Archives of Orthopaedic and Trauma Surgery (2025) 145:364
https://doi.org/10.1007/s00402-025-05971-0

RESEARCH

Correlation between frontal knee alignment and bone resection thicknesses during total knee arthroplasty without precision-enabling device: a retrospective study

Antoine Outrequin[1] · Julie Manon[1] · Amaury Ancion[1] · Emmanuel Thienpont[2]

Received: 12 April 2025 / Accepted: 21 June 2025

Abstract

Introduction Proper knee alignment is critical for optimizing postoperative function and implant longevity in total knee arthroplasty (TKA). While robotic-assisted surgery offers precision in bone resections, most surgeons still rely on conventional instrumentation. This study evaluates the relationship between pre- and postoperative frontal knee alignment and bone resections in TKA performed without precision-enabling devices to establish a correlation between thickness of resection and frontal angular correction.

Materials and methods This retrospective, single-center study analyzed data from patients undergoing TKA for end-stage osteoarthritis between June 2021 and April 2024. Intraoperative cuts were measured in a standard way. All procedures were performed by a single experienced surgeon without precision-enabling devices. Preoperative and six-week postoperative weight-bearing goniometry and anteroposterior (AP) radiographs were collected. The cohort consisted of 130 patients: 69 varus (= 177° HKA), 30 neutral (177°–183° HKA) and 31 valgus (= 183° HKA) knees. Patients were 36.9% male, with a mean age of 70.1 years (SD 8.2) and a BMI of 30.8 kg/m^2 (SD 5.6). Hip-knee-ankle (HKA) angle, anatomical and mechanical tibiofemoral angles and joint line convergence angles (JLCA) were measured. Statistical analysis was conducted to determine correlations between resection measurements and angular parameters.

Results The correlation between tibial resection (ΔT) and medial proximal tibial angle modification measured on goniometry (ΔMPTA(g)) followed a linear regression with a Spearman's correlation coefficient (r = 0.553). A weak positive correlation was observed between ΔT and ΔMPTA on AP radiographs (r = 0.505), as well as between distal femoral resection (ΔDF) and lateral distal femoral angle modification (ΔLDFA(g)) on goniometry (r = 0.350) and on AP radiographs ΔLDFA(s) (r = 0.187).

Conclusion This study suggests a moderate correlation between tibial resection thickness and angular correction in the coronal plane. However, the high variability observed indicates that surgical planning should not rely solely on this correlation.

Keywords Total knee arthroplasty · Caliper · Angular modification · Tibial resection · Distal femoral resection · Joint Line convergence angle · Medial proximal tibial angle · Lateral distal femoral angle · Correlation

✉ Antoine Outrequin
antoine.outrequin@student.uclouvain.be

Julie Manon
julie.manon@student.uclouvain.be

Amaury Ancion
amaury.ancion@student.uclouvain.be

Emmanuel Thienpont
emmanuelthienpontmd@gmail.com

1 Cliniques Universitaires Saint-Luc, Brussels, Belgium

2 Department of Orthopedics and Trauma, ZAS-Cadix Hospital, Antwerpen, Belgium, Belgium

Introduction

Total knee arthroplasty (TKA) is a widely performed surgical procedure for managing end-stage osteoarthritis, aiming to restore joint function and alleviate pain. Proper frontal plane alignment is crucial for optimizing postoperative outcomes, including implant longevity and functional recovery. While robotic-assisted techniques provide precision in bone resections, the majority of TKA procedures worldwide still rely on conventional mechanical instrumentation.

Given the ongoing debate about alignment philosophies (ranging from mechanical alignment to more personalized kinematical approaches) understanding the direct impact of bone cuts on postoperative alignment is essential for refining surgical techniques [1–4]. The accuracy of these bony resections can influence joint line orientation and load distribution, factors that ultimately affect implant survival and patient satisfaction [5, 6]. The precision of obtaining neutral mechanical alignment using robotic systems and patient-specific instrumentation has been questioned, similarly to the accuracy of caliper measurements in kinematic alignment [7–9]. Robotic-assisted TKA has been shown to be more precise than manual TKA, both in terms of bone cuts and component positioning [10, 11]. These high-cost surgical instruments have been seriously challenged by the caliper-based technique, which offers high accuracy in kinematic alignment, achieving absolute differences from the target as small as 0.175 ± 0.35 mm in relation to the femoral resection goal [7, 12].

It is well-established that foot positioning and weight-bearing status during radiographic imaging can affect knee alignment in the frontal plane. Consequently, variations in alignment measurements may stem from positional factors, underscoring the importance of standardizing radiographic techniques [13–15]. The value of preoperative planning in TKA has also been emphasized. Accurately assessing bony deformities and soft tissue laxity is crucial for determining resection levels and selecting the appropriate implant constraint [16]. Insufficient preoperative data can complicate cases, even for highly skilled surgeons, asking for more constraint or thicker polyethylenes than initially estimated.

To the best of our knowledge, the correlation between bone resection thicknesses and angular correction has not been established. For decades, surgeons cite the golden rule that 1 mm of resection correlates with 1° of angular correction, but without scientific data to confirm this adagio. Given the development of various alignment philosophies, the availability of precision-enabling devices, and the growing demand for knee arthroplasty, this study aimed to investigate this surgical approximate observation.

The primary objective of this study was to evaluate the impact of tibial and femoral bone resections on frontal postoperative alignment in TKA by analyzing radiographic measurements and bony resection pieces from a cohort of patients undergoing non-robotic TKA. Specifically, the study aims to determine whether a one-millimeter difference in bone resection resulted in a one-degree change in joint line angulations in the frontal plane.

Materials and methods

Study design

This is a single-center observational study conducted on a cohort of 130 patients. We analyzed the medical records of patients who underwent TKA for Kellgren-Lawrence grade 3 or 4 osteoarthritis between June 2021 and April 2024, all performed by a single experienced surgeon. This study was approved by the institutional ethical committee (approval number B403201523492).

Setting and participants

Inclusion criteria were the availability of preoperative and 6-week postoperative weight-bearing goniometry and anteroposterior (AP) radiographs, stored in our imaging system (PACS, CareStream Health, Zaventem, Belgium). Additionally, the measurements of all bony resections performed by the surgeon during the procedure had to be available. Both these data sources were matched.

Exclusion criteria were a history of distal tibial or femoral osteotomy, fractures or osteosynthesis.

Based on these criteria, 130 patients were included, with 11 patients excluded due to the following reasons: 8 lacking postoperative goniometry, 1 with a history of tibial fracture, 1 with a femoral fracture and 1 with a tibio-calcaneal arthrodesis. Additionally, any mention of ligamentous insufficiency or prior infection was considered an exclusion criterion, as these factors could potentially affect laxity or alignment (Table 1).

Patients were categorized based on preoperative alignment measured as Hip-Knee-Ankle (HKA) angle: varus was defined as HKA = 177° (*n* = 69), neutral alignment as HKA between 177° and 183° (*n* = 30), and valgus as HKA = 183° (*n* = 31) [17]. The cohort was 36.9% male, with a mean age of 70.1 years (SD 8.2) and a BMI of 30.8 kg/m^2 (SD 5.6) (Table 2).

