Patellofemoral Forces After Medial Patellofemoral Ligament Reconstruction

A Biomechanical Analysis

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INTRODUCTION

Patellofemoral joint instability and subluxation are common causes of anterior knee pain and dysfunction. A complex interaction takes place between the anatomic patellofemoral joint articular geometry and the mechanical forces that help stabilize the patella. Anatomic restraints to patellar stability include the lateral trochlear slope and the quadriceps (Q) angle.2,21

Mechanical forces that help with patellar stability are divided between active and passive restraints. The rectus femoris and vastus intermedius act directly along the femoral axis and encompass the active patellar restraints. Included with these muscle stabilizers are the vastus lateralis and medialis, which have oblique insertions onto the patella and help stabilize the patella in a medial/lateral direction.15 Passive restraints to patellar stability include the patellar tendon and the medial and lateral retinacula. The lateral retinaculum is a complex structure comprised of two major components: the deep transverse retinaculum and the superficial oblique retinaculum.16 The medial retinaculum consists of the medial meniscopatellar ligament and the medial patellofemoral ligament (MPFL).

The MPFL is the primary passive restraint to lateral subluxation/dislocation of the patella.5,7,8,11,19,30,31 Rupture of the MPFL is a well-known consequence of lateral patellar dislocations.8 Although conservative management is the first line of treatment for first-time lateral patellar dislocations,7,24 operative intervention, specifically reconstruction of the MPFL, has been a secondary treatment option in combination with other procedures for passive and dynamic patellar stabilization.17

The techniques for MPFL reconstruction have been well described in the literature.5,10,13,14,27,28,31,35 Prospective studies have demonstrated the effectiveness of MPFL reconstruction in mid-term follow-up.1,14,29 Evidence indicates that with isolated sectioning of the MPFL, a 50% increase in lateral patellar displacement is seen9,19 and normal patellar tracking can be restored with reconstruction of the MPFL.32

The specific indications for MPFL reconstruction, however, have been less clear, and isolated MPFL reconstruction has been used to reduce patellar tracking from a malaligned position back onto the central trochlea, thus risking medial patellofemoral joint overload.5,10 Therefore, although patellar stability can be achieved with surgical realignment, the ability to alleviate anterior knee pain is much less predictable.22,26 The authors are unaware of any study specifically looking at patellofemoral contact pressures after MPFL reconstruction in a distal patellar malalignment state. The hypothesis of this study is that correction of a laterally subluxated patella secondary to a distal malalignment (ie, abnormal tibial tubercle alignment) with only a reconstructed MPFL, leads to significantly increased pressures at the medial patellofemoral joint. These pressures are thought to be increased due to the posterosomedially directed forces created by the MPFL reconstruction. In addition, the contact forces at the patellofemoral joint after restoration of the distal malalignment to its normal state were also evaluated. The obvious long-
term concern would be the effect the posteromedially di-
rected forces have on the articular cartilage of the patel-
lofemoral joint and if this predisposes the knee to early
patellofemoral arthritis.

MATERIALS AND METHODS

Five fresh-frozen cadaver knee specimens were dis-
sected of all skin and subcutaneous tissues, visualizing
the proximal (rectus femoris, vastus intermedius, vastus
lateralis, vastus medialis), distal (patellar tendon), medial
(medial retinacular structures), and lateral (lateral reti-
nacular structures) patellar restraints. The tibia and femur
were each sectioned approximately 25 cm from the joint
line. The semitendinosus tendon was dissected and taken
as a free graft.

The quadriceps muscle was specifically dissected to
obtain clear visualization of the vastus lateralis, vastus
medialis, vastus intermedius, and rectus femoris muscles.
In addition, the biceps femoris and semimembranosus
muscles were also isolated. Medial and lateral parapatel-
lar incisions (including sectioning the native MPFL) were
made to isolate the quadriceps muscle and have full ac-
cess to the knee. With the extensor mechanism mobile,
pictures were taken of the articular cartilage of the knee
and areas of cartilage damage were recorded. One-inch
wide nylon straps were sewn onto each tendon/muscle
that was loaded (vastus medialis, vastus lateralis, vastus
intermedius/rectus femoris, biceps femoris, and semi-
membranosus) using a #2 Fiberwire (Arthrex Inc, Naples,
Fla) in a whipstitch type fashion.

