Original Article

Comparison of Femoral Component Rotational Axes in Computer-Assisted Total Knee Arthroplasty using the Gap Technique: A Retrospective Study

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Objective: To compare the deviation of three femoral rotational axes in computer assisted surgery [CAS] total knee arthroplasty [TKA] using the gap technique.

Materials and Methods: A retrospective cross-sectional study was conducted between 2004 and 2013 at the Department of Orthopaedics, Ramathibodi Hospital of patients who had undergone computer-assisted total knee arthroplasty. All patients were included with the exception of those who had had post-traumatic knee osteoarthritis, valgus knee, or trapezoidal medial-lateral gap. Baseline characteristics and femoral rotational axes (Whiteside, posterior condyle, and transepicondyle) were recorded. Comparison among the three axes was performed using analysis of variance.

Results: The study included 140 patients (114 women and 26 men) with an average age of 71.6±8.4 years, representing 140 total knee arthroplasties. The deviation of femoral component rotation axes were: Whiteside's line 0.42±4.49 degrees, posterior condylar line -1.43±4.82 degrees and transepicondylar line -3.93±5.00 (p<0.001).

Conclusion: Whiteside's line showed the smallest deviation in femoral component rotation compared to the gap technique in CAS TKA.

Keywords: Femoral component rotation, Computer-assisted, Total knee arthroplasty, Gap technique, Anatomical landmark

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Total knee arthroplasty [TKA] is the one of the most common procedures in orthopaedic surgery. Unfortunately, some TKA patients experience significant pain. One of the most common problems in TKA is femoral component malposition. Femoral component malrotation can cause patellofemoral complications[1], early wear of polyethylene[2], knee flexion instability[3], limited range of motion[4], and a decline in functional ability as measured by the Knee Society Function Score[5]. Obtaining the proper femoral rotation alignment during the TKA procedure is an important step in avoiding those problems.

Several bony landmarks have been proposed for use in obtaining proper rotational alignment of the femoral component, e.g., the transepicondylar axis, the posterior condylar axis, and Whiteside's line (the anteroposterior axis). Previous studies have had limited sample size[6], limiting the statistical significance of their results[7,8] and thus the ability definitively determine the most appropriate method.

Computer assisted surgery [CAS] had allowed for improved accuracy by the surgeon in performing many TKA steps, e.g., the bone cut, component positioning, gap balancing, and leg alignment. Nevertheless, presently available navigation systems still result in a deviation in component rotation from the registered bony anatomical landmarks intra-operatively[9,10].

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We aimed to determine the deviation of each femoral rotational axis compared with the gap technique using the navigation system currently installed in our hospital. In the present study, we attempted to identify the rotational axis for total knee arthroplasty using the gap technique that provides the most precise performance.

Materials and Methods

A cross-sectional study was conducted at the Department of Orthopaedics, Ramathibodi Hospital. We retrospectively reviewed the records of all patients who had had varus knee osteoarthritis and who had undergone CAS TKA between 2004 and 2013. Patients with post-traumatic osteoarthritis, valgus knee deformity, varus knee more than 10 degrees, trapezoidal gap (medial-lateral gap more or less than 3 millimeters), femoral hypoplasia, deformity affecting the rotational axis, and those for whom data was missing were excluded. The Institutional Review Board approved this study (ID 10-57-51).