Table 1 Patient demographics

Variable	Varus	Neutral	Valgus	Total
Numbers of patients	69	30	31	130
Men, n (%)	46.4% (32)	23.3% (7)	29.0% (9)	36.9% (48)
Women, n (%)	53.6% (37)	76.7% (23)	71.0% (22)	63.1% (82)
Age (years, mean ± SD)	69.2 (± 7.8)	73.8 (± 8.4)	68.4 (± 10.9)	70.1 (± 8.2)
BMI (kg/m^2, mean ± SD)	31.2 (± 5.9)	29.7 (± 4.9)	27.9 (± 4.3)	30.8 (± 5.6)

Table 2 Radiological measurements

Variable	Varus (Mean ± SD)	Neutral (Mean ± SD)	Valgus (Mean ± SD)	Total (Mean ± SD)
Preoperative goniometry				
mLDFA(g) (°)	88.7 (± 2.0)	87.0 (± 2.0)	84.4 (± 2.1)	87.3 (± 2.7)
mPTA(g) (°)	84.9 (± 2.7)	88.1 (± 2.0)	90.1 (± 2.4)	86.9 (± 3.3)
AMA(g) (°)	6.1 (± 0.5)	6.2 (± 0.7)	5.7 (± 0.6)	6.0 (± 0.6)
JLCA(g) (°)	− 5.1 (± 2.2)	– 1.1 (± 2.3)	2.5 (± 2.5)	-2.4 (± 3.9)
Preoperative AP radiographs				
mLDFA(s) (°)	89.0 (± 2.4)	87.9 (± 2.4)	85.7 (± 2.8)	88.0 (± 2.8)
mPTA(s) (°)	86.0 (± 2.6)	88.0 (± 1.5)	88.1 (± 1.6)	86.9 (± 2.4)
JLCA(s) (°)	− 5.9 (± 1.8)	− 0.4 (± 3.5)	3.8 (± 2.7)	-2.3 (± 4.8)
Postoperative goniometry				
mLDFA(g)' (°)	91.1 (± 1.8)	89.8 (± 1.5)	88.9 (± 1.8)	90.3 (± 1.9)
mPTA(g)' (°)	90.4 (± 1.3)	91.4 (± 1.4)	92.0 (± 1.7)	91.0 (± 1.6)
AMA(g)' (°)	6.1 (± 0.5)	5.9 (± 0.6)	5.7 (± 0.5)	6.0 (± 0.6)
JLCA(g)' (°)	− 0.2 (± 0.7)	0.2 (± 0.7)	0.3 (± 0.6)	0.0 (± 0.7)
Postoperative AP radiographs				
mLDFA(s)' (°)	92.1 (± 2.4)	90.8 (± 2.0)	90.3 (± 1.8)	91.4 (± 2.3)
mPTA(s)' (°)	89.4 (± 1.6)	89.9 (± 1.5)	90.0 (± 1.4)	89.7 (± 1.6)
JLCA(s)' (°)	− 0.3 (± 0.8)	0.1 (± 1.2)	0.5 (± 0.7)	0.0 (± 0.9)

ΔRadiographic measurements

All included patients underwent standardized imaging evaluations at our institution:

Goniometry: Performed using a Philips digital system (Amsterdam, Netherlands), with the receiver positioned 3 m from the patient. The patient stood barefoot, with legs extended, on a wooden platform in a bipedal stance, facing the machine. Separate images were taken for hips, knees and ankles, which were then electronically merged.

AP radiographs: Performed using the same device with a receiver placed 1.1 m from the patient. The patient stood barefoot, with their back to the emitter, feet parallel, and knees slightly flexed. The X-ray beam was angled 10° downward and set to 66 kV.

Analyses were performed by a single clinician to minimize inter-observer bias. Radiographic measurements were taken using PACS software, and the following angles were assessed on goniometry: HKA, anatomical-mechanical angle (AMA), mechanical lateral distal femoral angle (mLDFA), medial proximal tibial angle (MPTA) and joint line congruency angle (JLCA). On AP radiographs, the angles measured included JLCA, MPTA (using the center of the proximal tibial width, assuming equivalence between the anatomical and mechanical axes of the tibia) and anatomical lateral distal femoral angle (aLDFA). The mLDFA on AP radiographs (mLDFA(s)) was derived by summing the aLDFA with the AMA angle obtained from goniometric measurements performed the same day.

Finally, reproducibility of the measurements was assessed using the intraclass correlation coefficient (ICC).

Angles marked with (g) indicate measurements on goniometry, while those marked with (s) represent values assessed from weight-bearing radiographs centered on the knee. Angles with an apostrophe (') denote postoperative measurements, while those without correspond to preoperative values. For instance, MPTA (g) refers to the preoperative goniometric measurement, while MPTA(g)' represents the postoperative value. The difference between the postoperative (MPTA') and preoperative (MPTA) angles was then calculated on goniometry as ΔMPTA(g) = MPTA(g)'– MPTA(g). The same calculation was applied to ΔmLDFA, ΔaLDFA, and ΔMPTA(s).

A caliper was used to measure the medial and lateral distal femoral resections, as well as the tibial condyle thickness at the base of the tibial spine. The measurements included bone resection without accounting for the thickness or the kerf. The difference in tibial resection was calculated by subtracting the medial (Tmed) resection from the lateral (Tlat) resection, resulting in ΔT = Tlat - Tmed. Similarly, the difference in distal femoral resection was calculated by subtracting the lateral (DFlat) resection from the medial (DFmed) resection, resulting in ΔDF = DFmed - DFlat.

Statistical analysis

This dataset was analyzed sequentially using descriptive and univariate analyses. Variables were expressed as mean ± standard deviation and illustrated by boxplots. The normal distribution of variables was assessed with QQ plots and Shapiro-Wilk tests. Because of non-normal distribution, non-parametric Wilcoxon signed ranks tests were used to compare groups. Spearman's rho coefficients were used to test the correlation. All tests were two-sided and the statistical significance threshold was set for p-values less than 0.05. All analyses were performed using SPSS softwares

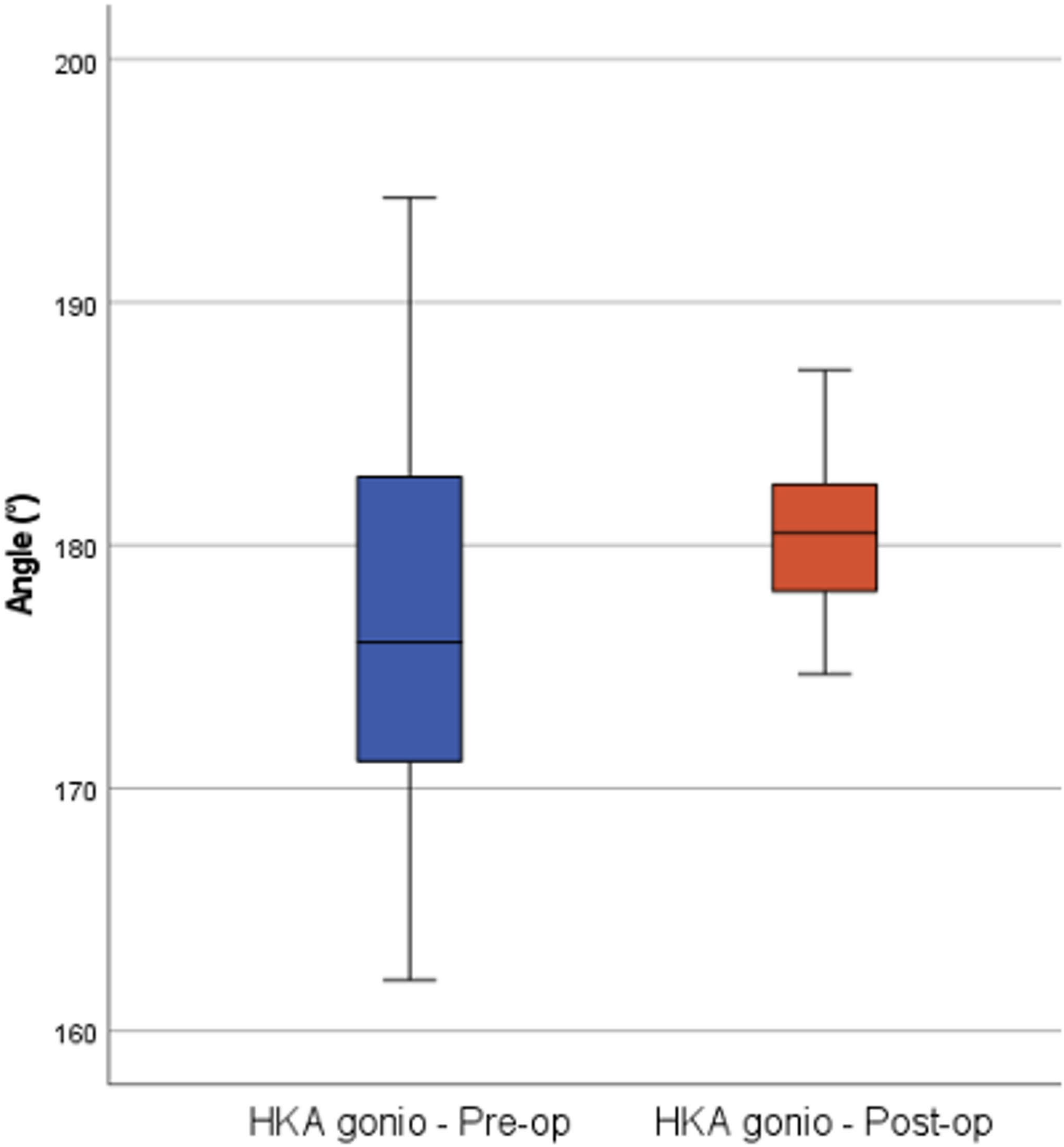

Fig. 1 Boxplot illustrating preoperative and postoperative HKA measurements obtained from goniometry

(v.28.0.1.1 (15), SPSS, Inc., Chicago, IL, USA). Finally, the intraclass correlation coefficient (ICC) was determined by having the same observer repeat the measurements ten times on different patients over multiple days (Figs. 1, 2).

