

The Contribution of Mobile Bearing Knee Design In Optimizing Tibial Rotation In Total Knee Arthroplasty

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Abstract

This study assessed alignment and rotation in mobile bearing total knee arthroplasty with the tibia cut first technique using an imageless referencing computer navigation protocol evaluating forty one patients. Prerelease mechanical alignment(MA) averaged 7° varus $\pm 5^{\circ}$ (Range- 8° valgus to 20° varus). Post implant mechanical alignment was 0.5° varus $\pm 1.2^{\circ}$ (Range: 2° Valgus to 3° Varus). Postoperative radiographic mechanical alignment was 0.3° varus $\pm 1.3^{\circ}$ (Range 2° Valgus to 2° Varus). The baseline measurement of tibial rotation from 0° to 90° flexion was 6° $\pm 7.2^{\circ}$ of tibial internal rotation (Range- 8° external rotation to 19.5° internal rotation). The post implant tibial rotation from 0° to 90° flexion was 3.6° $\pm 8^{\circ}$ of tibial internal rotation (Range- 17° external rotation to 29° internal rotation). Of baseline group, 25% demonstrated tibial external rotation with flexion. After TKA, 28% had tibial external rotation with flexion. When comparing the nominal tibial position in relation to the femur at 0° before and after TKA, the tibial rotation point at 0° moved more externally in 21% and more internally in the rest with mean change for the overall group of 3.9° of internal rotation(range: 17° internal to 5° external). This study identified significant changes in knee rotation that may be caused by correction of alignment and deformity. Mobile bearing implants by nature of unconstrained rotation are likely to accomodate these variations. This feature could be defined as a significant advantage over fixed-bearing prostheses.

Introduction:

Mobile bearing total knee arthroplasty has nearly 40 years of continuous successful experience with signal implants such as the Oxford unicondylar prosthesis and the LCS mobile prosthesis.[1,2] World wide, the concept continues to proliferate with the introduction of numerous copies and variations on the basic theme of the device. Principally, there are two potential advantages of a mobile bearing device over the typical fixed polyethylene prosthesis. The mobile bearing allows for dramatically increasing the surface contact areas of the metal prosthesis on the polyethylene. This has been shown to reduce surface contact stresses and the sliding ploughing movement known to increase implant wear.[3] Secondly, the mobile bearing device allows a margin of error for creating an optimal position match of the femur with the tibia. This accounts for the significant variations in the individual anatomy and the changes caused by the arthritic disease process.

Axial femorotibial rotation during flexion of the healthy knee has been seen in numerous in vitro and in vivo kinematic analyses [4,5,6]. 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) [4,5,6,7]. 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 [8-14]. 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 demonstrate the expected internal rotation with knee flexion, others will actually exhibit paradoxical external rotation with knee flexion [15,16]. 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 [17,18].

Imageless computer aided surgery (CAS) 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 study assessed parameters of alignment and rotation with the tibia cut first technique using an imageless referencing computer navigation protocol. Specifically, cases were assessed looking for trends with the particular operative technique such as changes in tibial rotation with ligament balancing, and to see the particular effects of the method on implant placement. The primary objective was to learn the spectrum of changes noted with tibial rotation after total knee prosthetic placement.

Methods:

A group of 41 patients underwent primary total knee arthroplasty using the “tibia cut first” technique performed by a single surgeon experienced with this technique (JBS). The implant used was the LCS mobile bearing prosthesis in all patients. 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.(Figure 1)

The patients were selected from a consecutive series of navigated cases performed from 2003 to 2005. There were 25 males and 16 females. The average age was 56 and average body mass index (BMI) was 31. 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 image-less 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.[19]

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. For the tibia reference, the tibial centre is defined as the bisection of the transverse tibial axis [21]. 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. 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 shown by anatomical studies to approximate the centre of the dome of the talus.

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 [22]. 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 is 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.

Results:

The CAS measurement of the prerelease mechanical alignment(MA) for the cohort averaged 7° varus +/-5° (Range- 8° valgus to 20° varus). The CAOS post implant

mechanical alignment was 0.5° varus $\pm 1.2^{\circ}$ (Range: 2° Valgus to 3° Varus). This compared to postoperative radiographic mechanical alignment of 0.3° varus $\pm 1.3^{\circ}$ (Range 2° Valgus to 2° Varus). The CAS measurement of the prerelease tibial shaft axis at 90° flexion was 3.6° varus $\pm 4.3^{\circ}$ (Range: 8° Valgus to 12° Varus). The CAS postrelease tibial shaft axis at 90° Flexion was 0.6° valgus $\pm 3.6^{\circ}$ (Range: 7° Valgus to 6° Varus). I noted that the tibial shaft axis at 90° changed significantly from baseline to post implant position. Of varus knees, 25% moved over 5 degrees of more valgus and 18% moved over 10 degrees valgus at 90° flexion. Two varus knees had post tibial shaft axis of greater varus. Finally, the final tibial shaft axis compared to the transepicondylar axis was greater than 2° in 56% and greater than 5° in 15%. Ordinarily, if the mechanical alignment was corrected to neutral, the tibial shaft axis could be expected to be the same or 0° to the transepicondylar axis unless the ligament release had caused abnormal femoral rotation.