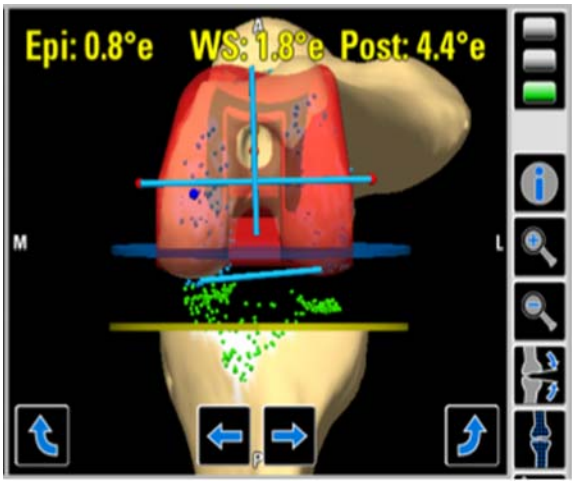
Surgical procedures

A single senior surgeon [TC] performed all the operations using a straight midline skin incision below the tourniquet using either the medial parapatellar or the midvastus approach. The patella was manually subluxated laterally after the initial cut and protected with a metal patellar guard. Osteophytes, both cruciate ligaments, and menisci were removed. After proper exposure was achieved, arrays of a computer-assisted navigation system (Ci™ Essential Knee System software version 2.0, Brainlab Company, Munich, Germany) were placed using the two threaded pins technique at the femur and tibia. The tibial cut first technique was entered into the work-flow of the computer-assisted program. The minimal acceptable error was set at ±1 degree and ±1 mm for calibration of the cut or measurement of the alignment during the operation. After the tibial cut at 90 degrees (perpendicular to the tibial axis), we used a tension device (Figure 1) to determine the femoral rotation cut (anteroposterior cut) using the navigation system. The other anatomical landmarks (posterior condylar axis, Whiteside's line, and transepicondylar axis) were displayed and recorded by the program (Figure 2). All cases underwent CAS TKA using instruments from DePuy Orthopaedics Inc, Warsaw, IN, USA) and posterior-stabilized rotating-platform knee implants (PFC-RP, PFC-RPF, and LCS, DePuy Orthopaedics Inc,Warsaw, IN, USA).

Gap technique

There are two techniques in TKA for cutting the femur in the anteroposterior aspect or for determination of the flexion gap. The gap technique in TKA replicated by balancing and tensioning the patient's ligaments during flexion of 90 degrees using a tension device, then performing the femoral rotational

Figure 1. Tension device used with the gap technique in CAS TKA (A and B). Intraoperative application of the tension device (C).



Epi = transepicondylar axis; WS = Whiteside's line; Post = Posterior condylar axis

Figure 2. View created by computer-assisted software. Posterior condylar axis compared with femoral rotation at 90 degrees of knee flexion using the gap technique.

cut parallel with the tibial cut. The measured resection technique uses an external rotation of 3 degrees to posterior femoral condyle, perpendicular to Whiteside's line, or parallel with the epicondylar axis cut.

Study factors and outcomes

Baseline characteristics included age, gender, side of the operative knee, as well as pre- and post-femoro-tibial axis. All data was retrieved from hospital patient profiles and intraoperative reports using Ci™ software. Outcomes of interest included the rotational profile from the Whiteside line, the posterior condylar axis, and the transepicondylar axis. Whiteside's line was determined by a line between two points: the deepest area of the anterior femoral groove and the superior most point of the posterior femoral groove. The posterior condylar axis [PCA] was determined by a line drawn between the medial and lateral posterior femoral condyles and externally rotated approximately 3 degrees. The surgical transepicondylar axis [sTEA] was a line drawn between the medial groove and the most prominent of the lateral epicondyles of the femur (Figure 3). All anatomical landmarks were defined by one surgeon during CAS TKA patient anatomy registration.

Femoral rotation assessment was done using computer-assisted surgery provided by a Vector Vision™ compact model (Brainlab Company, Munich, Germany) and Ci™ Essential Knee System software (version 2.0 DePuy Orthopaedics Inc, Warsaw, IN, USA). The deviation of rotation was set as a negative value for internal rotation using the gap balancing technique, and as a positive value for external rotation.

Statistical analysis

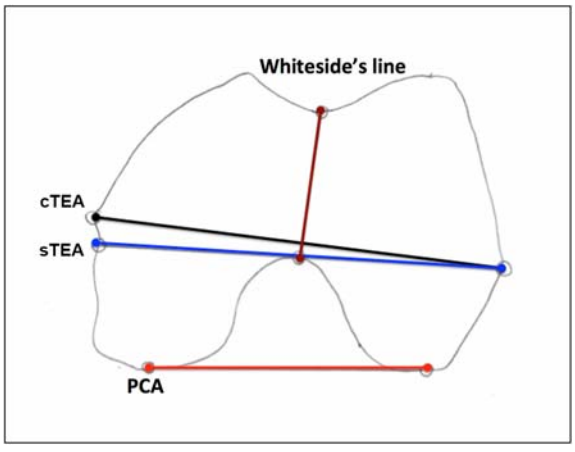
Means and standard deviations are presented for continuous variables. For categorical data, frequency and percentage were calculated. The comparison between two means was done using Student's t-test. The deviation of each femoral rotational axis was analyzed using one-way analysis of variance. Variances between means were tested using Bartlett's test, and post hoc analysis was performed using Scheffe's test. The significance of differences between the three means was determined by F-test. Statistical significance was set at $p<0.05$. All statistical analyses were performed using the STATA 12.0 Program (Stata Corp, College Station, TX, USA).