Results

The Wilcoxon signed-rank test results indicate no statistically significant difference between ΔMPTA Gonio and ΔT (p = 0.206), suggesting that the paired samples are comparable. In contrast, the comparison between ΔMPTA(s) on a

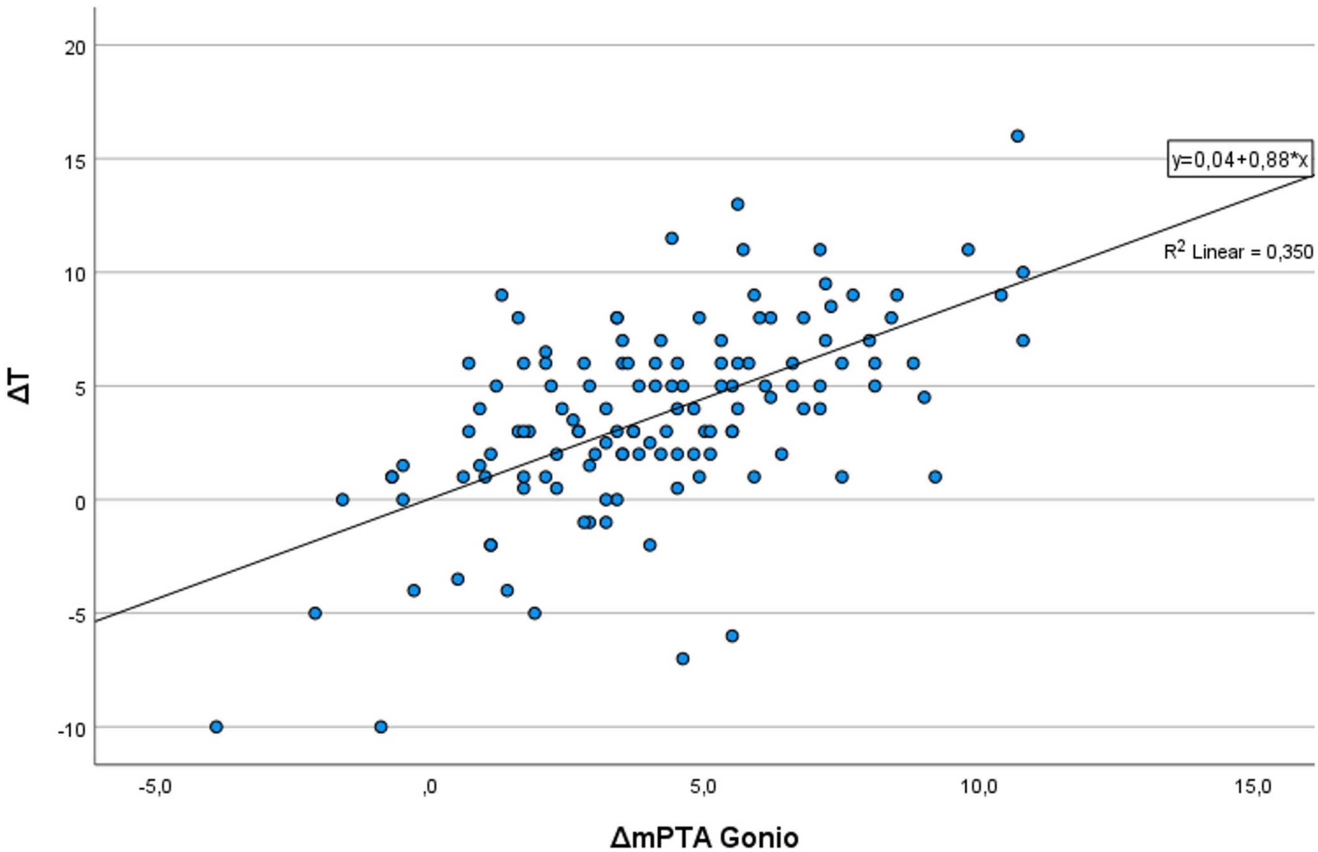

Fig. 2 Correlation between ΔmPTA measured using goniometry and ΔT

weight-bearing AP radiograph and ΔT shows a significant difference (p = 0.003), indicating meaningful variation. Likewise, highly significant differences are observed in ΔLDFA(g) measured by goniometry and ΔDF, as well as in ΔLDFA(s) from weight-bearing AP radiographs and ΔDF (both $p < 0.001$), highlighting substantial and consistent discrepancies in these paired measurements. Concerning the relation between ΔT and ΔMPTA based on goniometry measurements, the linear regression equation, y = 0.04 + 0.88x, indicates that each degree increase in ΔmPTA Gonio corresponds to an average increase of 0.88 mm in ΔT. The R^2 value of 0.35 suggests that 35% of the variance in ΔT is explained by ΔMPTA Gonio, demonstrating a moderate positive linear relationship between the two variables. Additionally, Spearman's correlation coefficient (r = 0.553) confirms that ΔMPTA(g) is a significant predictor of ΔT. However, 65% of the variance remains unexplained, likely due to other influencing factors or random variability (Fig. 3). The relation between ΔDF and ΔmLDFA(g) shows a weak positive correlation (Spearman's r = 0.350), while ΔT and ΔMPTA(s) exhibits a moderate positive correlation (r = 0.505). In contrast, ΔDF and ΔmLDFA(s) present a very weak correlation (r = 0.187), (Figs. 3, 4, 5 and 6). There is no significant difference between JLCA(g) and JLCA(s) in either the preoperative (p = 0.903) or postoperative phase (p = 0.799) (Fig. 7).

Discussion

The main finding of this study is the significant correlation between postoperative alignment and bone resection heights. Each one-degree increase in ΔmPTA(g) measured on goniometry corresponds to an average increase of 0.88 mm in ΔT, as described by the linear regression equation (y = 0.04 + 0.88x). This relationship is supported by a Spearman's correlation coefficient of r = 0.553, indicating a moderate positive association between ΔmPTA(g) and ΔT. We also observed a moderate positive correlation between ΔmPTA(s) and ΔT (r = 0.505) on AP radiographs.

