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Original research

A computer-assisted, tibia-first technique for improved femoral component rotation in total knee arthroplasty

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ABSTRACT

Background: The use of navigation for total knee arthroplasty (TKA) improves limb alignment in the coronal and sagittal planes. However, similar improvements in femoral and tibial component rotation have not yet been realized using currently available systems.

Methods: We developed a modified navigated TKA technique in which femoral rotation was set using the resected tibial plane as the reference with the aim of achieving a rectangular flexion gap. Limb alignment was assessed in a cohort of 30 knees using the navigation system. Post-operative limb alignment was measured using long-leg standing radiographs. Computed tomography was used to determine post-operative component orientation.

Results: Sagittal alignment data improved from a mean of 7.8° varus (pre-operative) to 0.0° (post-operative), assessed by intra-operative navigation. Post-operative hip-knee-ankle axis alignment was 0.9° valgus (mean; standard deviation [SD] 1.7°). Mean femoral component rotation was 0.5° internally rotated (SD 2.6°), relative to the surgical transepicondylar axis. Mean tibial component rotation was 0.9° externally rotated (SD 5.5°). No soft tissue releases were performed.

Conclusions: These results confirm that the desired femoral rotation, set using a tibia-first approach with the resected tibial plane as the reference, can be achieved without compromising overall limb alignment. Femoral component rotation was within a narrow range, with a moderate improvement in achieving more consistent tibial component rotation compared with other techniques. This technique may prove to be useful for surgeons wishing to employ a tibia-first philosophy for TKA while maximizing the benefits associated with computer-assisted navigation.

Introduction

Since the introduction of computer-assisted surgery systems to perform total knee arthroplasty (TKA) in the mid-2000s, the use of such systems has become widespread. There has also been a corresponding increase in the number of individual studies that have generated clinical evidence about their surgical utility and effects on patient outcomes. Recent meta-analyses have combined data from these studies to provide greater awareness of what has and what has not been validated by multiple studies [1,2]. Benefits include improved limb alignment in the sagittal and coronal planes, more accurate placement of femoral and tibial components in some planes, reduced revision rates, and so on.

Despite these benefits, several authors have reported an inability to consistently and accurately position the femoral component in terms of internal/external rotation in the axial plane [3]. This is largely due to limitations in defining appropriate reference axes accurately, regardless of the use of a computer navigation system [4-7].

Many different surgical philosophies and instrumentation systems have been developed to achieve the correct femoral component rotation for a specific implant design, including the use of various reference axes such as the transepicondylar axis (TEA) (both anatomical and surgical), the trochlear anterior/posterior or AP axis (aka Whiteside's line), and the posterior condylar axis [8].

There is no consensus as to which is the most reliable reference to use, and each has potential limitations, including inter-observer

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and intra-observer errors. There are often situations where one method may be preferable to another, as influenced by factors such as the pre-operative alignment, underlying anatomy, disease state, implant design, and so on.

Similarly, many different methods have been used to set tibial component rotation but none have been shown to provide consistent results [9-11]. Poor femoral and tibial component rotation has been demonstrated to affect patellar tracking and associated poor clinical outcomes [4,12]. The avoidance of excessive internal rotation of the femoral and tibial component has been reinforced as a key element of TKA surgical technique [12,13].

Current computer navigation systems present one or more (or combinations) of these axes as options for the surgeon to select and use as a guide for positioning the femoral cutting block. Despite the potential advantage of using a system that can provide detailed and accurate 3-dimensional positions, many such systems still rely on manual identification of the relevant anatomical landmarks, for example, medial and lateral femoral epicondyles and posterior femoral condyles, in a manner similar to conventional instrument systems. Therefore, they can suffer the same limitations such as inconsistency and inaccuracy, again resulting in a limited ability to accurately and reliably position the femoral component in axial rotation [14].