Sample size was estimated based on an alpha error of 0.05, power of the study of 0.8, mean rotation of the Whiteside technique of 2.1[11], mean rotation of other techniques of 2.7, and standard deviation of the Whiteside technique and other techniques of 1.5. The calculated sample size from STATA 13.0 Program was 99.

Results

Of the 167 patients who had varus knee osteoarthritis and who had undergone CAS TKA during the study period, 27 were excluded. Twenty of them had a medial-lateral gap >3 mm, and two patients had a gap <-3 mm. Four patients had a preoperative femoro-tibial angle <-10 degrees), and one patient had missing data. A total 140 cases (114 women, 26 men) were included in the study. Their mean age was 72±8.4 years (range; 47 to 93 years). Sixty-seven CAS TKAs (47.9%) were on the right knee (Table 1). The mean pre-operative femorotibial mechanical axis angle was varus 7.1±5.3 degrees. The mean post-operative femoro-tibial mechanical axis angle was 0.5±1.7 degrees. The average difference between the pre- and post-operative femoro-tibial mechanical axis was 6.6±0.4 with a *p*-value <0.0001.

The mean deviation of Whiteside's line from the gap balancing technique was 0.42±4.49 degrees (range, -12.0 to 11.5). The mean deviation of the posterior condylar axis from the gap balancing technique was -1.43±4.82 degrees (range, -16.5 to 7.5). The mean deviation of transepicondylar axis from the gap balancing technique was -3.93±5.00 degrees (range, -19.0 to 7.0) (Figure 4). Analysis of the differences between these femoral rotation axes found



PCA = Posterior condylar axis; cTEA = clinical transepicondylar axis; sTEA = surgical transepicondylar axis

Figure 3. Anatomical landmarks.

that the variance between the axes was not statistically significant (*p*-value from Bartlett's test 0.450). Therefore, the assumption for one-way analysis of variance was reached. There were significant difference between the axes (F-test *p*-value <0.001) (Table 2). Post hoc analysis showed the average Whiteside axis was significantly more accurate than the other two axes. The posterior condylar axis was significantly different from the transepicondylar axis (*p*-value <0.001).

Discussion

CAS TKA navigation provides better femoral rotational alignment than conventional knee arthroplasty[9]. Nevertheless, some patients still have postoperative outlier femoral rotation leading to knee pain and patellar instability. Bony landmarks may facilitate more reliable positioning of femoral components, but evidence from previous studies is limited[6-8]. Our study compared the suitability of bony landmarks using the gap technique in CAS TKA: the Whiteside technique, the posterior condyle, and the transepicondylar axis. The femoral rotational axis was significantly different among the three bony landmarks with an F-test *p*-value <0.001. The results from 140 CAS TKAs demonstrated that the Whiteside's line is the most reliable method, with an average femoral rotational axis. of 0.42 degrees, followed by posterior condylar line and transepicondylar axis.

Moon YW, et al[12] reported a wider variability in the femoral rotational axes compared with the gap balancing technique with no significant statistical difference among the axes. Although in a previous study, the tibial cut was confirmed to be perpendicular to the mechanical axis of the tibia, the tension may not have been symmetrically balanced which may have caused an error in the femoral rotation. In the present study, a trapezoidal gap was defined as a difference between the medial gap and the lateral gap of more than 3 mm. In a previous study, the trapezoidal gap, which may have affected femoral rotational alignment, was not excluded from the study. In addition, the sample in that study was also too small to identify significant differences. There are many factors affecting the flexion gap that impact on femoral rotation, e.g., a natural soft-tissue laxity in the lateral side opening 1 to 6 mm wider than the medial structure under tension[13], patellar position and thickness, and the degree of force applied by the tension device[14]. In this study, those