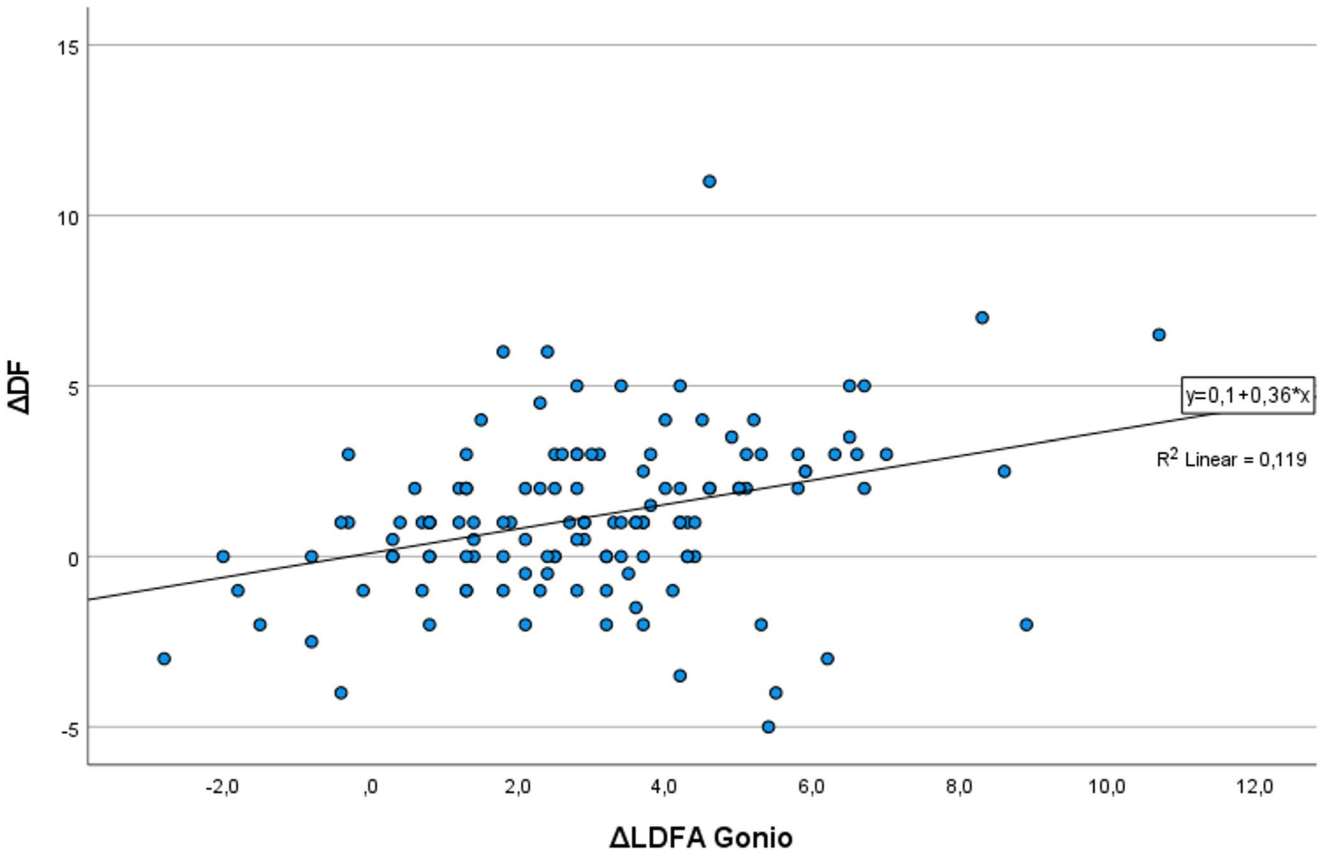

Fig. 3 Correlation between ΔLDFA measured using goniometry and ΔDF

Only a weak correlation between ΔLDFA(g) and ΔDF ($r = 0.350$) and a very weak correlation between ΔLDFA(s) and ΔDF ($r = 0.187$) was observed. These findings suggest that AP radiographs and goniometry are not reliable imaging modalities for assessing the impact of bone resections on angle modifications in femoral bone cuts. The authors hypothesized that the greater ratio of diaphyseal length to epiphyseal width in the femur, compared to the tibia, may have contributed to the reduced precision of femoral angle measurements relative to tibial ones. Additionally, the use of intramedullary guides to perform distal femoral and proximal tibial cuts tends to create a balanced angular correction between the medial and lateral compartments. However, when an eccentric angular correction is applied, the resulting bone resection is greater on the side opposite to the reference point. This factor should be taken into account when analyzing the relationship between bone resection thickness and angular changes. In a 2023 study, Liang Wen et al. examined the impact of joint line orientation on initial bone resection in mechanically aligned TKA using goniometry. The authors found that in varus knees with valgus femurs, the maximum bone resection—defined as the greater sum of either medial femoral and tibial resection or lateral femoral and tibial resection—was significantly correlated with both mLDFA ($r = 0.927$, $p < 0.001$) and MPTA ($r = 0.211$, $p = 0.01$) with regression coefficients of -0.426 and - 0.230, respectively [18]. However, the study did not directly analyze the correlation between bone cuts and their impact on angular modifications.

A comparison of our measurements reveals differences between the two radiologic modalities. For instance, in varus knees, the mean mPTA(s) measured on AP radiographs is 86.0° (± 2.6), compared to mPTA(g) 84.9° (± 2.7) on goniometry. Likewise, the mean mLDFA(s) is 89.0° (± 2.4) on AP radiographs versus mLDFA(g) 88.7° (± 2.0) on goniometry (Table 2). One possible explanation for these discrepancies lies in the subtle differences in patient positioning. During goniometry, patients are typically asked to stand with their feet together and patellae facing forward, promoting a more balanced stance. In contrast, standard

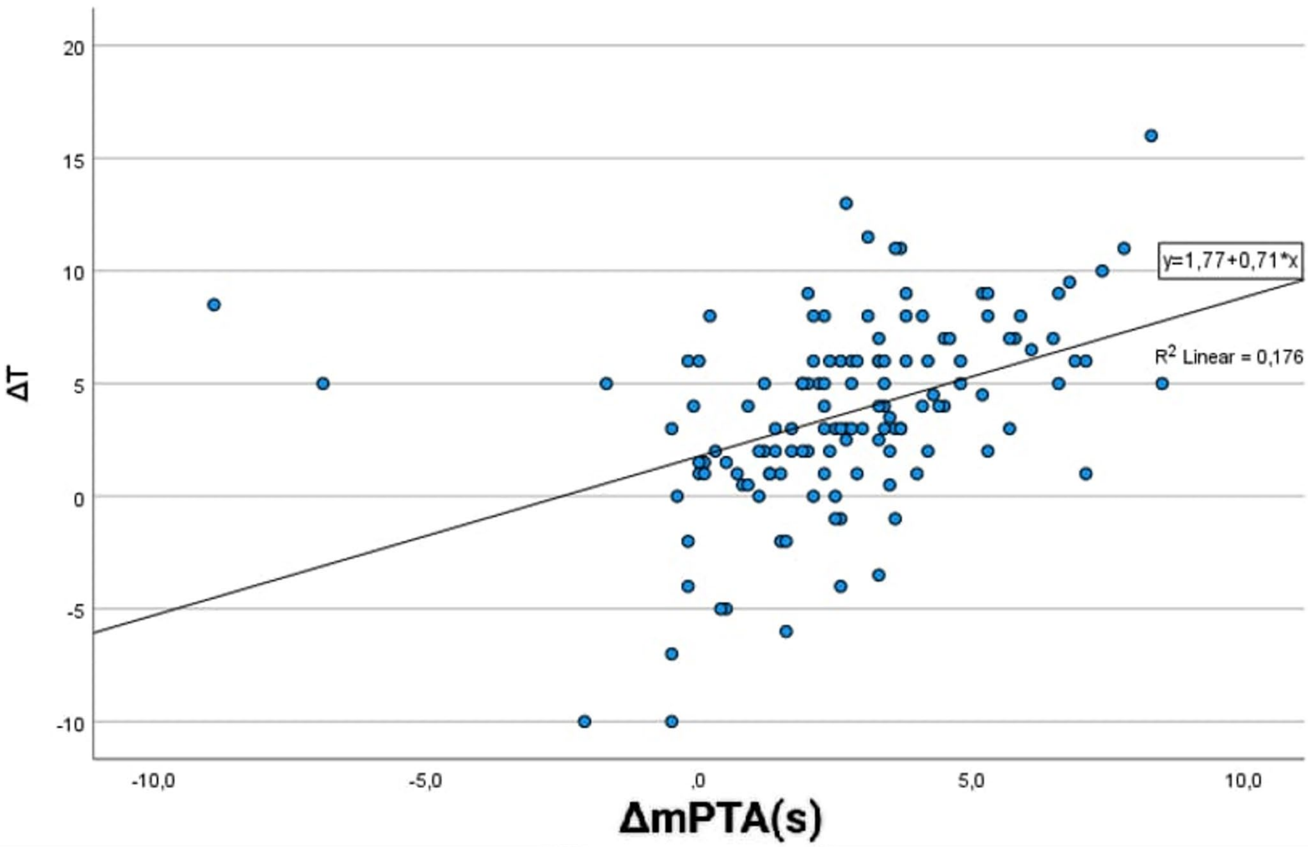

Fig. 4 Correlation between ΔmPTA measured using a weight-bearing AP radiograph and ΔT

