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Determining Femoral Component Position Using CAS and Measured Resection

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Abstract To evaluate the ability of computer-assisted surgery (CAS) to accurately size and determine rotational alignment of the femoral component in TKA, the author reviewed femoral component position after 50 consecutive primary TKAs using a femur-first, measured resection workflow. The computer software used allowed femoral rotation to be selected based on epicondylar axis, posterior condylar axis, or anteroposterior axis. The final femoral component size and position was determined by the surgeon to avoid anterior notching, match the posterior-medial condyle resection, and flexed to match the plane of the anterior femoral cortex. Femoral sizing was confirmed intraoperatively with a standard sizing guide. The femoral component was downsized in 52% of patients from the size recommended by the computer software. The posterior condylar axis matched the implanted rotational position of the femoral component to within 1° in 64% of patients in contrast to the epicondylar axis (32%) and anteroposterior axis (26%). CAS provides information to make surgical decisions but does not replace clinical judgment. Landmark referencing may be compromised by limited surgical exposures leading to variation in implant positioning by computer software. A clear understanding of the principles of TKA is critical when using CAS to optimize implant sizing and position.

The author certifies that he has no commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.
The author certifies that his institution has approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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Introduction

The use of computer-assisted surgery (CAS) in TKA has increased in the past decade. Clinical studies have documented the use of CAS can improve coronal alignment when compared with traditional surgical guides [9, 11, 12, 18, 23]. Although alignment is reportedly an important factor in implant survival no long-term studies confirm improved clinical outcomes with CAS [13, 14, 22, 27, 34].

Despite the fact that coronal alignment can be reliably reproduced with the use of CAS, there has been little documentation of its accuracy in determining implant sizing and rotation [7, 8, 23, 24, 26, 28, 38]. The software that guides implant sizing and placement is usually proprietary; the anatomic landmarks used to determine component alignment are universal. Intuitively one would assume the use of CAS would provide a greater level of accuracy and precision despite the fact that the identification of anatomic landmarks and instruments used to prepare the bone cuts are identical to those used in traditional TKA. To date, there has been little evidence to support this assumption. The author began using CAS in 2004 and soon realized the surgical planning information provided by the software was being manipulated intraoperatively to achieve the desired postoperative result.

The first objective was, then, to determine how the CAS-generated surgical plan, using anatomic referencing, correlated with the actual size of the femoral component implanted and, second, to determine the final rotational position of the femoral component.

Materials and Methods

I retrospectively reviewed implant data from 50 consecutive patients undergoing unilateral primary TKAs implanted using an imageless CAS system (BrainLAB, Munich, Germany) with specific attention to the femoral sizing and femoral component rotation. The study consisted of 29 female and 21 male patients, all with the primary diagnosis of osteoarthritis. The mean age was 69 years (range, 45–83 years).

The mechanical axis of the limb was determined at the time of surgery using the CAS system. The mean preoperative alignment for all 50 patients was 4.7° of varus (12° varus to 7.5° valgus). Six of the 50 patients (12%) had a preoperative valgus deformity (1.9°–7.5°). To evaluate extensor mechanism alignment, pre- and postoperative Merchant's radiographs were obtained on all patients. The patella tilt angle was measured, at both intervals, using the technique described by Gomes et al. [15, 16].

All procedures were performed through a minimidvastus approach using the same fixed-bearing cruciate-retaining implant (PFC Sigma CR; DePuy, Warsaw, IN). The patella was subluxated and not everted, and all patellae were resurfaced. Reference arrays were secured, through the main incision, by dual-threaded pin fixation in the metaphysis of the distal femur and proximal tibia. Registration of anatomic landmarks was performed before any bone resections using a navigation pointer to outline the distal-most and posterior points on both femoral condyles. These landmarks were used to determine the posterior condylar axis. The anteroposterior axis was determined by a line connecting the lowest point of the trochlear sulcus to the apex of the intracondylar notch. The femoral epicondyles were palpated and their location marked with a pointer. The exit point for the anterior bone cut was registered on the anterior cortex of the femur just proximal to the lateral trochlear ridge. This point, in addition to the posterior condyles of the femur, was used by the software to determine femoral sizing. In addition to the exit point anteriorly, the anterior cortex of the femur was registered in its midsagittal axis.

