The Effect of Femoral Component Rotation on the Extensor Retinaculum of the Knee

Kanishka M. Ghosh,1 Azhar M. Merican,2 Farhad Iranpour,3 David J. Deehan,1 and Andrew A. Amis4

1Orthopaedic Surgery Department, Newcastle University Hospital, Newcastle upon Tyne NE2 4HH, United Kingdom; 2University of Malaya Medical Centre, Kuala Lumpur, Malaysia; 3Musculoskeletal Surgery Department, Imperial College London, Charing Cross Hospital, London W6 8RF, United Kingdom; 4Departments of Mechanical Engineering and of Musculoskeletal Surgery, Imperial College London, London SW7 2AZ, United Kingdom

ABSTRACT: Malrotation of the femoral component may cause patellofemoral complications after total knee replacement (TKR). We hypothesized that femoral component malrotation would cause excessive lengthening of the retinacula. Retinacular length changes were measured by threading fine sutures along them and attaching these to the patella and to displacement transducers. The knee post-TKR was flexed-extended while the quadriceps were tensed, then the measurements repeated after rotating the femoral component 5° internally and then 5° externally. Internal rotation shortened the medial patellofemoral ligament (MPFL) significantly from 100° to 0° extension. External rotation lengthened the MPFL significantly from 90° to 0° extension. The transverse fibers of the lateral retinaculum showed no significant differences. The MPFL attaches directly from bone to bone, so it was lengthened directly by movement of the trochlea and patella, whereas the deep transverse fibers of the lateral retinaculum attach to the iliotibial tract, so they were not lengthened directly.

Keywords: extensor retinaculum; total knee arthroplasty; femoral component rotation; patellar tracking; lateral release

Malalignment is the most frequently discussed complication in total knee replacement (TKR)1–5 and occurs in about 10–30% of patients, depending on surgical technique and the anatomical landmarks used.6 Rotational malalignment of the femoral component is a common cause of revision surgery,7 with consequences including flexion gap asymmetry, patellar maltracking, and varus or valgus malalignment of the lower extremity in the flexed position, taking the tibia out of the sagittal plane.1,2,7,8 Not all patients with a malrotated femoral component report unsatisfactory results. Some studies reported that a relative internal rotation of the femoral component between 3° and 6° is tolerable,5,6,9 while external rotation as high as 8° may not always cause clinical problems.10 However, why some patients become so strongly symptomatic that they require revision surgery and others do not are open to question.

Retinacular tensions are important in patellofemoral stability, especially in early knee flexion.11 Abnormal tensions as a result of femoral malrotation after TKR may contribute to patellar maltracking, component wear, and pain. Even in experienced hands clinical estimation of the epicondylar axis is inaccurate and cannot be relied upon as the sole determinant of femoral component rotation.12 This is especially pertinent in patients with advanced degenerative disease where anatomical landmarks are less distinct. In this situation, knowledge of retinacular behavior may help in achieving optimal patellar tracking.

Our aim was to test the hypothesis that external femoral component rotation would move the prosthetic trochlea laterally, shortening the lateral retinaculum, and lengthening the medial retinaculum, and vice versa for internal rotation.

Correspondence to: A.A. Amis (T: +44-20-7594 7062; F: +44-20-7584-7239); E-mail: a.amis@imperial.ac.uk

© 2010 Orthopaedic Research Society. Published by Wiley Periodicals, Inc.
hanging fixed weights on a cable and pulley system. The ITB was loaded to 30 N, 0° lateral, and 6° posterior to the femoral axis.16,17 The quadriceps tensions were according to the mean physiological cross-sectional areas of the muscles: RF + VI 35%, VLL 33%, VLO 9%, VML 14%, and VMO 9%.14,18

To preserve the retinacula and reduce confounding factors such as variable suture tensioning affecting retinacular length changes after closure of a standard medial parapatellar approach, a longitudinal transpatellar approach was used. The lengths of the medial and lateral retinacula were not significantly affected by this arthrotomy.19

