Joint Implant Surgery & Research Foundation
Chagrin Falls, Ohio, USA

Rotational Alignment of the Femoral Component in Computer-Assisted Total Knee Arthroplasty

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Abstract:

This study compared two Computer Assisted Surgery (CAS) methods in 212 total knee arthroplasties to evaluate the differences between anatomic landmark axes in determining rotational position of the femoral component. Overall, there were large variations between CAS defined component orientation using an optimized gap-balancing technique and component orientation using anatomic reference axes (range, 16º internal rotation to 16º external rotation). If based on anatomic landmarks, these large variations would have led to asymmetrical flexion gaps in up to 60% of the knees studied. Of the anatomic axes studied, the posterior condylar axis was the only axis not significantly different from CAS optimized orientation. If anatomic landmarks are used for femoral component rotation with either a conventional or a CAS technique, asymmetric trapezoidal flexion gaps may result.

Key Words: *total knee arthroplasty, balancing, component rotation, Computer Assisted Surgery*

Introduction:

Total knee replacement surgery remains an excellent procedure for relief of pain, correction of deformities, and restoration of impaired function due to arthritis. Patients who have undergone total knee arthroplasty (TKA) are experiencing up to two decades of clinical success, with implant survivorship of certain designs topping 90% at 10 to 15 years.[1,2,3,4] Despite the good results, technical difficulties persist, such as the ability to achieve consistent alignment of the components.[5] This is particularly true of femoral component rotation, a variable which can markedly affect surgical outcome and is crucial to ensuring soft tissue balance of the knee in flexion. Inaccurate rotational position of the femoral component can lead to asymmetrical flexion gaps, anterior knee pain, undesirable changes in knee stability, patellar tracking, and patellofemoral contact points.[6,7] Despite its importance, rotational errors of at least three degrees have been reported in up to 45% of cases dependent upon the method for establishing component rotation.[8]

Computer-assisted surgery (CAS) has sought to improve the reliability with which components are implanted during TKA. Indeed, several CAS studies have demonstrated the ability to improve overall mechanical alignment accuracy and precision.[9,10,11] However, an increase in reliability of femoral component position, even with computer navigation, may depend upon the philosophy on which the navigation system operates. Most CAS systems balance the knee to the mechanical axis

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but use an anatomic landmark philosophy for determining rotation of the femoral component. With this philosophy, the anterior and posterior femoral resections are based off one of several anatomic reference axes (e.g., the transepicondylar axis, the anteroposterior axis (Whiteside's line) or the posterior condylar axis). The problem, however, is difficulty in consistently determining these reference landmarks due in part to variations in patient anatomy and bone distortion due to osteoarthritic changes[8,12,13] Although the aim is to have symmetric flexion and extension gaps throughout range of motion, use of anatomic reference axes can result in asymmetric flexion gaps and a poorly balanced knee. CAS with Optimized Work Flow (DePuy, a Johnson & Johnson Company, Warsaw, IN), however, is based on a gap-balancing philosophy. Rotation of the femoral component is determined after balancing the knee to the mechanical axis in extension, then rotating the femoral component so that the ligaments are also balanced at 90 degrees of flexion. The Optimized Work Flow also directs the anterior-posterior position of the femoral component to determine flexion gap width. This process results in extension and flexion gaps which are symmetric and rectangular and balanced throughout the knee's range of motion.

In the current study, CAS was performed using Optimized Work Flow with the computer determining rotation of the femoral component based on extension balancing. Femoral anatomic landmarks were also collected using the computer navigation system; however, these landmarks were not used to determine component rotation but were recorded for reference purposes only. Anatomic landmark axes were then compared to CAS optimized femoral component orientation to evaluate the difference among these landmarks in determining femoral rotational position. We hypothesized that there would be a large variation between the anatomic reference axes and the CAS Optimized Work Flow defined component orientation, indicating that a substantial portion of knees, if oriented, with respect, to a patient's anatomical structures, would not be balanced.

Materials and Methods

This study included all patients operated on by one of two CAS-experienced orthopaedic surgeons (D.P. and M.C.) on whom primary total knee arthroplasty was completed using the DePuy Ci navigation system (DePuy) with an Optimized Work Flow. Two hundred twelve knees, all implanted with PFC Sigma components (DePuy), were included in this study. Data for this study was obtained directly from the CAS system as was acquired during surgery. No patient identifiers or demographic data were obtained so as to protect patient information and to stay within the bounds of the hospital IRB's approval guidelines for this study.

Each TKA was performed using an Optimized Work Flow included several steps. In the first step, the proximal tibia cut was performed and verified. Using a dynamic tensioning device (Fig. 1), the knee was then balanced in full extension to the mechanical axis and the extension gap stored by the computer.

Fig. 1

Dynamic tensioning device used during ligament balancing in CAS optimized workflow.