A femur-first, measured resection workflow was used in all patients. The computer software allowed femoral rotation to be selected based on the posterior condylar axis, the epicondylar axis, or the anteroposterior axis, all of which were identified during registration. In knees referenced to the posterior condylar axis, the software would externally rotate the femoral component position 3° from the plane of the posterior condyles. If the epicondylar axis was chosen, the femoral component was oriented parallel to the line generated by the epicondyles. In cases using the anteroposterior axis for femoral rotation, the software would generate a perpendicular line to the anteroposterior axis (Whiteside's line) that was used to orient the rotation of the femoral component.

When the locations of the epicondyles could be easily identified during referencing, the epicondylar axis for the rotational alignment of the femur was preferentially selected. In varus knees when the epicondyles could not be definitively identified as a result of anatomic variation or excessive soft tissue, the posterior condylar axis was selected. In the 44 varus knees, posterior condylar referencing was selected in 27 and the epicondylar axis in 17. In the six valgus knees, the posterior condylar axis was selected in two, the epicondylar axis in three, and the anteroposterior axis in a single case. Based on the landmarks identified, and the surgeon's selected preference for femoral component rotation, the system software generated a planning proposal for the size and orientation of the femoral component. The software allows the surgeon to change implant size and position before initiating bone resection. The ultimate femoral component size and position was determined by the surgeon to align the anterior flange of the femoral component with the anterior cortex of the femur and match the posterior medial condyle. In cases in which the femur was downsized, it would be flexed up to 2° to avoid anterior femoral notching. In all cases, the femoral component was externally rotated from the posterior condylar axis. If, in a varus knee, when the epicondylar axis was chosen for rotational alignment, there was a large discrepancy between the epicondylar and posterior condylar axis (greater than 3°); the femur was rotated to a compromise between the two. Femoral component sizing was confirmed intraoperatively with a standard sizing guide after the distal femur resection and before anterior posterior bone cuts were made. Anterior femoral referencing for sizing was used by both the computer software and the standard sizing guide. If a component was downsized the AP resection block was shifted posterior to split the additional resection equally between the anterior and posterior femur.

Screenshots taken during surgery were saved to a flash drive and reviewed to determine what anatomic landmarks were chosen for femoral orientation. I compared the original size and rotation of the femoral component selected by the software with the final size and position selected for femoral implantation.

Results

In 26 patients (52%), the femoral component was downsized from the size recommended by the software. In 25 patients, the femoral size was reduced by one size and in a single patient, two sizes. Downsizing of the implant routinely required a change in the anteroposterior position to avoid notching anteriorly and/or overresection of the posterior condyles. The position selected was a compromise between the anterior and posterior resections. The final implant position was translated posteriorly from the position determined by the software a mean of 1.7 mm (range, 2 mm anterior to 6.5 mm posterior).

In 17 patients (34%), the rotational alignment of the femoral component was adjusted from the computer-modeled position. Fourteen patients had a more internally rotated component from the recommended position and in three patients (6%) the femoral component was more externally rotated (5° internally rotated to 2.5° externally rotated). When the epicondylar axis was chosen for femoral orientation, 13 of 20 patients (65%) were rotated to a different position. Twelve of the 13 patients underwent internal rotation (1°–5°) and in a single patient, the femoral component was externally rotated 1.5° to its implanted position. In contrast, when posterior condylar referencing was chosen, only four patients (14%) underwent a change in rotational orientation. Two patients were internally rotated and two externally rotated. In the single patient, in whom the anteroposterior axis was selected for orientation, the femoral component did not undergo any rotational position change before implantation (Table 1). Of the three valgus knees in which epicondylar referencing was used, two femoral components were rotated before implantation (5° internal rotation and 1.5° external rotation). Posterior condylar referencing was selected in two valgus knees and one knee was rotated 2.8° externally. A single knee was referenced to the anteroposterior axis and was not rotated from the position determined by the software using this reference.