Other manual techniques include the so-called “tibia-first” technique that uses the tibial resection plane to guide femoral component rotation, sometimes combined with the use of spacer blocks and/or tensioning devices to assess and assist with soft tissue balancing [8,15,16]. This method removes the need for identification of individual landmarks on the distal femur to identify a reference axis. The cut tibial surface will serve as a reference plane for further femoral resections. However, there is a requirement for accurate positioning of the proximal tibial cutting guide and the bony resection. Using the accuracy of a navigation system to perform this resection may offer improved accuracy over the traditional manual technique. The accuracy of computer navigation for the coronal plane is well established in the literature [1,2]. We are taking advantage of the strength of this coronal accuracy of the computer to bypass the inaccuracy of the computer for axial rotation.

The aim of this study is to develop a tibia-first approach for use with a computer navigation system and to assess the surgical outcomes of this technique in a cohort of 30 TKAs. In addition, we also aim to assess the validity of the tibial-first technique by using computed tomography (CT) measurements.

Material and methods

Patient cohort

Surgical procedures were performed on 30 knees in 20 consecutive patients (mean age 64.9 years; range 53-79 years; sex: 16 female, 4 male) scheduled for navigated TKA from November 10, 2014 to September 21, 2015. The primary diagnosis was osteoarthritis in 18 patients (27 knees) and rheumatoid arthritis in 2 patients (3 knees). Approval for this study was granted by the Independent Ethics Committee, and all patients provided written, informed consent (Reference 201503.1).

Surgical technique

All procedures were performed by a single surgeon (CML). An image-free navigation system was used to perform TKA (eNlite

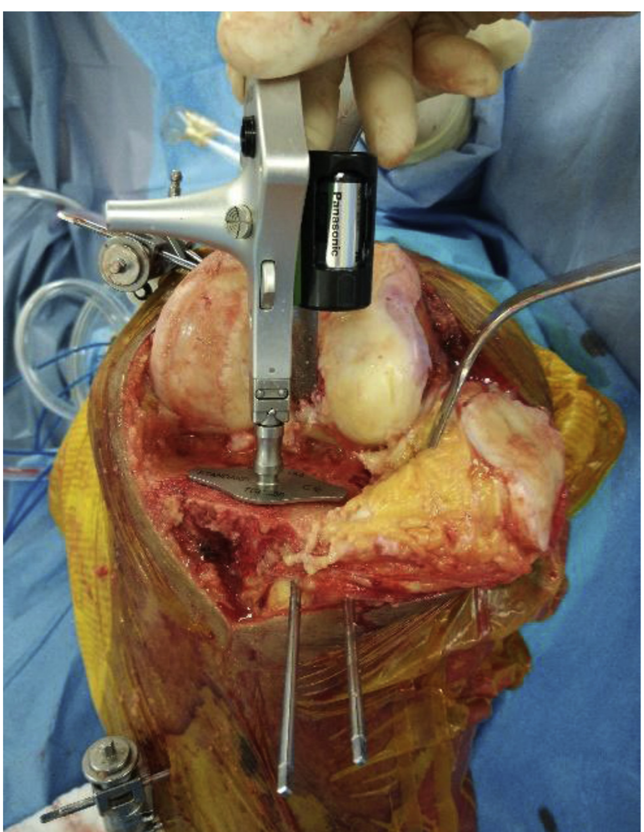

Figure 1. Proximal tibial resection performed and verified using navigation.