The baseline measurement of tibial rotation from 0° to 90° flexion was 6° $\pm 7.2^{\circ}$ of tibial internal rotation (Range- 8° external rotation to 19.5° internal rotation). The post implant tibial rotation from 0° to 90° flexion was 3.6° $\pm 8^{\circ}$ of tibial internal rotation (Range- 17° external rotation to 29° internal rotation). Of baseline group, it was found that 25% demonstrated tibial external rotation with flexion. After TKA, 28% had tibial external rotation with flexion. When comparing the nominal tibial position in relation to the femur at 0° before and after TKA, it was noted that the tibial rotation point at 0° moved more externally in 21% and more internally in the rest but the mean change for the overall group was 3.9° of internal rotation (range: 17° internal to 5° external). This would indicate that for the vast majority of knee, 79% had a permanent change of the

tibia to a more internal position in relation to the femur. Again factors that could cause abnormal preoperative external tibial rotational position are loss of the anterior cruciate ligament and arthritic deformity which moves the femoral/tibial articulation point more posterior on the medial femoral condyle. A change in direction of rotation in knees was noted before and after total knee arthroplasty with 21% moving more external after surgery, and 31% moved less internally. Most of these later cases had an abnormal prerelease internal rotation of 10° which was reduced to a more normal rotation.

Discussion:

This clinical study defined tibial rotation in total knee reconstruction where a mobile bearing design has been employed using the classic tibial cut first technique. Nonweight-bearing measurements were done intraoperatively using an imageless CAS system in 41 patients. The neutral mechanical axis alignment was restored within three degrees of variation in all cases. The mobile bearing prosthesis was found to accommodate the specific tibial rotation of each patient and this feature could be defined as an important attribute.

This study demonstrated some important findings regarding tibial rotation measured from prerelease of ligaments to the final positioning of the implants. There is high variability of tibial rotation in the diseased knees with many knees showing tibial external rotation with flexion. This rotation was modified by the surgical intervention. When compared with prior studies that use kinematic fluoroscopy, these changes are not unexpected. One could postulate a number of causes in the diseased state that affect tibial position. Disruption of the anterior cruciate ligament will force the tibia more

external in full extension. Lewis, et.al. identified this condition in patients who manifest a movement of the medial femoral tibial contact in a posterior direction as the proximal tibia moves into external rotation. This caused implant wear and failure to occur on the posteromedial surface of polyethylene inserts.[23] With abnormalities in ligaments and with medial osteophytes, the tibia does not necessarily externally rotate as the knee goes from flexion to extension.

This study identifies issues that may have an impact on the surgeon's specific surgical technique. There is a very clear change in position of the anterior posterior tibial axis in extension from prerelease measurement to the postrelease, post-arthroplasty measurement. This implies that release of ligaments, correction of the mechanical axis alignment, and placement of the prosthesis have an effect on this position. Many experts currently recommend a specific point on the proximal medial tibial plateau for centering the tibial prosthesis such as the medial one-third of the tibial tubercle. Additionally, the contemporary concept of a minimally invasive surgical approach increases the difficulty of placing the tibial base plate in the more external position which may be optimal if the external rotation of the anterior cruciate deficient knee is considered. Both of these problems are resolved by a mobile implant that seeks the best fit or relationship between the femur and tibia when the implants are finally inserted.

A limitation of the current study is that all CAS measurements were made non-weight-bearing. The radiographic control in this study was made with standardized weight-bearing long leg radiographs giving results similar to CAS measurements. However, most cadaveric studies and kinematic studies with roentgenographic spectro-photogrammetry (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 shown significant variability with attempting to identify the transepicondylar axis during surgery and when attempting to use computer navigation [24]. 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 [25].

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. Cadaveric studies have shown 14–19° of internal tibial rotation (positive screw-home) occurs throughout the arc of knee flexion in the normal knee [5,6,7] (Table 2). 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. 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 2). Results of this paper would confirm the presence of reverse screw-home in abnormal arthritic knees as this was identified in 25% 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 2). Studies using RSA have found that rotation may vary from 1 to 10° depending on the prosthesis and surgical

technique [12,13,14]. 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 [15]. 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 [24]. 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, tibial rotation in the arthritic knee is abnormal and is disturbed by the disease process. The surgeon seeks to optimize the prosthetic knee articulation by placing the implants in a neutral rotational position. This study demonstrates that tibial rotation can be quite variable and may be affected by changing alignment and releasing ligaments. The mobile bearing by its inherent rotational freedom allows the surgeon to compensate for these variables by allowing the bearing to seek the optimal position.

which may be difficult to identify during the surgical procedure. This feature could be defined as a significant advantage over fixed-bearing prostheses.