AP radiographs require the patient to stand barefoot with their back to the emitter, feet parallel, and knees slightly flexed, which may influence lower limb rotation and alter load distribution. These variations in posture could lead to a more symmetrical weight-bearing condition during goniometric imaging, potentially influencing alignment measurements. Due to practical and financial constraints limiting the use of full-limb radiographs for evaluating mechanical knee alignment, standard knee radiography remains a commonly used alternative to estimate mechanical alignment. However, despite the clinical importance of coronal knee alignment, studies have reported significant variability between mechanical and anatomical alignment measurements [19, 20]. Analyzing 102 knees, Chang et al. investigated the factors influencing the differences between anatomical and mechanical tibiofemoral angles (TFAs). Their study identified lateral femoral bowing as a key factor contributing to variations between mechanical and anatomical TFAs, particularly in relation to gender and advanced osteoarthritis. They also found that anatomical TFA measurements using more distant reference points from the knee joint are less affected by anatomical features that amplify discrepancies between anatomical and mechanical TFAs [21]. In a 2020 study by Nathan et al., analyzing full-leg weight-bearing radiographs from 120 patients, a significant difference was observed between lower limb alignment measurements obtained from TFA on AP radiographs and HKA on full-length weight-bearing radiographs. Compared to full-length measurements, 46.7% of standard AP measurements exceeded the minimal clinically important difference (defined by the authors as less than 2°). Despite these differences, the study found a strong positive correlation (r = 0.72) between the two alignment measurement methods [22]. While extra-articular deformities, such as tibial or femoral shaft bowing along with the progression of knee osteoarthritis may influence joint line orientation between weight-bearing anteroposterior radiographs and pan-goniometry, our study did not specifically assess these uncommon variations, which could explain the differences in articular angulation observed between the two imaging modalities. Additionally, analyzing the radiological characteristics of kinematic alignment TKA to assess the

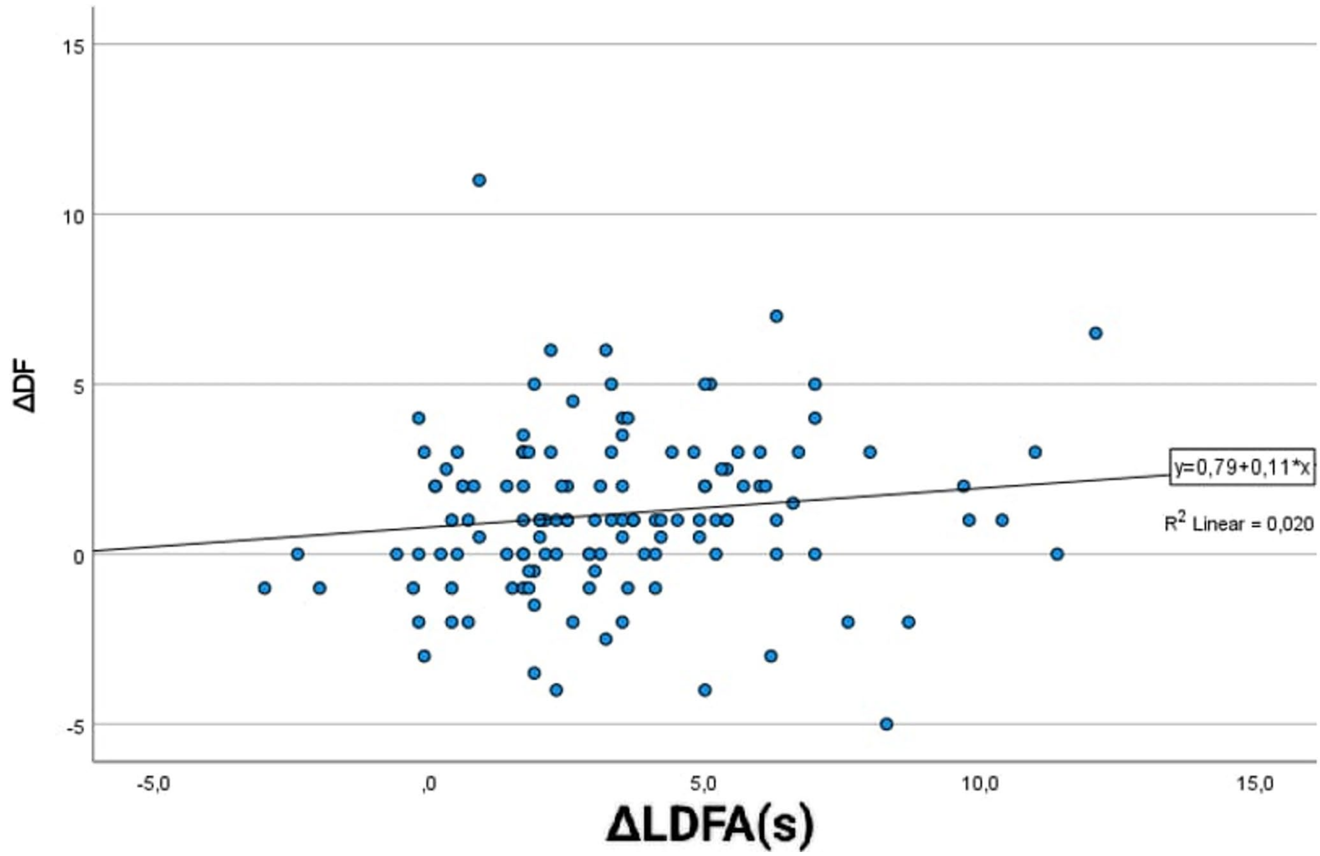

Fig. 5 Correlation between ΔLDFA measured using Schuss and ΔDF

correlation between angular modifications and bone cuts, which are expected to be equal [2], could provide valuable insights when comparing AP radiographs and goniometry.

JLCA values obtained from goniometry closely matched those from weight-bearing AP radiographs. The absence of significant differences between JLCA(g) and JLCA(s) in both the preoperative (p = 0.903) and postoperative phases (p = 0.799) suggests that these measurements are consistent and interchangeable. This supports the reliability of JLCA assessment using either goniometry or weight-bearing radiographs, making both modalities valid indicators of coronal plane laxity. Moreover, in preoperative valgus knees, a mean difference of 1.3° was observed between JLCA(g) (2.5° ± 2.5) and JLCA(s) (3.8° ± 2.7), suggesting the presence of medial laxity in valgus deformities. These findings are consistent with those reported by Paternostre et al., who highlighted that the dynamic load during weight-bearing tends to increase the HKA angle due to soft tissue laxity on the convex side of the deformity, both in varus and valgus knees. This effect is more pronounced in patients with advanced osteoarthritis (KL stages 3 and 4), particularly when the load-bearing axis shifts outside the articular surface [23]. In our mechanically aligned cohort, postoperative JLCA values were neutral across both radiographic modalities—JLCA(g)' (0.0 ± 0.7) and JLCA(s)' (0.0 ± 0.9) (Table 2)—which contrasts with findings typically observed in kinematic alignment approaches. A study by P. McEwen et al., published in 2019, analyzed the effects of kinematic TKA with cruciate-retaining implants, on JLCA changes observed in plain radiographs, as well as on lateral flexion and extension gaps, using a navigation system in 192 procedures. Their main finding was that knees with lateral flexion laxity greater than 2 mm demonstrated significantly better scores on various outcome measures. They reported post-operative JLCA values of − 1.1 (± 0.8) for varus, − 0.2 (± 0.8) for neutral, and 0.5 (± 0.7) for valgus (*p* < 0.001, ANOVA), but found no correlation between JLCA and any PROM score. Compared to our findings (−0.2 ± 0.7 for varus), kinematic alignment results in a more pronounced JLCA in varus, while values for neutral (0.2 ± 0.7) and valgus (0.3 ± 0.6) alignments remain comparable [24]. These findings are consistent with those of Nowakowski