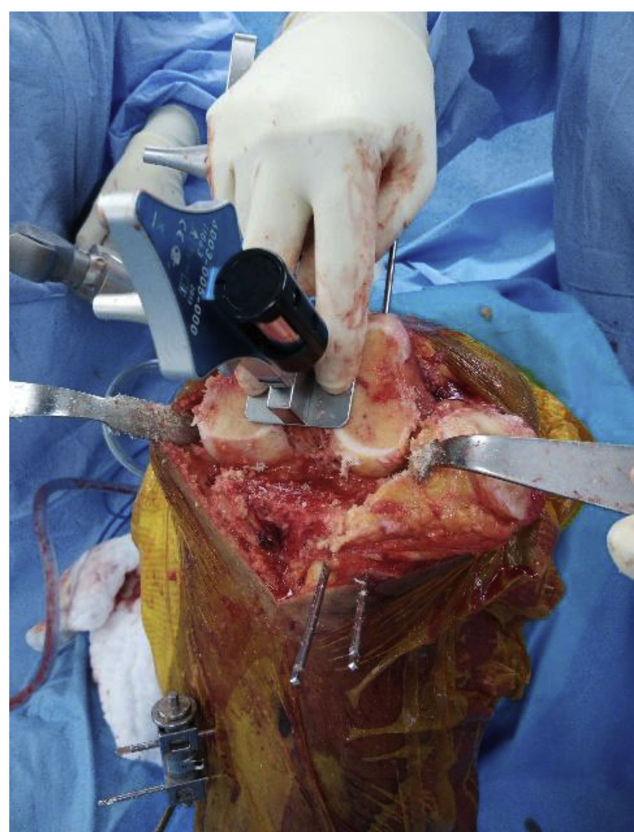

Figure 2. Distal femoral resection performed and verified using navigation.

Navigation System with precisioN Knee Navigation Software v3.1; Stryker, Kalamazoo, MI). The TKA implants used were posterior-stabilized Scorpio Non-Restrictive Geometry (Stryker), combined with bone cement (Palacos G; Heraeus Kulzer GmbH, Hanau, Germany).

The surgical technique is briefly described. A medial parapatellar approach was used and the patella everted. Two threaded pins (3.0-mm diameter) were placed within the incision into the supracondylar region of the femur and two pins placed via stab incisions in the proximal third of the tibia were used to secure the navigation trackers. The navigation trackers were secured using the OrthoLock System (Stryker). Registration of the various bony landmarks around the hip, knee, and ankle was performed according to the navigation protocol.

The navigation workflow was adjusted to perform a tibia-first technique. Resection of the proximal tibia was performed first (Fig. 1). This cut is verified to confirm that the desired resection has been carried out as this plane will be the reference plane for further femoral cuts. The distal femoral resection is performed and verified by the usual navigation protocol (Fig. 2). With the knee flexed to 90°, custom spacer blocks of varying thickness (corresponding to the tibial resection and planned insert thickness) with attached computer trackers were placed into the joint space (Fig. 3). The "align femoral rotation" dialog in the navigation workflow was used in this step. In effect, we are instructing the computer to measure the rotation of the distal femur relative to the cut tibial plane. This measured angle will be used to set the 4-in-1 femoral cutting jig in the next step using the "align femoral rotation" dialog of the navigation workflow. This will make the femoral rotation cut parallel to the proximal tibial resection plane with the knee at 90° (Fig. 4). The navigation AP axis (Whiteside line) and the navigation TEA were also measured. They are used for comparative purposes of this study and were never utilized for the surgical procedure. After completion of all bone resections, trial components were used to confirm the appropriate size and position. A floating technique was used to set the rotational alignment of the tibial tray by moving the knee through a range of motion [17]. Definitive components were implanted using bone cement.

Patellar tracking was assessed before final closure of the joint. The "no thumb" technique was used to qualitatively assess contact through the knee range of motion. Three grades were used to record patellar tracking: excellent, patella sits flush with no tilt; good, slight tilt (<10°); fair, tilt >10°.

Limb alignment was recorded intra-operatively using the navigation system at 2 instances: during the registration process before any joint dissection (pre-operative) and after implantation of the prosthetic components before closure of the joint (post-operative) (Table 1).

