Technology and Health Care 30 (2022) 1147–1154
DOI 10.3233/THC-213535
IOS Press

Can tibia-first total knee arthroplasty using computer-assisted system improve anterior and posterior knee stability?

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Received 10 October 2021
Accepted 28 February 2022

Abstract.
BACKGROUND: Total knee arthroplasty (TKA) is a widely performed procedure to alleviate pain and restore function of patients with end-stage knee osteoarthritis.
OBJECTIVE: The study aim was to determine if tibia-first (TF) total knee arthroplasty (TKA) using a novel computer-assisted surgery (CAS) system can yield better anterior and posterior (AP) knee stability.
METHODS: Patients with knee osteoarthritis with obvious varus knee who met the indication for and underwent TKA from May 2019 to November 2020 were included. Forty-one measured resection (MR)-TKAs and 32 TF-TKAs were compared. The varus-valgus ligament balance and joint tension at a joint center-gap setting equal to the tibial-baseplate thickness were measured, and appropriate polyethylene inserts with 0°, 30°, 45°, 60°, 90°, and 120° of knee flexion were placed. A Kneelax 3 arthrometer was used to measure knee AP laxity in the postoperative anesthetized patients with 30° and 90° of knee flexion.
RESULTS: The horizontal gap balance was significantly closer in the TF-TKA group than the MR-TKA group for 0°, 30°, 45°, and 60° of knee flexion. In contrast, no significant differences were observed for 90° and 120° of knee flexion. No significant differences in joint-gap tensions among all knee-flexion angles were observed. Translation was significantly smaller in the TF-TKA group than the MR-TKA group for AP laxity with 30° of knee flexion (8.8 ± 2.9 mm vs. 10.7 ± 3.1 mm, $P = 0.0079$). In contrast, no significant AP laxity was observed with 90° of knee flexion (7.2 ± 2.8 mm vs. 7.2 ± 3.5 mm).
CONCLUSION: TF-TKA using a novel CAS system provided better AP knee stability with close to horizontal gap balances.

Keywords: Total knee arthroplasty, computer-assisted surgery, tibia-first technique, anterior and posterior knee stability, gap balance

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1. Introduction

Total knee arthroplasty (TKA) is a widely performed procedure to alleviate pain and restore function of patients with end-stage knee osteoarthritis (KOA). Prerequisites of successful TKA are restoring coronal mechanical alignment within 3° and balanced ligamentous frame. Mal-positioning of the prosthesis can lead to asymmetric tibial-femoral tracking resulting in excessive stresses on the weight-bearing surfaces of the prosthesis, leading to early loosening [1].

Computer-assisted surgery (CAS) for TKA has become widely used since the mid-2000s [2], and CAS-TKA has been reported to provide better sagittal and coronal component alignment [3]. On the other hand, however, better functional outcome or longer implant survivability after navigation-assisted TKA has not been demonstrated from past studies using registry data [4]. A plausible reason is that most CAS systems can provide only static information for 0° knee-extension and 90° knee-flexion positions. Because of the limited information about balance in only extension and flexion but no information about the mid-flexion position, gap measurement does not sufficiently predict joint stability during load-bearing conditions in daily activity. Recently, to overcome these problems, a novel CAS system was introduced that enables measurements of ligamentous status throughout the entire knee range of motion (ROM) under dynamic conditions. Quantitative dynamic gap measurements under valgus and varus stress before and after tibia and femur cuts throughout the ROM can be performed to measure maximum gap sizes. Both the reproducibility and reliability of dynamic testing using this CAS system have previously been reported to be high [5]. Intraoperative soft tissue balance is reported to influence the postoperative clinical outcomes [6] and use of a predictive joint tensioning tool improved the final balance and clinical outcomes [7]. However, it is currently unclear if implant placement using this novel CAS system would result in better anterior and posterior (AP) knee stability.

The “tibia-first” (TF) technique uses the tibial resection plane to guide femoral component rotation, which removes the need for identification of individual landmarks on the distal femur to identify a reference axis and may have the advantage of predicting the final soft-tissue balance before femoral osteotomies [8]. This technique might result in good ligamentous balance without excessive soft-tissue release and lead to accurate femoral resection.