With the tensioning device still in place, and the patella in an anatomic position, the knee was flexed to 90º and the flexion gap information (symmetry and width) is stored. The computer then optimized the femoral component position. This comprises femoral component size, distal femoral cut which determines the extension gap and the posterior femoral cut and rotation which determines the flexion gap. This results in a balanced extension/flexion gap. This plan was created prior to making any bone resections of the femur. The surgeons have the ability to modify the femoral component position and size to create the optimal position with maximal posterior condylar offset and the least bone resection

The tensioning device independently tensions the medial and lateral compartments with independent springs which are not linked by a central pivot. The distraction force is 23kg/N using the navigation system, the surgeons registered the location of femoral anatomic landmarks which the computer used to determine anatomic axes. The anatomic landmark axes were used for reference and comparison purposes and were not used to determine component rotation. These reference axes included 1) the transepicondylar axis, defined by the prominences of the medial and lateral epicondyles; 2) Whiteside's line, a line perpendicular to the anteroposterior axis, defined by the trochlear groove and the apex of the condylar notch; 14 and 3) the posterior condylar axis as defined by the posterior-most margins of the posterior femoral condyles. This was obtained by collecting multiple data points over the posterior femoral condyle.

Statistical analyses were performed using SPSS software (SPSS Version 8.0, SPSS Incorporated, Chicago, IL). Because the data were normally distributed, parametric statistics were employed. A one-sample T-test was used to determine whether mean orientation for the anatomic axes were significantly different from zero, indicating an overall mean discrepancy between the reference axis and CAS optimized femoral component orientation. Person's correlation was used to assess relationships among the three anatomic reference axes. Probability values less than 0.05 were considered indicative of statistical significance.

Results

Overall, there were large variations in anatomic reference axes. Relative to femoral component orientation determined by CAS optimized technique to provide balanced and rectangular flexion and extension gaps (that is, position 0; Fig. 2), the transepicondylar axis varied between 12.6° internally rotated to 14.7° externally rotated.

The mean value of the transepicondylar axis was 0.9° ± 5.4° externally rotated. This average was significantly different from 0 ($p=0.02$, one sample T-test), indicating that there was a significant discrepancy between the mean orientation of the transepicondylar axis and the component orientation determined by CAS optimized technique. In 58.5% of the knees, the transepicondylar axis was not within ± 3° of the optimized CAS orientation.

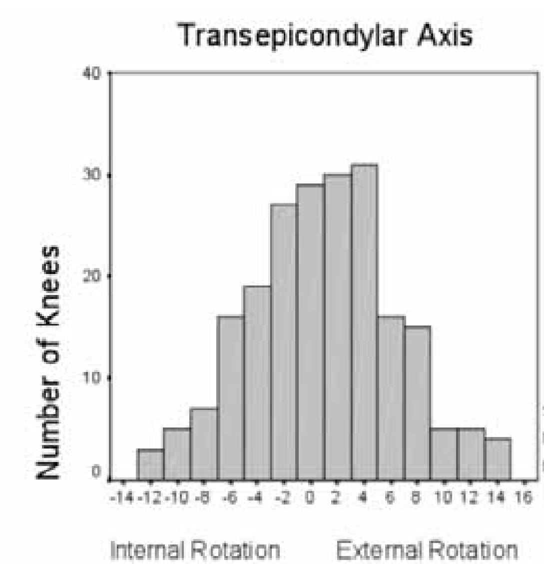

Fig 2: The orientation of the transepicondylar axis with respect to femoral component orientation determined by CAS optimized technique. Negative values denote internal rotation and positive values denote external rotation.

Relative to the femoral component position determined by the CAS Optimized Work Flow, Whiteside's line varied between 13.5° internally rotated to 16.3° externally rotated with a mean orientation of 1.9° ± 5.2° external rotation (Fig. 3).

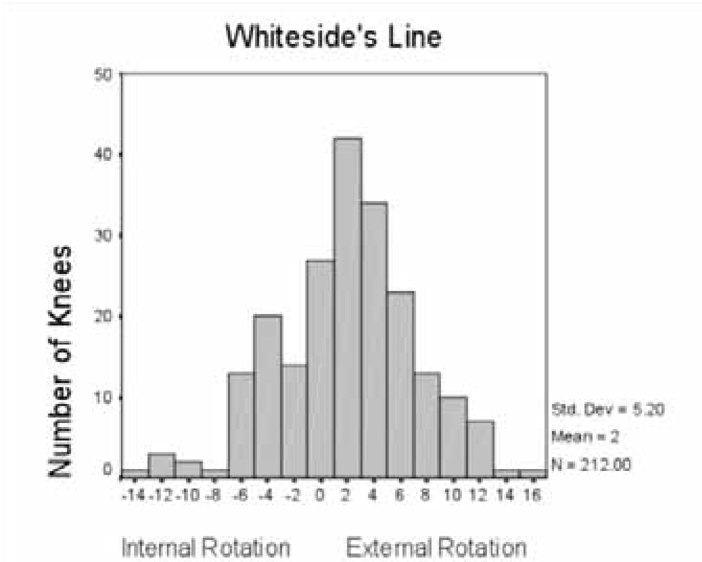

Fig 3: The orientation of Whiteside's line with respect to femoral component orientation determined by CAS optimized technique. Negative values denote internal rotation and positive values denote external rotation.

