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An anatomic-functional implant positioning technique with robotic assistance for primary TKA allows the restoration of the native knee alignment and a natural functional ligament pattern, with a faster recovery at 6 months compared to an adjusted mechanical technique

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Abstract

Purpose An anatomic-functional implant positioning (AFIP) technique in total knee arthroplasty (TKA) could restore physiological ligament balance (symmetric gap in extension, asymmetric gap in flexion). The purposes were to compare (1) ligament balancing in extension and flexion after TKA in the AFIP group, (2) TKA alignment, implant positioning and patellar tracking between AFIP and adjusted mechanical alignment (aMA) techniques, (3) clinical outcomes between both groups at 12 months.

Methods All robotic-assisted TKA with an AFIP technique were included ($n=40$). Exclusion criteria were genu valgum (HKA angle $> 183^\circ$), extra-articular deformity more than 10° , and patellar maltracking (high-grade J-sign). One control patient with a TKA implanted by an aMA technique was matched for each case, based on age, body mass index, sex, and knee alignment. Ligament balancing (medial and lateral gaps in millimeters) in full extension and at 90° of flexion after TKA in the AFIP group was assessed with the robotic system. TKA alignment (HKA angle), implants positioning (femoral and tibial coronal axis, tibial slope, joint-line orientation), patellar tracking (patellar tilt and translation) and the Knee Society Score (KSS) at 6 and 12 months were compared between both groups. The ligament balancing was compared using a *t* test for paired samples in the AFIP group. The radiographic measurements and KSS scores were compared between groups using a *t* test for independent samples.

Results In the AFIP group, there was no significant difference between the medial and lateral gap laxity in extension (NS). A significant opening of the lateral gap was observed in flexion compared to extension (mean: $+2.9$ mm; $p < 0.0001$). The mean postoperative HKA angle was comparable between both groups ($177.3^\circ \pm 2.1$ in the AFIP group vs $176.8^\circ \pm 3.2$; NS). In the AFIP group, the femoral anatomy was restored ($90.9^\circ \pm 1.6$) and the tibial varus was partially corrected ($87.4^\circ \pm 1.8$). The improvement of Knee and Function KSS at 6 months was better in the AFIP group (59.3 ± 11.9 and 51.7 ± 20 , respectively, versus 49.3 ± 9.7 and 20.8 ± 13 ; $p < 0.001$).

Conclusion The AFIP concept allowed the restoration of the native knee alignment and a natural functional ligament pattern. With a more physiological target for ligament balancing, the AFIP technique had equivalent clinical outcomes at 12 months compared to aMA, with a faster recovery.

Level of evidence III retrospective therapeutic case control series.

Keywords Total knee arthroplasty · ROSA · Robotic-assisted surgery · Anatomic-functional implant positioning · Patellar tracking · Ligament balancing · Lateral gap laxity

Abbreviations

AFIP Anatomical-functional implant positioning
BMI Body mass index

HKA Hip-knee angle
JLCA Joint-line convergence angle
JLO Joint-line orientation
KA Kinematic alignment
KSS Knee Society Score
MA Mechanical alignment
MCL Medial collateral ligament

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mMDFa	Mechanical medial distal femoral angle
MPTA	Medial proximal tibial angle
PA	Personalized alignment
raTKA	Robotic-assisted total knee arthroplasty
ROM	Range of motion
TKA	Total knee arthroplasty

Introduction

The philosophy of a neutral postoperative alignment with symmetrical gaps in extension in total knee arthroplasty (TKA) was driven by the concept of equalizing load on the implant to decrease wear and loosening rather than to restore normal knee kinematics [44, 45]. New alignment paradigms, defined as personalized alignments (PA), have been described to restore a more anatomical alignment and avoid ligament releases to improve patient satisfaction [7, 19, 31]. The ligament balancing is briefly described for PA techniques in the literature. This ligament balancing follows the traditional assumption that a symmetrical gap in extension and flexion should be achieved. Nevertheless, in native knees, the lateral laxity is significantly greater than the medial laxity in flexion [13, 47, 52].

A ligament balancing closer to the one observed in the native knee has been described in cruciate-retaining TKA [34]. However, determining the exact goal in TKA for the alignment and the ligament balancing remains challenging. The first goal is to obtain stability during walking activities, with symmetrical medial and lateral gaps in extension. The second goal is to keep a stable knee during other activities of daily life, with a stable medial compartment all along the arc of knee flexion to avoid mid-flexion instability without excessive tension of the lateral structures [3]. To achieve these functional goals, the concept of an anatomic-functional implant positioning (AFIP) is proposed in this study. This involves not only the alignment, but also the restoration of the shapes of the distal femur and the proximal tibia including joint-line orientation, femoral offset, a proper patellofemoral tracking, and a physiological ligament balance (symmetric gap in extension, asymmetric gap in flexion).

Therefore, the aims were (1) to evaluate the capacity to achieve a ligament balancing in extension and flexion after the TKA implantation in the AFIP group measured using the robotic-assisted system; (2) to compare the postoperative radiographic implant positioning, limb alignment, and patellar tracking between AFIP and aMA techniques (limb alignment, femoral and tibial mechanical axis, tibial slope, postoperative femoral offset, joint-line orientation, patellar tilt, and translation); and (3) to compare the clinical outcomes (KSS score and patient satisfaction) and complications between both groups at a minimum follow-up of 12 months.

The hypothesis was that using the AFIP technique would restore the native knee alignment and the physiological ligament balance with equivalent clinical scores and patient satisfaction compared to a traditional adjusted mechanical alignment (aMA) technique.

