Comparison of tibial rotation in fixed and mobile bearing total knee arthroplasty using computer navigation

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Received: 10 February 2008 / Revised: 26 February 2008 / Accepted: 10 March 2008 / Published online: 11 July 2008
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Abstract Tibial rotation is an important aspect of knee function and can be altered after total knee arthroplasty (TKA). These alterations include decreased internal rotation with knee flexion as compared to the normal state and paradoxical external rotation with flexion. Mobile bearing total knee prostheses may allow greater unconstrained tibial rotation. I compared tibial rotation after fixed bearing or mobile bearing total knee arthroplasty in 82 patients who underwent TKA with the tibia cut first technique to ascertain any differences. Using intraoperative imageless computer navigation, measurements included the determination of tibial rotation from extension to 90° flexion before and after prosthetic implantation with non-weight-bearing range of motion. I found that tibial rotation was significantly reduced after fixed bearing total knee replacement as compared to mobile bearing. In addition, the tibial position compared to the distal femur in extension was more external in fixed bearings compared to mobile bearings. Placing the fixed tibial tray with increased internal rotation could explain this difference.

Résumé La rotation du tibia est un élément important sur le plan fonctionnel. Elle peut être altérée après une prothèse totale du genou. Ces altérations de la rotation portent sur une diminution de la rotation interne et paradoxalement une augmentation de la rotation externe en flexion. Une prothèse totale du genou à plateau mobile permet une

libération plus importante de la rotation tibiale. Nous avons comparé cette rotation à partir de prothèses à la plateau fixe et à plateau mobile sur une série de 82 patients ayant bénéficié de cette arthroplastie avec une coupe première du tibia. Nous avons utilisé pour cela un système de navigation per opératoire. Nous avons trouvé à l'issue de cette étude que les rotations tibiales étaient significativement réduites après prothèse totale à plateau fixe versus prothèses à plateau mobile. Par ailleurs, la position du tibia en extension est en rotation externe par rapport au fémur distal. Cette rotation est plus importante dans les prothèses à plateau fixe que dans les prothèses à plateau mobile. Le positionnement du plateau tibial en rotation interne lors de l'intervention peut expliquer cette différence.

Introduction

Axial femorotibial rotation during flexion of the healthy knee has been seen in numerous previous in vitro and in vivo kinematic analyses [5, 8, 10, 16]. With knee flexion, the tibia typically internally rotates relative to the femur, and conversely, externally rotates with knee extension (i.e. normal screw-home mechanism) [8, 10, 15, 16]. Previous total knee arthroplasty (TKA) studies have been limited and have analysed small numbers of patients, often using non-weight-bearing conditions or only throughout a limited percentage of the entire flexion range [1, 2, 7, 11, 12, 18, 19]. It is assumed that different axial rotation magnitudes and patterns (i.e. direction of rotation, internal or external tibial rotation versus the femur) may occur after TKA because of removal or alteration of the cruciate ligaments and failure to exactly duplicate geometry of the medial and lateral femoral and tibial condyles. Fluoroscopic video kinematic studies have demonstrated that while some cases

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demonstrate the expected internal rotation with knee flexion, others will actually exhibit paradoxical external rotation with knee flexion [6, 24]. Knowledge of rotational movement is an important consideration for understanding polyethylene wear patterns where exaggerated sliding motion coupled with rotation may produce detrimental delamination wear [4, 17, 25].

Computer-assisted surgical navigation (CAOS) offers a unique opportunity to evaluate tibial rotation intraoperatively along with numerous other parameters such as mechanical alignment, joint flexion, ligament balance and tibial axis alignment in flexion. This report retrospectively reviewed tibial rotation documented before and after mobile and fixed total knee arthroplasty in a group of patients where the “tibia cut first” surgical technique was used with both implants. While the mobile bearing prosthesis tested offers the potential for unconstrained rotational motion, it was believed that the semi-constrained fixed bearing prosthesis has enough geometric freedom to allow similar rotational movement. The hypothesis was that there should be no significant difference between the fixed and mobile bearing tibial insert with regard to rotational movement in total knee arthroplasty. More specifically, a fixed bearing total knee prosthesis should easily accommodate the typical amount of tibial rotation that has been shown to occur by analysing prior kinematic studies assessing arthritic knee rotation.