Again, this average was significantly different from 0 ($p<0.01$, one sample T-test), indicating a significant discrepancy between Whiteside's line and component orientation determined by CAS. In 60.4% of these knees, orientation was not within ± 3° of optimized CAS orientation.

The posterior condylar axis ranged from 15.6° internal to 11.4° external rotation (mean, 0.4° ± 4.3° internally rotated) as compared to the CAS optimized orientation with 48.1% of the knees falling outside ± 3° of the optimized orientation (Fig. 4).

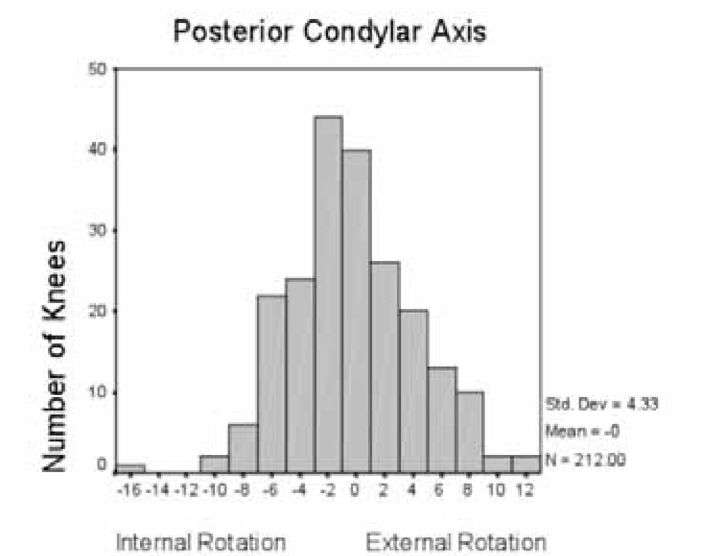

Fig 4: The orientation of the posterior condylar axis with respect to femoral component orientation determined by CAS optimized technique. Negative values denote internal rotation and positive values denote external rotation.

Unlike the other two axes, there was no significant difference between the posterior condylar axis and femoral orientation determined by CAS optimized technique ($p=0.23$, one sample T-test).

Although the three anatomic reference axes were all significantly correlated with one another ($p<0.001$ for all correlations; Person's correlation), there was a fair amount of variability between datasets ($r2 < 0.40$ for all correlations). As an example, Figure 5 demonstrates the variability between measurements of the transepicondylar axis and Whiteside's line. The maximum variation between the three anatomic references axes ranged from 0.5° to 19.9° with an average of 6.1°.

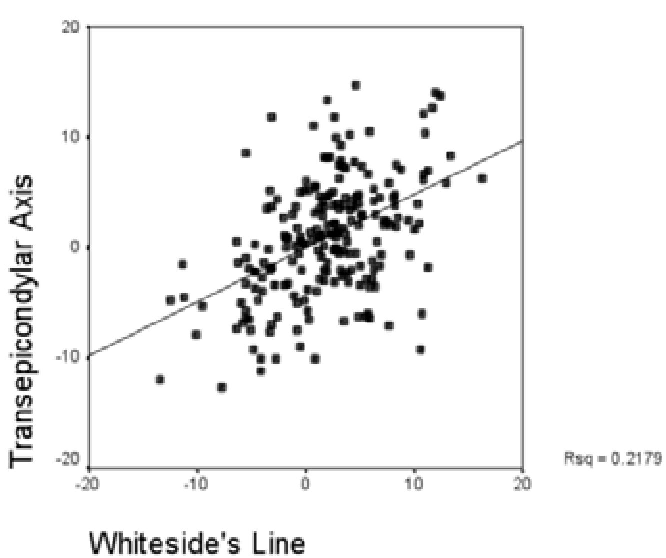

Fig 5: Although there was a significant correlation between anatomic axes ($p<0.01$), there was a fair amount of variation in the data as evidenced by correlation coefficients less than or equal to 0.40.

The data collected by each surgeon was compared to determine whether there was any difference between the two surgeons. There was no difference $p=0.55$.

