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Chapter 4

Transepicondylar axis accuracy in computer assisted knee surgery. A comparison of the CT-based measured axis versus the CAS determined axis.

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■ Abstract

Rotational malalignment is recognized as one of the major reasons for knee pain after total knee arthroplasty. Although computer assisted orthopedic surgery systems (CAOS) have been developed to achieve more accurate and consistently aligned implants, it is still unknown if they significantly improve the accuracy of femoral rotational alignment as compared to conventional techniques.

We evaluated the accuracy of the intra-operatively determined transepicondylar axis with that from postoperative CT-based measurement in twenty navigated total knee arthroplasties (TKA). The intraoperatively determined axis during CAOS was marked with tantalum (RSA)-markers. Two observers measured the posterior condylar angle (PCA) on postoperative CT scans.

The PCA measured using the intraoperatively pointed axis showed an interobserver correlation of 0.93 between the two observers. The intraobserver correlation was slightly better than using the CT based angle, being 0.96. The PCA had a range of -6 (internal rotation) to 8 (external rotation) degrees with a mean of 3.6 degrees for observer 1 (SD 4.02) and 2.8 degrees for observer 2 (SD 3.42). The maximum difference between the two observers was 4 degrees. All knees had a patellar component inserted with good patellar tracking and no anterior knee pain. The mean postoperative flexion was 113 degrees (SD 12.9).

The mean difference between both epicondylar line angles was 3.1 degrees (SD 5.37 degrees), with the CT based PCA being bigger.
During CT-free navigation in TKA, a systematic error of 3 degrees was made in determining the transepicondylar axis. It is emphasized that the intraoperative epicondylar axis is different from the actual CT based epicondylar axis.

■ Introduction

The outcome of a total knee arthroplasty (TKA) depends on several factors, both patient and surgery related. It is known that the size of the components and especially their position and alignment are of great influence on the clinical outcome (1). Primary malalignment and inadequate positioning of in particular the femoral component may lead to an unsatisfactory outcome, including patella maltracking, anterior knee pain, flexion instability (2-4). Malalignment is a common indication for revision and can be the underlying reason for failure PE wear, loosening and instability (5). The revision rate because of malalignment may therefore be higher than already stated in literature.

External rotation of the femoral component of 3 to maximum of 5 degrees with respect to the posterior condylar line or 0 degree placement with respect to the transepicondylar line is thought best for optimal functionality (6). Using the conventional and bony reference point methods, rotation of the femoral component can be determined intra-operatively by the use of the transepicondylar line, the posterior condylar line and/or the Whiteside line (7;8).

Whilst many opinions are expressed in the literature as to which axes are the most reliable and/or show the least intra-/inter-observer variability, none seems to be superior (9).

Several studies have shown improvement in AP alignment using Computer Assisted Orthopaedic Surgery (CAOS) (10-12), but little is known about the attainment of better rotational alignment of the components when using CAOS (13-15).

Although these systems have been developed in an attempt to align implants more accurately and more consistently, it is unknown if navigation systems can improve the accuracy of femoral rotational alignment as compared to traditional techniques using mechanical guiding devices. Since postoperative knee prosthesis problems are related to rotational mal-alignment, CAOS systems should reduce these errors. We studied the accuracy of intraoperative axis determination by the surgeon. To this end the accuracy of the intra-operatively palpated and digitized TEA was compared to the postoperatively CT-based epicondylar axis in twenty navigated total knee arthroplasties (TKA).

■ Materials and Methods

Patients

Twenty navigated TKAs in 18 patients – 9 female and 9 male – were studied with a mean age of 69 years (range 46 – 85 years). Half of them had primary osteoarthritis; the others had secondary osteoarthritis due to rheumatoid arthritis. In all patients the NexGen Legacy Total Knee Prosthesis (Zimmer, Warsaw, IN, USA) was implanted with the use of cement, and in all cases the patella was resurfaced. All TKAs were performed by one single surgeon (HMJvdL). All patients participated in a prospective roentgenstereophotogrammetric (RSA) study on possible postoperative migration of the knee prostheses in CAOS TKA after informed consent, including marker insertion and postoperative CT scans. To this end tantalum (RSA) markers were inserted in the bone. Postoperatively a CT scan was made to measure component position.

