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Distribution of patellofemoral joint pressures after femoral trochlear osteotomy

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Abstract Anterior osteotomy of the lateral femoral condyle was designed for the treatment of recurrent patellar dislocations. This study examined whether anterior femoral trochlear osteotomy significantly elevates contact pressures in the patellofemoral joint. Static intrajoint loads and contact area determination were recorded using prescale Fuji pressure-sensitive film under static loading. Peak pressures, average pressures and contact areas of the patellofemoral joint were calculated on intact specimens and after anterior osteotomy of the lateral condyle. Our results indicate that a 6-mm or 10-mm anterior osteotomy of the lateral condyle significantly elevates patellofemoral contact pressures.

Keywords Osteotomy · Patellofemoral · Pressure · Intrajoint · Static loading

Introduction

More than 100 surgical procedures have been proposed for the treatment of recurrent dislocation of the patella and patellofemoral malalignment [2, 3, 4, 5, 6, 8, 9, 11, 13, 16]. Despite the numerous surgical procedures described, few have attempted to correct a deficiency of the lateral femoral condyle when present [1, 18]. Anterior osteotomy of the lateral femoral condyle was introduced by Albee in 1915 [1] This procedure was designed to elevate the lateral femoral condyle and deepen the trochlea. It has been recommended for refractory patellar dislocations associated with either patella alta or with hypoplasia of the femoral trochlea. Although this surgical procedure has been used for decades, only one clinical report on long-term results has been published [19]. No reports have been published on the biomechanical effects. This study was designed to test the hypothesis that anterior femoral trochlear osteotomy significantly elevates contact pressures of the patellofemoral joint.

Materials and methods

Specimen preparation

Six frozen human cadaver knees (three female, three male) were obtained with a mean age of 54 years (range 38–71 years). All specimens were radiographed in the anterior/posterior, lateral, and Merchant et al. [17] views. Patellar geometry was characterized by the method of Wiberg [20]. Patellofemoral alignment and the congruence angle were also recorded. The patellar height was measured using the Insall – Salvati [12] index.

The specimens were stored at –20°C and thawed to room temperature prior to use. Following resection of the skin, the vastus medialis and vastus lateralis were individually isolated. In contrast, the rectus femoris and vastus intermedius were maintained intact through the fascial attachment. The vastus medialis oblique was isolated.

In order to maintain consistency between specimens, each leg was amputated at the midtibia, 20 cm distal to the tibial plateau, and embedded in an aluminum cylinder using polymethylmethacrylate (Dentsply, Milford, Del., USA). The neutral anatomical position was determined by aligning the cylinder coaxial to the axis of the proximal tibia. The fibula was cut 3 cm distal to the fibular head and fixed to the tibia with a 4 mm cortical screw.

Loading fixture and applied forces

The specimens were positioned and mounted into a custom knee testing fixture (Fig. 1). When the knee was flexed to 90°, the tibia/tube assembly remained perpendicular to the floor. Concurrently the long axis of the femur was maintained coaxial to the center of the femoral mounting device and used as a reference line to approximate the orientation of the extensor mechanism muscle forces during knee flexion. The respective tension angles of the vastus medialis oblique and vastus lateralis were 50°and 17° and were set according to the method described by Lieb and Perry [14]. The hamstrings were directed coaxially to the femoral axis. A 45-N load was applied to the vastus medialis oblique, vastus lateralis, and hamstrings through a pulley system. Both the rectus femoris and intermedius were attached to the actuator of a materials testing machine (Bionix 858, MTS Systems, Eden Prairie, Minn., USA) to simulate active contraction. The addition of a 90-N force through a pulley mechanism was used to generate a knee flexion moment equally distributed on both sides of the tibial fixture. Thus a simulated ground reaction force through the joint was generated in addition to a hamstrings knee flexion moment.

The force applied to the knee as an additional flexion moment does not represent an actual ground reaction force, but it is also recognized that purely loading the hamstring tendons and the quadriceps tendon would not simulate a weight-bearing loading condition. The flexion moment generated about the knee by the ground reaction force increases as the knee flexion angle increases. Therefore our pulley system accommodated a vector anchored at the simulated foot and passing through the simulated hip and lying posterior to the axis of the knee joint with any degree of knee flexion. The distance of the vector from the axis of the knee joint would systematically increase with increasing knee flexion angles. Although this does not reproduce a true ground reaction force, it does produce a variable force about the knee that changes in the same direction as would the ground reaction force.