The registered posterior condylar axis, with 3° of external rotation, matched the implanted position in 26 of the 50 cases (52%) and was within 1° of the final implanted position in 62% of cases. The registered epicondylar axis was less accurate, matching the implanted femoral position only 12% of the time and falling within 1° 32% of the time. The registered anteroposterior axis matched the implanted position in 6% of patients and was within 1° in 26% of patients (Table 2).

The mean preoperative patellar tilt was 6.1° (range, 0°–15°) and decreased postoperatively to an average of 2.3° (range, −5°–11°). There were no lateral releases performed and there were no complications related to patellar tracking or the patellofemoral joint.

Table 1. Axis selected for femoral rotation and change before implantation

Axis selected for femoral rotation	No change in rotation	Change in rotation	Rotated internally	Rotated externally
Posterior condylar	25	4	2	2
Epicondylar	7	13	12	1
Anteroposterior	1	—	—	—
Total	33 (66%)	17 (34%)	14	3

Table 2. Femoral component position relative to referenced anatomic landmark

Rotational orientation	Postcondylar axis	Epicondylar axis	Anteroposterior axis
Matched implanted femoral position	26 (52%)	6 (12%)	3 (6%)
± 1°	32 (64%)	16 (32%)	13 (26%)
Range (standard deviation)	6° ER–3° IR (1.5°)	8° ER–7.1° IR (2.9°)	7.5° ER–10° IR (3.9°)

ER = external rotation; IR = internal rotation.

Discussion

The purpose of this study was to review how the surgical plan developed by a CAS system using anatomic referencing was actually implemented intraoperatively to determine femoral component size and position.

The study has several shortcomings. Although the number of patients was small, the author believes the group is representative of patients presenting for TKA. The conclusions are based on the use of proprietary software using a measured resection technique and they may not be applicable to other software systems and surgical workflows. However, because most all clinically available CAS systems use the same anatomic landmarks to determine alignment and implant size, the findings may still be applicable across other surgical systems. The author's bias with the use of posterior condylar and epicondylar referencing may have affected the accuracy of registration. Registration may have also been compromised by the use of a limited incision. There was no postoperative computed tomography confirmation of femoral position, but it could be argued that all anatomic landmarks may be arbitrary reference points that are not applicable in every patient. Although the surgical technique for determining the rotational position of the femur may appear somewhat arbitrary, the technique did not result in flexion instability or patellar complications, as evidenced by the lack of lateral releases and improvement in patellar tilt, that have been attributable to femoral component missizing or malpositioning [1, 6, 25, 32].

During TKA, the change in orientation of the tibial articular surface, as a result of a perpendicular tibial resection, requires a change in the femoral articular orientation in flexion as well as extension. Proper rotation of the femoral component is not only critical for flexion stability and kinematics, but it also plays a major role in patellar tracking [1, 6, 29, 32, 33]. The classic technique developed by Insall to determine femoral rotation uses flexion gap balancing combined with ligament releases [21, 37]. Because of the known relationship between the orientation of the posterior femoral condyles and the desired position of the femoral component, many believe it is reasonable to determine the femoral component rotation using the posterior condyles for orientation [5, 17, 19, 20, 30]. This technique is suitable for many knees, especially those with varus deformities, but may not be appropriate for knees with valgus deformities [39]. In these patients, the lateral femoral condyle commonly has substantial hypoplasia that makes the posterior condylar axis unsuitable for referencing. Other anatomic references have been identified to determine appropriate rotational alignment of the femoral component, including the epicondylar axis and the anteroposterior axis [2–4, 6, 10, 30, 31, 36, 39].

When using anatomic referencing to determine femoral component rotation, most CAS systems base the femoral position on anatomic landmarks that are registered by the surgeon before initiation of any bony cuts. Some landmarks (anterior femoral cortex, center of femur, and condylar topography) are more reliably and reproducibly identified. Others, like the femoral epicondyles and anteroposterior axis, can be more subjective and are potential sources of introducing error into the data used by the computer software to plan implant positioning. Referencing the epicondylar axis can be compromised if soft tissue contractures or limited surgical exposure impair the ability to localize the position of the condyles. Determining the anteroposterior axis can be difficult in patients in whom the trochlear anatomy is distorted by severe patellofemoral arthritis.