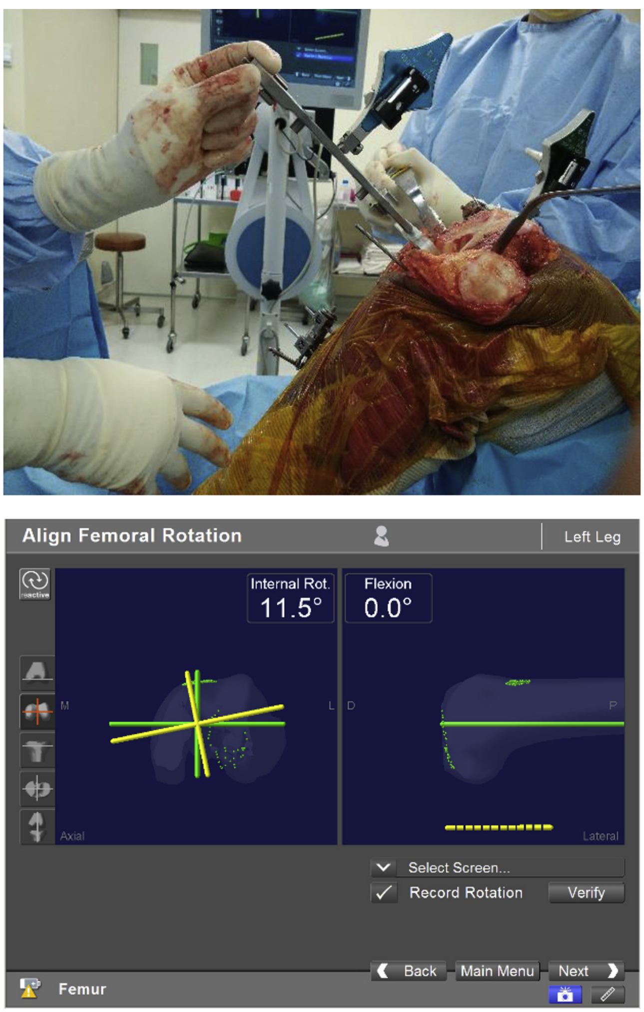

Figure 3. A custom spacer with a navigation tracker attached was inserted with the knee in 90° flexion (upper image). The inferior surface of the spacer was flush with the resected tibia and the posterior femoral condyles are resting on the superior surface of the spacer. The navigation step "align femoral rotation" dialog was used to determine the magnitude of internal/external rotation, as displayed on the navigation display (lower image).

Figure 4. Femoral preparation was performed using a 4-in-1 cutting jig. The magnitude of the femoral internal/external rotation determined in the previous step (ie, 11.5°) was used to align the cutting jig. This allowed for the femoral component to be positioned parallel to the proximal tibial resection plane.

Table 1
Series demographics.

Patient	Navigation pre-op	Navigation post-op	Standing radiographic AP axis	Standing radiographic joint axis	CT femoral rotation	CT tibia rotation	Navigation Whiteside	Navigation TEA
1	−8.5	0.0	1.15	−1.15	−2.14	0.99	0.0	−15.5
2	−8.5	0.0	1.46	−2	−1.68	0.22	4	−18.5
3	−8	−0.5	−1.43	1	−0.25	1.68	−8.5	−17
4	−15.5	0.5	1.04	0	−2.22	1.18	−3.5	−27.5
5	−7.5	0.0	1.05	1	0.72	−1.77	−5.5	−16.6
6	−13	0.5	0.63	0.5	0	−0.63	0.0	−10.5
7	−7.5	−1	1.33	0	−0.6	−0.73	−10.5	−20
8	−3	0.5	3.21	−2	−2.53	−0.68	−1	−13
9	−12.5	1	0.37	0	−0.31	0.68	−10	−14.5
10	−12.5	−1.5	0.5	0	−0.5	−1	−5.5	−20
11	−12.5	0.0	0.65	0	−0.07	−0.58	−16	−36
12	−17	0.0	1.16	−0.5	−0.54	−0.62	0.0	−9.5
13	−5	−0.5	−0.48	1	0.48	0	−10.5	−13.5
14	−8	0.0	−2.48	−1	0.69	1.79	1	−1.5
15	−6	0.0	−1.79	2	0.23	−0.12	2	−14
16	−6	1	2.42	0	0.27	−2.69	−0.5	−17.5
17	−6.5	0.5	3.04	1	−3.01	−0.03	−2	−16.5
18	−7.5	0.5	0.88	−1	−0.88	0	−11	−19
19	−12	−1	1.27	0.5	−1.27	0	1	−16.5
20	5	2.5	1.44	−1	−1.27	−0.17	0.0	−19
21	2.5	−2	3.11	−2	−3.83	0.72	−9	−23
22	−9	0.5	−0.77	2	2.74	−1.97	−9	−16
23	−10	−0.5	2.6	−2	−1.2	−1.4	−5.5	−22
24	−7	−0.5	−1.26	−3.5	−0.83	1.64	−4	−14.5
25	−0.5	1.5	2.01	4	1.34	−3.35	−2.5	−10.5
26	−4.5	0.0	4.89	0	−2.23	−2.66	−2	−24
27	−7.5	−1	2.5	0	−2	−0.5	−1.5	−14.5
28	−8.5	−0.5	1	−1	−1	0	−4.5	−18
29	−6.5	0	1.03	1.5	0.88	−1.91	−3	−9
30	−10	0	−2.6	0	3.15	−0.55	10	−15.5
Mean	−7.77	0	0.93	−0.14	−0.52	0.89	−4.13	−16.77
Median	−7.75	0	1.05	0	0.16	2.23	−3.75	−16.5