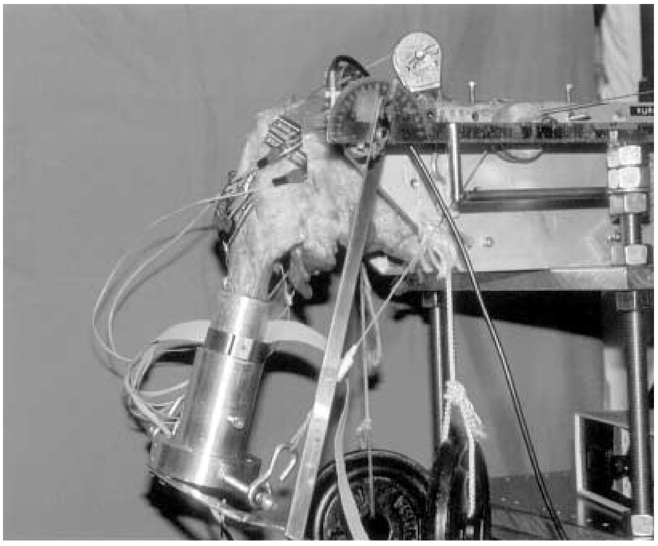


Fig. 1 Photograph illustrating the cable/pulley system mounted to the hydraulic actuator of the testing machine. Static tests were performed at 15° and 45° of knee flexion

All pulleys were terminated with free rotating swivel joints in order to minimize external bending moments encountered due to individual specimen variations in varus, valgus, and rotation. An external electro-goniometer mounted at the approximate center of knee rotation was used by the servohydraulic controller as control feedback for actuator motion to apply tensile loads through the quadriceps mechanism in order to move the knee to the flexion angles of 15° and 45°. The authors selected 15° and 45° of knee flexion as a knee flexion angles common to the walking and running gait cycles, respectively. The Q angle was measured by drawing a line coaxial with the femur and second line from the tibial tuberosity to the geometric center of the patella with the leg placed in full extension (0°) This anatomical Q angle is an estimate of the clinical Q angle and was based on availability of landmarks common to all of the specimens tested [10, 20].

Intrajoint loads measurement

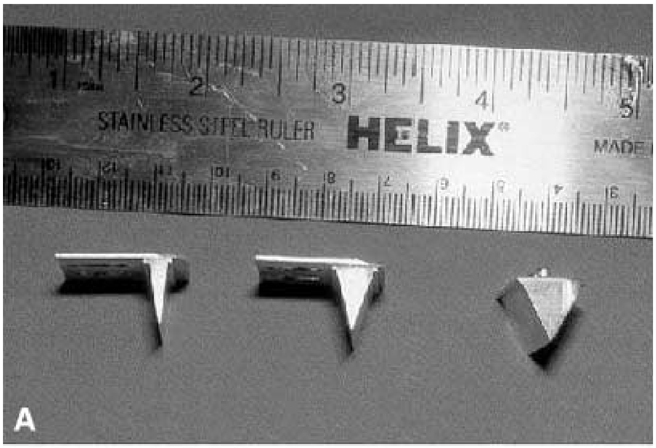
Prior to each experiment the specimen was subjected to six continuous loading cycles through a range of motion from 15° to 75° in order to precondition the specimen. Intrajoint pressures were recorded using super low prescale Fuji pressure-sensitive film (Sensor Products, East Hanover, N.J., USA). The film was cut to the appropriate geometry for placement within the patellofemoral joint. Sealing of the film in Steri-Drape (3M Healthcare D46325, Vorken, Germany) eliminated contamination of the film with fluids.

Regarding the method of capsulotomy used for this study, we made an initial incision through the suprapatellar synovial pouch and inserted the Fuji film for each test through this suprapatellar approach. This synovial pouch incision was not closed for any testing. However, an anterolateral arthrotomy was required for completion of the osteotomy and insertion of the various wedges. The anterolateral capsule was closed for each test, and care was taken to place the capsular and retinacular sutures in the same location with each repair and test. We recognize that a potential variation in capsular/retinacular tension could occur affecting results, but we felt this error was minimized by closing the capsule reproducibly with each test, maintaining medial and lateral capsular/retinacular tensions, and inserting the Fuji film through the suprapatellar pouch opening.

To position the film reproducibly three location points were made on the superior and lateral margins of the patella and the corresponding location of the inserted film was marked with a metal pin and “magic marker.” This allowed for the subsequent assessment of orientation of the film relative to the patella. Once the film was reproducibly positioned, the capsulotomy was closed, and the joint was subjected to static loading for 2 min. Using a Fuji-film color density analysis system (Topaq) calibrated to the color density scale of the film used, analysis for peak and average contact pressure as well as contact area and force was performed at 15° and 45° of knee flexion before and after trochlear osteotomy.