Preoperatively the AP (anterior-posterior) leg alignment was measured on long-leg standing radiographs using the hip-knee-angle (HKA) and the femoral-tibial-angle (FTA). The mean preoperative HKA was 181 degrees (SD 4.1) with a range of 172 to 188 degrees; the mean FTA was 176 degrees (SD 7.2) with a range of 166 to 180. The mean extra time needed for navigation during the surgery was twenty minutes.

Computer Navigation

We used the Vector Vision CT free computer navigation system, software version 1.5.2 (BrainLAB, Feldkirchen, Germany). During surgery two infrared receivers are fixed on the leg; one on the femur and one on the tibia. Identification of the anatomical landmarks, bony surfaces and axes of the knee and leg was undertaken initially. A blunt pointer with an infrared receiver was used. The femoral localization points consisted of identifying the medial and lateral epicondyles (Figure 1), the anterior sulcus, the femoral mechanical axis and posterior condyles.

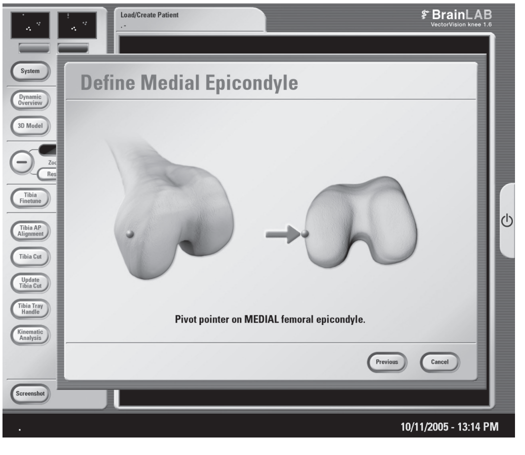

Figure 1. Screen of the navigation system during registration of the epicondyles of the femur.

Before identification of the bone and rotational centres of the leg and knee, the surgeon chose which reference axis was to be used for determining the correct position (i.e. rotation) of the femoral component. These reference axes in the BrainLAB system are the epicondylar line, the posterior condylar line or the Whitesides line (16). After the localization is completed, the software calculates the ideal position of the femoral and tibial component based on the pointed axes and surfaces. With regard to rotation, the system uses the chosen rotational axes and but does not take into account all three. Hence, it shows the displacement of the component compared to all three axes (Figure 2).

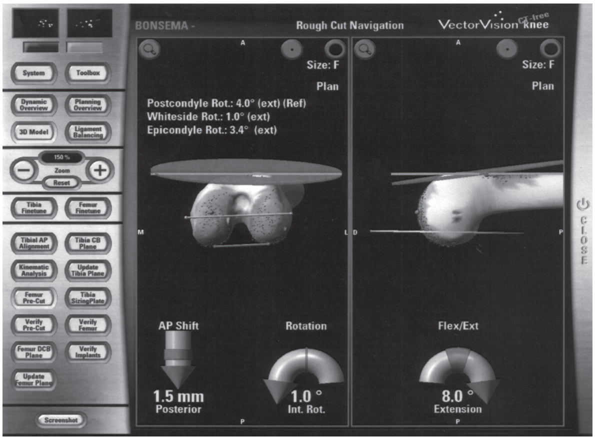

Figure 2. The position of the femoral component, showing the calculated position to the rotation axis.

The selected rotational reference line was in all of our cases the epicondylar axes. To be able to postoperatively identify the pointed and registrated epicondylar points on CT, the digitized lateral and medial points on the epicondyles were marked by a 1-milimeter diameter tantalum marker. These markers can be assessed highly accurately on CT scans and radiographs.