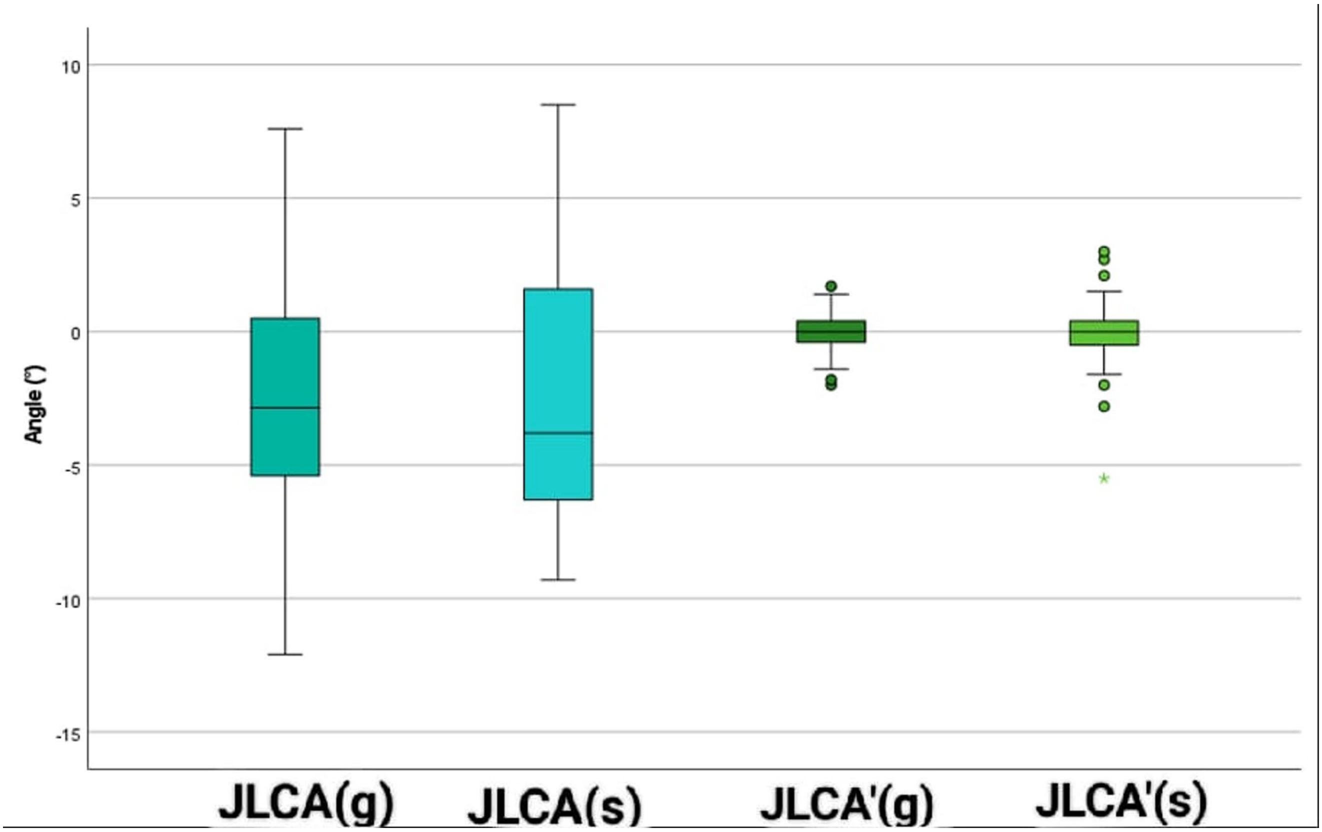

Fig. 6 Boxplot comparing preoperative and postoperative JLCA measurements from goniometry (JLCA(g)) and weight-bearing AP radiographs (JLCA(s))

(2011), who analyzed flexion and extension frontal laxity in ten cadaveric knees using a tensioning device. The study revealed that the lateral compartment could be stretched more than the medial ($P < 0.001$), with significantly greater corresponding flexion gap values. While kinematic alignment seeks to restore the native pre-arthritic deformation in extension and for knees with similar stability, varus TKA tends to open the lateral compartment more easily, whereas valgus TKA affects the medial compartment [25]. The study by Jia et al. demonstrates that, regardless of the accuracy of varus alignment correction during total knee arthroplasty (TKA), the tension in the internal and external soft tissues can be remodeled in the early postoperative period [26]. However, this adjustment does not significantly impact the alignment of the lower limbs. This finding is consistent with the results of Hatayama et al.'s study, which shows that residual varus alignment does not lead to increased lateral relaxation even after five years of follow-up [27]. Our results demonstrate that mechanical alignment, which aims to achieve parallelism between the MPTA and LDFA, leads to a neutral postoperative JLCA (Tables 3, 4, 5, 6, 7).

Our findings provide valuable guidance for knee surgeons using conventional instrumentation, particularly those employing caliper-based kinematic alignment, to adjust tibial varus/valgus alignment during surgery. By considering the impact of a one-millimeter difference between the internal and external tibial cuts on frontal tibial alignment, surgeons can adjust the mPTA and knee balance accordingly, with the assistance of a caliper. Based on our results, we recommend caution when modifying femoral alignment due to the weak correlation between ΔLDFA gonio or ΔLDFA(s) and ΔT. In the light of Howell et al.'s results, we suggest that the learning curve for routinely using a caliper may be relatively short [7].

This study presents several limitations. First, potential errors in radiological measurements due to rotational malpositioning and fixed flexion contractures cannot be entirely excluded. Advanced imaging techniques, such as the EOS system, may provide greater accuracy in these cases [28].

