A COMPARISON OF THE MECHANICAL AND DIMENSIONAL PROPERTIES OF THE HUMAN MEDIAL AND LATERAL PATELLOFEMORAL LIGAMENTS.

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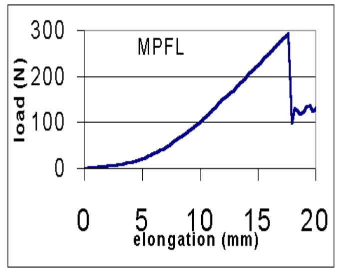
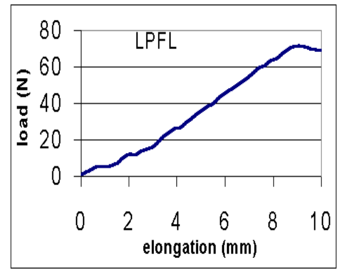
INTRODUCTION Clinical studies document that the knee is one of the most common sites of chronic pain, reported to affect one in four individuals (1). Typically, knee pain, while non-specific, is reported to emanate from the anterior compartment of the knee (2), thus implicating the patella. Numerous and varied hypotheses have been suggested to explain anterior knee pain, including: patellofemoral incongruence (3), extra-articular abnormalities such as tight (4) or weak lateral retinaculum (5), abnormal Q-angle (6), patella alta (6), patellar/femoral dysplasia (6), abnormal gait (7), chondromalacia secondary to abnormal patellar tracking (5), trauma and secondary sequelae (Atkinson), subluxation-dislocation-giving away (6). While these maladies may appear somewhat divergent, a common, associated finding in these studies is abnormal patellar tracking as the knee is flexed. That is, concomitant with knee pain and the above listed painful conditions, the patella is also observed to track abnormally against the femur. In the majority of cases, the abnormal tracking is considered a secondary consequence of the primary condition. This is supported by additional studies which report that among all knee disorders, patellofemoral disorders are among the most common (8, 9) and are thought to be related to patellar maltracking. In the normal knee, the quadriceps muscles develop large loads that pull on the patella to extend the leg. The wedge-shaped patella is prevented from medial-lateral movement by tracking in the deep femoral trochlear groove. However, when the knee approaches 30°-40° of flexion, the trochlear groove becomes somewhat flat and medial-lateral restraint is largely derived from the passive medial-lateral stabilizers (10). Abnormalities in any of the above parameters can upset the delicate balance of forces that maintain normal tracking and a typically pain-free knee. Recent studies have advocated reconstruction of the patellofemoral ligaments due to injury or dysplasia. However, the mechanical properties of these ligaments is not well understood. In fact, we are unaware of a study documenting the mechanical and dimensional properties of paired medial and lateral patellofemoral ligaments. In the current study, medial patellofemoral ligaments (MPFL's) and lateral patellofemoral ligaments (LPFL's) taken from human cadavers were studied to determine their biomechanical properties.

METHODS The medial and lateral patellofemoral ligaments were harvested from 4 human cadaver knees taken from three subjects with no evidence of knee trauma. Bone-ligament-bone units were isolated by cutting a 2x2x2 cm bone block from the femur and the patella at the ligament's insertion sites. The thickness and width of the ligament was taken as the average of three measurements taken at three equally spaced sites along the length of the ligament using vernier calipers (11). The length was also measured and was defined as the distance between the bony insertion sites. The bone blocks were then secured in specially designed steel boxes which provided a clearance slot for the ligament. The patellar bone block was rotated about an axis perpendicular to the transverse axis of the ligament to better approximate in situ loading of the ligament. The boxes were installed into a materials testing machine and a water bath was fitted around the ligament preparation. The bath was filled with 37°C, 0.9% saline and the tissue was allowed time to equilibrate. A tensile test was then performed in which the tissue was first subjected to a cyclic relaxation test (sine wave, 3% strain amplitude, 20 cycles, 1 Hz) followed immediately by a ramp loading to failure (50% strain loaded at 100% length dimension per second). The load-elongation curve was analyzed to determine the peak load and stiffness. The stiffness was taken as the slope in the linear range of the load-elongation response. An estimate of the tensile modulus was calculated as the stiffness multiplied by the ratio of ligament length divided by cross-sectional area.

RESULTS At dissection, the MPFL's and LPFL's exhibited a similar general appearance: both ligaments began as a narrow band of tissue at their respective femoral insertions and then fanned out into a much wider and thicker structure at the respective patellar insertion. Analysis of the medial and lateral ligament tissue dimensions (Table) revealed that the MPFL was approximately 50% longer and thicker than the paired LPFL's and these differences were significant. While the MPFL's tended to have a greater cross-sectional area, this difference was not significant. Analysis of the load-elongation curve revealed that all MPFL's exhibited a pronounced 'toe' response while the LPFL's were almost completely linear (Figure). While there was a trend for the maximum load, stiffness and estimated tensile modulus to be greater for the MPFL, this difference was not significant.





Tissue	Length (mm)	Area (mm^2)	Width (mm)	Thickness (mm)	Max Load (N)	Stiffness (N/mm)	Modulus (MPa)
MPFL	59.2± 6.5•	42.7± 9.6	14.5± 3.1	2.9± 0.2•	167.6± 85.6	15.9± 6.4	19.1± 6.3
LPFL	38.8± 11.7	28.5± 11.3	16.0± 1.4	1.8± 0.7	101.1± 51.7	11.7± 5.8	17.0± 9.9
• Significantly different than the paired LPFL property							

DISCUSSION The data from the current study show that within the normal human knee, the medial and lateral patellofemoral ligaments are similar in width and modulus, while the MPFL is significantly longer and thicker than the LPFL. In addition, trends in the data suggest that the MPFL can tolerate greater loads and are a stiffer structure than the LPFL. Besides the bony constraint of the femoral condyles, the patellofemoral ligaments are the main source of patellofemoral stability intrinsic to the knee (12, 13). The ligaments provide the greatest degree of restraint at the lower flexion angles since there is less bony restraint due to the shallow femoral groove. The importance of these tissues at lower knee flexion is underscored by clinical studies which show that patellar subluxation/dislocation occur at approximately 20° to 30° of flexion (14). Thus, knowledge of the properties of these ligaments is important to better understand and study patellar tracking and knee instability (15). For example, the load data from the current study show that the ligaments can provide as much as several hundred newtons of medial-lateral patellar restraint. Thus, future theoretical and experimental studies of patellar tracking may want to include the effect of these ligaments to better simulate realistic tracking. For example, in the intact human knee, the patella is known to tilt about a perpendicular axis as a function of flexion angle. The attachment sites of the patellofemoral ligaments suggest that they would affect patellar tilt since the ligaments would attempt to center the patella. By not considering the ligaments, excessive and unnatural tilt may be expected. In addition, surgical procedures which transection the patellofemoral ligaments (i.e. TKA) may have an effect on post-surgical knee kinematics (14). Further studies are needed to better understand the effect of the patellofemoral ligaments.

REFERENCES 1) Labrier and O'Neil, 1993; 2) Caylor et al., 1993; 3) Aglietti, et al., 1983; 4) Cascells, 1979; 5) Ficat, et al., 1979; 6) Nottage, et al.,1981; 7) Radin, et al., 1991; 8) Reider, et al., 1981; 9) Koh, et al., 1992; 10) Skalley, et al., 1993; 11) Atkinson, et al., 1999; 12) Teitge, et al., 1996; 13) Conlan, et al., 1993; 14) Luo, et al., 1997; 15) Hautamaa, et al, 1998

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