Length Change Patterns of the Extensor Retinaculum and the Effect of Total Knee Replacement

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ABSTRACT: Patellofemoral dysfunction following total knee replacement (TKR) is a significant clinical problem, but little information exists on the mechanics of the patellofemoral retinaculum or the effects of TKR on these structures. We hypothesized that TKR would cause significant elongation of the retinaculum. Retinacular length changes were measured by threading sutures along the retinaculum, fixing the sutures to the patella and the iliotibial band (ITB), and attaching the femoral ends to displacement transducers. The intact knee was flexed-extended while the quadriceps and ITB were tensed and the retinacular length change patterns were recorded. The measurements were repeated post-TKR. The medial patellofemoral ligament (MPFL) was close to isometric, stretching 2 mm in terminal knee extension, whereas the lateral retinaculum slackened 8 mm from 110° to 0° flexion. TKR did not cause significant elongation of either of the retinacula, the largest change being 3 mm elongation of the MPFL around 40°, which stretched the MPFL by 1.4 mm above its maximum natural length. Thus, this work did not support the hypothesis that TKR causes significant elongation of the retinaculum sufficient to affect knee function. © 2009 Orthopaedic Research Society. Published by Wiley Periodicals, Inc. J Orthop Res 27:865–870, 2009

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Demand is increasing for improved knee function after surgery. Despite continuing evolution in prosthetic design and surgical methods, stiffness after total knee replacement (TKR) remains a disabling complication. The prevalence appears to be relatively low, but has not been clearly defined, primarily due to ambiguity in the literature concerning its definition. The prevalence of knee stiffness was recently reported as 1.3%–3.7%,1,2 though higher levels (8%–12%) were reported in older literature.3

Stiffness after TKR may be caused by limited preoperative motion, biological predisposition, intraoperative technical problems, poor patient motivation, and inadequate postoperative rehabilitation.1,4–6 During knee motion, tensions in the ligaments, capsule, and extensor envelope may restrict flexion and affect implant wear.6,7 Awareness of the role of the extensor retinaculum in patellofemoral kinematics is increasing.8 While studies to date have focused on its role in patellar instability,8–11 the influence of TKR is unknown.

The positioning and thickness of TKR components may cause the surrounding soft tissues to be stretched. Abnormal soft tissue tensions post-arthroplasty may alter patellofemoral kinematics and stability; the literature shows that these mechanical factors can lead to clinical problems such as pain, stiffness, and excessive wear. Our aims were: to measure the length change patterns of the medial and lateral retinaculum during knee extension; and to test the hypothesis that insertion of a TKR would cause significant elongations of the retinaculum.

MATERIALS AND METHODS

Specimen Preparation

Eight right knees aged 69 years (range, 57–87 years) and including 20 cm of femur and 15 cm of tibia were obtained from a tissue bank following ethical approval. They were sealed in polyethylene bags and frozen at −20°C prior to use. They were thawed in a refrigerator at 3°C for 24–36 h, kept moist using normal saline, and then prepared as in previous work.12 The skin, underlying fat, and muscles other than the distal quadriceps were removed. Care was taken to preserve the retinaculum, quadriceps muscles fasciae, and the iliotibial band (ITB). The quadriceps were then separated into six components: rectus femoris (RF), vastus intermedius (VI), vastus lateralis longus (VLL), vastus lateralis obliquus (VLO), vastus medialis longus (VML), and vastus medialis obliquus (VMO). The distal muscle fibers merged together and were left intact to ensure that their actions were as physiologic as possible. The VI was separated from the femur. Cloth strips were looped over and sutured to the proximal end of each muscle and the ITB to provide attachment for a muscle loading cable. The RF and VI were looped together to form a central muscle group. The head of the fibula was fixed to the tibia by two bone screws, to maintain its anatomical position. A brass intramedullary sleeve was secured into the femur, and an intramedullary rod into the distal tibia, using polymethylmethacrylate (PMMA) bone cement.

Experiment Set-Up

The knee specimen was mounted into the testing rig (Fig. 1) by sliding the intramedullary brass sleeve over a fixed rod and clamping tightly. This allowed axial rotation of the femur, ensuring that a line joining the most-posterior points of the condyles was horizontal. The muscle alignment system was adjustable, allowing each muscle head to be loaded in its physiologic direction relative to the femoral axis.13,14 A 175 N load was applied to the quadriceps muscle groups by 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.15,16 The
quadriceps tension distribution was according to the mean physiologic cross-sectional areas of the muscles.  

Data Collection

Tibiofemoral flexion was measured using a Polaris Optical Tracking System (NDI Intl., Waterloo, Canada). One optical tracker was placed on the femur and another on the tibia. The fully extended position was defined as when the tibial intramedullary rod was parallel in the sagittal plane to the femoral anatomical axis. Knee flexion was calculated using Visual 3D (C-Motion Inc, Rockville, MD).