A cruciate retaining TKR (Genesis II, Smith & Nephew, Memphis, TN) was used. The procedure was performed by the same consultant surgeon on all eight knees. The patella was resurfaced using a dome shaped inlay button centered along the median ridge. A digital vernier caliper was used to adjust the resection so that the thickness of the assembly matched the intact patella within 0.5 mm. The femoral component had a thicker posterolateral than posteroomedial condyle, enabling the implant to sit at 3° external rotation from the posterior condylar axis and maintain an equal flexion gap without the need to remove excess bone from the posteroomedial condyle. The component was positioned ensuring the posterior condyles of the implant were horizontal; this was checked with a spirit level and defined as neutral rotation. A fixed marker screw in the anterior femur was used as a datum to ensure that the anterior trochlear height and the femoral length matched the natural knee within 0.5 mm. After establishing this position, the femoral component was cemented over a “conversion module” from the TKR revision system, which allowed it to be rotated within the closed knee. Extra bone cuts on the distal femur allowed rotation of the femoral component while preserving the ligament attachments (Fig. 2a). The tibial cut was made using an extramedullary guide aligned with the rod. The trial tibial tray was allowed to “float” to a functional position relative to the femoral component—in all cases this lay just lateral to the medial edge of the tibial tubercle. Flexion and extension gaps were assessed subjectively in full extension and 90° of flexion. The transpatellar arthrotomy was closed using two cannulated cancellous screws placed across the patella.19 The incisions in the quadriceps and patellar tendon were approximated using Vicryl 2/0 (Ethicon Co., Somerville, NJ).

Tibiofemoral flexion was measured dynamically using a Polaris Optical Tracking System (NDI Intl., Waterloo, ON, Canada). One optical tracker was placed on each of the femur and tibia. The specimen orientation was then defined by digitizing landmarks including the most posterior points of the femoral condyles to define the medial-lateral direction. Knee flexion was calculated as the angle between the femoral and tibial axes in the sagittal plane perpendicular to the medial–lateral axis using Visual 3D (C-Motion Inc., Rockville, MD).20

Retinacular length changes were measured using a previously described technique,13 using monofilament sutures (Ethilon 2/0, Ethicon Co.) attached to Linear Variable Displacement Transducers (LVDTs—Solartron Metrology, Bognor Regis, UK). Length changes were recorded using device specific software (Solartron “Orbit” Excel). To measure length changes in the MPFL, a suture was passed from the LVDT through a screw eye secured at the epicondylar origin of the MPFL, then threaded along the ligament’s fibers and secured at the superomedial corner of the patella. Because the deep transverse band in the lateral retinaculum originates and inserts into two mobile structures (ITB and lateral patella), we measured their
movements separately to calculate the length change of the fibers in between. The transverse band linked the superolateral corner of the patella to the deep aspect of the ITB. One suture passed from the LVDT through an eyelet secured on the ITB to the patella along the transverse band of fibers. A second LVDT had a suture passing to the ITB eyelet only (Fig. 1). Thus, length change in the deep transverse band was calculated from the difference between the two values.

Ten preconditioning cycles of passive flexion-extension were performed with the quadriceps loaded before testing. The knee was flexed by pushing posteriorly against the tibial intramedullary rod, using a transverse nylon rod, to avoid imposing secondary moments. Data were sampled at 12 Hz while the quadriceps extended the knee slowly from 110° to 0°. Testing was first conducted with the standard TKA with the femoral component in neutral rotation, then repeated with the femoral component internally rotated 5° and then externally rotated 5°.

Two-way repeated-measures ANOVA with post-hoc Student’s paired t-tests were used to examine length changes between neutral and internal rotation or neutral and external rotation and knee flexion at 10° intervals, for each of the retinacula. Significance was set at $p < 0.05$.

**RESULTS**

The mean pattern of length change in the MPFL after TKR in neutral rotation was close to isometric, with a lengthening of $3.0 \pm 1.9$ mm as the knee extended from 110° to 30° ($p = 0.044$) followed by a shortening of $0.5 \pm 2.2$ mm as the knee extended fully (Fig. 3). With the femoral component in neutral rotation, the deep transverse band of the lateral retinaculum shortened by a mean of $7.9 \pm 6.3$ mm as the knee extended from 80° to 0° ($p < 0.0001$, Fig. 4).