Methods

A group of 82 patients underwent primary total knee arthroplasty using the “tibia cut first” technique performed by a single surgeon experienced with this technique (JBS). Implants used were either the LCS mobile bearing prosthesis or the NexGen LPS Flex prosthesis. The low contact stress mobile prosthesis is a total condylar design that offers very high conformity of the femoral and tibial insert from 0 to 40° of flexion followed by less congruity with deeper flexion resulting from diminished radii of curvature of the posterior femoral condyles. The tibial insert has a central cone that articulates with a matching reverse cone on the tibial tray. Tibial rotation is unconstrained with this device. The NexGen LPS Flex prosthesis is a total condylar design that articulates with semi-constrained fixed tibial insert. The condylar geometry is reasonably conforming but will allow up to 7° of coronal plane “lift-off” and up to 12° of tibial internal or external rotation.

The groups were selected from a consecutive series of navigated cases performed from 2003 to 2005 and were chosen such that the amount of deformity was matched for the two groups. For the mobile bearing cohort, the average

amount of preoperative deformity was 7° of varus. There were 25 males and 16 females. The average age was 56 and average body mass index (BMI) was 31. Postoperative, the average deformity was corrected to an average of 0.7° varus. For the fixed bearing group, the average deformity was 6.2° of varus. There were 15 males and 26 females. The average age was 69 and BMI was 31. Postoperative, the deformity was corrected to an average of 0.5° of varus (Table 1). The Medtronic Stealth Treon system with the Universal Imageless Total Knee software (Medtronic, Inc., Louisville, CO, USA) was used in all cases with dynamic reference base markers attached to either the medial proximal tibia or the distal medial femur over the medial epicondyle. The tibial rotation was defined mathematically by the relationship of the transepicondylar axis and a vector measured from the tibial centre to the midpoint prominence of the tibial tubercle. More recently, the Medtronic imageless protocol added the femoral anterior/posterior axis of Whiteside as an additional mark to determine femoral rotation eliminating the need for the transepicondylar axis reference.

Navigation referencing protocol

The specifics of the navigation referencing are an important element of the technique and require detailed description. Hip centre determination is done using the kinematic method originally described by Saragaglia et al. [20]. Femoral referencing is done with the two most important points being the femoral centre and the cortical reference of the anterior femoral cortex (Fig. 1). For the tibia reference, the tibial centre is defined as the bisection of the transverse tibial axis [3]. The transverse tibial axis is a line that connects the anterior/posterior (AP) midpoints of the medial and lateral condylar surfaces. The tibial centre approximates the lateral insertion of the anterior cruciate ligament (ACL). The anterior/posterior tibial axis is a perpendicular extension of the tibial centre of the transverse tibial axis (Fig. 2). This point typically matches the extension of the femoral AP axis that may be extended onto the anterior surface of the tibia. The computer algorithm then picks a point on the transmalleolar axis which is 40% from the most medial point which has been

Table 1 Demographics of both cohorts

	LPS High Flex	LCS rotating platform	Statistical significance
Age	68.6	56.3	$P < .001$
Sex	36% male	60% male	
BMI	30.0	31.0	NSD
Deformity	6.1° varus (SD: 4.8°)	7.1° varus (SD: 5.7°)	NSD

Fig. 1 Femoral centre reference point match which is located under the roof of the intercondylar notch and lies both on the anterior/posterior axis of Whiteside and the transepicondylar axis

shown by anatomical studies to approximate the centre of the dome of the talus.

“Tibia cut first” surgical technique

The “tibia cut first” method with total knee arthroplasty follows the original technique of Insall where ligament balancing is done initially in extension before any bone cuts are made [9]. The tibia cut is made perpendicular to the mechanical axis with a 7° posterior slope to the proximal tibia. The anterior distal femoral cut is made precisely at the distal anterior surface of the femur, and the flexion gap is cut with a block that removes the posterior condyles after ligament tensioning has been done. Ligament tension is determined either with a gap spacer or a custom tensioner that adjusts and measures the amount of tension to cut a specific gap. Distal femoral chamfer and notch cuts complete femoral preparation. Following final preparation for femoral implantation, trials are inserted to assess the tension of the gaps that are created. These gaps typically will not have laxity over 3 mm, with a maximum allowed laxity in any plane of 5–6 mm.

