to the neglect of soft tissue incompetency in the uKA cohort, which may have resulted in a compensatory gait pattern.

A well-expected finding was demonstrated in the control group of the current study: patients in this cohort walked faster and in a more efficient way compared to both TKA groups, as shown by a minor trunk flexion and a minor stride length variability. Since the control group walked faster compared to both TKA groups, the CoG vertical variation was not considered, in the current study, as a valid parameter to assist gait efficiency since it is classically impacted by gait speed [25]. However, these differences could also be the consequence of the physiological aging process, given the important age difference between the two TKA groups and the control group. It is well known that elderly adults tend to walk slower as the result of a longer double support period to improve the stability in the lower extremities joints [40]. Moreover, it has been shown that elderly adults have a propensity to walk with a lean trunk, aiming to increase hip extensor muscles' contribution to lower limb stability since these muscles are less prone to aging process atrophy compared to knee extensor and ankle flexor muscles, which are common sarcopenia target [40]. Nevertheless, in the current study, the authors were not able to demonstrate if it was simply aging, volitional choice, or overlooked neuromuscular pathologies causing these deficits in trunk position [41]. Because of this theoretical caveat, in the current study, the authors selected healthy young adults as a control group and not age-matched subjects.

Unfortunately, it was not possible to make a broader comparison between the results of this study and other similar studies because of the heterogeneity of the outcomes used to assess gait analysis in other TKA studies [42]; nevertheless, this is the first gait analysis study assessing the difference between unrestricted KA and robotic-assisted restricted KA workflows.

Several limitations could have skewed the results of this study. First, its retrospective design exposes a risk of selection bias: despite the fact that the patients included in the study could be considered a good representative sample of a generic TKA population, the decision to rule out valgus morphotype made the result of this study not applicable to valgus morphotype osteoarthritic patients.

Additionally, given that both TKA groups had a low BMI, the conclusions cannot be extended to obese patients, who can represent an important percentage of TKA candidates. Moreover, even though a complete preoperative physical examination ruled out any lower limb neuromuscular impairment, a preoperative gait analysis would be more precise in this task, making possible a more accurate patient categorization. Another limitation is the lack of rotational data that could have given major insights regarding the potential restoration of important knee kinematic behavior, namely screw home mechanism and femoral rollback.

Furthermore, since all the interventions were performed by the same surgeons, with consolidated experience in personalized alignment and robotic-assisted TKA surgery, the results of this study cannot be generalized to all TKA surgeons.

Finally, despite the two TKA implants examined in the current study sharing similar kinematic concepts (ie, reproduction of the medial pivot kinematics), it must be recognized that the two designs had unique features that could have introduced a confounding factor.

Conclusions

This study showed that modern alignment techniques attempting to restore the native joint line obliquity, a milestone of the uKA surgical technique, do not guarantee the reproduction of the native knee kinematics as hypothesized by several authors supportive of KA principles. This study also showed that setting alignment boundaries, determining a slight intercompartmental gap asymmetry, and selecting a medially stabilized design, all favored a closer to normal knee kinematics. More studies with larger cohorts of patients are needed to confirm the findings of the current study.

Conflicts of interest

P. F. Indelli is a speaker bureau of Microport, bioMerieux, and Biocomposites; is a paid consultant for Microport; and is a board/committee member for ESSKA and PAS. All other authors declare no potential conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2024.101586.

CRediT authorship contribution statement

Andrea Giordano Salvi: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Pieralberto Valpiana:** Project administration, Investigation, Conceptualization. **Bernardo Innocenti:** Writing – review & editing, Visualization, Supervision, Formal analysis. **Stefano Ghirardelli:** Visualization, Resources, Funding acquisition. **Matteo Bernardi:** Methodology, Investigation, Formal analysis, Data curation. **Giuseppe Petralia:** Software, Formal analysis, Data curation. **Giuseppe Aloisi:** Software, Resources, Formal analysis, Data curation. **Karlos Zepeda:** Writing – review & editing, Validation. **Christian Schaller:** Resources, Funding acquisition. **Pier Francesco Indelli:** Writing – review & editing, Supervision, Conceptualization.

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