Length changes were measured in the principal structures of the medial and lateral parapatellar retinacula. On the medial side, the most important soft tissue structure for patellar stability is the medial patellofemoral ligament (MPFL). The MPFL was found in all eight specimens running transversely between the proximal half of the medial border of the patella to the femur immediately proximal to the medial epicondyle in the second tissue layer, below the superficial fascia and above the capsule. The lateral retinaculum is more complex, because of the overlying ITB passing alongside the patella forming a multilayered structure. The deep aspect of the ITB acts as the origin for a distinct transverse lateral retinacular structure that attaches to the mid-lateral edge of the patella. Often called the lateral patellofemoral band, it is not attached to the femur, except indirectly via the proximal and distal ITB attachments. It is this “deep transverse band” that is transected in a conventional open lateral release procedure, so this was selected for length change measurements.

Length changes were measured using a monofilament suture attached to the sliding core of a linear variable displacement transducer (LVDT; Solartron Metrology, Bognor Regis, UK; 1 μm resolution) (Fig. 2), and device-specific software (“Orbit” Excel, Solartron Metrology). The suture was kept under constant low tension (about 0.2 N) by attaching a rubber band to the LVDT core. A single monofilament suture (Ethilon 2/0, Ethicon, Somerville, NJ) was used to measure length changes in the MPFL. A suture was passed from the LVDT through a screw eye secured at the origin of the MPFL at the mid-point of its width in the deepest part of the sulcus between the medial epicondyle and the adductor tubercle. The suture was then threaded along the fibers of the ligament and secured at its attachment to the superomedial corner of the patella. This method has been used...
to measure length changes in the fibers of the anterior cruciate ligament. 25

Because the deep transverse band in the lateral retinaculum originates and inserts into two mobile structures (ITB and lateral patella), it was necessary to measure motion of the two structures separately to calculate the length change of the fibers in between (Fig. 2). With the quadriceps loaded and the knee extended, the palpably thick transverse band lay in a straight line from the superolateral corner of the patella, passing posteriorly to the deep aspect of the ITB. Movements were measured along one suture passing from an LVDT through an eyelet sutured into the ITB to the patella along the transverse band of fibers. A second LVDT measured movements with a suture passing to the ITB eyelet only. Thus, length change in the deep transverse band was calculated by subtracting the two values.

Before testing, 10 preconditioning cycles of passive flexion-extension were performed against the extending action of the quadriceps tension. This was done by pushing posteriorly against the tibial intramedullary rod, using a nylon rod hand-held transversely across the end of the rod to avoid imposing secondary movements with a suture passing to the ITB eyelet only. Thus, length change in the deep transverse band was calculated by subtracting the two values.

Total Knee Replacement

To preserve the retinaculum and reduce confounding factors such as variable suture tensioning from affecting ligament length changes after closure of a standard medial parapatellar approach, a transpatellar approach extending 5 cm proximally into the quadriceps tendon and 3 cm distally into the patellar tendon in the line of fibers was used to access the joint. 26 This approach does not cause significant length changes in the medial and lateral retinacula.

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 onlay button centered on the median ridge. The thickness of the patella was measured pre- and post-TKR using vernier calipers to ensure that the original thickness was restored to within ±0.5 mm. A standard surgical protocol and instruments were used for component implantation as recommended by the implant manufacturer. Anterior referencing femoral instrumentation was used to ensure restoration of the thickness of the patellofemoral joint. If the indicated size fell between two sizes, the smaller size was chosen to avoid overstuffing of the flexion space. As the distal half of the tibia was absent, the tibial cut was made using an extramedullary guide aligned with the intramedullary rod. Flexion and extension gaps were assessed subjectively in extension and 90° flexion. The Genesis II system uses a modified femoral component with a thicker posterior-lateral than posterior-medial condyle. This enabled the implant to have 3° external rotation from the posterior condylar axis and maintain an equal flexion gap without the need to remove excess bone from the postero-medial condyle. The component was positioned at 3° external rotation from the posterior condylar axis by ensuring the posterior condyles of the implant were in the same position as the native knee; this was confirmed to correlate with the epicondylar axis throughout the work and was defined as neutral rotation. The transpatellar arthroscopy was closed using two cannulated cancellous screws placed through pilot holes drilled prior to the arthroscopy across the patella proximally and distally, without disrupting suture attachment points. The cuts in the quadriceps and patellar tendons were approximated without tension using Vicryl 2/0 sutures (Ethicon).

Statistical Analysis

A two-way repeated-measures ANOVA with Bonferroni post-tests was used to determine differences in length of the MPFL and deep transverse band of the lateral retinaculum between the intact knee and TKR as the knee extended from 110° to 0°. Significance was set at p < 0.05.

RESULTS

Length Changes in the MPFL of the Intact Knee

The mean length change pattern for the MPFL in the intact knee was close to isometric (Fig. 3), with a mean tightening of 1.9 ± 2.3 mm (−4.3 to +4.7 mm) (mean ± SD; range) from 70° flexion to extension; this was not significant (p = 0.09).

Length Changes in the Deep Transverse Band of the Lateral Retinaculum in the Intact Knee

The lateral retinaculum slackened (Fig. 3) by 8.0 ± 5.0 mm (14.2–0.5 mm) as the knee extended from 110° to 0° (p < 0.0001).