A custom loading setup was used for mounting of the
cadaver specimens (Figure 1). The setup included clamps
for securing the femur in a horizontal position, with the
tibia hanging freely, in addition to a pulley system for
loading the quadriceps and hamstring muscles through
the nylon straps. According to previous studies, the quadri-
ceps was loaded in a specific fashion. The tension angle
of the vastus medialis (proximal fibers) was 15°-18° medially
in the frontal plane. The tension angle of the vastus late-
ralis was 12°-15° laterally in the frontal plane. The vastus
intermedius had a tension angle parallel with the plane of
the anterior surface of the femoral shaft. The rectus femo-
ris muscle had a tension angle of 7°-10° medially in the
frontal plane and 3°-5° anteriorly in the sagittal plane. The
hamstring muscles were loaded in line with the axis of
the femur. The vastus medialis, vastus lateralis, rectus
femoris, vastus intermedius, and hamstring muscles were
each loaded with a 45 N weight.

To track the patella in space to determine tilt and sub-
luxation, three Polhemus Fastrak (Polhemus Inc, Colches-
ter, Vt) sensors (a six degree-of-freedom motion tracking
system) were mounted on each knee specimen: one on
the proximal femur, one at the distal anteromedial surface
of the tibia, and one on the anterior surface of the patella.

The pressure at the patellofemoral articulation dur-
ing knee range of motion was recorded using a K-scan
#4000 sensor (TekScan Inc, South Boston, Mass), which
is a real-time pressure mapping and force measurement
device. The K-scan #4000 sensor includes two separate
sensor pads that record data simultaneously. The sensor
was calibrated according to the manufacturer’s recom-
mandations. Each sensor was preconditioned using five
pressures within the range expected during the experi-
ment. The pressure was evenly applied to all of the sen-
sors and the sensitivity of the sensors was adjusted so that
the output for all of the sensors was equal. The final cali-

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Figure 2. The mounted TekScan pads are shown on the trochlea.

Figure 3. Lateralization of the tibial tubercle using a flat osteotomy cut. This created the laterally subluxated patellar state.

bration, as the loads recorded will be over a large range of forces. Two loads of known pressure were applied to the sensor pads. The sensor was placed between two hard metal surfaces with a thin sheet of urethane on the top of the sensor to evenly distribute the load. The pressures chosen were 2-3 times greater than one another to yield a calibration equation approximately $Y = AX^b$. The sensor pads were then mounted on the medial and lateral femoral trochlea using tacks that were flush with the articular cartilage (Figure 2). The K-scan sensor was then attached to a computer for data acquisition.

A methylene-blue marker was used to identify specific locations on the patella, femur, and tibia. The central patellar ridge was located on the articular side of the patella and using pins placed at the proximal and distal locations of the ridge from the inside out, the ridge was marked on the anterior surface of the patella for ease of visualization. Two points on the tibial tubercle 1 cm apart and two points in the center of the femoral trochlea in a superior-inferior direction along Whiteside’s line were chosen and marked with methylene-blue dye. Each of these points was recorded in relation to a coordinate system based on the mounting setup using a MicroScribe digitizer (Immersion Corp, San Jose, Calif). The relation of the points on the tibial tubercle to the trochlea was used to define the tibial tubercle to trochlear groove (TT-TG) measurement and allow lateralization of the tibial tubercle in a standardized fashion. The relation of the central patellar ridge to the trochlear points was used to define the subluxation of the patella (ie, patellar centralization).