Internal rotation of the femoral component caused an overall shortening of the MPFL when compared to neutral rotation ($p < 0.0001$). Significant changes occurred from 100° to 0° of extension; as the knee extended this became more significant: 100°: $-0.9 \pm 0.3$ mm ($p < 0.05$); 90° to 80°: $-1.03 \pm 0.1$ mm ($p < 0.01$);

70° to 0°: $-1.4 \pm 0.2$ mm ($p < 0.001$). External rotation caused an overall lengthening ($p < 0.0001$). Significant changes were found from 80° to 0° of knee extension; 80°: $-1.2 \pm 0.1$ mm ($p < 0.01$) and 70° to 0°: $-1.4 \pm 0.1$ mm ($p < 0.001$, Fig. 3).

Internal or external rotation of the femoral component caused small but significant ($p = 0.0002$ for internal and $p < 0.0001$ for external) overall differences in length of the lateral retinaculum (Fig. 4). However, no significant differences occurred at any flexion angle with internal or external rotation.

**DISCUSSION**

We tested the hypothesis that malrotation of the femoral component following TKR would stretch the retinaculum. This was quantified by measuring length changes in the principal structures of the medial and lateral retinaculum. We speculated that, because the patella is guided by the trochlear groove, femoral malrotation would cause maltracking. We hypothesized that the resultant tilt and shift of the patella would cause significant lengthening of the retinaculum on one side along with shortening of the other, and vice versa.

Five degrees of internal or external rotation caused significant length changes in the MPFL. External rotation resulted in lengthening and internal rotation caused shortening. Significant differences in length change patterns occurred over a wider arc of motion when the femoral component was internally rotated (100°–0°). In contrast, femoral component rotation did not cause significant length changes in the deep transverse fibers of the lateral retinaculum. We have not reported the length changes of the retinacula as “stretching” or “slackening” because our interobserver comparisons found such large differences of identification of the transition point between slack and taut fibers.
that to report what was stretching or slackening would be unreliable.

Because the patella is guided by the trochlear groove, it moves with the prosthesis when the femoral component is malrotated (Fig. 5). Malrotation when the knee is near extension causes more marked changes in trochlear groove position than in flexion, where the groove is close to the axis of rotation of the femoral component. External component rotation shifts the trochlear groove laterally and decreases the effectiveness of the lateral ridge in resisting lateral translation of the patella. This is partly counteracted by the reduction of lateral forces from the reduced Q angle. The lengthening of the MPFL in this experiment indicates that a resultant lateral shift and/or tilt of the patella occurred within the lateralized trochlear groove.\(^7\) Conversely, internal component rotation causes the lateral flange to rise, shifts the trochlear groove medially, and only the shallow medial trochlear facet resists medial translation of the patellar component. The reduction in the length of the MPFL meant that a medial translation and/or tilt of the patellar component had occurred.

The lateral retinaculum behaved in an unexpected manner: femoral component rotation of \(\pm 5^\circ\) did not cause significant changes in the length of the deep transverse fibers. Therefore, the ITB moved backwards and forwards not only with flexion and extension, but also with the patellar tilt and shift that accompanied the movement of the prosthetic trochlea (Fig. 5). Thus, femoral component external rotation allowed the deep transverse fibers of the lateral retinaculum to move posteriorly and the ITB with them, so length changes in the transverse band were nonsignificant. In degenerative disease, capsular structures are stiffer,\(^22\) possibly resulting in abnormal tensioning of the lateral retinaculum, but no data exist to allow us to simulate that situation. Since doing this experiment, we found\(^23\) that the deep transverse fibers of the lateral retinaculum are an order of magnitude stiffer than the MPFL,\(^24\) so the MPFL is more likely to demonstrate length changes.

Patellofemoral problems cause a considerable proportion of complications after TKR, including loosening, wear, instability, and patellar fracture.\(^1\) In vitro studies showed that femoral component malposition affects patellofemoral kinematics and abnormal tensioning of the soft tissues may also occur.\(^1,21,25,26\) In general, the position of the patella followed the movement of the trochlear groove, shifting and tilting laterally with femoral external rotation. Over-stuffing the patellofemoral joint causes significant lengthening of the retinacula\(^27\) and insertion of a TKR may increase retinacular tension.\(^28\) Our data could be useful for computer modeling of the patellofemoral joint.