CT scanning

Postoperatively, prosthesis placement was checked by multislice CT. Based on availability, either a 16-slice (9 patients) or 64-slice (9 patients) machine was used (Aquilion, Toshiba, Otawara, Japan). CT protocols were developed based on recommendations by the BrainLAB company. For 16-slice

CT, scanning parameters were beam collimation 16x1mm and pitch 0.938; images were reconstructed using a medium-smooth kernel with 1mm slice thickness and 1mm reconstruction index. For 64-slice CT, scanning parameters were beam collimation 64x0.5mm and pitch 0.828; images were reconstructed using a standard kernel with 1mm slice thickness and 1mm reconstruction index.

Images were interactively viewed on a workstation (Vitrea2, Vital Images, Minnetonka, MN, USA) using an extended window scale (16-bit deep, up to a window width and level of 65,500. Therefore, no dedicated metal artefact reduction filtering techniques needed to be employed.

After aligning the markers into a single plane by thin MPR, thin-slice (1-2mm) images of the distal femur were used to measure the postoperative rotational axes (Figure 3). If necessary, thick MPR may be employed to help visualize both tantalum markers at the same time.

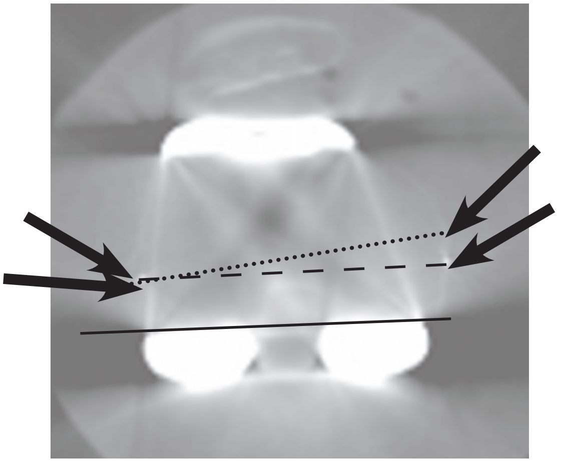

Figure 3. Example of a CT slice (1 mm) of the distal femur (dotted line = CT based Transepicondylar Line, dashed line = Pointed and marked line by tantalum markers, solid line = Posterior condylar line). The angle between these CT Based line and Pointed line to the posterior condylar line was measured.

On the postoperative CT scan, the most prominent part of the epicondyles was used to draw a line, the CT-based Transepicondylar line (CTB-TEL). The other reference line was drawn between the tantalum markers; the so-called marker based transepicondylar line (MB-TEL). The reference posterior condylar line (PCL) was drawn following the inner border of the posterior part of the femoral component, being the posterior condylar femoral osteotomy. We measured the posterior condylar angle (PCA): this is the angle between the PCL and the transepicondylar line (figure 3) (17). This was done for the CTB-TEL and the MB-TEL separately: the CT Based Angle (CTBA) and the marker-based Angle (MBA), respectively. In both instances the same PCL was used. The CTBA and the MBA were measured twice by observer 1 (HMJvdL) and by observer 2 (RGHHN) separately.

Since the true TEL is not known, the mean of the two PCAs (CTBA and MBA) can be used as the best estimate (limits of agreement). The difference in the two measurements for each observer of the PCA was statistically evaluated by the method of Bland and Altman (18), a non-parametric approach to compare two methods of clinical measurement. Cohen's Kappa is calculated to assess the agreement between the two observers, where kappa is 1.0 implies perfect agreement and kappa is 0 suggests that the agreement is no better than that which would be obtained by chance.

■ Results

The mean measured CTBA was 3.6 degrees for observer 1 (95% confidence interval between 1.72 and 5.48) and 2.8 degrees (95% confidence interval between 1.21 and 1.59) for observer 2.