Previous studies created abnormal patellofemoral tracking by transferring the tibial tubercle medially or laterally to decrease or increase the Q-angle, respectively. Abnormal patellofemoral tracking usually is a combination of not only an abnormal tibial tubercle location, but an abnormality of the entire lower extremity. The authors believe that an abnormal tibial tubercle location would reproduce the lower extremity abnormality in a more predictable fashion. Therefore, a laterally subluxated patella was created for this study by lateralizing the tibial tubercle (ie, increasing the Q-angle of the lower extremity) with a flat osteotomy cut to a TT-TG distance of 12 mm. A digital MicroScribe device was used to confirm the lateralization of the tibial tubercle.

Testing Protocol

The testing protocol consisted of four distinct phases. The first phase, the intact state, consisted of the specimen mounted on the jig with the quadriceps and hamstring muscles loaded as described above. The Polhemus tracking system and TekScan sensor pads were also attached to the knee. At five specific knee flexion angles (0°, 15°, 30°, 45°, and 60°), data from the knee were recorded, including TT-TG distance, patellar centralization, patellar tilt, and patellofemoral force readings. All knee flexion angles were confirmed with a goniometer.

In the second phase, the tibial tubercle was laterali- zed with a flat osteotomy cut and secured with two fully threaded 4.5-mm cortical screws (Figure 3). The lateralization of the tubercle produced a 12-mm TT-TG and created the abnormal patellar subluxated state. The quadriceps and hamstring muscles were reloaded, and the specimen was taken through the pre-defined flexion angles recording to the TT-TG distance, patellar centralization, patellar tilt, and patellofemoral forces.

The third phase consisted of reducing the patella to its centralized state using an MPFL reconstruction (Figure 4),
The technique for MPFL reconstruction was based on using a free tendon graft (semitendinosus) secured to the femoral attachment site with a Bio-Tenodesis screw (7, 8, 9), and attachment of the graft to the patella via two 3.0-mm Bio-Suture-Tak Anchors (Arthrex Inc). The semitendinosus graft ends were secured with a #2 Fiberwire (Arthrex Inc) in a whipstitch type fashion for a distance of 20 mm. The graft was then folded in half and the center portion was secured with a #2 Fiberwire whipstitch for a distance of 20 mm. This produced a graft with two tails. The graft was then sized and the same size reamer as graft size was chosen.

The origin of the MPFL was identified using the landmarks of the medial epicondyle, the medial collateral ligament, and the adductor tubercle. The femoral origin of the MPFL resides in the “saddle” between the adductor tubercle and the medial epicondyle. A 2.4-mm Beath pin was placed in the center of the MPFL femoral attachment and drilled across the knee exiting the other side. A reamer was used to create the femoral bone tunnel to a depth of 20 mm with the appropriately sized reamer. The tails of the suture at the folded end were passed via the Beath pin across the femur and the graft pulled into the femoral socket. A guide wire was placed into the femoral tunnel and the graft secured using a Bio-Tenodesis screw (Arthrex Inc).

Two Arthrex 3.0-mm Bio-Suture-Tak anchors with needles were placed in a cancellous trough created at the medial edge of the patella (from the mid-waist, superiorly) anterior to the articular cartilage. Prior to insertion of the suture anchors, the sutures were re-threaded to produce a loop out of one end of the suture anchor. With the anchors in place, each free limb of the graft was placed into one loop of the suture anchor, and with the knee at 30° of flexion and the patella centralized in the trochlear groove, the loops were cinched tight around the graft and tied. The free ends of the graft were doubled over and sutured to themselves.

The quadriceps and hamstring muscles were then loaded and the knee brought through the pre-defined flexion angles with recording of the same data sequence as in the other phases.

The fourth phase consisted of bringing the lateralized tubercle back to its original position and performing the knee range of motion and data collection as described in the previous phases.

