The Role of Anterior Capsular Laxity in Hip Microinstability

A Novel Biomechanical Model

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Background: Hip microinstability is an increasingly recognized source of hip pain and disability. Although the clinical entity has been well described, the pathomechanics of this disease remain poorly understood.

Purpose/Hypothesis: The purpose of this study was to determine the role of capsular laxity in atraumatic hip microinstability. Our hypothesis was that cyclic stretching of the anterior hip capsule would result in increased hip range of motion and femoral head displacement.

Study Design: Controlled laboratory study.

Methods: In this study, 7 hip specimens met inclusion criteria (age, 18-46 years). Specimens were stripped of all soft tissue, aligned, cut, and potted by use of a custom jig. A materials testing system was used to cyclically stretch the anterior hip capsule in extension and external rotation while rotating about the mechanical axis of the hip. A motion tracking system was used to record hip rotation and displacement of the femoral head relative to the acetabulum in the anterior-posterior, medial-lateral, and superior-inferior directions. Testing was conducted at baseline, after venting, and after capsular stretching.

Results: With the hip in anatomic neutral alignment, cyclic stretching of the anterior hip capsule resulted in increased hip rotation ($P < .001$). Femoral head displacement significantly increased relative to the vented state in the medial-lateral ($P < .001$), anterior-posterior ($P = .013$), and superior-inferior ($P = .036$) planes after cyclic stretching of the anterior hip capsule.

Conclusion: The anterior hip capsule plays an important role in controlling hip rotation and femoral head displacement. This study is the first to display significant increases in femoral head displacement through a controlled cyclic stretching protocol of the anterior hip capsule.

Clinical Relevance: This study is directly applicable to the treatment of atraumatic hip microinstability. The results quantitatively define the relative importance of the hip capsule in controlling femoral head motion. This allows for a better understanding of the pathophysiological process of hip microinstability and serves as a platform to develop effective surgical techniques for treatment of this disease.

Keywords: hip microinstability; capsular laxity; cadaveric; biomechanical

Awareness of hip microinstability has increased, leading to more frequent diagnoses and research emphasis in recent years.[3,5-8,12,19,23,24] Sources of traumatic instability are prior dislocation events, subluxation events, or iatrogenic causes due to a failed or incomplete capsular closure.[25] The atraumatic instability population has hyperlaxity due to repetitive microtraumatic activities such as ballet and gymnastics, a genetic predisposition such as in Marfan or Ehlers-Danlos syndrome, or benign hypermobility syndrome.[6,7,14] A classification has been proposed for hip microinstability that divides patients into 6 categories based on underlying causes: significant bony abnormalities or developmental dysplasia of the hip, connective tissue disorders, posttraumatic processes, athletics/microtrauma, iatrogenic causes, and idiopathic causes.[13] These patients often have vague anterior hip pain made worse in hip extension and external rotation (ER) activities, where the iliofemoral ligament is stressed. Although attempts have been made to better characterize hip instability on physical examination or magnetic resonance imaging, clear diagnostic criteria for atraumatic instability have yet to be widely recognized.[11,15]

The iliofemoral ligament is considered the strongest ligament in the human body (Appendix Figure A1, available in the online version of this article), and prior research has demonstrated that this ligament is the primary

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restraint in limiting ER and anterior translation of the femur.[1,17,19] Previous biomechanical models have assessed the role of the capsule and iliofemoral ligament in microinstability through various nonphysiologic techniques of inducing capsular insufficiency.[9,12] Jackson et al[12] simulated instability by stretching the hip in extension for 1 hour in neutral rotation, whereas Han et al[9] used a "pie crusting" technique that places a regular array of incisions in the iliofemoral, pubofemoral, and ischiofemoral ligaments. Although these models add to the limited understanding of hip microinstability, they do not replicate the pathologic laxity of atraumatic microinstability. Current theory is that microinstability is the result of the capsular insufficiency that occurs from repeated stretching events in extension and ER. Thus, the development of a model that resembles the pathomechanism of microinstability in the young hip is warranted.