Fig. 2 Proximal tibial centre point match which is located at the intersection of the transcondylar axis (line bisecting the anterior/posterior midpoints of the medial and lateral tibial condyles) and the anterior/posterior axis which bisects and is perpendicular to the transcondylar axis

Statistical and error analysis

Statistical analysis was performed using the Data Analysis tools in Excel 2004 for MAC. This included the Student’s *t*-test for two samples assuming equal variances and the F-test for two samples for determining variances. Statistical significance was determined at the $P < 0.05$ level for all measures.

An error analysis was determined for the computer navigation system where multiple tests were measured in the operating room setting using a single normal cadaver. After initial referencing, measurements of tibial rotation were done at full extension and 90° of flexion. Repeatability of one surgeon performing eight consecutive referencing trials revealed a mean of 13.1° internal rotation [SD: 1.5; range: 11–16°; 95% confidence interval (CI): 1.2]. Reproducibility of three surgeons performing the same tests on the same cadaver revealed a mean 12.7° internal rotation (SD: 2.1°; range: 9–16°; 95% CI: 0.9).

Results

Compared to the baseline measurement of the arthritic knee, tibial rotation was significantly reduced with postoperative fixed bearing total knee replacement. The variation of rotation was significantly reduced from baseline to the post-implant measurement in the fixed bearing with an F ratio of 2.79 ($P < 0.0007$). Comparing the fixed and mobile prostheses groups, there was significantly lower rotation and variance in rotation in the fixed bearing group with an F ratio of 0.36 ($P < 0.0008$) (Table 2). These results reject the hypothesis that there should be no difference between the two implant types with regard to post-implantation tibial rotation.

A post hoc power analysis was performed to determine if the conclusion of difference in tibial rotation between the two devices was reliable. With the fixed bearing group, the mean rotation regardless of direction was 4.9° (SD=2.8°). For the mobile group, mean rotation regardless of direction was 6.9° (SD=5.3°). Using Student’s *t*-test, these two group

Table 2 Outcome data from this study

	Baseline arthritic knee (LPS)	LPS High Flex	Baseline arthritic knee (LCS)	LCS rotating pPlatform	Statistical difference
Mechanical axis preoperative	6.1° (SD: 4.8°)		7.1 (SD: 5.7°)		NSD
Mechanical axis postoperative		0.7° (SD: 1.0°)		0.4° (SD: 1.2°)	NSD
Tibial rotation with flexion (direction ignored)	7.6° (SD: 5.2°)*	4.9° (SD: 2.8°)*	7.9° (SD: 5.0°)	6.9° (SD: 5.3°)*	Baseline vs LPS $P < .004$ LPS vs LCS $P < .02$
Tibial rotation with flexion (by direction)	4.6° Internal (aver.) (SD: 8.0)	3.0° Internal (aver.) (SD: 4.8°) Range: 9° external to 11° internal	5.9° Internal (aver.) (SD: 7.3°)	3.7° Internal (aver.) (SD: 8.0) Range: 10° external to 29.5° internal	NSD
Tibial rotation with flexion; variance	Baseline vs LPS* F-test 2.79	LPS vs LCS* F-test 0.36	Baseline vs LCS F-test 0.89	LPS vs LCS* F-test 0.36	Baseline vs LPS $p < .0007$ LPS vs LCS $P < .0008$
Tibial position in extension (Δ)		2.1° Internal (SD: 0.9°)*		4.2° Internal (SD: 4.5°)*	LPS vs LCS $P < .05$
Direction of rotation with flexion	27% External 66% Internal	22% External 73% Internal	21% External 71% Internal	29% External 71% Internal	NSD
Change in rotation pre- to postoperative		17% Int. to ext. 15% Ext. to int.		21% Ext to int. 15% Int. to ext.	NSD

* $P < .05$

were different at $P < .02$. Using PC-Size and a pooled standard deviation, this investigation had a post hoc power of 79% to demonstrate a difference, if the difference were present.

From the baseline position of the tibia as measured in relation to the distal femur at full extension to the position after total knee arthroplasty, the tibia position changed and moved more internally in 68% of knees. Comparing the fixed and mobile bearing prosthesis, we found significantly greater change for the mobile prosthesis, i.e. the tibia moved internally to a greater degree. Again, this finding rejects the hypothesis that there would no difference between the two prosthetic types. Two explanations for this difference could be that the surgeon did not optimise the tibial tray position with the fixed bearing prosthesis placing it more internally on the proximal tibia. Alternatively, the mobile bearing device, being unconstrained, may allow for alteration of the external tibial placement found at baseline in arthritic knees that have loss of the anterior cruciate ligament.