The mean measured MBA was 0.55 degrees for observer 1 (95% confidence interval between -1.18 and 2.28) and 0.95 degrees (95% confidence interval between -0.76 and 2.66) for observer 2. So, overall a bigger PCA was found using the CTB-TEL as compared with the MB-TEL (figure 4).

The interobserver relationship between measurement of the CTBA by observer 1 and 2 was calculated and showed a linear pattern with a correlation coefficient of 0.95. The intraobserver correlation was kappa = 0.93 for the CTBA and 0.96 for the MBA (Cohen's Kappa is good if > 0.80).

The mean difference found between both epicondylar line measurement methods was 3,1 degrees (range 0,5 to 8 degrees, SD 5,37 degrees) (figure 4).

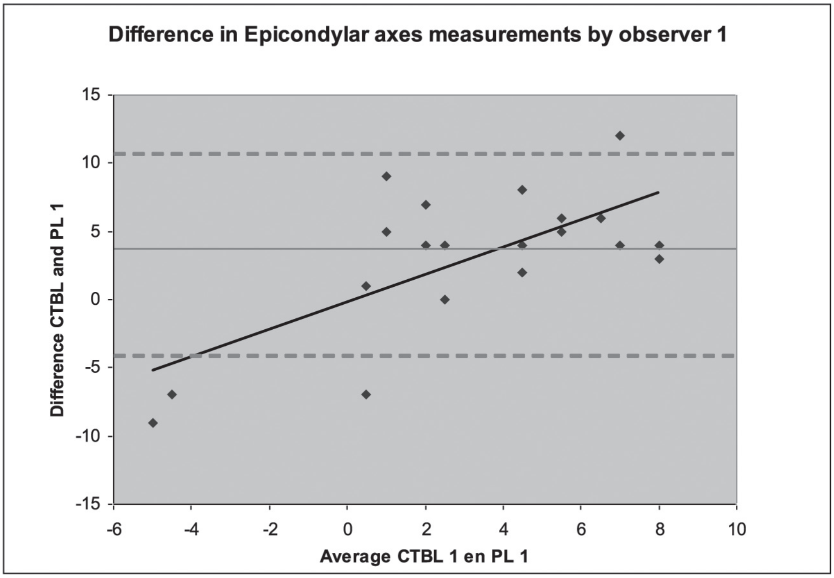

Figure 4. A plot of the differences in measurements between the two PCA methods (line = average difference of 3,18 degrees, upper dashed line = +2 standard deviation, lower dashed line = -2 standard deviation (SD = 3,67))

All knees had a patellar component with good patellar tracking and no anterior knee pain. The mean postoperative maximum flexion was 113 degrees (SD 12,9).

■ Discussion

Determination of the TEA during surgery is reproducible, however comparison of the intraoperatively determined axis with a postoperative CT scan showed a systematic error of 3 degrees. In general, determining the accurate rotation of the femoral and tibial component is difficult. However correct component rotation is very important in total knee arthroplasty in order to optimize patellofemoral and tibiofemoral kinematics. We studied the accuracy of intraoperative axis determination by the surgeon using CAOS and found an inaccuracy of 3 degrees.

There are three methods for determining femoral rotation based on bony landmarks: (1) posterior condyles with 3 degrees of external rotation, (2) anterior-posterior axis according to Whiteside and (3) the TEA.

The TEA approximates the flexion axis of the knee. Alignment of the femoral component parallel to the epicondylar axis results in the most normal patellar tracking and minimized patellofemoral shear forces early in flexion according to Miller et al. (19). But Kinzel et al. stated that even in experienced hands clinical estimation of the epicondylar axis is inaccurate and should not be relied upon as the sole determinant of femoral rotation (20).

The goal of CAOS in TKA is assisting the surgeon in determining the optimal rotational position of the components. Although accuracy in the coronal (AP) alignment is improved by CAOS (21-23), less is known about the influence on (or improvement in) rotational alignment as compared to that achieved with more traditional techniques involving mechanical guides (24-26).