Length Changes in the MPFL after TKR

The mean pattern of length change in the MPFL after TKR remained close to isometric (Fig. 4), with a
tightening of 3.0 ± 1.9 mm (−1.1 to +5.8 mm) as the knee extended from 90° to 30°. While the overall pattern of MPFL length was significantly different \( (p < 0.0001) \) between the native knee and post-TKR, post-testing did not show significant differences at any specific flexion angle \( (p > 0.05) \). The largest difference between the native knee and post-TKR was 3.1 mm at 40° flexion (95% CI of difference: −0.3 to 6.5 mm). The greatest stretching above the native length was 1.4 mm at 30° flexion.

Length Changes in the Deep Transverse Band of the Lateral Retinaculum after TKR

The lateral retinaculum was close to isometric when the knee extended from 110° to 70° (Fig. 5), after which it slackened by 10.2 ± 6.3 mm (14.5 mm slackening to 0.5 mm tightening) as the knee reached full extension. An overall mean slackening of 0.4 mm occurred post-TKR \( (p = 0.01) \), ranging from 2.5 mm slack at 0° \( (p < 0.001, 95\% \text{ CI: } −4.1 \text{ to } −0.9 \text{ mm}) \) to 0.4 mm tighter at 70° \( (p > 0.05, \text{ from } 10° \text{ to } 110°) \).

DISCUSSION

This study yielded data on the length changes of both the medial and lateral patellar retinacula during knee extension and on the effects of TKR on those length change patterns. In the intact knee, there were contrasting length change patterns, between the medial and lateral retinacula. The MPFL was close to isometric across the range of motion, lengthening by a mean of 2 mm in the final 30° of knee extension. The MPFL was close to isometric across the range of motion, lengthening by a mean of 2 mm in the final 30° of knee extension. In contrast, the lateral retinaculum was longest in the flexed knee and slackened by a mean of 8 mm in the final 70° of knee extension. The implantation of a knee replacement did not cause significant stretching of the retinacula. The MPFL was 3 mm tighter than normal across the arc from 60° to 20° extension while the lateral retinaculum slackened 2 mm in the terminal 20° of knee extension. Neither change took the lengths of the retinacula above 2 mm extension beyond their normal maximum lengths. Thus, our findings refute the hypothesis that TKR causes retinacular elongation that might affect knee function. Although our results are related to this specific implant type and surgical technique, the authors have not found prior measurements of the length change behavior of the lateral retinaculum or of the effect of TKR on the lengths of either the medial or lateral retinaculum.

Several studies reported the length change pattern of the MPFL; the general consensus has been that it is desirable to create an isometric reconstruction. However, a study of the effect of MPFL deficiency on patellar lateral stability showed that the MPFL had its largest effect in the last 20° of extension. That led to the suggestion that it might be preferable to ensure that the MPFL graft was longest in extension, slackening in flexion. That would avoid over-pressurizing the medial trochlea and fits with our data.

The finding that the transverse band of the lateral retinaculum slackened by 8 mm when the knee was extended is in accordance with the motion of the ITB alongside the knee, moving anteriorly with knee extension and pulling posteriorly in flexion. Other work found that lateral retinaculum tension rose to a maximum at 60° flexion in vitro, or found a continuous rise in tension to 120° flexion during surgery in vivo; these tension patterns match our length changes.

After TKR, the length changes in the retinacula will be affected by the femoral condylar geometry and the tracking of the patella, so our study implies that TKR...
design and alignment did not significantly alter patellar tracking. Two prior studies\textsuperscript{32,33} found that patellar tracking was not altered from the intact knee, examining the Genesis II (Smith & Nephew, Memphis, TN), NexGen (Zimmer, Warsaw, IN), and PFC Sigma (DePuy J&J, New Brunswick, NJ) prostheses. In four of the eight knees that we tested, the MPFL lengthened as the TKR knee extended to 40°, then slackened towards full extension. Although this was not a significant effect for the whole group of knees, we presume that it reflects patellar tracking over the most-prominent anterodistal part of the femoral component. Again, our results relate to one implant design, and the femoral component was positioned carefully to match the original femoral component. Other prostheses, with different sagittal plane geometries, would likely cause different length change patterns in the retinacula, also as would different choices of component position and size.

The main limitations of our study were that the experiments were performed on normal cadaveric knees without overt signs of degenerative disease. Thus, we could not simulate pathological changes in the soft tissues that may be relevant, such as tight bands in the lateral retinaculum. The presence of such pathology might magnify the changes produced in this experiment. The force applied to the quadriceps was limited by tearing of the muscles, and so normal physiologic magnitudes were not attained. In addition, only the extensor muscles and ITB were loaded, so the effects of antagonistic muscle co-contraction on the retinacula remain unknown. This may have affected the length change patterns presented.

In summary, a method to measure the length changes in the retinacula was developed. Differing behavior was found between the medial and lateral retinacula: the MPFL was close to isometric, while the lateral retinaculum slackened by 8 mm over the last 70° of extension. Insertion of a particular design of TKR in the recommended alignment did not cause significant elongation of the retinacula when compared to the intact knee. Future work could use this method to examine effects such as femoral component rotation and patellar overstuffing.

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**REFERENCES**