Material and methods

After receiving approval from the internal review board (study ID Number: MF3867, approval date: 20th December 2020), a consecutive series of patients who underwent a primary robotic-assisted TKA (raTKA) using posterior-stabilized implants with an AFIP technique at a single institution between January 2020 and September 2020 ($n = 49$) was retrospectively reviewed. All cases were performed after the senior author had ample experience with the robotic arm. The indication for surgery was end-stage medial femorotibial or tricompartmental osteoarthritis. Exclusion criteria were preoperative genu valgum defined as a hip–knee–ankle (HKA) angle superior to 183° , preoperative extra-articular deformity more than 10° , patellar maltracking with preoperative patellar tilt more than 20° or patellar subluxation (defined by a preoperative high-grade J-sign [14]), and previous femoral or tibial osteotomy. Of the 49 primary raTKA procedures performed during this period, 40 met the criteria (Fig. 1). For each case, one control patient was matched based on age (by 10-year periods), BMI (by subgroups: < 18.5 ; 18.5 – 25 ; 25 – 30 ; 30 – 35 ; > 35), sex, and knee alignment ($HKA \pm 3^\circ$). All control patients had the same primary cemented posterior-stabilized TKA (Persona[®], Zimmer Biomet, Warsaw, IN, USA), implanted by a conventional aMA technique in 2019, with the same exclusion criteria as the AFIP group. The demographic data are summarized in Tables 1 and 2.

Surgery

The surgical approach was a tourniquet-less medial subvastus approach without any medial or lateral release and a conservative exposure of the medial tibial plateau avoiding any extensive release of the medial collateral ligament (MCL), such as the pie crust technique or the release of the superficial MCL on the distal tibia. A standardized postoperative protocol was applied for all the patients with early active range of motion (ROM) and full weight-bearing.

Anatomic-functional implant positioning technique

All the implantations of the AFIP group were performed image free using the ROSA[®] Knee System (Zimmer Biomet, Montreal, Quebec, Canada) according to the described technique in a previous study [5]. This surgical technique

Fig. 1 Flowchart

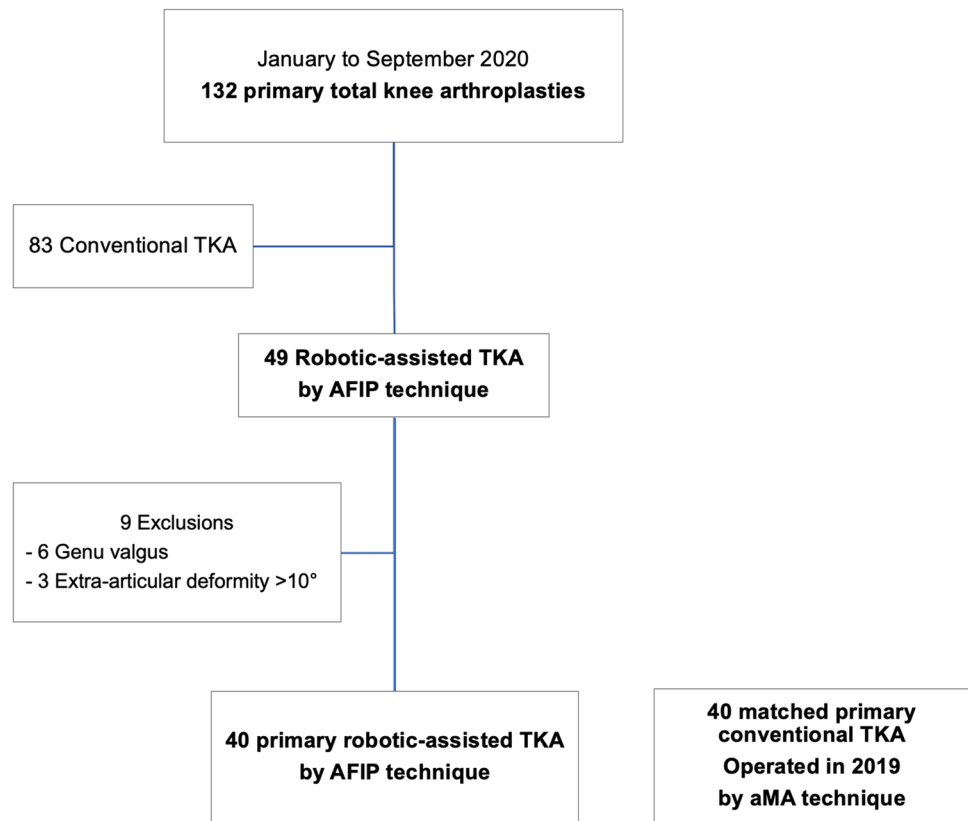


Table 1 Preoperative demographic and clinical data in the AFIP and aMA groups

	AFIP group <i>N</i> = 40 patients	aMA group <i>N</i> = 40 patients	<i>p</i> value
Age (years) mean ± SD [min; max]	60.0 ± 8.3 [40;80]	60.4 ± 7.6 [47;73]	NS
BMI (kg/m ²) Mean ± SD [Min; Max]	34.0 ± 5.9 [20.8;45.9]	34.0 ± 5.9 [20.8;45.9]	NS
Side (right)	24 (60%)	23 (57.5%)	NS
Male Sex	15 (37.5%)	17 (42.5%)	NS
Flexion Mean ± SD [Min; Max]	114 ± 8.8 [100;135]	116 ± 10 [90;140]	NS
Flexion contracture Mean ± SD [Min; Max]	8.0 ± 5.5 [0;20]	5.4 ± 6.4 [0;20]	NS
KSS score – function Mean ± SD [Min; Max]	37.4 ± 17 [0;65]	49.5 ± 16 [0;70]	0.001
KSS score – knee Mean ± SD [Min; Max]	35.3 ± 8.8 [0;47]	37.5 ± 6 [27;50]	NS

BMI body mass index, *KSS* Knee Society Score, *SD* standard deviation

is considered as "femur-driven". The femoral planning was done to restore the anatomy of the femur in a kinematic manner (compensating for the wear). The frontal positioning of the femur was performed with the aim to obtain the same amount of resection for the two distal condyles equal

to the implant thickness minus the wear for the worn medial side. The posterior resection was planned to be aligned to the posterior condylar axis without any additional femoral rotation. The planning for the tibial cut was then performed using the anatomical principle for the frontal plane and the slope. The amount of tibial varus was determined on the planning screen to reach these values with a maximum limit of 4° of varus. The posterior slope value was set up to replicate the natural slope up to 9°. Though 9° is slightly higher than what has been recommended, as noted by de Boer et al. [11], this is in line with the patient population of this study [11, 36, 51] and occurred in only 15 patients (37.5%) in the AFIP group with an extremely high preoperative posterior tibial slope of [68–80°]. After the final verification of the planning, the cuts were performed using the robotic arm to complete the distal femoral cut first, the anterior and posterior cuts, and then the tibial cut. At the end of the procedure, the gap assessment was performed using the gap balance tool of the robotic system and recorded in full extension and at 90° of knee flexion with the patella in situ (Fig. 2).