The patellar tilt, patellar centralization, and peak forces at the medial femoral condyle articulating with the medial patellar facet were averaged for each specimen at each knee flexion angle. The TekScan pressure and force mapping system also included a center of force reading, which determines where the average force lies between the sensor pads, essentially recording the point of peak force between the medial and lateral femoral trochlea (Figure 5). The center of force was measured as a percentage of the entire femoral trochlea in contact with the K-Scan #4000 sensors, with 0% corresponding to a center of force at the most lateral portion of the lateral trochlea and 100% corresponding to a center of force at the most medial portion of the medial trochlea. The center of force readings were also averaged for each specimen at each flexion angle. Figure 6 represents the TekScan color visual information for each of the four phases of the experiment.

Statistical Analysis

The results of the patellar tilt, patellar centralization, peak force, and center of force readings were analyzed using analysis of variance (ANOVA) testing with Kruskall-Wallace post-hoc analysis (SPSS software; SPSS, Chicago, Ill) for each flexion angle tested (0°, 15°, 30°, 45°, and 60°) in relation to the phase of the experimental protocol (ie, intact, lateralized, MPFL, and final reconstruction). The P value for statistical significance was set to 0.05.

RESULTS

The average age of the five specimens (2 men and 3 women) was 62±3 years. In terms of patellar tilt, Figure 7 shows the average patellar tilt at each flexion angle and experimental phase for all specimens tested. The data show that lateralization of the tubial tubercle by 12 mm causes a trend for increased patellar tilt (ie, medial side of the patella tilts anteriorly and the lateral side of the patella tilts posteriorly) at 0° of knee flexion from the intact state of 23.24°±19.60° to 49.16°±14.26° and at 15° of knee flexion from the intact state of 17.38°±16.22° to 29.24°±11.25°. With the MPFL reconstruction, a statistically significant decrease (P=0.024) in the patellar tilt occurred at 0° of knee flexion, from 49.16°±14.26° in the lateralized state to 18.33°±11.25° in the MPFL reconstructed state. A trend for the same decrease in patellar tilt...
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was noted at 15° of knee flexion from 29.24°±11.35° in the lateralized state to 14.65°±12.53° in the reconstructed state. The patellar tilt of the MPFL reconstructed state at 0° of knee flexion was not statistically significant when compared to the intact state patellar tilt (P=.70). Figure 7 also shows that by 30° of knee flexion, the normal anatomy of the trochlea and patellar facets act to reduce the patellar tilt to its intact state in all phases of the protocol.

When looking at patellar subluxation, Figure 8 shows the average centralization (ie, how close the central patellar ridge articulates with the anatomic trochlear groove) at each flexion angle and experimental phase for all specimens. In the intact state, the patella followed a lateral to medial centralization toward the center of the trochlea and anatomic tracking from 0°-30° of knee flexion. With lateralization of the tibial tubercle, the central patellar ridge was also lateralized at 0° of knee flexion from 8.73±9.77 mm in the intact state to 20.20±9.90 mm in the lateralized state. By 30° of knee flexion, the engagement of the patella by the trochlear groove reduced the patellar lateralization (2.94±1.85 mm) to the intact state values (1.74±1.05 mm) (P=.302). With the MPFL reconstruction, a statistically significant decrease was noted in the patellar lateralization at 0° of knee flexion from 20.20±9.90 mm in the lateralized state to 5.54±6.80 mm in the MPFL reconstructed state (P=.049). The MPFL reconstructed state values were not statistically significant when compared to the intact state values (P=.45 at 0°). A similar trend was noted at 15° of knee flexion of a decrease in patellar lateralization with MPFL reconstruction from 12.28±8.36 mm in the lateralized state to 4.30±5.60 mm in the MPFL reconstructed state. The MPFL reconstruction restored the lateral patellar subluxation to intact state values at 0° (P=.45) and 15° (P=.69) of knee flexion prior to assistance by the trochlea at 30° of knee flexion.