Therefore, we hypothesized that better AP knee stability could be achieved by TF-TKA using a novel CAS system than by the conventional measured resection technique (MR)-TKA. The purpose of this study was to test this hypothesis.

2. Material and methods

2.1. Patient enrollment

Institutional Bioethics Committee for Medical Research approved the study and waived the requirement for informed consent from individual participants (Approval ID: A20-067). Patients with KOA with varus knee who met the indication for and underwent TKA from May 2019 to November 2020 were included, and MR-TKA was performed from May 2019 until February 2020. TF-TKA was performed from March 2020 to November 2020. All surgeries were performed by one senior board-certified orthopedic surgeon.

The indication of TKA was diagnosed on the basis of clinical findings, such as a decreased ROM, decline in activities of daily living, and radiological findings according to the Kellgren-Lawrence classification. The exclusion criteria were history of previous TKA who planned to undergo revision surgery, patients after high-tibial osteotomy, or patients with previous collateral ligament injury because of the potential effects of these conditions on postoperative AP knee stability.

2.2. Surgical procedure for the MR technique

MR-TKAs were performed by using a cruciate-retaining, cemented, fixed-bearing implant (Attune; DepuySynthes, Inc., Warsaw, IN, USA) using a mid-vastus approach. Pneumatic tourniquets were applied to all patients. The anterior cruciate ligament was dissected and the posterior cruciate ligament (PCL) was retained in all cases. Patella resurfacing was not performed. Infrapatellar fat pad excision was only performed when the surgical visual field was insufficient and was minimized to avoid anterior knee pain [9]. We performed a mechanically aligned TKA to achieve neutral coronal mechanical limb alignment by making the femoral and tibial bone cuts such that the rectangular flexion and extension gaps were perpendicular to the mechanical axes. The surgery was performed according to the manufacturer's instructions. The distal femoral cut was made by using an intramedullary alignment system. The posterior femoral cuts were made with a referencing guide to make the bony resection line parallel to the surgical epicondylar line and perpendicular to Whiteside's line. The proximal tibial cut was made by using an extramedullary alignment system. Significant posterior osteophytes were removed. Trial components were inserted, and the ROM of the knee and other intraoperative parameters were checked as described above. Release of the collateral and retinacular ligaments to balance the flexion and extension gaps was not performed. The definitive components were introduced with cement fixation, and a final evaluation of the ROM was made.

2.3. Surgical procedure of the TF technique using a CAS

TF-TKAs were performed by using the same implant and approach as used for the MR technique. First, anatomical landmarks and the individual biomechanical knee data were obtained; the ROM, varus-valgus angles of the leg axis, and gap sizes throughout the entire ROM were obtained at the beginning of surgery for registration of the navigation system [5]. A tibial osteotomy was first performed to ensure that the tibial bony resection was perpendicular to the anatomical tibial axis. Insertion of the PCL was protected by creating a bony island if necessary. After tibial bony resection, the necessary osteophyte removal was performed but medial collateral ligament (MCL) release, if required, was not performed. Following the tibial bony resection, the gap sizes were measured dynamically by performing varus-valgus stress tests for the medial and lateral gaps to balance the extension gap by using a tibial trial component. Those stress tests were performed from extension to full flexion. The amount of distal femoral osteotomy was determined parallel to the tibia shown on the screen of the navigation system. Then, the amount of the posterior femoral osteotomy and varus-valgus balance were determined on the screen of the navigation system to create an adequate gap. Based on the gaps obtained, the femoral component position was planned to reach total balance, meaning identical medial and lateral gaps throughout the entire ROM (Fig. 1). The distal femoral cut was made first followed by the dorsal cut. The same dynamic varus-valgus stress tests after femoral resections with all trial components placed were performed. The definitive components were introduced with cement fixation, and a final evaluation of the ROM was made.

2.4. Intraoperative joint-gap measurement using a tensor

Following each bony resection, we fixed the tensor and femoral trial prostheses, and the patella was reduced. At this point, we measured the varus-valgus ligament balance and a joint tension at a joint center-gap setting equal to the tibial baseplate thickness, and appropriate polyethylene inserts of 0°, 30°, 45°, 60°, 90°, and 120° of knee flexion were placed (Fig. 2). The varus-valgus ligament balances were defined as positive and negative, respectively.