Adjusted mechanical alignment technique

This technique was used systematically by the senior surgeon before January 2020. The aMA technique is an adaptation of the conventional MA technique, but with under-correction of

Table 2 Knee phenotypes in the preoperative radiographs in the AFIP and aMA groups, according to the Hirschmann classification [19]

			AFIP group <i>N</i> = 40 patients	aMA group <i>N</i> = 40 patients	<i>p</i> value		
HKA (°) (Mean ± SD) [Min; Max]			170.4 ± 4.2 [163.5; 180]	171.4 ± 4.3 [165; 180]	NS		
VAR _{HKA} 15	VAR _{FMA} 6	NEU _{TMA} 0	4 (10%)	1	3 (7.5%)	0	NS
		VAR _{FMA} 3		1		0	
		VAR _{TMA} 6		1		0	
		VAR _{TMA} 3		2		1	
VAR _{HKA} 12		NEU _{TMA} 0		0		1	NS
	VAR _{FMA} 6	NEU _{FMA} 0		0		1	
		VAR _{TMA} 6	13 (32.5%)	1	12 (30%)	0	
	VAR _{FMA} 3	VAR _{TMA} 3		0		3	
		VAR _{TMA} 6		6		5	
		NEU _{TMA} 0		1		0	
VAR _{HKA} 9	VAR _{FMA} 6	NEU _{FMA} 0		1		1	NS
		VAR _{TMA} 6	10 (25%)	1	14 (35%)	0	
	VAR _{FMA} 3	VAR _{TMA} 3		0		2	
		VAR _{TMA} 6		0		2	
		NEU _{TMA} 0		2		2	
		VAL _{TMA} 3		1		0	
VAR _{HKA} 6	VAR _{FMA} 6	NEU _{FMA} 0		0		1	NS
		VAR _{TMA} 6	8 (20%)	0	8 (20%)	1	
	VAR _{FMA} 3	VAR _{TMA} 3		0		2	
		VAR _{TMA} 6		1		2	
		NEU _{TMA} 0		2		1	
		VAL _{TMA} 3		2		1	
VAR _{HKA} 3	VAR _{FMA} 3	NEU _{FMA} 0		0		1	NS
		VAR _{TMA} 6	3 (7.5%)	0	2 (5%)	1	
	NEU _{FMA} 0	VAR _{TMA} 3		4		1	
		NEU _{TMA} 0		2		0	
NEU _{HKA} 0	VAR _{FMA} 3	NEU _{TMA} 0	2 (5%)	1	1 (2.5%)	1	NS
	VAL _{FMA} 3	VAL _{TMA} 3		1		0	

HKA hip knee ankle angle, FMA femoral mechanical Axis, TMA tibial mechanical axis; VAR: varus; NEU: neutral; VAL: valgus

constitutional coronal deformity, within a limit of $\pm 3^\circ$. The femoral resection is adjusted to preserve mild constitutional deformity and/or reduce more severe deformity while leaving the tibial component mechanically aligned. The tibial component was positioned with the aim to be perpendicular to the mechanical tibial axis. The tibial slope was between 0 and 3° . For the flexion gap and the extension gap, the femoral component was positioned to achieve symmetrical residual laxity of 1–2 mm in both compartments while remaining within an HKA angle safe zone of 177 – 183° . To

obtain this symmetric gap in flexion, 3° of lateral femoral rotation has been applied for all the patients.

Data assessment

Intraoperative data in the AFIP group were used for the ligament balancing assessment using the robotic software (Fig. 2). This system allowed measurement of medial and lateral gaps in full extension and at 90° of flexion, in 0.1 mm increments [5, 41]. The width of a gap was defined as the



Fig. 2 Screening of the ligament balancing assessment after the implantation of the definitive TKA, showing a symmetric gap in extension and an asymmetric gap in flexion

minimum spatial distance between the most distal femoral point and the most proximal tibial point. The femoral points differed depending on the angle of flexion. While the most distal point was used for the extension gap, the most posterior point was used for flexion gap calculation. For each gap, tension was applied manually until resistance was met and further distraction would have required application of a substantially inadequate force. Thus, during this assessment, the collateral ligaments were tensed with their maximal tensions. For each case, measurements were repeated twice to ensure the reproducibility of the measurements and a third time in case of discrepancy, the average of the two closest measurements was recorded as the final value.

The radiographic assessment preoperatively and at 6 months included: anteroposterior view, lateral view, patellar axial view of the knee, and a long leg standing radiograph performed according to a standardized protocol in the same center. Axial views were performed using the Merchant method. Standardized radiographic measurements were performed: HKA angle, mechanical medial distal femoral angle (mMDFA), medial proximal tibial angle (MPTA), tibial slope, joint-line convergence angle (JLCA) [7], joint-line orientation (JLO) [50], femoral posterior offset, patellar tilt and translation. The JLO was measured as the angle between a parallel to the floor and the tangential to the medial and lateral tibial plateau [50]. Positive values represent a lateral

open angle and negative values a medial open angle. The offset was measured as the distance between the axis of the posterior cortex of the femoral diaphysis and the posterior part of the femoral condyle on preoperative and postoperative lateral radiographs [6]. Patellar tilt was measured as the angle between the patellar cut surface and the tangent to the anterior border of femoral condyles. Angles opening medially received a positive value. The patellar translation was measured by the distance between the middle of the prosthetic trochlear groove and the middle of the prosthetic implant of the patella. The threshold was 5° for patellar tilt and 5 mm for patellar translation [15]. Radiological measurements were performed twice by two independent reviewers (CB and BYO*) for all measurements to assess the reliability of each measurement.