Alignment (−) denotes varus and ( ) denotes valgus; rotation (−) denotes internal rotation and ( ) denotes external rotation.

Radiographic assessment

Long-leg alignment in the AP plane was assessed post-operatively on day 5 by performing a bilateral knee radiograph with patients in a standing position (Fig. 5). Patients stood on a stool facing the radiographic tube with their feet internally rotated and the patellae facing forwards toward the radiographic source (Optimus CP 80; Philips Healthcare, Amsterdam, The Netherlands). The radiographic beam was expanded to ensure coverage from the hips to the ankle joints. Image analysis involved identification of bony landmarks to define the individual axes of the femur and the tibia, according to the method described by Shi et al [18].

On post-operative day 3, patients underwent a scan of the knee in a supine position using a dual-source CT scanner (slice thickness 0.75 mm; voltage 120 kV; effective mAs 140; SOMATOM Definition Flash; Siemens AG, Munich, Germany) with multi-planar reconstruction performed on a Siemens multimodality workstation. A radiologist (MKD) and radiographer (MAS) identified the required landmarks and generated lines through the corresponding points on the CT images. The resultant images were then analyzed using ImageJ (National Institutes of Health, Bethesda, MD; available from http://rsb.info.nih.gov/ij).

The measurement and analysis of the CT images followed the method described by Chauhan et al [19]. A 3-dimensional CT reconstruction of the proximal tibia was used to confirm the position of the tibial tuberosity (Fig. 6). Tibial rotation was defined as follows. A line was drawn anteriorly from the tibial tuberosity. The medial third was selected to represent the middle of the tibia. This point was connected to the center of the knee, represented by the center of the tibial post. This line defined the axis of the tibia. The angle made between this axis and the perpendicular to a line joining the most posterior points of the tibial flange defined the rotation of the tibial component (Fig. 6).

The surgical TEA was defined by a line from the most prominent point of the lateral femoral epicondyle to the sulcus of the medial epicondyle (Fig. 7). The angle between the anterior flange of the femoral component and the TEA defined the femoral component rotation. Relative rotation of the femoral component to the tibial component (femoro-tibial mismatch) in extension was defined as the angle formed between the pegs of the femoral component and the posterior points of the tibial component.

Results

The surgical technique described above was performed on a consecutive series of TKA patients. There was minimal disruption to the standard navigation workflow associated with the changes incorporated to achieve the surgeon-preferred tibia-first surgical technique. Of note, no soft tissue releases other than for exposure of articular surfaces were required for any procedures. Patellar tracking was rated as excellent in 16 knees, good in 13 knees, and fair in 1 knee using the no thumb technique. There was no patellar dislocation. No lateral release was required for patellar tracking. At a minimum of 2 years of follow-up, there were no deep infections, pin sites complications including fractures, patellar maltracking, loosening, instability, deep vein thrombosis, and medical complications.