At baseline, 23% of all arthritic knees demonstrated tibial external rotation (reverse screw-home) with flexion while 23% had tibial external rotation after TKA. In 38% of cases there was a change in the direction in tibial rotation from the baseline measurement to the final measurement after total knee arthroplasty.

Discussion

The results of this study would indicate that the amount of tibial rotation after total knee arthroplasty was significantly less than the baseline for the fixed bearing prosthesis but not for the mobile bearing prosthesis. Contrary to the original hypothesis, when comparing fixed and mobile bearing knees done using a similar “tibia cut first” technique, there was significantly lower tibial rotation in the fixed bearing knees. In addition, there was significantly lower variation of rotation in the fixed bearing group. The results parallel those of an earlier in vivo fluoroscopic kinematic study comparing a fixed bearing posterior stabilised design with an unconstrained posterior cruciate retaining prosthesis where the PS design had significantly lower rotation. Those authors also believed that the PS design was more sensitive to alignment of the prosthesis in the patient’s knee (Table 3).

A limitation of the current study is that all measurements were made non-weight-bearing. However, most cadaveric studies and kinematic studies with roentgenographic spectrophotogrammetry (RSA) have also been done non-weight-bearing. Secondly, the inaccuracy of referencing the transepicondylar axis and the tibial tubercle are such that only relative numbers are possible. Siston et al. have

Table 3 Comparison of kinematic and clinical data regarding tibial rotation after total knee arthroplasty

Author	Test method	Knee condition, prosthesis	Findings	Significance
Lafortune et al.	In vivo, gait, cortical pins	Normal ($n=5$)	5° (SD: 1.6°) Internal rotation at heel strike; 9° (SD: 2.7°) external rotation at toe off	14° Rotation with normal gait
Ishii et al.	In vivo, non-weight-bearing, flex to 60°, linked hinge with cortical pins	Normal ($n=5$)	10.6° (SD: 2.8°) Internal rotation with flexion to 60°	Positive screw-home in all patients
Jonsson et al.	RSA, non-weight-bearing, 30° flexion to extension	ACL deficient ($n=13$)	6° Internal rotation on extension followed by external rotation	
Karrholm et al.	RSA, non-weight-bearing, flex to 60°	ACL deficient ($n=10$)	Reduced internal rotation in flexion for ACL deficient	Tibia more external to femur; 50% negative screw-home rotation
Nilsson et al.	RSA, non-weight-bearing, extension to 55°	Normal ($n=23$)	6.5° Internal rotation	Tibia more external to femur in TKA than normal
Nilsson et al.	RSA, non-weight-bearing, extension to 55°	Tricon-M ($n=11$)	3.9° Internal rotation	
		Miller-Galante ($n=10$)	4° Internal rotation	Tibia more external to femur compared to normal
		LCS ($n=5$)	1° Internal rotation	
		LCS ($n=5$)	1° Internal rotation	
Stiehl et al.	In vivo fluoroscopic; deep knee bend	Whiteside PCR ($n=6$)	4.7° (SD: 3.7°) Internal rotation; maximum 9° internal rotation	Rotation coupled with medial condyle anterior/posterior motion
Stiehl et al.	In vivo fluoroscopic; deep knee bend	LCS ($n=20$)	0.5° Internal (aver.); range: 9° internal to 6° internal	40% Reverse screw-home rotation; 50% medial condylar rotation greater than lateral
Banks et al.	In vivo fluoroscopic; weight bearing gait	Posterior cruciate retaining ($n=6$); posterior stabilised ($n=5$)	PCR: 6.5° (SD: 2.6°) PS: 4.9° (SD: 2.4°) PS: 4.9° (SD: 2.4°)	PS had lower rotation ($P<.05$) than PCR; PS may be sensitive to axial alignment of implant
Dennis et al.	In vivo fluoroscopic; deep knee bend	Normal ($n=10$)	16.5° Internal (aver.); maximum 27°	Positive screw-home in all knees
Dennis et al.	In vivo fluoroscopic; deep knee bend	ACL deficient ($n=5$)	8.1° Internal (aver.); maximum 11.8°	40% Reverse screw-home rotation
Dennis et al.	In vivo fluoroscopic; deep knee bend (overall)	Total knee ($n=760$)	3.7° Internal (aver.); range: 21° internal to 22° external	26% Reverse screw-home rotation
Dennis et al.	In vivo fluoroscopic; deep knee bend	Posterior stabilised ($n=212$); mobile bearing cruciate sacrificing ($n=76$)	PS: 3.1° internal (aver.); range: 8° internal to 11° external MB: 3.3° internal (aver.); range: 6° internal to 11° external	PS: 24% reverse screw-home rotation MB: 27% reverse screw-home rotation MB: 27% reverse screw-home rotation
Argenson et al.	In vivo fluoroscopic; deep knee bend	LPS High Flex ($n=20$)	5.4° Internal (aver.)(SD: 5.6°); range: 9° external to 13° internal rotation	Results similar to current study