Discussion

The method for determining femoral component rotation in TKA remains controversial, but is crucial to ensuring soft tissue balance while the knee is in flexion. Some advocate a measured resection technique based on anatomic landmarks, while others prefer a gap balancing technique with hopes of obtaining a symmetrical and rectangular flexion and extension gaps. Regardless of opinion, the goal is a well balanced knee, aligned to the mechanical axis that functions well throughout a full range of motion. In the past, anatomic landmarks have been used as a reference in setting femoral component orientation.[14,15] This method, however, has been linked to rotational errors in a substantial number of knees, resulting in trapezoidal rather than rectangular flexion gaps.[8,12,13] While Computer Assisted Surgery (CAS) has been shown to improve overall mechanical alignment accuracy and precision, CAS performed using anatomic landmarks as reference for femoral component rotation can lead to errors similar to conventional methods. As such, CAS may offer no advantages over conventional methods for determining femoral component rotation. This study sought to examine this question by comparing femoral component orientation determined by two CAS techniques.

Using CAS with an anatomic landmark philosophy, this study documented large variations in the orientation of anatomic reference axes. The axes varied from 16° internal rotation to 16° external rotation as compared to femoral orientation determined by CAS optimized gap-balancing technique. This was not entirely unexpected, as surgeons have been shown to be inaccurate in locating the anatomic landmarks recommended for femoral component rotation.[13,16,17] Kinzel and Ledger et al studied femoral component rotational alignment in 74 total knee arthroplasties in which the femoral epicondyles were marked intraoperatively by the surgeon and the femoral components subsequently positioned parallel to the transepicondylar axis.[17] Postoperatively, axial CT scans were performed to compare the surgeons' determination of the transepicondylar axis with the same axis as determined by the postoperative CT scan. Kinzel and Ledger et al found that in only 75% of the knees were the femoral components positioned within ± 3º of the true transepicondylar axis as determined by the CT scan.[17] The error was also large, varying from 6º external rotation to 11º of internal rotation, suggesting it is difficult to accurately identify this axis in a highly reproducible fashion.[17]

With the current study, computer navigation was used to calculate the orientation of the axes. However, the method still required the surgeon to register his perception of where the anatomic landmarks were located, opening the method to inter- and intra-observer error. Moreover, differences in patient anatomy and existing deformities could have also contributed to errors in determining landmark axes. For example, a varus knee deformity with medial posterior condylar loss can affect the accuracy of the posterior condylar axis. If not taken into account, this could lead to an externally rotated femoral component, medial flexion instability, and femoral component lift off. Conversely, using the posterior condylar axis to determine femoral component orientation in a valgus knee with a hypoplastic lateral femoral condyle could lead to an internally rotated femoral component, lateral flexion instability, femoral component lift-off, and poor patella tracking.

Despite the use of CAS, this study shows that if based on anatomic landmarks, the large variations in femoral component rotation would have led to asymmetrical flexion gaps in many of the knees studied. Whiteside's line and the transepicondylar axes were found to be significantly different from the orientation determined by CAS optimized workflow. This could reflect the fact that surgeons in the current study found Whiteside's line and the transepicondylar axes more difficult to accurately locate intraoperatively than expected, further increasing variability and decreasing potential accuracy. Of the three anatomic axes, the posterior condylar axis was the most reliable, the least variable, and the only axis not significantly different from CAS optimized orientation. Nevertheless, the orientation of the posterior condylar axis was not within ± 3º of the optimized CAS orientation in 48% of the knees, indicating that these knees likely would have asymmetrical flexion gaps. Moreover, this study demonstrates large variability among the three anatomic axes themselves, with the maximum variation among the axes ranging from 0.5º to 19.9º with an average of 6.1º.

We acknowledge one limitation of the current study is the fact that selection of anatomic references is highly surgeon dependent. Siston et al noted that establishing femoral rotational alignment via anatomic structures is influenced by an individual surgeon's skills and preferences and not by the different techniques used to establish this alignment.[16] We acknowledge it is possible that the amount of variation in landmark axes reported in this study could be less if assessed by other surgeons. However, surgeons in the current study were fellowship trained in joint reconstruction, maintain busy arthroplasty practices, and have extensive experience performing TKA utilizing computer assisted navigation. There was also no significant difference in the landmark axes collected between the two surgeons. As such, their variability in determining anatomic landmarks is at least likely to represent the typical joint replacement surgeon.

Ultimately, the significance of the study is demonstrating that there is a large variability in how surgeons determine anatomic landmarks, and the logical inference that computer referencing systems can only be as accurate as the data fed into the system.

In conclusion, this study shows a significant variation in femoral component rotation when comparing orientation defined by anatomic landmarks to orientation defined by a CAS balanced extension/flexion gap technique. If anatomic landmarks are used for femoral component rotation with either a conventional or a CAS technique, asymmetric trapezoidal flexion gaps may result.

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