Navigation data were collected on pre-operative and post-operative limb alignment. Prosthetic component and joint line orientation were also assessed post-operatively.

Figure 5. Sample of long-leg standing radiographic image of the patient with bilateral TKA. Landmarks and axes were defined according to the method of Shi et al [18].

Initial coronal and sagittal (pre-operative) limb alignments measured during the navigation registration process were 7.8° varus (mean; standard deviation [SD] 4.7°) and 7.2° flexion (mean; SD 8.9°), respectively (Table 1).

Coronal and sagittal alignments of the definitive prosthetic components measured using navigation after implantation were 0.0° varus/valgus (mean; SD 1.0°) and 1.6° hyperextension (mean; SD 1.4°), respectively (Table 1). All coronal alignment values were within ±3° of neutral alignment. This surgeon has a preference for leaving the final knee alignment in slight extension, as the majority of knees encountered in his practice typically have a pre-operative flexion contracture and achieving post-operative extension is more challenging than obtaining flexion during rehabilitation. Measurement of final femoral cutting jig position relative to Whiteside line and TEA axis using intraoperative navigation mean of was 4.1° varus and 16.8° varus, respectively (Table 1). These figures were recorded for study purposes only and were never used in the surgical procedure.

Assessment of post-operative limb alignment from long-leg standing radiographs showed that, in the coronal plane, orientation of the femoral component relative to the femoral mechanical axis was 0.6° valgus (mean; SD 1.6°).The orientation of the tibial component relative to the tibial mechanical axis was 0.4° valgus (mean; SD 1.3°). The post-operative hip-knee-ankle axis limb alignment was 0.9° valgus (mean; SD 1.7°). Of these, 90% were within ±3° of neutral alignment. Alignment of the joint line relative to horizontal was 0.1° varus (SD 1.5°) (Table 1).

Assessment of prosthetic component orientation using the post-operative CT scan showed a mean femoral component rotation of 0.5° internally rotated (SD 2.6°). Mean tibial component rotation was 0.9° externally rotated (SD 5.5°). Femoro-tibial mismatch had a mean value of 3.0° (SD 5.4°) (Table 1).

Discussion

Many different surgical techniques for performing TKA have been developed over time, influenced by a range of factors such as implant design, available instrumentation, an individual surgeon's preferences, and a balance between competing priorities such as alignment, soft tissue balance, minimal bone resection, and so on. Early navigation systems provided limited options in terms of available workflows, in contrast to the multitude of options available to surgeons today [20]. The aim of this study is to implement a surgeon-preferred workflow in which the proximal tibial resection was performed first and this plane then used to set femoral rotation. This was able to be achieved with a minimum of disruption to the standard navigation workflow.

One of the underlying philosophies of the tibia-first technique is that it respected the integrity of soft tissues. It is a common observation that soft tissue release is significantly reduced using computer navigation [21,22]. Goudie and Deep reported that in 224 cases of navigated TKR only 2.2% needed soft tissue release. The pre-operative deformity ranges from 27° valgus to 25° varus. They opined that the deformity in arthritic knees is the result of a combination of bone dysplasia, erosion of the articulating surfaces, osteophytes, and capsular and collateral ligamentous adhesions. The authors believe that when these factors are taken care of, to a large extent by the TKA surgery with bone cuts in the correct orientation and osteophytes removal, there is no need for release of the ligaments in many cases. This has also been my experience using computer-assisted TKR and the results are reflected in this study where the desired surgical outcome was able to be achieved without the need for releases of the soft tissue structures surrounding the joint. The ability of the navigation system to accommodate this new method is a testament to how currently available systems have changed from their earlier versions.

Post-operative coronal alignment measured using both navigation and long-leg standing radiographs showed excellent results, with 100% and 90% of limbs having values within ±3°, respectively; the range usually considered a benchmark in previous studies. This confirmed that the modified surgical technique described herein did not compromise the fundamental outcome for TKA.