shown significant variability with attempting to identify the transepicondylar axis during surgery and when attempting to use computer navigation [23]. The same authors evaluated methods to determine tibial tray rotational alignment finding that tibial tubercle referencing in computer navigation produced greater variability than even conventional total knee instrumentation [22]. Another source of error could be positioning of the knee and how the leg is held as the surgeon passes the knee through a passive range of motion. The error analysis would suggest that the potential variation from this factor is limited with a standard deviation of 1.5–2.0° for measured rotation. Finally, the author confirms that results were not changed by the selection criteria of matching the two groups for

preoperative deformity. This selection was done as the surgeon who collected this series did not typically use the LCS prosthesis in cases with severe valgus deformity. However, there was a significant difference in age and sex between the two groups with the LCS prosthesis being chosen in greater numbers for younger males. It is unknown if differences in sex and age could affect the outcome.

In this study, baseline intraoperative tibial rotation and measurement after total knee arthroplasty were less than typically shown in the normal knee. Cadaveric studies have shown 14–19° of internal tibial rotation (positive screw-home) occurs throughout the arc of knee flexion in the normal knee [10, 15, 16] (Table 3). Several studies have

assessed the effect of anterior cruciate ligament disruption on non-weight-bearing tibial rotation finding that rotation is typically diminished compared to normal [13, 14]. Throughout the flexion range tested, ACL-deficient knee tibias were positioned more externally relative to the distal femur compared to that seen in normal knees. Additionally, although an average positive screw-home rotation pattern was noted in ACL-deficient knees, other reports note that aberrant external rotation (reverse screw-home) may occur in some knees (Table 3). Results of this paper would confirm the presence of reverse screw-home in abnormal arthritic knees as this was identified in 23% of arthritic knees at baseline. While the current methodology cannot show that the arthritic tibias were more externally placed than normal at baseline measurement, a trend towards reduction of external tibial position was seen after placement of a prosthesis.

Kinematic studies have shown diminished tibial rotation with flexion in patients after total knee replacement (Table 3). Studies using RSA have found that rotation may vary from 1 to 10° depending on the prosthesis and surgical technique [12, 18, 19]. In vivo weight-bearing video fluoroscopy has been used to evaluate tibial rotation in a large number of patients following total knee arthroplasty compared to normal and ACL-deficient knees [6]. In one study, screw-home rotation in normal knees averaged 16.5° while that found in ACL-deficient knees averaged 8.1° and following total knee replacement 3.7°. However, the maximum range of motion on deep knee bend was notable with internal rotation of 21.3° internal rotation and external rotation of 22.3° in total knees.

The results noted in this study are consistent with most prior studies and offer new insights when comparing the baseline and postoperative total knee findings. It has been stated in the recent literature that total knee arthroplasty will result in abnormal kinematics. Siston et al. have shown in cadavers and intraoperative patients that osteoarthritic knees have reduced normal screw-home rotation which also persists after total knee arthroplasty [21]. One could argue that arthritic joints often have loss of normal anterior cruciate ligament function, altered articular load bearing position, and altered ligament tension, and are not likely to perform as a normal joint would. These changes could explain the tendency of the tibia to be externally rotated in the baseline arthritic state.

In conclusion, the most significant finding of this study is that normal screw-home rotation is reduced in postoperative total knee arthroplasty. Fixed bearing total knees demonstrated significantly less rotation than mobile bearing total knees and tended to have a greater external position of the tibia in relationship to the distal femur as compared to mobile bearing total knees. Factors such as prosthetic constraint and surgical technique for tibial tray placement may explain some of these differences.

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