The center of force data from the TekScan force measurement system is shown in Figure 9. The average center of force for each of the experimental phases (initial, lateralized, MPFL, and final) at each knee flexion angle is shown in the Table. Before the trochlear anatomy could center the patella anatomically (ie, at 0°, 15°, and 30° of knee flexion), a shifting of the center of force towards the lateral trochlea was noted in going from the intact state to the lateralized tibial tubercle state at 0° and 15°. A statistically significant lateralization of the center of force

Figure 5. Radiographic images depicting parameters that were measured in the study—patellar tilt [A], patellar centralization [B], center of force measurement on the trochlea [C], and patellofemoral contact pressures at the medial femoral condyle [D].
(P=.022) occurred at 30° of knee flexion in going from the intact state to the lateralized tibial tubercle state. After 30° of knee flexion, no statistically significant change was noted in the center of force between the initial state and the lateralized state (P=.15 at 45°, P=.09 at 60°). When starting from the lateralized state, there was a trend at 0° and 15° and a statistically significant increase (P=.03) at 30° of knee flexion in the change of center of force towards the medial trochlea when going from the lateralized tibial tubercle (ie, lateralized patella) state to the MPFL reconstruction state. However, the center of force readings with the MPFL reconstruction were never higher than the initial state. The final center of force readings with the tibial tubercle realigned and the MPFL reconstruction (ie, final state) were not statistically significant when compared to the initial state at all knee flexion angles (P=.47 at 0°, P=.378 at 15°, P=.542 at 30°, P=.815 at 45°, P=.539 at 60°).

Figure 10 shows the medial trochlear forces at 0°, 15°, and 30° of knee flexion for each phase of the experiment. These angles were chosen because 0° and 15° represent the only angles where the normal trochlear anatomy does not interfere with the patellar centralization or patellar tilt in relation to the MPFL and 30° represents the patello-femoral joint as the trochlea is just engaging the patella. In going from the intact state to the lateralized state, the patellar tilt and centralization were so great that no force was recorded at 0° or 15° on the medial trochlea and at only 30° of knee flexion, did the medial trochlea begin to experience increased pressures. With the MPFL reconstruction from the lateralized tibial tubercle state, there was a trend for higher forces on the medial trochlea at 0°, 15°, and 30° of knee flexion. When comparing the intact state to the MPFL reconstructed state, no statistically significant difference was noted in forces seen at the medial trochlea (P=.57 at 0°, P=.798 at 15°, P=.196 at 30°), and

Figure 6. Actual TekScan film in the different tested phases of the experiment. The center of force dot is labeled. The colored areas represent forces on the medial and lateral trochlea with higher forces represented by red colors and lower forces represented by blue colors. The gray pane in the center of each of the TekScan phases represents the way the presentation program from TekScan outputs the results. It does not represent a gap between the medial and lateral trochlea.

Figure 7. Graph showing the average patellar tilt at the predefined knee flexion angles for each phase of the experiment (ie, intact, lateralized, MPFL, and final).

Figure 8. Graph showing the average patellar centralization [subluxation] at the predefined knee flexion angles for each phase of the experiment.
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the medial trochlear forces in the MPFL reconstructed state (with the tibial tubercle still lateralized) never were recorded above the intact state values.

**DISCUSSION**

Rupture of the MPFL is a well-known consequence of lateral patellar dislocations. In addition, recent literature has shown the distinct role of the MPFL as a passive restraint to lateral subluxation/dislocation of the patella. Although conservative management is the first line of treatment for first time lateral patellar dislocations, operative intervention, specifically reconstruction of the MPFL, has been a secondary treatment option in combination with other procedures for passive and dynamic patellar stabilization.

The preliminary hypothesis of this study was that correction of a laterally subluxated patella secondary to a distal malalignment (ie, abnormal tibial tubercle alignment), with only a reconstructed MPFL, would lead to significantly increased pressures on the medial femoral trochlea. This was thought to be due to the posteriorly oriented pull of the MPFL and the amount of force that would have to be applied to bring the patella to a centralized position, both in the coronal and axial planes. The obvious long-term concern would be the effect that posteromedially directed forces have on the articular cartilage of the patellofemoral joint and if this predisposes the knee to early patellofemoral arthritis.