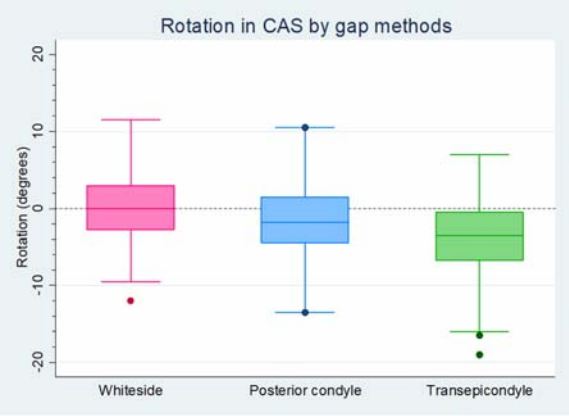


Figure 4. Comparison of femoral rotation axes with CAS TKA using different gap methods.

Table 1. Baseline characteristics of CAS TKA patients

Baseline characteristics	n = 140
Age (years), mean (SD)	71.6 (8.4)
Female (%)	114 (81.4)
Right side (%)	67 (47.9)
Pre-operative femoro-tibial angle (degrees), mean (SD)	7.1 (5.3)
Post-operative femoro-tibial angle (degrees), mean (SD)	0.5 (1.7)

SD = standard deviation

Table 2. Comparison among femoral rotational axes using the gap technique

Femoral rotational axis (degrees)	Whiteside	Posterior condyle	Transepicondyle	*p*-value
Mean (SD)	0.42 (4.49)	-1.43 (4.82)	-3.93 (5.00)	<0.001
Range	-12, 11.5	-16.5, 7.5	-19.0, 7.0	
Mean difference				
- Whiteside vs. posterior condyle		4.34		0.006
- Whiteside vs. transepicondyle			2.49	< 0.001
- Posterior condyle vs. transepicondyle			4.34	< 0.001

factors were controlled for by consistently using the same tension device with all patients (Figure 2), by closing the patellar gap, and by clearing posterior osteophytes before measuring the gap.

A major strength of the present study was having an adequate sample size to identify significant differences. Another is that confounding factors that could potentially result in rotational error to the femoral component were excluded, i.e., valgus knee, which could be concomitant with hypoplasia of the femoral condyle and severe knee deformity causing erosion of the femoral condyle. Finally, the gap balancing technique offers good rotational alignment if the tension is set correctly to achieve a rectangular gap. On the other hand, different tension devices balance the tension of collateral ligaments with differing degrees of precision. That is, a rectangular gap indirectly indicates proper tension balance. In this study, we validated the gap balancing technique and excluded trapezoidal gaps in order to achieve optimal femoral component rotational alignment.

A limitation of our study is that the information available in a retrospective study may be incomplete and some factors could not be controlled for, e.g., the surgical approach, which may affect the identification of the anatomical landmarks during registration in computer assisted surgery. Also, the midvastus approach or MIS may limit the possible exposure to identify epicondyle, and trochlear wear may cause the Whiteside's line to be in error. Finally, it is possible that the navigation system may not be as effective in determining the femoral rotation as a CT scan. However, the advantages of the navigation system were simultaneously compared with the gap technique using multiple references in the same patient while performing CAS TKA using the gap technique and double checking optimal rotation using anatomical landmarks. Further study with CT scans as a measurement tool might be worthwhile. Nevertheless, the CT scan, although considered the gold standard, has limitations such as high cost and high radiation exposure. Therefore, CAS TKA with a consistent and reliable gap technique may be more affordable as well as clinically appropriate.

Conclusion

Rotation of the femoral component has the smallest deviation from Whiteside's line with the CAS TKA using the gap technique. This bony landmark may be useful in determining the optimal femoral rotational axis in clinical practice.

What is already known on this topic?

Femoral rotation varies when using the gap technique in TKA. Most studies have indicated that femoral rotation measurements made using a CT scan or radiographic film only become available postoperatively.

What this study adds?

This study shows that CAS TKA using the gap technique can provide real-time intraoperative data. The Whiteside line is more reliable than the transepicondylar axis or the posterior condylar axis during CAS TKA.

Potential conflicts of interest

The authors declare no conflict of interest.

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