MECHANICAL PROPERTIES OF THE HUMAN HIP JOINT CAPSULE LIGAMENTS

Introduction: The hip joint capsule plays an important biomechanical role in stabilizing hip joint articulation. Previous study of the hip joint capsule has been confined to anatomical description, while the biomechanical properties of the capsule have not been examined. The goal of this study was to quantify the maximum tensile force, maximum structural and material strain, and maximum stress at failure of the iliofemoral ligament, the ischiofemoral (IS) ligament and the femoral arcuate (FA) ligament.

The iliofemoral ligament originates between the anterior inferior iliac spine and acetabular rim and inserts along the intertrochanteric line. The ischiofemoral complex originates along the ischial rim of the acetabulum and inserts around the posterior circumference of the femoral neck. The femoral arcuate ligament originates at the greater trochanter. It runs around the posterior circumference of the femoral neck deep to the ischiofemoral ligament and inserts at the lesser trochanter (1). We hypothesize that significant differences exist in both the material and structural mechanical properties of the three ligaments.

Methods: Ten specimens of each ligament were dissected from fresh frozen cadavers (9 female, 4 male; age range: 50-99) and prepared as bone-ligament-bone specimens. The iliofemoral ligament was divided longitudinally into superior (I1) and inferior (I2) halves. A preconditioning routine of ten cycles to 5% strain at 0.5 mm/sec was performed (2). Displacement was then applied to the ligament along the fiber axis at 0.04 mm/sec until failure (3).

Stress was calculated by dividing force, as measured by a load cell, by the initial cross sectional area of the ligament. Material engineering strain was determined by optically measuring the displacement of transverse marker lines in the central third of the ligament using a video analysis system (4).

Structural engineering strain was calculated by dividing the displacement of the piston of the servohydraulic testing machine by the initial length of the ligament. A multivariate analysis of variance and the Newman-Keuls post-hoc test were applied to the results for statistical evaluation.

Results: Multivariate analysis of variance revealed that the ligaments differ significantly in the mechanical properties tested (p<0.00005). Nine femoral arcuate ligaments failed in the midsubstance, and one failed as an avulsion from the greater trochanter. Of the ischiofemoral ligaments tested, five failed in the midsubstance, and five avulsed at the femur. Failure locations for the superior half of the iliofemoral ligament included two in the midsubstance, three avulsions at the femur, and five avulsions at the hip. Of the inferior half of the iliofemoral ligament, one failed in the midsubstance, two avulsed at the femur, and seven avulsed at the hip.

Mean maximum force (Fig. 1) was 78.2N ± 37.9N (S.D.) for the femoral arcuate, 136.0N ± 74.6N for the ischiofemoral, 320.3N ± 267.7N for the superior half of the iliofemoral and 351.3N ± 159.4N for the inferior half of the iliofemoral ligament (p<0.01 for FA v. IS & I1; p<0.05 for IS v. I1 & I2).

Mean maximum stress (Fig. 2) was 6.16MPa ± 3.52MPa for the femoral arcuate, 2.29MPa ± 1.69MPa for the ischiofemoral, 2.90MPa ± 1.52MPa for the superior half of the iliofemoral and 4.49MPa ± 2.77MPa for the inferior half of the iliofemoral ligament (p<0.01 for FA v. IS & I1).

Mean material strain (Fig. 3) at failure was 15.0% ± 7.5% for the femoral arcuate ligament, 9.3% ± 3.4% for the ischiofemoral ligament, 7.7% ± 2.2% for the superior half of the iliofemoral ligament and 10.3% ± 5.0% for the inferior half (p<0.05 for FA v. IS, I1 & I2).

Mean structural strain (Fig. 3) at failure was 39.4% ± 13.0% for the femoral arcuate ligament, 25.6% ± 9.5% for the ischiofemoral ligament, 17.0% ± 5.6% for the superior half of the iliofemoral ligament and 18.9% ± 5.4% for the inferior half (p<0.005 for FA v. IS, I1 & I2).

The slope of the linear region of the force-displacement curve (Fig. 4) represented stiffness and averaged 10.4N/cm ± 4.4N/cm for the femoral arcuate ligament, 36.9N/cm ± 24.4N/cm for the ischiofemoral ligament, 97.8N/cm ± 67.5N/cm for the superior half of the iliofemoral ligament and 100.7N/cm ± 54.0N/cm for the inferior half of the iliofemoral ligament (p<0.001 for FA v. I1 & I2; p>0.01 for IS v. I1 & I2).

The slope of the toe region of the force-displacement curve was 0.76N/cm ± 0.4N/cm for the femoral arcuate, 1.1N/cm ± 0.5N/cm for the ischiofemoral, 2.1N/cm ± 2.8N/cm for the superior half of the iliofemoral and 1.7N/cm ± 1.2N/cm for the inferior half of the iliofemoral ligament. The energy absorbed by each of the ligaments, or the area under the force-displacement curve, was 0.43N m ± 0.33N m for the femoral arcuate ligament, 0.44N m ± 0.36N m for the ischiofemoral ligament, 0.95N m ± 1.07N m for the superior half of the iliofemoral ligament and 1.17N m ± 0.76N m for the inferior half of the iliofemoral ligament.

Discussion: To our knowledge, this study is the first to examine the mechanical properties of the hip joint capsule. Our findings indicate that the ligaments of the capsule differ significantly in their structural and material properties as well as their anatomy.

In particular, the iliofemoral ligament differed significantly from the other ligaments in all measures despite being tested as two discrete bone-ligament-bone specimens. The two halves of the iliofemoral ligaments, which ischiofemoral or femoral arcuate ligaments. This behavior is consistent with the high ratios of posterior to anterior hip dislocations observed clinically. Material strain in the central third of the ligaments represented 36-54% of the structural strain indicating that a large portion of the structural strain occurred around the site of origin or insertion. No significant difference was detected from our data in the amount of energy absorbed at failure by any of the ligaments.

The stress and strain data of the hip joint ligaments are very similar to data previously reported for the shoulder joint capsule ligaments (3). However, the hip ligaments generally have larger cross sectional areas than the shoulder ligaments and consequently can withstand greater tensile force. This difference likely contributes to the greater incidence of dislocation in the shoulder compared to the hip.

Understanding the mechanical properties of the hip joint capsule ligaments can help determine which structures are important to joint stability and thus which ones to avoid or repair when entering the joint capsule surgically. Knowledge of the ligament strength may also assist in developing materials and techniques to repair the joint capsule. In addition, information about the hip joint ligaments can offer insight into the mechanisms of hip dislocation.


Acknowledgements: Funding provided by the Virginia Flowers Baker Endowment and an unrestricted research grant from Johnson and Johnson P.I.