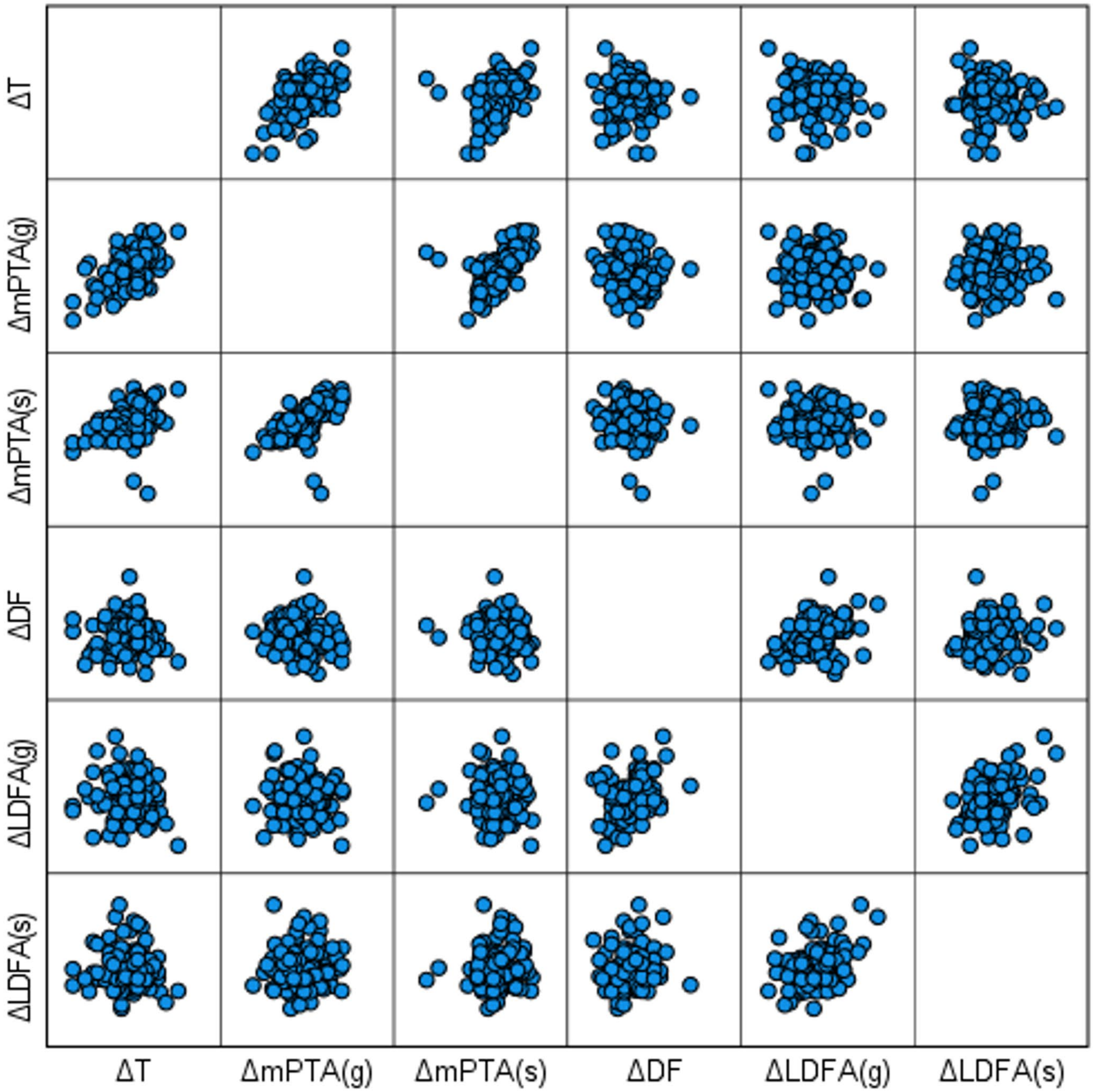

Fig. 7 Correlation matrix

Second, due to our limitations in resources, conducting a second evaluation by another observer of the numerous radiological parameters falls outside the scope of this study, which limits our analysis in the absence of assessing inter-observer variability. However, the intraclass correlation coefficient in this study is relatively high, indicating good measurement reliability. Moreover, having a single experienced evaluator reduces variability and resource requirements, enhancing the study's feasibility. Third, this was a prospective study conducted on a retrospective patient cohort, without randomization for factors such as age, gender, or ethnic background, which may introduce selection bias. Another limitation of this study is the lack of data on pre- and peroperative soft tissue laxity, which prevented us from performing a multivariate regression analysis to examine the influence of factors such as age, BMI, and deformity severity on the soft tissues. This methodological discrepancy could impact the accuracy of the correlation analysis.

Table 3 Descriptive statistics

Variable	*N*	Mean	Std. Deviation	Minimum	Maximum
HKA(g) Pre-op	130	177.224	7.6464	162.1	194.3
HKA'(g) Post-op	130	180.513	2.9788	174.7	187.2
JLCA (g) Pre-op	130	− 2.369	3.9411	− 12.1	7.6
JLCA' (g) Post-op	130	− 0.002	0.6993	− 2.0	1.7
JLCA (s) Pre-op	130	− 2.302	4.7925	−9.3	8.5
JLCA' (s) Post-op	130	− 0.024	0.9218	−5.5	3.0
ΔT	130	3.69	4.226	− 10	16
ΔDF	130	1.18	2.372	− 5	11
ΔmPTA (g)	130	4.125	2.8271	− 3.9	10.8
ΔmPTA (s)	130	2.719	2.5096	− 8.9	8.5
ΔLDFA (g)	130	3.041	2.2928	− 2.8	10.7
ΔLDFA (s)	130	3.431	2.9354	− 3.0	14.1

Table 4 Measurements bone resection cuts

Variable	Varus (Mean ± SD)	Neutral (Mean ± SD)	Valgus (Mean ± SD)	Total (Mean ± SD)
Distal femoral internal (mm)	7.9 (± 1.6)	8.3 (± 2.5)	7.7 (± 2.0)	8.0 (± 1.2)
Distal femoral external (mm)	7.3 (± 1.7)	6.8 (± 1.3)	5.6 (± 1.9)	6.8 (± 1.8)
Proximal tibial internal (mm)	4.2 (± 2.5)	4.7 (± 2.4)	5.6 (± 2.8)	4.6 (± 2.6)
Proximal tibial external (mm)	9.7 (± 2.8)	7.0 (± 3.0)	6.4 (± 2.8)	8.3 (± 3.2)

Table 5 Wilcoxon signed ranks test

Variable	Z	Asymp. Sig. (2-tailed)
JLCA (s)– JLCA (g) Pre-op	− 0.121[a]	0.903
JLCA' (s)– JLCA' (g) Post-op	− 0.255[a]	0.799
ΔmPTA(g) - ΔT	−1.264[b]	0.206
ΔmPTA(s) - ΔT	− 3.020[a]	0.003
ΔLDFA(g) - ΔDF	− 7.055[b]	< 0.001
ΔLDFA(s) - ΔDF	− 6.663[b]	< 0.001

[a]Based on positive ranks

[b]Based on negative ranks

Table 6 Intra class correlation

	HKA	mLDFA	mPTA	AMA	JLCA
ICC	0.999	0.993	0.977	0.982	0.995
ICC (CI 5%)	0.998	0.978	0.933	0.946	0.985
ICC (CI 95%)	1.000	0.999	0.997	0.998	0.999

Conclusion

A moderate correlation was observed between the mPTA angles and the thickness of the tibial cuts, with approximately 1 mm of thickness change corresponding to each 1° of angular correction. In contrast, no similar correlation was found for the femoral cuts, highlighting the need for caution when applying the same principles in preoperative planning.

Table 7 Correlation matrix

		ΔT	ΔmPTA(g)	ΔmPTA(s)	ΔDF	ΔLDFA(g)	ΔLDFA(s)
Spearman's rho							
ΔT	Correlation Coefficient	–					
	Sig (2-tailed)						
	N	130					
ΔmPTA(g)	Correlation Coefficient	0.553**	–				
	Sig (2-tailed)	< 0,001					
	N	130	130				
ΔmPTA(s)	Correlation Coefficient	0.505**	0.682**	–			
	Sig (2-tailed)	< 0.001	< 0.001				
	N	130	130	130			
ΔDF	Correlation Coefficient	−0.050	−0.166	−0.137	–		
	Sig (2−tailed)	0.574	0.059	1.21			
	N	130	130	130	130		
ΔLDFA(g)	Correlation Coefficient	−0.094	−0.028	−0.021	0.350**	–	
	Sig (2−tailed)	0.287	0.751	0.815	< 0.001		
	N	130	130	130	130	130	
ΔLDFA(s)	Correlation Coefficient	−0.025	0.021	0.116	0.187*	0.347**	–
	Sig (2−tailed)	0.774	0.814	0.188	0,034	< 0,001	
	N	130	130	130	130	130	130

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

Author contributions AO, ET, and AA contributed to writing and revising the manuscript. AO created the database and provided the tables. JM supplied the statistical analysis and figures.

Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no competing interests.