The sample size calculation by matched samples *t* test was performed from clinical data (KSS score) from a previous randomized study assessing two kinds of knee alignment [12]. With an alpha value of 0.05 and power of 0.8, the calculated sample size was 38 participants per arm. Patient-reported outcomes (PROs) were measured using the Knee Society Scoring System at 6 and 12 months [4]. Recent studies have reported no difference in PROMS at 1 and 2 years postoperatively in the total joint arthroplasty population [33, 42, 48]. Additionally, when using this specific implant system, Mathijssen et al. demonstrate improved PROMs out to

1 year, with no difference in 1- and 2-year outcomes [33]. As such, additional 2-year follow-up should be similar in this study, and 2-year data were not reviewed in an effort to report these findings sooner than later. A minimal detectable change (MDC) of half the standard deviation of the postoperative score for the aMA group was used to assess clinical significance [39]. This was chosen as it is the largest standard deviation between both groups and visits and, therefore, the most conservative estimate. The standard deviation was 19; thus an MDC of 9.5 was used to assess clinical significance. This MDC is consistent with recent minimal clinically important difference (MCID) values reported for the original KSS function score of 6.3–10.3 [28]. ROM was measured preoperatively and postoperatively at 6 and 12 months. A clinical patellar maltracking was assessed with the J-sign classification [14]. Adverse events that occurred during routine follow-up were reviewed. All reoperations and revisions were evaluated, along with the reason for the reoperation or revision.

Statistical analysis

Statistical analysis was performed using the XL STAT software (Version 2021.2.1, Addinsoft Inc., Paris, France). Continuous variables were described using means, standard deviation, and ranges. Categorical variables were described using counts (percent). The ligament balancing in extension and flexion was also compared using a *t* test for paired samples in the AFIP group. The radiographic measurements and the clinical scores were compared pre- and postoperatively using a *t* test for paired samples in each group. Similarly, the improvement, the post- minus preoperative clinical scores, was also compared. The preoperative and postoperative rates of patellar tilt were compared using Fisher's exact test. The preoperative data, radiographic measurements and postoperative KSS scores were compared between groups using a *t* test for independent samples for the continuous variables and a Fisher's exact test for the categorical variables. A *p* value < 0.05 was considered statistically significant for all analyses. Correlations between ligament balancing, radiographic measurements, and demographic data were analyzed using the Pearson correlation coefficient in the AFIP group.

The intra-observer reliability of the radiographic measurements and of the ligament balancing measurements were evaluated by an intraclass correlation coefficient. The strength of agreement for the kappa coefficient was interpreted as follows: < 0.20 = unacceptable, 0.20–0.39 = questionable, 0.40–0.59 = good, 0.60–0.79 = very good, and 0.80–1 = excellent [43]. The ligament balancing measurements showed very good to excellent intra-observer agreement, and the radiographic measurements showed very good to excellent intra-observer and inter-observer agreements (Table 3).

Table 3 Intraobserver coefficients for the ligament balancing measurement, and intraobserver and interobserver coefficients for the radiographic measurement

	Intra observer ICC	Inter observer ICC	Agreement
Medial gap in extension	0.82	–	Excellent
Lateral gap in extension	0.77	–	Very good
Medial gap at 90°	0.75	–	Very good
Lateral gap at 90°	0.84	–	Excellent
HKA angle	0.92	0.86	Excellent
mMDFA	0.91	0.89	Excellent
MPTA	0.89	0.83	Excellent
Tibial slope	0.78	0.72	Very good
JLO	0.87	0.87	Excellent
Posterior offset	0.79	0.74	Very good

Strength of agreement for the kappa coefficient was interpreted as follows: < 0.20 = unacceptable, 0.20–0.39 = questionable, 0.40–0.59 = good, 0.60–0.79 = very good, and 0.80–1 = excellent

Table 4 Ligament balancing in the medial and lateral compartments in extension and flexion, measured at the end of the TKA procedure in AFIP group

Frontal laxity (mm) (mean ± SD) [Min; Max]	Medial	Lateral	<i>P</i> value
Extension	1.7 ± 0.8 [0.5;4.3]	1.8 ± 0.9 [0.5;3.7]	NS
Flexion at 90°	1.9 ± 0.7 [0.5;4]	4.7 ± 1.9 [1.2;9.5]	< 0.0001
<i>P</i> value	NS	< 0.0001	-
Gap in flexion – Gap in extension	0.1 ± 1.1 [– 2.9;2.3]	2.9 ± 2.2 [– 2.4;7.2]	

SD standard deviation

Results

The mean follow-up was 14.1 months ± 2.5 in the AFIP group and 15.2 months ± 3.3 in the aMA group with a minimum follow-up of 12 months.

Ligament balancing in the AFIP group

There was no significant difference between the medial gap laxity and the lateral gap laxity in extension (NS). A significant opening of the lateral gap was observed in flexion compared to the lateral gap in extension (*p* < 0.001, Table 4, Fig. 3). Thirty-three patients (82.5%) were in the target of ligament balancing (symmetric gap in extension, asymmetric gap in flexion), while 7 patients (17.5%) had a