Most studies of femoral component rotation have rotated the component from the posterior condylar axis to the transepicondylar axis and then noted more physiological tracking. Because the Genesis II was designed to sit in \(3\,^\circ\) external rotation from the posterior condylar axis, direct comparisons with other published work required that the implants were taken beyond the transepicondylar axis in both directions. Miller et al.\(^29\) found that if the femoral component was aligned parallel to the transepicondylar axis, more normal patellar tracking occurred, minimizing patellofemoral shear forces early in flexion.

Clinical studies have shown that external rotation of the femoral component results in a reduction in lateral release rates.\(^1,25,30\) Internal rotation can be expected to stretch the lateral retinaculum, increasing the likelihood of lateral retinacular release.\(^26\) However, our study did not show significant length changes in the transverse fibers of the lateral retinaculum following femoral malrotation, suggesting that other retinacular structures may be affected.

The main limitations of our study arose from the use of normal cadaveric knees, without obvious degenerative disease. We could not simulate pathological changes such as tight bands in the lateral retinaculum. The clinical aim of TKR is to restore normal knee behavior, and so it is necessary to start with normal knees to isolate and understand the effects of femoral component rotation. Development of the cadaveric model should include the effects of degenerative pathology after clinical research to define the tissue changes. Factors such as the chronicity of the degenerative process and height of the patella will contribute to the large variability expected clinically, making meaningful experimental findings elusive. Also, there is a lack of uniformity in clinical studies, regarding which anatomical structures are released and differing and ill-defined indications for doing a lateral release. The force applied to the quadriceps was limited by tearing of the muscles of the elderly specimens, so normal physiological magnitudes were not attained. The muscle tension was constant across the arc of knee flexion, whereas in life the tension increases as we squat down; this may have affected the length change patterns recorded. Knee flexion beyond \(110^\circ\) would have been desirable, but aspects of the rig prevented this. Despite these limi-
tions, we measured the effects of femoral prosthesis malrotation on length changes in the retinaculum. Measurements were made dynamically to capture transient events. The muscles were loaded in physiological directions. The ITB was also loaded in accordance with earlier studies\textsuperscript{16,17} that showed that it affects patellar tracking.\textsuperscript{17,31}

Alterations in patellar tracking may cause abnormal retinacular tensions, and the extensor retinaculum contributes significantly to patellar stability.\textsuperscript{15,18,32} Malrotation of the femoral component following TKR causes significant differences in length change patterns within the principal structures of the retinaculum. This may be related to lateral retinacular release after TKR, which may have an incidence as high as 50\%\textsuperscript{33} and has been related to loosening of the patellar component.\textsuperscript{34} This effect was larger in the MPFL than in the deep transverse fibers of the lateral retinaculum, contrary to popular understanding. These length changes may be related to the tensile behavior of the retinaculum: the MPFL stretches 26 ± 7 mm to failure,\textsuperscript{24} the deep transverse fibers of the lateral retinaculum 11 ± 4 mm.\textsuperscript{23} A recent study of patellar stability found that the lateral capsule was a greater contributor than the transverse fibers near knee extension,\textsuperscript{35} so this structure may affect patellar tracking if the femoral component is malpositioned in internal rotation. It has become accepted that patellar maltracking often relates to excessive tension in the lateral retinaculum. Our study and previous work\textsuperscript{13} found that the transverse fiber band of the lateral retinaculum shortens when the knee extends, because the ITB tract to which it attaches moves anteriorly with extension. In contrast, the MPFL attaches directly from bone to bone, so movement of the femoral component, and with it the patella, directly affects its length.

ACKNOWLEDGMENTS
K.M. Ghosh was supported by Smith & Nephew (UK) Ltd, A.M. Merican by the University of Malaya Medical Centre and the Arthritis Research Campaign, and F. Iranpour by the Furlong Charitable Foundation for Research. The tissue specimens were supplied by the International Institute for the Advancement of Medicine, Jessup, PA.

REFERENCES