The femoral trochlear osteotomy technique

After anterolateral capsulotomy the external condyle was osteotomized from a point just anterior to the weight bearing surface of the tibiofemoral articulation in full extension to a point 10 mm proximal to the trochlea. The osteotomy was carried to a depth approximating the middle point of the trochlea. The lateral condyle was elevated, producing an incomplete fracture near the trochlear groove. Prefabricated aluminum wedges measuring 3, 6, and 10 mm in height were used to simulate various size bone grafts (Fig. 2). Any variation in osteotomy technique could be found in



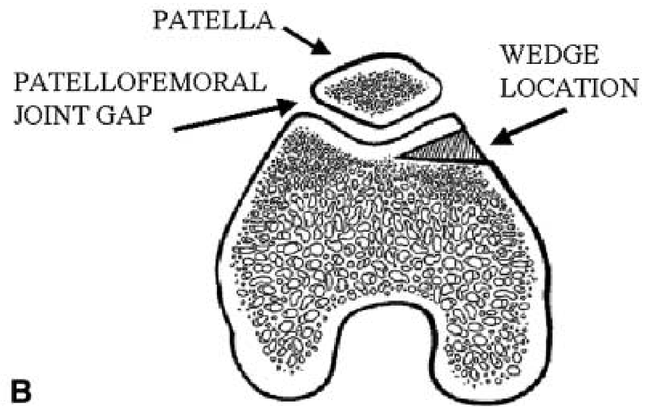


Fig. 2 **A** Photograph illustrating the aluminum wedges used to simulate 3, 6, and 10 mm of anterior elevation of the condyle. **B** The condyle is osteotomized from a point anterior to the weight bearing surface of the tibiofemoral articulation in full extension to a point 10 mm proximal to the trochlea

the actual depth of penetration of the osteotomy and the actual resultant distance of the tip of the osteotomy from the trochlear groove. This distance was not measured. However, the prefabricated aluminum wedges were inserted until the base of the wedge was confluent with the lateral cortex of the lateral femoral condyle, and therefore uniformity of the amount of opening wedge was achieved. In each knee joint contact pressures, forces, and areas were measured at 15° and 45° of the knee flexion prior to and following trochlear osteotomies of 3, 6, and 10 mm.

The authors recognize that while cadaver specimens with patellofemoral dysplasia would be the ideal model, such specimens are difficult to obtain. However, realizing that trochlear dysplasia is a *spectrum* of geometrical variations, and that *congruence* may be as important as the sulcus angle itself, our subsequent results should be viewed as the assessment of relative change in joint loading created by the deviation from the native, congruent state of the patellofemoral joint. Altering the femoral trochlea to fabricate a flat surface would alter the congruence between the patella and the trochlea and thus create artifactual data.

Data analysis

For all six specimens Fuji film data were obtained at 15° and 45° of knee flexion under the intact, 3, 6, and 10 mm trochlear osteotomy conditions. Differences due to condylar elevation conditions at knee flexion angles of 15° and 45° were analyzed using Dunnett's multiple group comparison (Prism 2.01, GraphPad Software, San Diego, Calif., USA) with the intact condition set as the control group. The average and peak contact pressures as well as contact forces and areas for the patellofemoral joint were compared under elevation of the condyle from the intact to 10 mm condition. Group comparisons were deemed statistically significant at *P* values less than 0.05.

Table 1 Characteristics of tested specimens

Specimen no.	Wiberg classification	Congruence angle (°)	Sulcus angle (°)	Insall-Salvati index
1	III	+5	133	0.942
2	II	–16	126	0.979
3	II	+9	140	1.125
4	III	–10	123	1.040
5	II	+11	130	1.195
6	II	+8	128	1.064

Results

Contact areas

For the specimens tested the mean congruence angle was +1.17±10.32° while the mean Insall-Salvati index was 1.058±0.127. Four of the six specimens displayed a type II Gunner-Wiberg classification while type III was seen in the remaining two specimens (Table 1). No significant changes in contact area size were detected with respect to the intact control condition after elevation of the lateral trochlea at either 15° or 45° of flexion (P>0.05). As the amount of elevation increased from 0 to 10 mm, the location of peak contact pressure moved from the center of the patella to the lateral facet of patella surface (Fig. 3). With respect to the pressure data, all values within each group are shown as the mean ±standard deviation of the mean.

Average contact pressure

Average contact pressure significantly increased at 10 mm elevation at 15° (19%) and 45° (40%) of flexion (P<0.01; Fig. 4).