Although the use of CAS has been documented to result in improved alignment in the coronal plane [9, 11, 12, 18, 23], the ability to accurately determine femoral component rotation with CAS using anatomic landmarks has been less encouraging. Siston et al. [35], in a cadaver study using an imageless CAS system, evaluated the use of posterior condylar axis, anteroposterior axis, and epicondyles to determine femoral component rotation. They demonstrated only 17% of the actual registered landmarks fell within 5° of the true epicondylar axis. All 11 of the surgeons participating in the study registered landmarks that tended to overly externally rotate the femoral component relative to the true epicondylar axis. Chauhan et al., in a cadaver study and a followup clinical evaluation, demonstrated excessive external rotation of the femoral component relative to the epicondylar axis identified by computed tomographic scanning [7, 8]. Stockl et al. [38] compared a series of TKAs performed with standard instrumentation versus CAS and evaluated the femoral component position relative to the epicondylar axis using postoperative computed tomography scans. Both groups demonstrated relatively large variations in femoral component rotation (14° standard versus 11° CAS). Kim et al. [26] performed a study of 100 patients undergoing bilateral TKA in whom one knee was operated on with CAS and the other with standard instrumentation. Both techniques used posterior condylar referencing and a femur-first resection technique. Postoperative computed tomography scans were obtained to determine component orientation relative to the true epicondylar axis. Femoral rotation exceeded 3° of deviation from the epicondylar axis in 29% of the CAS knees and only 15% of those performed with standard instrumentation [26]. Other studies have demonstrated a similar lack of accuracy and reproducibility using CAS and anatomic referencing.

In this study, the posterior condylar axis most frequently corresponded to the rotational alignment of the implanted femoral component, falling within ± 1° in 62% of patients. In contrast, the registered epicondylar axis was only accurate to within 1° 34% of the time, whereas the registered anteroposterior axis was accurate only 26% of the time. Most of the patients, 44 of 50 (88%), had preoperative varus deformities and as a result, it is difficult to reach any definitive conclusions regarding anatomic referencing with CAS in knees with valgus deformities. The use of the referenced epicondylar axis resulted in positioning the femoral component in excessive external rotation. Twelve of 20 knees using epicondylar referencing were rotated internally from the position determined by the planning software before initiation of bone cuts. The tendency for CAS systems to externally rotate the femoral component when epicondylar referencing is used has been documented in previous studies using a variety of systems [7, 8, 35, 38].

The femoral component was downsized from the computer modeling in 52% of patients. The implications of oversizing the femoral component on soft tissue balancing and flexion kinematics are important and would have created problems if the software-determined surgical planning was executed [13].

Despite the fact that CAS has the potential to provide the surgeon with a wealth of intraoperative information that can be used to guide implant placement, it does have its limitations. In all existing imageless CAS systems, the anatomic information used by the software to determine implant alignment and sizing is provided by the surgeon. Although CAS software programs may use anatomic referencing points that are familiar to most knee surgeons, care should be taken in assuming the information is implemented in the same manner that the surgeon is familiar with. The location of many of the anatomic points referenced can be subjective, and the surgeon must be willing to critically evaluate the surgical plan intraoperatively with regard to implant size and position.

Rote application of the surgical planning provided by the CAS software would have resulted, in this series, in errors in implant sizing and alignment.

It is important to remember when embracing this technology that it is computer "assisted" surgery and not computer directed surgery. Like with any surgical instrument, repetitive use and familiarity allow for more effective deployment. Computer-assisted surgery provides information that can be used to make surgical decisions but does not take the place of clinical judgment. The surgeon should recognize landmark referencing may be compromised by limited surgical exposures leading to variation in implant positioning by computer software. A clear understanding of the principles of TKA is critical when using CAS to optimize implant sizing and position.

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