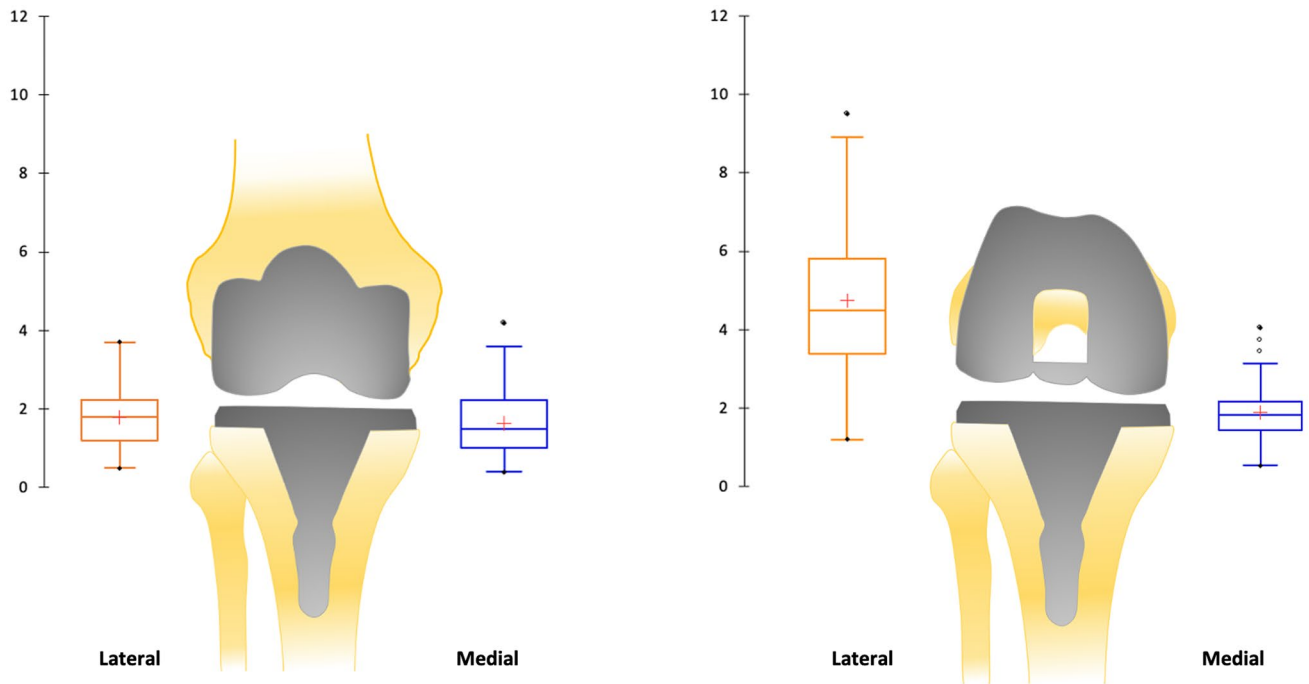


Fig. 3 **a** Representation by boxplots of the mean (in mm) of medial and lateral ligament balancing in extension after the TKA implantation in the AFIP group: symmetric gap in extension. **b** Representation

by boxplots of the mean (in mm) of medial and lateral ligament balancing in flexion after the TKA implantation in the AFIP group: asymmetric gap in flexion

symmetric gap laxity in flexion. No correlation was found between this absence of lateral laxity in flexion and the preoperative or postoperative limb alignment (HKA angle, mMDFA, MPTA, slope) or the demographic data. No soft-tissue release was required, except the surgical approach and the osteophyte resection. The ligament balancing was obtained with adjustment of the tibial cut. The polyethylene thickness was either 10 mm ($n = 21$; 52.5%) or 11 mm ($n = 19$; 47.5%) for all patients.

Alignment and implant positioning in AFIP and aMA groups

With the AFIP technique, there was a partial correction of the tibial varus and restoration of the native femoral anatomy (Fig. 4). With the aMA technique, the femoral implant was significantly more varus than preoperatively ($p < 0.0001$), and the tibial implant was significantly less varus than preoperatively ($p < 0.0001$) (Table 5, Fig. 5). The cases with postoperative HKA $< 175^\circ$ in the AFIP group had a severe preoperative deformity (HKA $< 170^\circ$) before the TKA.

Clinical outcomes in the AFIP and aMA groups

The improvement of the KSS Knee and Function scores at 6 months were better in the AFIP group ($p = 0.0003$ and $p < 0.0001$, respectively) (Table 6). Clinical relevance may

be considered, as the mean difference of KSS function was 10.4 units which exceeds the MDC of 9.5 units.

There was no perioperative complication in either group. There was one complication in each group: one acute infection in the AFIP group needing a DAIR (debridement, antibiotics, implant retention) at 2 months, and one traumatic distal femoral fracture in the aMA needing an osteosynthesis at 1 month.

Discussion

The most important findings of this present study were that the AFIP technique allowed restoration of knee alignment and ligament balance in extension and flexion, with comparable clinical outcomes at 12-month follow-up compared to the aMA technique. However, the AFIP technique had a better improvement of the clinical outcomes at 6 months compared to the aMA technique.

The AFIP technique aimed to restore not only the alignment of the native non-osteoarthritic knee [1, 38, 53], but also the global knee kinematics without periarticular soft tissue release. Reestablishing native knee kinematics requires the restoration of ligament balance in extension and flexion, and thus an asymmetric gap in flexion as described for the native knee [13]. No study described this asymmetrical gap in flexion with a posterior stabilized TKA. For most

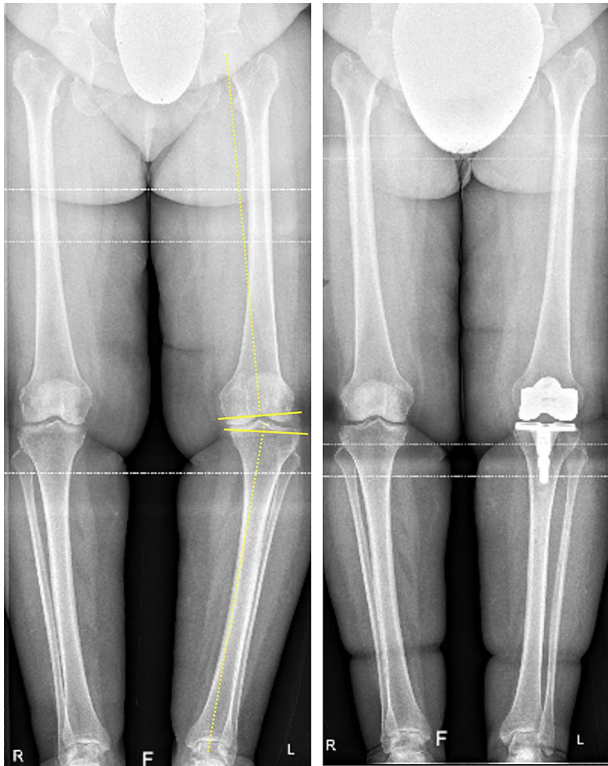


Fig. 4 An example of preoperative and postoperative standing long-leg radiographs of one patient in the AFIP group. The preoperative varus (preoperatively, HKA: 165°, mMDFA: 91°, MPTA: 84°) was partially corrected with the TKA with a restoration of the femur and a partial correction of the tibial varus (postoperatively, HKA: 175°, mMDFA: 91°, MPTA: 87°)