Peak contact pressure

No significant changes were detected in peak contact pressure at 15° of flexion (P>0.05). At 45° of flexion peak contact pressure significantly increased at 6 mm (P<0.05) and at 10 mm elevation (P<0.01; Fig. 5).

Discussion

Numerous surgical procedures have been described for the management of patellar instability [2, 3, 4, 5, 6, 8, 9,

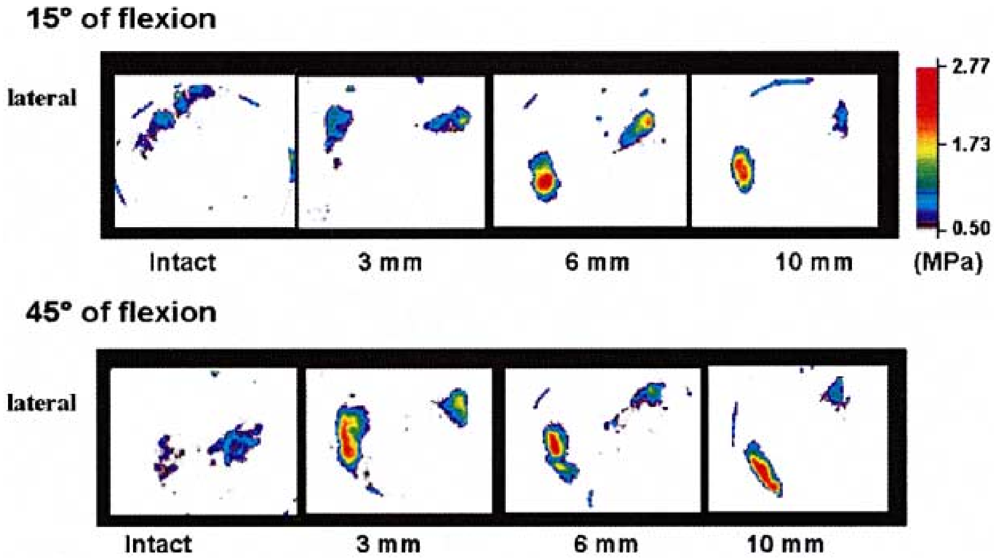


Fig. 3 Digital image of Fuji film patellar contact area and pressure distribution with the intact knee and following 3, 6, and 10 mm of lateral trochlear elevation at 15° and 45° of knee flexion. The contact area moved from the center of the patella to both ends of the patellar surface. Lateral contact pressure increased with lateral trochlear elevation

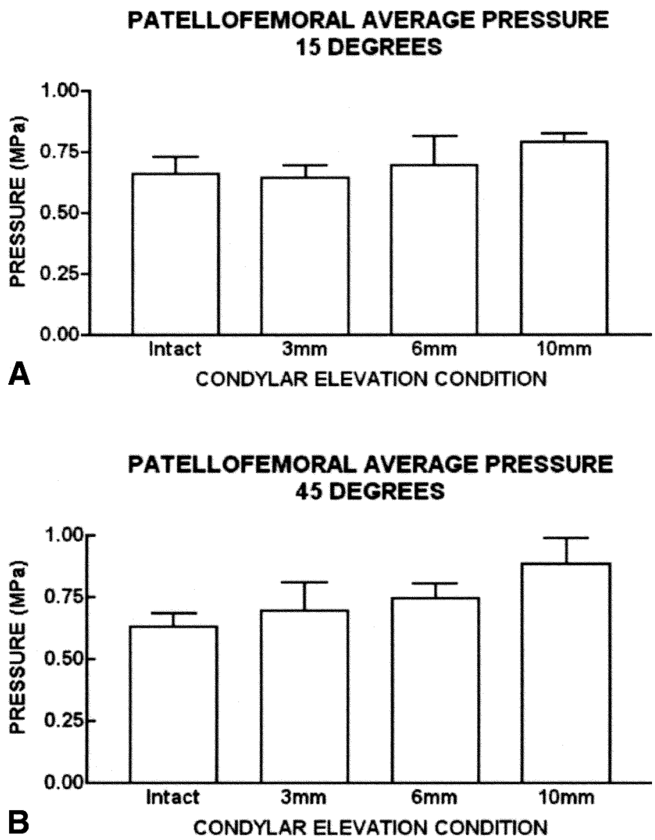


Fig. 4 Average contact pressure in the patellofemoral joint at 15° (**A**) and 45° (**B**) of knee flexion