The data from the TekScan force measurement system looking at both the center of force and the absolute forces on the medial femoral trochlea do not support the authors' initial hypothesis (Figures 9 and 10). Overload of the medial femoral trochlea was not noted with reconstruction of the MPFL in an experimentally created lateralized patella.

The reasons for this are three-fold. First, the specimens tested were “normal” knee specimens with no anatomic evidence for a predisposition to lateral patellar subluxation in the intact state. In addition, it is known that the patella is well centralized in a normal trochlear groove by 30° of knee flexion. Therefore, with normal trochlear groove anatomy and because the MPFL reconstruction...
technique calls for tensioning of the MPFL ligament reconstruction at 30° of knee flexion, the trochlear groove anatomy already centered the patella to its “normal” state and prevented the preferential overload of the medial femoral trochlea by over-tensioning of the MPFL reconstruction.

Second, the technique of MPFL reconstruction used, incorporating the suture anchors in the patella with a loop that cinches the MPFL graft limbs, is such that it is difficult to over-constrain the medial side of the knee and cause abnormal patellar tilting or medial subluxation. Of course, the technique calls for the tensioning to be done at 30°, which with a normal trochlea already self-centers the patella. Other techniques in the literature call for a pull through of the graft into the patella and can easily over-constrain and tilt the medial patella if not careful with the reconstruction.

Third, the authors had a thorough understanding of the attachment sites of the MPFL on the patella and most importantly on the femur. Literature has shown that the femoral tunnel placement (more specifically the superior femoral attachment) for the MPFL reconstruction is more sensitive than the patellar attachment in terms of achieving an anatomometric graft placement. If errors occur in isometric tunnel placement, this could easily over-constrain the knee and lead to higher forces on the medial femoral trochlea. The MPFL is a guiding structure that acts in a complimentary fashion with the other proximal restraints on the patella to help center the patella on the trochlea in the first 30° of knee flexion.

In addition to pure pressure measurements of the patellofemoral joint during the experimental phases of this study, patellar tilt and patellar centralization were also recorded. This was done to evaluate what the effect of an MPFL reconstruction from a laterally subluxated patellar state had on patellar bony alignment and patellar stability.

Patellar tilt was recorded using Polhemus Fastrak (Polhemus Inc) sensors (a six degree-of-freedom motion tracking system) mounted on the femur, tibia, and anterior patella. The results (Figure 7) show that from an intact to a lateralized state, a trend existed towards increasing lateral patellar tilt at 0° and 15° of knee flexion. This relates to the laterally subluxated patellar model used in this study, where lateralization of the tibial tubercle not only produces lateralization of the patella but also tilt of the patella. With the normal trochlear anatomy on each specimen, by 30° of knee flexion, the trochlea acts to engage the patella and reduce the tilt produced by the distal malalignment. This is seen at 30°, 45°, and 60° of knee flexion with no statistically significant differences in patellar tilt between any of the experimental phases.

The MPFL reconstruction with a distally maligned patella showed a statistically significant decrease in patellar tilt to intact state values at 0° of knee flexion. The same trend was followed at 15° of knee flexion. Again, because of normal trochlear anatomy, patellar tilt was not statistically significant from any other experimental state at 30°, 45°, and 60° of knee flexion. In fact, no statistically significant differences were noted in patellar tilt values from the MPFL reconstructed state with distal malalignment to the initial intact state at each flexion angle (especially important at 0° and 15°). This signifies that the MPFL reconstruction did not over-tilt the patella medially and acted to simulate normal patellar tilt values, even in the presence of distal malalignment.

Patellar centralization was measured using the Micro-Scribe digitizer (Immersion Corp). Using points on the anterior surface of the patella that anatomically corresponded to the orientation of the central patellar ridge, these points were tracked in relation to points marked on the femoral trochlea prior to the start of the experimental trials. The difference between these two sets of points allowed the position of the patella in the coronal plane to be monitored — what the authors have herein called patellar centralization or, in cases of patellar malalignment, lack of patellar centralization.