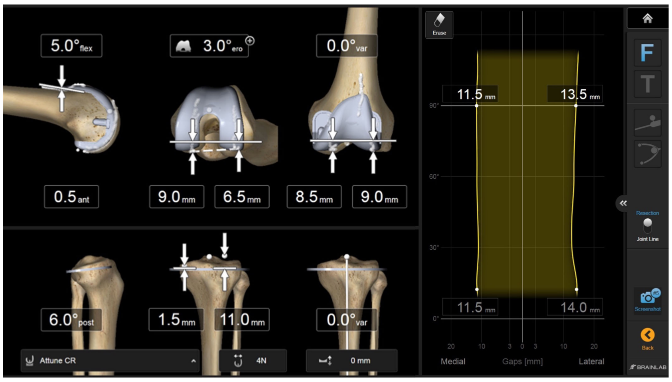

Fig. 1. The right screen shows a graph of gaps from full knee extension to full flexion. The lateral gap is shown on the right side, and the medial gap is shown on the right side. The left screen shows the component alignments and estimated widths of bony resection.

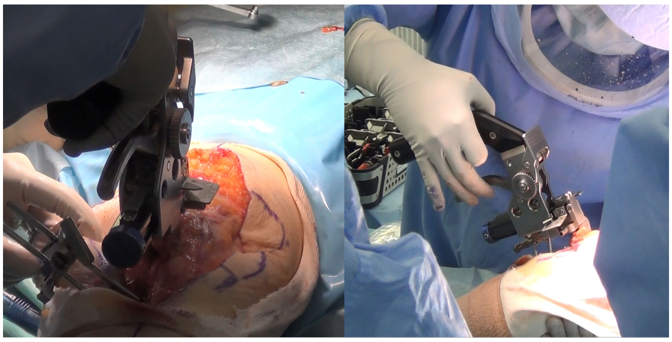

Fig. 2. Measurements of the varus-valgus ligament balance and joint tension at a joint center-gap setting equal to the tibial baseplate and an appropriate polyethylene insert.

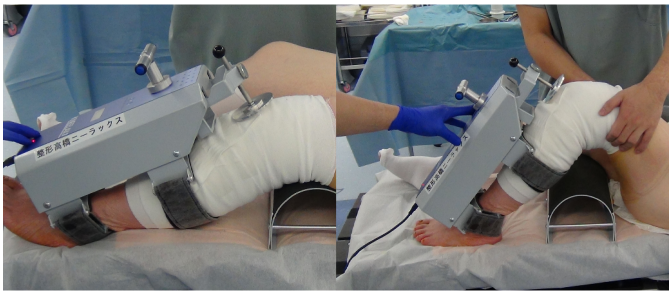

Fig. 3. Postoperative knee AP laxity measurements made by using a Kneelax 3 arthrometer at 30° and 90° of knee flexion.

2.5. *Postoperative measurement of AP laxity by using a Kneelax 3 arthrometer*

Immediately after surgery, anesthetized patients underwent knee AP laxity measurement by using a Kneelax 3 arthrometer with 30° and 90° of knee flexion, as described in a previous study by Shi et al. [10]. One surgeon performed the AP drawer test to apply a force of 132 N to the tibia relative to the femur anteriorly and posteriorly (Fig. 3). The AP laxity was calculated and recorded.

Table 1
Patient demographics

Parameter	
Sex	26 males/47 females
Age (years)	72.5 ± 7.4 years (43–87)
HKA	12.2° ± 6.5° (1°– 27.1°)

HKA denotes the hip-knee angle in degrees. *Data are expressed as the mean ± standard deviation (range).

Table 2
Comparisons of preoperative backgrounds

	TF-TKA	MR-TKA	P-value
Male/female	13/19	13/28	0.47
Age (years)	73.3 ± 7.6	71.8 ± 7.3	0.37
Preoperative HKA (°)	13.4 ± 7.1	10.6 ± 5.3	0.063

HKA, MR, and TF denote; hip knee angle, measured resection, and tibia first, respectively. *Data are expressed as the mean ± standard deviation.