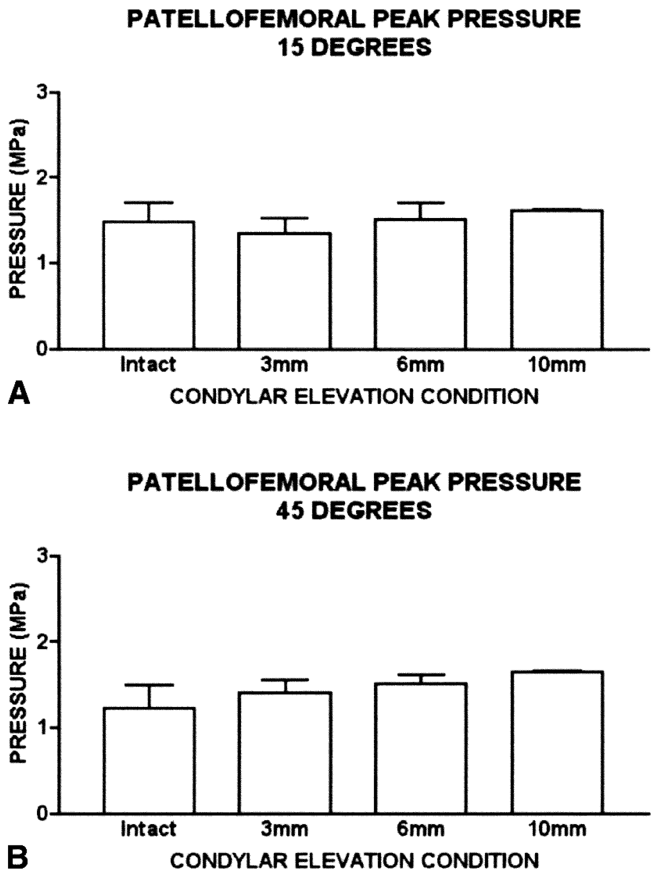


Fig. 5 Peak contact pressure in the patellofemoral joint at 15° (**A**) and 45° (**B**) of knee flexion

11, 12, 16], but few have attempted to correct the presentation of a deficiency in the femoral groove [1, 7, 18]. We recognize that this study did not represent a trochlear dysplasia model. To our knowledge, an in vitro model for trochlear dysplasia does not exist. However, although simply lowering the lateral femoral condyle would more closely simulate the dysplastic trochlea, this procedure would alter the congruence of the patellofemoral joint. Therefore our data should be assessed as relative increases in pressure with anterior elevation of the lateral femoral condyle in a congruent patellofemoral joint.

The osteotomy of the lateral femoral trochlea (Albee osteotomy) has been used only as a salvage procedure for disabling patellofemoral instability. Complications can include loss of motion [19]. The results of our study showed that in this model a 10-mm anterior elevation of the lateral femoral condyle significantly increased average patellofemoral contact pressure at both 15° and 45° of flexion. Furthermore, a 6-mm anterior elevation significantly increased peak patellofemoral contact pressure at 45° of flexion. This pressure elevation was detected on the lateral facet of the patellofemoral joint.

We chose not to monitor intrajoint loading and motion through the preconditioning phase. Although this would have given insight with respect to the viscoelastic alterations within extensor mechanism, it would have added a considerable amount of time to the testing protocol, which ultimately could give rise to artifactual data in the latter stages of testing. The static nature of the testing protocol and the pressure acquisition methods employed in the study did not permit examination of motion properties associated with the intact and surgically altered specimens.

Weiker et al. [19] recommended that anterior elevation of the lateral femoral condyle should be approximately 8–10 mm. Albee did not specify the amount of elevation. In contrast, Malghem et al. [15] reported that the trochlear depth in 40 patients undergoing surgery for recurrent dislocation or subluxation of the patella was 2.74 mm, compared to 5.94 mm in asymptomatic subjects. With a difference between these two conditions being only 3.2 mm, a 3-mm elevation should suffice to normalize the depth of the trochlear groove in the mild to moderate case of patellar dysplasia and thus avoid excessive increases in patellofemoral contact pressures. For cases involving severe dysplasia a 6-mm anterior elevation is warranted.

Conclusion

A 3-mm elevation of the trochlea above the normal position does not significantly increase contact pressures within the patellofemoral joint. Continued increases in trochlear elevation to 6 and 10 mm above the normal/native position displayed significantly increased mean and peak contact patellofemoral contact pressures. Our results suggest that this surgical procedure should be used with caution in the presence of patellofemoral chondrosis involving the lateral patellar facet and/or the anterior lateral femoral condyle.

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