PA techniques reported in the literature, the target for ligament balancing is described as symmetrical in extension and flexion. This assumption is classically admitted even if, in native knees, there is a higher lateral laxity in flexion than in extension or than in the medial compartment [13, 40, 52]. In extension, the knee must have an excellent stability for the walking activities, particularly during the heel-strike phase of the gait. The medial compartment must also remain stable along the arc of knee flexion to avoid mid-flexion instability during other activities of daily life [27]. Then, to obtain an adapted femoral rollback in flexion without femorotibial overload, the knee needs a slight lateral laxity in flexion [8, 18, 22]. A recent study found that most of the varus knees with osteoarthritis also have a larger lateral extension gap than the medial extension gap [17]. The medial–lateral gap size difference increased when the varus deformity was more severe. However, this result concerned varus knees with osteoarthritis and probably should not be conserved after the TKA. The improvement of the functional outcomes with PA compared to MA remains uncertain and extensively debated in the literature [12, 30, 35, 54]. The targets for knee restoration and ligament balancing are probably not completely

exact. The fear of instability in flexion with posterior-stabilized TKA resulted in a target of a symmetric gap in flexion in a conventional technique. Nevertheless, with the robotic-assisted system, the accuracy of the implants' positioning and the possibility to check the ligament balancing at the end of the procedure limit the risk of observing a significant instability. In this present study, the target of ligament balancing was obtained in most of TKA, without release or high polyethylene. Only one clinical study on cruciate-retaining TKA performed by kinematic alignment has assessed the clinical outcomes according to the lateral laxity in flexion [34]. They reported that in knees where lateral flexion laxity was higher than 2 mm, significantly better scores were reported for clinical outcomes.

The AFIP technique allowed the femoral restoration reliably compared to the aMA technique. Indeed, the femoral implant in the aMA group was significantly more in varus, as expected, than preoperatively or compared to the AFIP technique. In the AFIP group, the tibial axis was, as planned, partially restored with a moderate correction of the tibial varus. Indeed, the surgeon must remain cautious about a tibial positioning with more than 5° of varus. In a finite element study, the maximum stress in kinematic alignment (KA) TKA increased by 24.8% and 32.2% for a moderate (10°) and severe (15°) varus knee models, compared to MA TKA [37]. This difference in the anatomy restoration between AFIP and aMA groups has impacted the JLO. In a previous study, JLO was of $0.2^\circ \pm 2.2^\circ$ in a healthy population with varus deformity versus $-1.9^\circ \pm 3.5^\circ$ in an osteoarthritic population with varus deformity [50], which is comparable to the values observed in the AFIP group. The JLO is not restored in the aMA group, where the femoral and tibial anatomy restoration is not obtained. In KA, the posterior femoral resection parallel to the posterior condylar axis [21] often results in a more internally rotated femoral component than in MA [29, 46], increasing the risk of patellar maltracking according to some studies [2, 20, 26]. The results in this study found good patellar tracking in both groups. Currently, no unambiguous and robust study has demonstrated what is the best alignment technique for patellar tracking. A recent study reported a significantly higher incidence of lateral patellar tilt postoperatively in the KA TKA compared to MA TKA [26]. Nevertheless, they also found a higher incidence of medial patellar tilt in MA, a sign of non-restoration of the native femoral rotation. Other studies reported an improvement of the patellar tracking due to KA, with a good restoration of the groove location and sulcus angle [10, 29, 46]. It is difficult to consider all the parameters impacting the patellar tracking between native knee anatomy, MA TKA, or KA TKA [46].

The clinical outcomes of the AFIP and aMA techniques in this study were equivalent at 12-month follow-up and at least as good as other studies with PA [9, 12]. The early

Table 5 Preoperative and postoperative radiographic measurements and outliers in the AFIP and aMA groups