Identification of the transepicondylar line during navigation is performed using a blunt pointer that the surgeon places on the palpated medial and lateral epicondyle(s) (27).

However, the shape and the soft tissue coverage of the epicondyles make these points difficult to assess, even more so due to the different shape of the medial and lateral epicondyles. The most prominent point of the medial epicondyle appears to be more easy detectable than the medial sulcus (28;29).

Since the most prominent point medially and the centre of the sulcus are on a line 2 degrees different, an error may be introduced, explaining the systematic error in this study between the CT and markers based measurement. RSA markers have not been used previously although Jerosch et al. used digital analysis by video registration (30).

Intraobserver error in obtaining the TEA has been found to be considerable (Yau et al. (31) and Jenni et al. (32)). The CT free navigation software does not take into account the difference in shape of the epicondyles. The users tend to use the most prominent and thus most easily palpable point to identify the landmarks. In developing computer assisted surgical techniques, one must be certain of the validity of measurements, inter-rater reliability, and reproducibility. The current method of localization of the epicondyles therefore is not ideal.

The PCA can best be measured on CT-scans (33). This 'gold' standard was compared with the intraoperative determined angle. The reproducibility of this measurements and the observer agreement between the PCA using both CTB-TEL and MB-TEL, is very good. Further, reproducibility was evaluated for observer 1 showing an equally good result (0.93 respectively 0.96).

We found that, overall, a larger PCA is measured using the CTB-TEL of 3 degrees. Thus, the current localization procedure of the epicondyles in CAOS could lead to less external rotation of the femoral component when based on the epicondylar line. One should be aware of this difference and possible relative internal rotation.

In general using CAOS, besides trying to achieve an adequate position of the sawing block, one must be aware of cutting errors and errors made while cementing. Because of partially sclerotic bone in an arthritic knee, the saw can divert from the bone and change the direction of the surface. Therefore, after cutting the bone the surface must be checked. But by using a computer-assisted technique, the surgeon becomes aware of cutting errors and therefore will be able to correct these (34).

Using the current software in CAOS in TKA, one should check the rotational alignment of the components using the 'conventional' techniques, using ligament balancing. A combination of the Whiteside's line and PCA provides a visual rotational alignment check during primary arthroplasty (17).

Using only the posterior condylar line is not reliable also. Hypoplasia and/or distorsion of the lateral condyle are described in the valgus knee (35) thereby influencing the PCA (36). There is also a tendency for the PCA to increase with age, causing a variation of the posterior condylar angle in knees (37). Hence the posterior condyles are potentially unreliable reference points for femoral component rotation in some knees (38), with wide interindividual variability of the PCA (39).

Lastly, all three bony landmarks have the disadvantage that they will not create a symmetric flexion gap in all cases. The balanced flexion gap method has the disadvantage that the femoral component may not be aligned parallel to the epicondylar axis in some cases. However, Olcott et al. stated that the TEA most consistently recreated a balanced flexion space (40). It is not known which of the two methods will produce better clinical results.

■ Conclusion

During navigation in total knee arthroplasty using the CT-free BrainLAB system, a systematic error is made between the intra-operatively transepicondylar pointed axis and CT based bony axis.

We believe that a need exists for a more accurate method to determine the epicondyles / rotation axes, thereby improving the position of the femoral component. It is necessary to be aware of a systematic error whilst using a navigation system. Determination of the best fit axis may require that a combination of all rotational axes or a cloud of points at the epicondyles be used in the software to improve the accuracy of rotation.

The operating surgeon should be aware that the computer is only providing information based on the software flow of the program. Thus, "expecting the computer to recognize the epicondylar axis when we have no ' iron clad' way ourselves exposes the true limitations of any computer assisted surgery" (DiGioia 2002).

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