2.6. *Statistical analysis*

Data are presented as the mean and standard deviation. A priori power analysis was performed by using G* Power 3.1 (Franz Paul, Kiel, Germany). A sample size of 19 patients in the TF-TKA group and 38 patients in the MR-TKA group was calculated to achieve 80.2% power with an effect size of 0.8 to test the null hypothesis. There were 32 patients in the TF-TKA group and 41 patients in the MR-TKA group, and post hoc analysis showed 91.7% power with an effect size of 0.8. Values of $P < 0.05$ were considered to be indicative of statistical significance. All statistical analyses were performed by using EZR software.

3. Results

3.1. *Patient characteristics*

A total of 73 patients, 32 in the TF-TKA group and 41 in the MR-TKA group, were included, with 26 males and 47 females and an average age of 72.5 ± 7.4 (range: 43–87) years. The average preoperative hip-knee angle (HKA) was 12.2° ± 6.5° varus (range: 1°–27.1°) (Table 1). No significant differences in the male:female ratio, average age, and preoperative HKA were observed between the groups (Table 2).

3.2. *Comparisons of bony resection width*

No significant differences in the width of bony resection in the distal femur and proximal tibia on the medial and lateral sides and in the dorsal femur on the lateral side between the TF-TKA and MR-TKA were observed. On the other hand, the width of bony resection in the dorsal femur on the medial side was significantly smaller in the TF-TKA group than in the MR-TKA group (9.0 ± 2.2 mm vs. 9.8 ± 1.3 mm, $P = 0.039$) (Table 3).

3.3. *Comparisons of intraoperative joint-gap measurements using a tensor*

The horizontal gap balance was significantly closer in the TF-TKA group than in the MR-TKA group

Table 3
Comparisons of the width of bony resection measurements

	TF-TKA	MR-TKA	P-value
Distal femur (mm)			
Medial	7.6 ± 1.3	7.0 ± 1.3	0.066
Lateral	6.7 ± 1.2	7.0 ± 1.0	0.20
Dorsal femur (mm)			
Medial	9.0 ± 2.2	9.8 ± 1.3	0.039
Lateral	6.8 ± 1.7	6.8 ± 1.0	0.93
Proximal tibia (mm)			
Medial	4.4 ± 1.6	3.5 ± 2.7	0.098
Lateral	10.4 ± 1.6	10.7 ± 1.8	0.37

*Data are expressed as the mean ± standard deviation.

Table 4
Comparisons of gap-balance measurements

Knee-flexion angle	TF-TKA (°)	MR-TKA (°)	P-value
0°	0.25 ± 0.72	2.4 ± 2.3	< 0.001
30°	0.094 ± 1.1	1.6 ± 2.5	0.0018
45°	−0.062 ± 1.2	1.3 ± 2.5	0.0046
60°	−0.063 ± 0.98	1.1 ± 2.6	0.022
90°	0.13 ± 1.7	0.95 ± 3.2	0.19
120°	0.94 ± 1.6	1.5 ± 3.0	0.37

*Data are expressed as the mean ± standard deviation.

Table 5
Comparisons of gap-tension measurements

Knee-flexion angle	TF-TKA (lbf)	MR-TKA (lbf)	P-value
0°	20.3 ± 6.6	19.2 ± 6.7	0.49
30°	16.5 ± 5.0	17.4 ± 7.2	0.55
45°	18.1 ± 5.3	18.0 ± 6.6	0.99
60°	18.4 ± 6.0	18.3 ± 6.8	0.97
90°	19.2 ± 4.9	19.1 ± 7.0	0.96
120°	22.7 ± 6.6	21.8 ± 6.7	0.55

*Data are expressed as the mean ± standard deviation.

with 0°, 30°, 45°, and 60° of knee flexion, but there were no significant differences between the groups for 90° and 120° of knee flexion (Table 4). No significant differences in joint-gap tensions among all knee flexion angles were observed (Table 5).