Previous research has identified limitations with both manual and computer-assisted surgical techniques to provide greater consistency and accuracy of femoral and tibial component rotation [6,10,23]. We report a range of approximately ±5° internal-external femoral component rotation and ±10° internal-external tibial component rotation. In contrast to the work reported by Siston et al [6], we found that 28 of 30 (93.3%) knees in this study had femoral component rotations of ±5°, compared with 17% with ±5° averaged across 5 different techniques. This indicates that this new technique was able to achieve greater consistency in setting the femoral component rotation. This may be a result of the fact that no soft tissue releases were performed and may be an inherent characteristic of this tibia-first approach. For the tibial component, there appeared to be no additional benefit resulting from this new technique, based on the fact that the floating technique to set

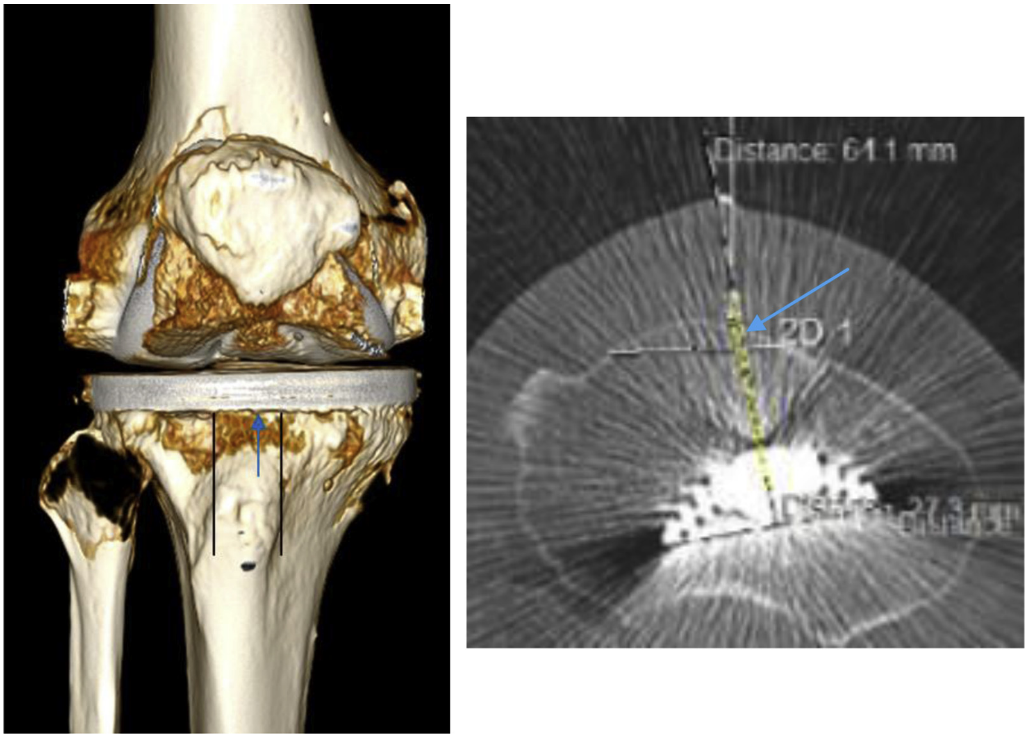

Figure 6. Sample of 3-dimensional CT scan reconstruction to confirm location of tibial tuberosity and center of tibia (blue arrow).

rotation was not influenced by the use of navigation. Nevertheless, we were able to attain excellent and good patellar tracking in 29 of 30 knees (96.7%) and this may be attributed to the optimum rotational orientation of the components we were able to achieve using this technique.

Analysis of the CT scans confirmed that the surgical technique did, in fact, result in accurate and consistent placement of the femoral component rotation (mean = 0.5° internal rotation; SD 2.6°). Tibial component rotation was less consistent (mean = 0.9° external rotation; SD 5.5°), but was an improvement on results reported in previous studies.