	AFIP group (n=40)		P value	aMA group (n=40)		P value	P value AFIP vs aMA postop
	Preop data	Postop data		Preop data	Postop data		
HKA (°) (Mean ± SD) [Min; Max]	170.4 ± 4.2 [163.5;180]	177.3 ± 2.1 [172;181]	<0.0001	171.4 ± 4.3 [165;180]	176.8 ± 3.2 [171;180]	<0.0001	NS
OUTLIERS: HKA < 175°	–	4 (10%)	–	–	8 (20%)	–	NS
mMDFA (°) (Mean ± SD) [Min; Max]	91.2 ± 2.2 [87;95]	90.9 ± 1.6 [87;93]	NS	91 ± 2.1 [87;94]	88.4 ± 2.0 [86;94]	<0.0001	<0.0001
OUTLIERS: mMDFA < 88°	–	1 (2.5%)	–	–	10 (25%)	–	0.007
OUTLIERS: mMDFA > 93°	–	1 (2.5%)	–	–	1 (2.5%)	–	NS
MPTA (°) (Mean ± SD) [Min; Max]	85.8 ± 2.2 [82;90]	87.6 ± 2.0 [83;93]	<0.0001	85.6 ± 2.8 [80;93]	88.9 ± 2.4 [83;93]	<0.0001	0.025
OUTLIERS: MPTA < 86°	–	6 (15%)	–	–	2 (5%)	–	NS
OUTLIERS: MPTA > 90°	–	2 (5%)	–	–	7 (17.5%)	–	NS
JLCA (°) (Mean ± SD) [Min; Max]	6.2 ± 2.2 [1;12]	–	–	4.3 ± 2.1 [0.5;10]	–	–	NS
JLO (°) (mean ± SD) [Min; Max]	– 0.9 ± 2.4 [– 7;5]	0.9 ± 1.7 [– 2;4]	0.0002	– 0.1 ± 2.2 [– 5;5]	– 0.9 ± 2.3 [– 6;4]	NS	0.0003
OUTLIERS JLO > 3°	–	3 (7.5%)	–	–	8 (20%)	–	NS
Slope (°) (Mean ± SD) [Min; Max]	81.4 ± 3.7 [68;89]	86.9 ± 2.2 [83;95]	<0.0001	81.1 ± 3.1 [74;86]	82.4 ± 2.7 [77;88]	NS	<0.0001
OUTLIERS Slope < 80°	–	0	–	–	4 (10%)	–	NS
Difference Post–Pre of Posterior femoral offset (mm) (Mean ± SD) [Min; Max]	1.9 ± 1 [0.08;5.5]	–	–	3.6 ± 1.3 [0.09;8]	–	–	NS
Patellar tilt (°) (Mean ± SD) [Min; Max]	4.7 ± 4.8 [0;16]	2.9 ± 3.2 [0;11]	NS	4.0 ± 5.1 [0;17]	1.2 ± 3.4 [0;12]	0.023	NS
Patellar tilt > 5°	15 (37.5%)	4 (10%)	0.008	10 (25%)	4 (10%)	NS	NS
Patellar translation (mm) (Mean ± SD) [Min; Max]	0.5 ± 2.3 [0;14]	0.4 ± 1.4 [0;6]	NS	0.3 ± 1.2 [0;5]	1.1 ± 3.3 [0;13]	NS	NS
Patellar translation > 5 mm	1 (2.5%)	1 (2.5%)	NS	0	2 (5%)	NS	NS

HKA hip knee ankle angle, mMDFA mechanical medial distal femoral angle, MPTA medial proximal tibial angle, JLCA joint-line convergence angle, JLO joint-line orientation, SD standard deviation

outcomes at 6 months were significantly better in the AFIP group compared to the aMA group. Further, the Knee Society Functional Score achieved a patient-acceptable symptom state (PASS) at 6 months by surpassing the score of 77.5 reported by Goh et al. [16]. This was not achieved by the aMA group. Some studies reported better early functional recovery with a personalized alignment [53] or a more accurate surgical technique such as robotic-assisted systems [25, 32, 49]. This faster recovery for functional outcomes can be explained by a better restoration of knee kinematics associated with better implant positioning [23] or by less damage on the soft tissues [24]. Better restoration of the native knee anatomy and ligament balancing could explain this faster recovery in the AFIP group. The posterior stabilized TKA with an asymmetric gap in flexion should be evaluated in the mid- and long term to assess the patients' functional outcomes and quality of life. This study did not report a specific complication of the AFIP technique. There was notably no

instability despite the asymmetric gap balancing in flexion and no extensor mechanism complication despite the lack of lateral femoral rotation.

Several limitations should be outlined in this present study. First, the mean follow-up was short. Nevertheless, early evaluations of this surgical technique are primordial to assess adverse events and early implant outcomes to adjust the technique in case of poor results. Second, the number of patients was small. However, a sample size calculation was performed for the clinical outcomes, and this study wanted first to evaluate the feasibility of the surgical technique and its accuracy and reproducibility. Third, the gap laxity was assessed only for the AFIP group and only during the surgery by the robotic system. Nevertheless, very few systems can evaluate postoperatively the gap laxity in vivo in a reliable manner. Although gap laxities were recorded with a clinically relevant and validated technique, the forces involved were not quantified and only registered at 0 and 90°

Fig. 5 a Boxplots showing the evolution of the HKA angle between preoperative and postoperative radiographs in the AFIP and aMA groups. **b** Boxplots showing the evolution of the mMDFA postoperatively compared to preoperative mMDFA in the AFIP and aMA groups, and the postoperative difference between both groups. **c** Boxplots showing the evolution of the MPTA between the preoperative and postoperative radiographs in the AFIP and aMA groups, and the postoperative difference between both groups