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Table 1. Data from assessment of nonweightbearing alignment and tibial rotation of the LCS mobile bearing total knee implant.

Measurement	Average (SD)	Range
Baseline Mechanical Axis	7° varus +/-5	8° valgus to 20° varus
Implant Mechanical Axis	0.5° varus +/-1.2°	2° Valgus to 3° Varus
Implant Mechanical Axis (Radiographic)	0.3° varus +/-1.3°	2° Valgus to 2° Varus
Baseline Tibial Shaft Axis	3.6° varus +/-4.3°	8° Valgus to 12° Varus
Implant Tibial Shaft Axis	0.6° valgus +/- 3.6°	7° Valgus to 6° Varus
Baseline Tibial Rotation	6° +/- 7.2° internal rotation	8° external rotation to 19.5° internal rotation
Implant Tibial Rotation	3.6° +/- 8° internal rotation	17° external rotation to 29° internal rotation
Baseline to Implant Tibial Position Change at 0°	3.9° internal rotation	17° internal to 5° external

Table 2. Comparison of kinematic and clinical data regarding tibial rotation after total knee arthroplasty.

Author	Test Method	Knee Condition, Prosthesis	Findings	Significance
La Fortune, et.al.(6)	Invivo, 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° of Rotation with normal gait.
Ishii, et.al.(5)	Invivo, 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.(11)	RSA, Non-weight bearing, 30° flexion to extension	ACL Deficient (n=13)	6° Internal Rotation on extension followed by external rotation	
Karrholm, et.al.(17)	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.(13)	RSA, Non-weight bearing, extension to 55°	Normal (n= 23) Tri-Con M (n=11)	6.5° Internal rotation 3.9° Internal Rotation	Tibia more external to femur in TKA than normal
Nilsson, et.al.(14)	RSA, Non-weight bearing, extension to 55°	Miller Galante (n=10) LCS (n=5)	4° Internal rotation 1° Internal rotation	Tibia more external to femur compared to normal
Stiehl, et.al.	Invivo Fluoroscopic; deep knee bend	Whiteside PCR (n=6)	4.7° (SD: 3.7°) Internal rotation; maximum 9° internal	Rotation coupled with medial condyle anterior/posterior motion

Stiehl, et.al.(18)	Invivo Fluoroscopic; deep knee bend	LCS (n=20)	rotation 0.5° Internal (ave.); range 9° internal to 6° internal	40% Reverse screw home rotation; 50% medial condylar rotation greater than lateral
Banks, et.al.(9)	Invivo Fluorscopic; weight bearing gait	Posterior cruciate retaining(n=6); posterior stabilized (n=5)	PCR: 6.5° (SD: 2.6°) 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.(15)	Invivo Fluoroscopic; deep knee bend	Normal (n=10)	16.5° Internal (ave.); maximum 27°	Positive screw home in all knees.
Dennis, et.al.(15)	Invivo Fluoroscopic; deep knee bend	ACL Deficient (n=5)	8.1° Internal (ave.); maximum 11.8°	40% Reverse screw home rotation
Dennis, et.al.(15)	Invivo Fluoroscopic; deep knee bend (overall)	Total Knee (n=760)	3.7° Internal (ave.); Range: 21° Internal to 22° External	26% Reverse screw home rotation
Dennis, et.al.(15)	Invivo Fluoroscopic; deep knee bend	Posterior stabilized (n=212); Mobile bearing cruciate sacrificing (n=76)	PS: 3.1° Internal (ave.) Range: 8° Internal to 11° External MB: 3.3° Internal (ave.) Range: 6° Internal to 11° External	PS: 24% f Reverse screw home rotation MB: 27% Reverse screw home rotation
Argenson, et.al.(8)	Invivo Fluoroscopic, deep knee bend	LPS High Flex (n=20)	5.4° Internal (ave.)(SD: 5.6°; Range 9° external to 13° internal rotation	Results similar to current study.

Legend

Figure 1. a.) LCS(Depuy Inc., Warsaw, Indiana) mobile bearing rotating platform implant utilized in this study features a central peg on the tibial insert that allows rotation around the center axis of the proximal tibia; b.) retrieval from a patient who had a successfully performing LCS mobile bearing rotating platform implant for over 10 years.



