The Journal of Arthroplasty Vol. 26 No. 2 2011

Are Current Total Knee Arthroplasty Implants Designed to Restore Normal Trochlear Groove Anatomy?

Kartik M. Varadarajan, PhD,*† Harry E. Rubash, MD,* and Guoan Li, PhD*

Abstract: Biomechanical studies have shown that external rotation of the femoral TKA component improves patellar tracking but does not restore it to physiologic values. We hypothesized that this could be due to differences in the trochlear groove geometry of TKA and normal knees. This was investigated via a virtual TKA procedure that mounted femoral components on to 3-dimensional models of healthy femurs, followed by measurement of the trochlear geometry before and after the simulated TKA. The results showed that (1) external rotation of the component brought the trochlear groove closer to normal anatomy than no external rotation; (2) however, even with external rotation, the trochlear anatomy was only partially restored to normal. Further work is needed to determine implications for patellofemoral complications observed with current TKA designs. **Keywords:** patellar tracking, trochlear groove geometry, total knee arthroplasty, virtual TKA, knee biomechanics.

Although total knee arthroplasty (TKA) has proven to be a highly successful surgical procedure, patellofemoral complications are commonly observed postsurgery. These complications include chronic pain, patellar subluxation, patellar tilt, patellar dislocation, patellar component loosening, patellar component fracture, and patellar component wear [1-4]. With recent improvements in implant designs and surgical techniques, the reported complication rates have reduced to 1% to 20% [5-8], down from 10% to 35% rate reported historically [9-11]. Nonetheless, patellofemoral complications have been implicated as a major cause of revision surgeries [4,7,8,12], with similar revision rates for TKAs with resurfaced and unresurfaced patella [13-16].

One of the key factors leading to patellofemoral complications is malpositioning of the TKA component [1,3,7,17]. For example, Berger et al [1] showed that small amounts of combined femoral-tibial internal rotation correlated to lateral patella tracking and tilting, whereas large amounts of rotation correlated to patellar dislocations and component failure. Current surgical protocol involves placement of the femoral TKA component in approximately 3° external rotation relative to the posterior condylar line (in absence of significant condylar deficiencies) or in line with the femoral transepicondylar axis (TEA). This allows both for a balanced flexion gap and favorable patellar tracking [18-22]. It is somewhat surprising that the optimal positioning of the femoral component has arisen from the results of clinical and biomechanical studies [18-22] rather than being directly provided by the implant manufacturers/designers. Perhaps this indicates that the design of the patellofemoral compartment in TKA has been developed somewhat independent of considerations regarding the effect of component positioning, and surgical protocol has evolved to work with the given component design and to optimize its performance. Nonetheless, biomechanical studies have shown that even the externally rotated position of the femoral component does not fully restore normal patellar tracking [23-26]. This suggests that even with external rotation of the component, the TKA trochlear groove may still be significantly different from the normal trochlea, and this may in part explain why patellar tracking is not fully restored to physiologic values.

A review of literature showed that although there are many studies relating to patellar kinematics in TKA knees and its relationship to femoral component position [23,25-27], there is little information regarding how the complex anatomy of the normal trochlea compares to that of the TKA component [28,29].

*From the *Bioengineering Laboratory, Orthopedic Surgery, MGH/Harvard Medical School, Boston, Massachusetts; and †Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.*
Submitted October 16, 2009; accepted December 8, 2009.
No benefits or funds were received in support of the study.
Reprint request: Guoan Li, PhD, Bioengineering Laboratory, MGH/Harvard Medical School, 55 Fruit St., GRJ 1215, Boston, MA 02114.

0883-5403/2602-0018$36.00/0
doi:10.1016/j.arth.2009.12.009

Although it is well established that external rotation of the femoral component improves patellar tracking, how this external rotation affects the effective geometry of the trochlea is poorly understood. A detailed and quantitative knowledge of the trochlear geometry in normal and TKA knees is critical for improvement of existing implant designs and for better understanding of relationship between femoral component position and resulting patellar tracking patterns so as to improve the surgical technique.