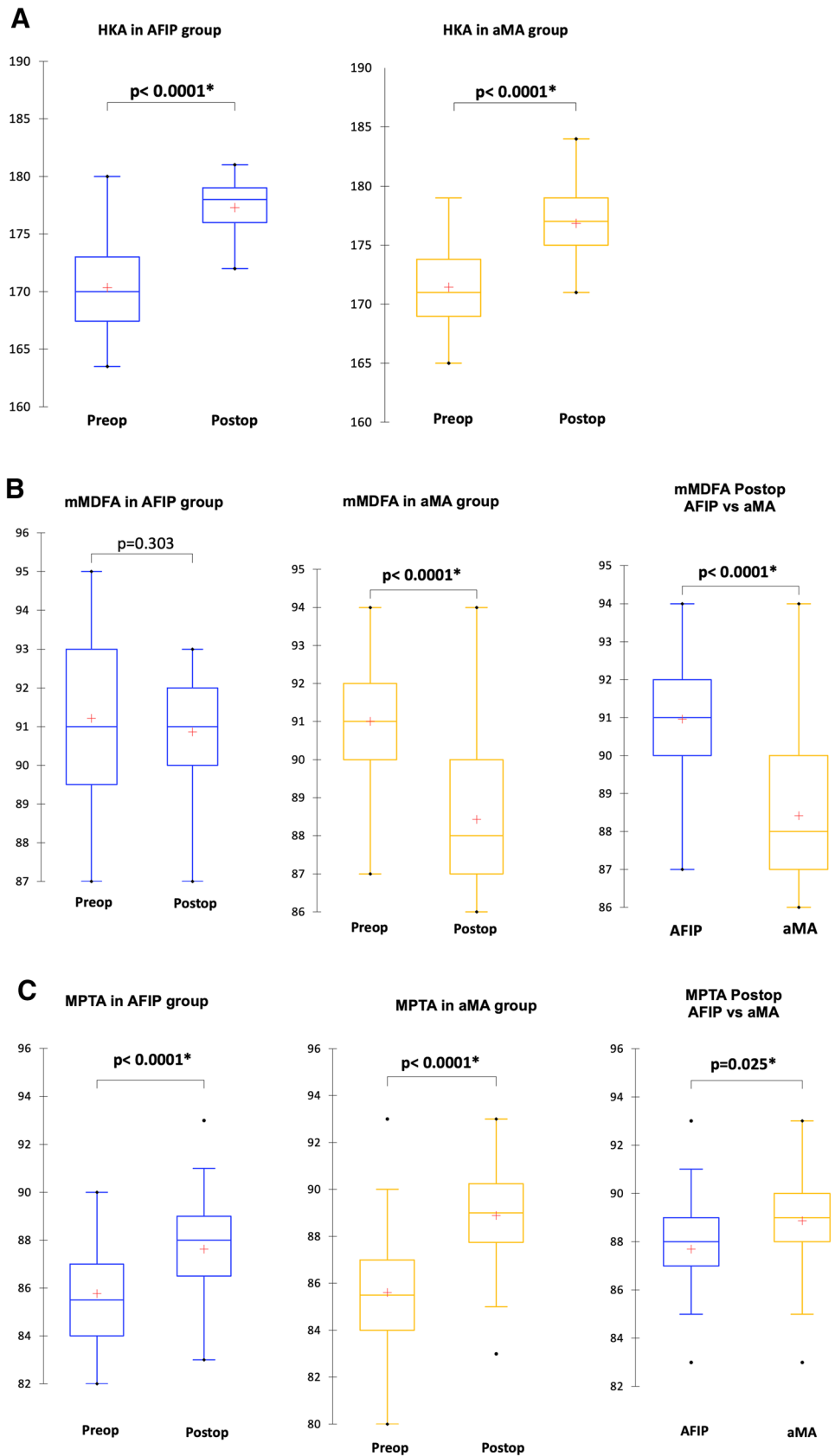


Table 6 Postoperative clinical outcomes in AFIP and aMA groups

	AFIP group (n=40)	aMA group (n=40)	p value
At 6 months			
Flexion M6	131.1±8.6	131.7±11	NS
Mean±SD [Min; Max]	[120;150]	[110;150]	
KSS score – function M6	83.7±15	73.3±15	0.008
Mean±SD [Min; Max]	[40;100]	[40;100]	
Improvement Function KSS M6	51.7±20	20.8±13	<0.0001
Mean±SD [Min; Max]	[- 5;90]	[- 10;50]	
KSS score – knee M6	90±7.9	87.2±7.6	NS
Mean±SD [Min; Max]	[69;100]	[67;97]	
Improvement Knee KSS M6	59.3±11.9	49.3±9.7	0.0003
Mean±SD [Min; Max]	[23;90]	[28;66]	
At 1 year			
Flexion 1y	135.8±10.2	132.9±14	NS
Mean±SD [Min; Max]	[120;150]	[110;150]	
KSS score – function 1y	84.6±15	79.1±19	NS
Mean±SD [Min; Max]	[45;100]	[20;100]	
Improvement Knee Function 1y	48±26	29.5±20	0.004
Mean±SD [Min; Max]	[- 5;90]	[- 30;60]	
KSS score—knee 1y	92.3±10	93.2±6	NS
Mean±SD [Min; Max]	[57;100]	[79;100]	
Improvement Knee KSS 1y	58±11	55.4±8	NS
Mean±SD [Min; Max]	[26;78]	[39;69]	
Satisfaction at 1 year			
Very satisfied	25 (62.5%)	16 (40%)	NS
Satisfied	13 (32.5%)	21 (52.5%)	
Dissatisfied	2 (5%)	3 (7.5%)	
Very dissatisfied	0	0	

BMI body mass index, *KSS* Knee Society Score, *SD* standard deviation

of knee flexion as commonly described in the literature [34]. Understanding of intraoperative medial and lateral laxity has been improved with technology-assisted surgery, as these techniques provide the objective data previously unavailable with conventional methods. Finally, there is a potential for a selection bias in the control group, as these cases were from a prior retrospective cohort and were not consecutive cases. However, we matched the robotic cases with the historical controls based on age, sex, BMI, and alignment.

Despite these limitations, this study is one of the first to assess the clinical outcomes after TKA performed with the ROSA® Knee System. Moreover, it is one of the few studies describing and assessing the target of ligament balancing with an asymmetrical gap in flexion after TKA. In the context of PA, the restoration of physiological ligament balancing is an essential question. This study brings objective data and clinical outcomes on ligament balancing with a symmetrical gap in extension and a moderate lateral laxity in flexion after a posterior-stabilized TKA.

Conclusion

The results of this study demonstrated that the concept of anatomic-functional implant positioning allowed the restoration of not only the native knee alignment including the joint line and respecting a “safe zone” for the tibial implant, but also a satisfying patellar tracking and a natural functional ligament pattern. With a more physiological target for the ligament balancing, this AFIP technique had equivalent clinical outcomes at 12-month follow-up compared to the aMA technique, with a faster recovery.

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Declarations

Conflict of interest SP: Royalties from Zimmer Biomet and Newclip; Consultant for Zimmer Biomet; Treasurer for European Knee Society. PVO: Consultant for Microport; Shareholder for MoveUP. MB: Employee from Zimmer Biomet. BYO: Consultant for Smith and Nephew. CB: Grant from SoFCOT (Société française de chirurgie orthopédique et traumatologique).

Ethical approval All procedures were performed in accordance with the ethical standards of the institutional and/or national research committee, the 1964 Helsinki declaration, and its later amendments, or comparable ethical standards. The approval from the internal review board was obtained (study ID Number: MF3867, approval date: 20th December 2020).

Informed consent All patient participants provided informed consent for review of their medical records.

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