3.4. *Comparisons of intraoperative AP laxity measurements*

Translation was significantly smaller in the TF-TKA group than in the MR-TKA group for AP laxity with 30° of knee flexion (8.8 ± 2.9 mm vs. 10.7 ± 3.1 mm, $P = 0.0079$). On the other hand, no significant AP laxity was observed for 90° of knee flexion (7.2 ± 2.8 mm vs. 7.2 ± 3.5 mm) (Table 6).

4. Discussion

There were several main findings in this study. First, postoperative AP laxity after TKA was significantly smaller in the TF-TKA group than in the MR-TKA group for 30° of knee flexion. Second, closer to

Table 6
Comparisons of postoperative anterior-posterior knee-laxity measurements

	TF-TKA	MR-TKA	P-value
AP translation of 30° (mm)	8.8 ± 2.9	10.7 ± 3.1	0.0079
AP translation of 90° (mm)	7.2 ± 2.8	7.2 ± 3.5	0.91

AP, MR, and TF denote; anterior-posterior, measured resection, and tibia first, respectively. *Data are expressed as the mean ± standard deviation.

horizontal gap balances were observed in the TF-TKA group for knee extension-to-mid flexion angles. Third, joint-gap tensions among all flexion angles and widths of bony resections except for the dorsal femur on the medial side were not significantly different between the groups.

We aim to achieve equal medial and lateral gaps when we perform TKA [11], and those gaps ideally should be equal throughout the entire ROM [12]. However, conventional static gap measurements were made only at extension and at 90° of knee flexion by using gap tensioners, and midrange instability that leads to poor clinical outcomes could not be evaluated intraoperatively [13,14]. By using this technique with the novel CAS system, the gaps could be reproducibly analyzed throughout the entire ROM, which enabled us to measure the medial and lateral sides also at mid-flexion angles. This CAS system has previously been proven to be reliable with high intra- and interobserver reliability [5].

The surgical principle of TF-TKA is that it respects the integrity of soft tissues. It is a common observation that soft-tissue release is significantly reduced by using computer navigation [15]. Following proximal tibia resection, we used a navigation system to determine the extension and rotational alignments of the femoral component based on the gap sizes measured dynamically by performing varus-valgus stress tests for the medial and lateral gaps to balance the extension gap by using a tibia trial component. Subsequently, we performed distal and posterior femoral resections. A potential advantage of using the TF-TKA is that it can prevent mismatch before and after resection of the femoral posterior condyle and placement of the femoral component [8]. In addition, bony resection can be set with increments of 0.5 mm and angles with increments of 0.5°, which are smaller increments than those possible with the surgical equipment used in MR-TKA, thus enabling resection of the femoral posterior condyle to achieve balanced gaps in both the extension and flexion positions obtained in the current study. We speculate that this was a plausible explanation for why the width of the bony resection in the dorsal femur on the medial side was slightly smaller in the TF-TKA group than in the MR-TKA and how gap balances closer to horizontal among knee extension to mid flexion angles were achieved in the TF-TKA group.

4.1. Limitations

There were several limitations in this study. First, we did not assess the interobserver variation in instrumental measurements for the reason mentioned earlier. Second, all TKA surgeries were CR-TKAs performed by one consultant knee surgeon who used the mid-vastus approach. Therefore, these results cannot be generalized to TKAs using others approaches or to posterior-stabilized TKA. Third, a comparison between pre- and postoperative joint lines was not performed in this study but is a topic for future investigation. Fourth, it is uncertain if the lesser AP knee stability in both the mid- and deep-flexion angles and the closer to horizontal gap balances in extension-to-mid-flexion knee angles were related to the TF technique, use of the novel CAS system, or a combination of both. A future separate analysis would be required to answer this important clinical question.

Despite these limitations, this study is the first to show that TF-TKA using a novel CAS system achieved better AP knee stability in mid- and deep-flexion angles than those achieved by using the conventional MR-TKA, with closer to horizontal gap balances in extension-to-mid-flexion knee angles. Future comparative studies would be required to determine if these findings will result in better clinical outcomes and patient satisfaction.

5. Conclusions

This study showed that better AP knee stability in mid-flexion angles and closer to horizontal gap balances were achieved by TF-TKA using a novel CAS system than by MR-TKA.

Conflict of interest

None to report.

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