The present study aimed to provide this knowledge via investigation of 2 hypotheses: (1) external rotation of the TKA component brings the trochlear groove closer to the normal anatomy than no external rotation, and (2) even with external rotation of the component, the trochlear groove in current TKA does not fully restore normal trochlear anatomy. These hypotheses were investigated via a virtual TKA procedure to mount femoral components on to 3-dimensional models of healthy femur, followed by direct comparison of trochlear geometry before and after simulated TKA.

Materials and Methods

Overview

To test the hypotheses discussed above, the trochlear geometry was first measured using 3-dimensional models of normal femurs created from magnetic resonance imaging scans of healthy subjects' knees. Next, the trochlear geometry was remeasured after a virtual TKA procedure performed in a solid modeling software to mount femoral TKA components on to the knee models in accordance with standard surgical protocol, including 3° external rotation of the component relative to the posterior femoral condyle. In addition, the trochlear anatomy was also measured with the femoral component aligned with the posterior condyle, that is, with no external rotation. Finally, a direct comparison of the trochlear groove anatomy before and after the simulated TKA implantations was performed using paired *t* test, with significance level set at $P < .05$. The virtual TKA procedure allowed for (1) incorporation of surgical procedure that determines the position and orientation of the implant and thereby has significant effect on the effective geometry of the trochlea and (2) a direct comparison of trochlear geometry before and after TKA within the same knees, thus, minimizing the effect of interspecimen variations.

Subject Recruitment and Creation of 3-Dimensional Femur Models

Twenty-three subjects (12 male and 11 female) were recruited for this study following approval by our institute review board, and informed consent was obtained from all subjects. Only one knee from each subject was studied, and the choice of side was made randomly (9 right, 12 left). There was no significant difference in the age of the male and female subjects (32.2 ± 7.1 years and 29.6 ± 10.8 years; $P = .51$). All knees included in this study were healthy without any symptoms of soft tissue injuries or osteoarthritis, as verified via clinical examination and magnetic resonance imaging.

Magnetic resonance scans of each knee were obtained using a 3.0 Tesla magnet (Siemens, Malvern, Pa) and fat suppressed 3-dimensional spoiled gradient-recalled sequence. Sagittal plane image slices (1-mm spacing, 512 × 512 resolution, 180 × 180-mm field of view) were then segmented within a 3-dimensional modeling software (Rhinoceros, Robert McNeel and Associates, Seattle, Wash) to create 3-dimensional mesh models of the femur including the bone and articular cartilage [30,31].

Virtual TKA to Mount Femoral Component on Knee Models

The virtual TKA procedure was performed within the solid modeling software using custom written programs to mount NexGen Cruciate-Retaining (CR) and Legacy Posterior-stabilized (LPS) femoral components (Zimmer Inc, Warsaw, Ind) onto the 3-dimensional femur models. The NexGen CR and LPS components had identical trochlear groove geometries except that the trochlea extended more distally in the CR components. Therefore, only the data for CR components are presented in the results section. In coronal plane, the femoral component was mounted with a 5° valgus angle relative to the axis of the distal femoral shaft. In the sagittal plane, the distal femoral cut was made perpendicular to the shaft axis. The distal and posterior femoral cuts equaled 9 mm, measured relative to the lateral femoral condyle, and matched the thickness of the TKA component.

In the axial view, the TKA component was mounted first with a 3° external rotation relative to the posterior condylar line and next with no external rotation, that is, aligned with the posterior condylar line. In mounting the femoral component in an externally rotated position, we used the posterior condylar line as reference. Although this is one of the surgical landmarks defined in clinical literature, this landmark has been shown to be not as reliable as the TEA in case of condylar deficiencies, particularly for knees with valgus deformity [20,22,32]. However, the knee models used in this study were healthy and did not have varus or valgus deformity. In addition, the angle between TEA and posterior condylar line for knees in this study was measured to be 3.1° ± 2.1°, which agrees with values reported in literature [22,32].

Overall, the mounting protocol was similar to a measured resection technique with posterior referencing. In situations where the anteroposterior size of the femur fell between component sizes, the component closest to the femoral size was chosen. The exception was in cases of excessive mediolateral overhang, where