References

1. Rivière C, Iranpour F, Auvinet E, Howell S, Vendittoli PA, Cobb J, Parratte S (2017) Alignment options for total knee arthroplasty: a systematic review. Orthop Traumatol Surg Res 103(7):1047–1056. https://doi.org/10.1016/j.otsr.2017.07.010 (**Epub 2017 Aug 31 PMID: 28864235**)
2. Howell SM (2019) Calipered kinematically aligned total knee arthroplasty: an accurate technique that improves patient outcomes and implant survival. Orthopedics 42(3):126–135. https://doi.org/10.3928/01477447-20190424-02 (**PMID: 31099877**)
3. Fang DM, Ritter MA, Davis KE (2009) Coronal alignment in total knee arthroplasty: just how important is it? J Arthroplasty 24(6 Suppl):39–43. https://doi.org/10.1016/j.arth.2009.04.034 (**Epub 2009 Jun 24 PMID: 19553073**)
4. Hirschmann MT, Becker R, Tandogan R, Vendittoli PA, Howell S (2019) Alignment in TKA: what has been clear is not anymore! Knee Surg Sports Traumatol Arthrosc 27(7):2037–2039. https://doi.org/10.1007/s00167-019-05558-4 (**Epub 2019 Jun 12 PMID: 31190246**)
5. Parratte S, Pagnano MW, Trousdale RT, Berry DJ (2010) Effect of postoperative mechanical axis alignment on the fifteen-year survival of modern, cemented total knee replacements. J Bone Joint Surg Am 92(12):2143–9. https://doi.org/10.2106/JBJS.I.01398 (**PMID: 20844155**)
6. Martin JR, Wronski PT, Schilkowsky RM, Orfanos AV, Fehring TK, Mason JB. Chitranjan S (2022) Ranawat award: motion during total knee cementing significantly decreases tibial implant fixation strength. J Arthroplasty 37(6S):S12-S18. https://doi.org/10.1016/j.arth.2022.02.091 (**Epub 2022 Feb 26. PMID: 35231563**)
7. Howell SM, Nedopil AJ, Hull ML (2022) Negligible effect of surgeon experience on the accuracy and time to perform unrestricted caliper verified kinematically aligned TKA with manual instruments. Knee Surg Sports Traumatol Arthrosc 30(9):2966–2974. https://doi.org/10.1007/s00167-022-06939-y (**Epub 2022 Apr 2. PMID: 35366075; PMCID: PMC9418297**)
8. Klasan A, Putnis SE, Grasso S, Neri T, Coolican MR (2020) Conventional instruments are more accurate for measuring the depth of the tibial cut than computer-assisted surgery in total knee arthroplasty: a prospective study. Arch Orthop Trauma Surg 140(6):801–806. https://doi.org/10.1007/s00402-020-03403-9 (**Epub 2020 Mar 7 PMID: 32146591**)
9. Li C, Zhang Z, Wang G, Rong C, Zhu W, Lu X, Liu Y, Zhang H (2022) Accuracies of bone resection, implant position, and limb alignment in robotic-arm-assisted total knee arthroplasty: a prospective single-centre study. J Orthop Surg Res 17(1):61. https://doi.org/10.1186/s13018-022-02957-1 (**PMID: 35093133; PMCID: PMC8800350**)
10. Hampp EL, Chughtai M, Scholl LY, Sodhi N, Bhowmik-Stoker M, Jacofsky DJ, Mont MA (2019) Robotic-arm assisted total knee arthroplasty demonstrated greater accuracy and precision to plan compared with manual techniques. J Knee Surg 32(3):239–250. https://doi.org/10.1055/s-0038-1641729 (**Epub 2018 May 1. PMID: 29715696**)
11. Deckey DG, Rosenow CS, Verhey JT, Brinkman JC, Mayfield CK, Clarke HD, Bingham JS (2021) Robotic-assisted total knee arthroplasty improves accuracy and precision compared to conventional techniques. Bone Joint J 103B(6 Supple A):74–80. https://doi.org/10.1302/0301-620X.103B6.BJJ-2020-2003.R1 (**PMID: 34053292**)
12. Scott DF, Horton EN (2025) Femoral resection accuracy and precision in manual caliper-verified kinematic alignment total knee arthroplasty. J Exp Orthop 12(2). https://doi.org/10.1002/jeo2.70234 (**PMID: 40256668; PMCID: PMC12006286**)
13. Ishii Y, Noguchi H, Matsuda Y, Kiga H, Takeda M, Toyabe S (2009) Preoperative laxity in osteoarthritis patients undergoing total knee arthroplasty. Int Orthop 33(1):105–9. https://doi.org/10.1007/s00264-007-0467-x (**Epub 2007 Oct 16. PMID: 17938923; PMCID: PMC2899222**)
14. Bellemans J, Colyn W, Vandenneucker H, Victor J (2012) The Chitranjan Ranawat Award. Is neutral mechanical alignment normal for all patients? The concept of constitutional varus. Clin Orthop Relat Res 470(1):45–53
15. Wen L, Yu Y, Ma D, Wang Z (2023) Effect of joint line orientation parameters on initial bone resection in mechanically aligned total knee arthroplasty: a retrospective clinicoradiological correlation study. BMC Musculoskelet Disord 24(1):222. https://doi.org/10.1186/s12891-023-06299-9 (**PMID: 36964533; PMCID: PMC10037864**)
16. Hinman RS, May RL, Crossley KM (2006) Is there an alternative to the full-leg radiograph for determining knee joint alignment in osteoarthritis? Arthritis Rheum 55(2):306–13. https://doi.org/10.1002/art.21836 (**PMID: 16583430**)
17. Moreland JR, Bassett LW, Hanker GJ (1987) Radiographic analysis of the axial alignment of the lower extremity. J Bone Joint Surg Am 69(5):745–9 (**PMID: 3597474**)
18. Chang CB, Choi JY, Koh IJ, Seo ES, Seong SC, Kim TK (2010) What should be considered in using standard knee radiographs to estimate mechanical alignment of the knee? Osteoarth Cartil 18(4):530–8. https://doi.org/10.1016/j.joca.2009.12.004 (**Epub 2009 Dec 21. PMID: 20060951**)
19. Graden NR, Dean RS, Kahat DH, DePhillipo NN, LaPrade RF (2020) True mechanical alignment is found only on full-limb and not on standard anteroposterior radiographs. Arthrosc Sports Med Rehabil 2(6):e753–e759. https://doi.org/10.1016/j.asmr.2020.06.010 (**PMID: 33364613; PMCID: PMC7754530**)
20. Paternostre F, Schwab PE, Thienpont E (2014) The difference between weight-bearing and non-weight-bearing alignment in patient-specific instrumentation planning. Knee Surg Sports Traumatol Arthrosc 22(3):674–9. https://doi.org/10.1007/s00167-013-2687-5 (**Epub 2013 Sep 20. PMID: 24051507**)
21. McEwen P, Balendra G, Doma K (2019) Medial and lateral gap laxity differential in computer-assisted kinematic total knee arthroplasty. Bone Joint J 101-B(3):331–339. https://doi.org/10.1302/0301-620X.101B3.BJJ-2018-0544.R1 (**PMID: 30813796**)
22. Nowakowski AM, Majewski M, Müller-Gerbl M, Valderrabano V (2012) Measurement of knee joint gaps without bone resection: "physiologic" extension and flexion gaps in total knee arthroplasty are asymmetric and unequal and anterior and posterior cruciate ligament resections produce different gap changes. J Orthop Res 30(4):522–7. https://doi.org/10.1002/jor.21564 (**PMID: 22416291**)
23. Jia Y, Zhai L, Qin S, Xu J, Gao W, Zhang B, Wang X, Zhou K, Sun Z, Niu Y, Bao H, Sun R (2023) Residual varus alignment after posterior-stabilized total knee arthroplasty limits medial soft tissue remodeling. BMC Musculoskelet Disord 24(1):918. https://doi.org/10.1186/s12891-023-07048-8 (**PMID: 38017454; PMCID: PMC10683269**)

24. Hatayama K, Terauchi M, Saito K, Higuchi H (2017) Does residual varus alignment cause increasing varus laxity at a minimum of 5 years after total knee arthroplasty? J Arthroplasty 32(6):1808–1813. https://doi.org/10.1016/j.arth.2017.01.006 (**Epub 2017 Jan 17. PMID: 28185754**)
25. Than P, Szuper K, Somoskeöy S, Warta V, Illés T (2012) Geometrical values of the normal and arthritic hip and knee detected with the EOS imaging system. Int Orthop 36(6):1291–7. https://doi.org/10.1007/s00264-011-1403-7 (**Epub 2011 Nov 18. PMID: 22095137; PMCID: PMC3353085**)
26. Marques Luís N, Varatojo R (2021) Radiological assessment of lower limb alignment. EFORT Open Rev 6(6):487–494. https://doi.org/10.1302/2058-5241.6.210015 (**PMID: 34267938; PMCID: PMC8246117**)
27. Specogna AV, Birmingham TB, Hunt MA, Jones IC, Jenkyn TR, Fowler PJ, Giffin JR (2007) Radiographic measures of knee alignment in patients with varus gonarthrosis: effect of weightbearing status and associations with dynamic joint load. Am J Sports Med 35(1):65–70. https://doi.org/10.1177/0363546506293024 (**Epub 2006 Sep 22 PMID: 16998083**)
28. Hungerford DS, Krackow KA (1985) Total joint arthroplasty of the knee. Clin Orthop Relat Res 192:23–33 (**PMID: 3967427**)