Femoro-tibial rotation was assessed using CT with the patient in a supine, unloaded state. In such a position, congruency of the femoral component and the tibial insert and the specifics of the prosthesis design can influence how these components are positioned relative to each other. The Scorpio Non-Restrictive Geometry design is designed to allow greater rotational flexibility by incorporating a spherical tibial insert geometry and a rounded post [24]. Although this was primarily intended to allow relatively unrestricted rotation during deep flexion, it would also allow rotation of the femoral component to the tibial component during extension. Tamaki et al [24] recorded a range of −8° to 18° in 0° flexion, similar to the range recorded in this study. Implants with more constrained geometries may not demonstrate similar behavior.

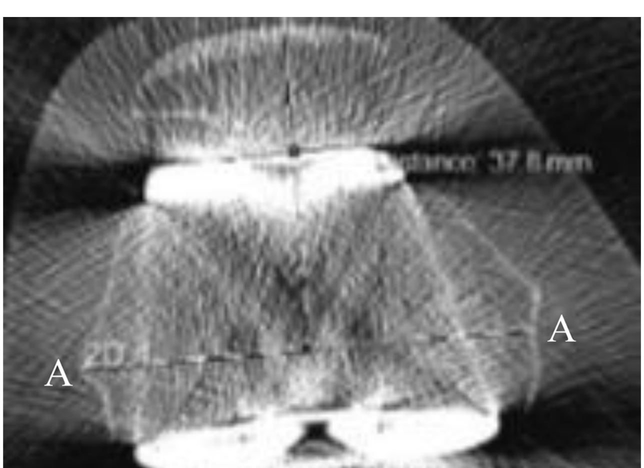

Figure 7. Measurement of femoral rotation with CT scan. A-A indicates surgical TEA.

A number of methods were used to assess lower limb alignment in this study. Each of these methods has inherent sources of errors and confounding variables, making direct comparison difficult [25-27]. The results obtained using post-operative radiographs showed that overall limb alignment was excellent with this new surgical technique. By incorporating a range of methods into the study design, a more comprehensive analysis could be undertaken, minimizing any major discrepancies between the different methods. A comparison of limb alignment assessed by intra-operative navigation and post-operative long-leg alignment proved to be useful. Overall, post-operative alignment in the coronal plane assessed using navigation was found to be close to that assessed using post-operative radiograph: mean 0.0° neutral versus mean 0.9° valgus, respectively. This favorable comparison confirmed that this navigation tibia-first technique did not compromise coronal alignment. It also confirmed that the final navigation measurement is an accurate assessment of coronal alignment when compared to post-operative standing radiograph. The accuracy of the computer in the coronal plane is well established in the literature.

Navigation relies on the use of reference axes to guide orientation of the femoral and tibial components. Whiteside's line is a commonly used axis. A comparison was made between Whiteside's line and the TEA measurements during navigation with femoral rotation determined using CT. The resulting mean values of 4.1° internal rotation (Whiteside's line) and 16.8° internal rotation (TEA) compared with 0.5° internal rotation (CT scan) showed that registration of Whiteside's line with navigation was superior to the

TEA as a predictor of post-operative component orientation. However, the femoral rotation obtained using the navigated Whiteside's line and TEA were inferior compared to the femoral rotation achieved using the tibia-first technique. In this study, we were able to successfully take advantage of the accuracy of the computer in coronal and sagittal alignment to bypass the inaccuracy of rotational alignment.

In addition, this study was able to confirm the validity of the tibia-first technique in TKR. Even though this long-established technique was used in gap balancing, the results of this study were able to confirm its ability to set proper femoral rotation.

There were a number of limitations associated with this study. The study was limited to a single surgeon at a single center. Although the patient series was relatively small, it was of benefit in quantifying the surgical outcome of this new technique. Assessments were limited to limb and implant orientation and no functional outcomes were included.

Conclusions

In summary, a new navigated TKA technique was developed that allowed femoral component internal/external rotation to be set using the proximal tibial resection plane and respected the action of the soft tissues. Surgical outcomes were assessed in a patient cohort and confirmed that satisfactory sagittal limb alignment was achieved. Femoral component rotation was found to be within a relatively tight range, demonstrating an improvement over previously reported methods.

Acknowledgments

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