Normal patellar tracking follows a slightly lateral to medial orientation prior to the patella engaging the trochlear groove. The results of this study (Figure 8) show that the authors were able to reproducibly record this anatomic motion in the intact state from 0°-30° of knee flexion. When comparing the intact state to the distally malaligned state (ie, lateralized tibial tubercle), a trend towards a statistically significant lateralization of the patella at 0° and 15° of knee flexion was noted. By 30° of knee flexion, the normal trochlear anatomy engaged the patella and self-centered it, despite the distally malaligned state. Therefore, the patellar subluxation model used in this study was not only able to reproduce patellar tilt, but also patellar lateralization prior to engagement of the patella by the trochlear groove.

The MPFL reconstruction with a distally malaligned tibial tubercle showed a statistically significant centralization of the patella to intact state values at 0° of knee flexion and a trend towards the same at 15° of knee flexion. The patellar centralization values after MPFL reconstruction were similar to the intact state patellar centralization values at all angles of knee flexion tested.

Therefore, an MPFL reconstruction with a distally malaligned tibial tubercle and tensioning the MPFL at 30° of knee flexion in specimens with normal trochlear anatomy did not over-constrain the patella in terms of over-centralization or excessive medial patellar tilt.

Several limitations exist in this study. The first and foremost is that most subjects with an increased TT-TG measurement have some type of developmental trochlear dysplasia. The model used in this study does not account...
for this. Without the centering guidance of the normal trochlea, tensioning the patella at the proper tilt and centralization could prove to be difficult and may alter patellofemoral forces. Literature recently presented in abstract form looking at patellar tracking from a normal to dysplastic trochlear model state showed that with simulated trochlear dysplasia, the patella had a highly significant loss of stability at 20°-30° of knee flexion with erratic behavior in the medial to lateral direction.4 Further study in the authors’ model would entail the creation of a dysplastic trochlear state and retesting of the specimens through the same experimental states.

Although the data obtained by the authors do not show that medial trochlear forces are increased with MPFL reconstruction in the distally malaligned state, other structures about the knee may bear the abnormal anatomic load. For example, with the tibial tubercle moved laterally and medialization of the patella with the MPFL reconstruction, an excessive angle exists between the patella and tubercle, of which the patellar tendon now experiences the abnormal anatomic orientation. One could propose that degenerative changes may occur in the patellar tendon collagen with this excessive force that could lead to patellar tendinitis and/or rupture over time. Strain transducers can be used to measure the strain in the surrounding knee ligaments during the experimental phases to record any undue tension on the surrounding anatomic structures.

The model for patellar subluxation used in this study is based on tibial tubercle lateralization of 12 mm. The authors do not know how much lateralization is required in each specimen to produce adequate patellar subluxation based on the trochlear anatomy of that particular specimen. Therefore, tubercle lateralization for the purpose of this study was standardized to 12 mm. Increasing the lateralization above 12-13 mm caused total lateral patellar dislocation at 0°, and the specimens were unable to be tested. It should be noted though, that this is 12-13 mm above the 13 mm that the tibial tubercle normally sits lateral to the trochlear groove. So the total lateralization of the tubercle from the trochlea is upwards of 24-26 mm, which is grossly abnormal.

Patellar height also can have an effect on knee kinematics, especially of the patellofemoral joint. Knees with patellar instability can have a component of patella alta, which can affect the distribution of the patellofemoral contact stresses. Patellar height was not measured in this study and could have an impact on some of the patellofemoral mechanics and contact stresses. Another important limitation of the study is the small number of specimens used, which could have been increased to enhance the power of the findings.

CONCLUSION

In cadaver knees with normal trochlear anatomy but a distal malalignment syndrome (ie, lateralization of the tibial tubercle, increased TT-TG), reconstruction of the MPFL with biotenodesis femoral fixation and double-bundle patellar suture anchor fixation allows the recreation of intact state patellar centralization, intact state patellar tilt, and does not show evidence of increased load on the medial femoral trochlea both in a lateralized patellar state and even after a MPFL reconstruction.

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