The goals of this cadaveric study were (1) to create a reliable model of atraumatic hip capsular laxity and (2) to determine the influence of capsular laxity on hip stability. Our primary hypothesis was that range of motion in internal rotation (IR) and ER would increase after cyclic stretching. Our secondary hypothesis was that femoral head displacements would increase after cyclic stretching.

METHODS

The study used 8 hips from 7 cadaveric pelvises (1 bilateral) with full femurs (mean age, 31 ± 11 years; range, 18-46 years; 5 male, 2 female). Specimens of this age range were selected as this is the general age range of patients undergoing hip arthroscopy for nonarthritic problems, including microinstability. Specimens were commercially obtained from licensed third-party organizations. These companies have access to the donor's medical history, and only donors with no history of hip surgery were eligible for this study. Internal review board approval was not necessary at our institution, as this was a cadaveric laboratory-based study. Anteroposterior (AP) and lateral radiographs were taken before dissection to ensure absence of arthritis, dysplasia, prior fracture, and bony deformity. Specimens underwent 2 freeze-thaw cycles for this study, the first for dissection and alignment and the second for mechanical testing. Specimens were maintained moist throughout preparation and testing with phosphate-buffered saline. At the completion of testing, hips were disarticulated and examined through direct visualization and probing for pretesting labral pathologic features, femoroacetabular syndrome, or significant arthritis. Any specimens with pathologic features (eg, chondrolabral separation, chondral injury with exposed bone) identified after disarticulation would be excluded from the study. One hip was excluded because of abnormal motion values outside of expected parameters on initial testing, causing concern for capsular injury during preparation. In this specimen, the contralateral side was used for evaluation. Thus, 7 independent hips were studied.

After a thawing period of at least 24 hours, all soft tissue was removed from the femur and pelvis, with care taken to preserve the hip capsule. The intercondylar notch of the knee was deepened to allow for insertion of a push pin at the coronal and sagittal central point of the distal femoral condyles. The distal point along the femoral mechanical axis was defined in the coronal plane as the midpoint between the medial and lateral condyles and in the sagittal plane as the center of the lateral femoral condyle.[22,27] This point was confirmed radiographically.

With a metal rod overlying the hip joint, the radiographic center of the femoral head on AP and lateral radiography defined the proximal point of the femoral mechanical axis (Figure 1B), and this center point was marked on the inferior hip capsule with a permanent marker in line with the distal femoral center point. A screw was placed in the medial proximal femur in line with the femoral head center point (Figure 1C). A string was tied between the proximal femoral screw and the distal femoral push pin, temporarily marking the mechanical axis (Figure 1, C and D). The metal rod was again used to confirm that the string was now running in line with the mechanical axis and connecting the center of the femoral head to the center of the distal femur. Then 2 metal screws were inserted along this axis of the proximal femur 75 mm and 125 mm distal to the greater trochanter (Figure 1C). The screws were buried so that the center of the head of the screw touched the string. The axis connecting these screw heads served as the alignment tool for the mechanical axis after cutting and potting of the specimen.

The pelvis was then mounted in a custom apparatus in neutral alignment (Figure 1, A and C). The sagittal orientation of the pelvis was established by creating a vertical plane from each anterior superior iliac spine (ASIS) and the pubic symphysis.[12] The coronal orientation of the pelvis was defined as the most superior aspect of the iliac crests bilaterally. Neutral alignment of the femur relative to the pelvis was defined with the mechanical axis of the femur oriented in 3° of valgus in the coronal plane and vertical in the sagittal plane through use of a digital goniometer.[4] Anatomic neutral rotation (IR-ER) of the femur was defined as the posterior condylar axis parallel with the ASIS plane.

With the aid of a jig, a single 3-mm threaded rod was placed lateral to medial in the femur, and two 3-mm

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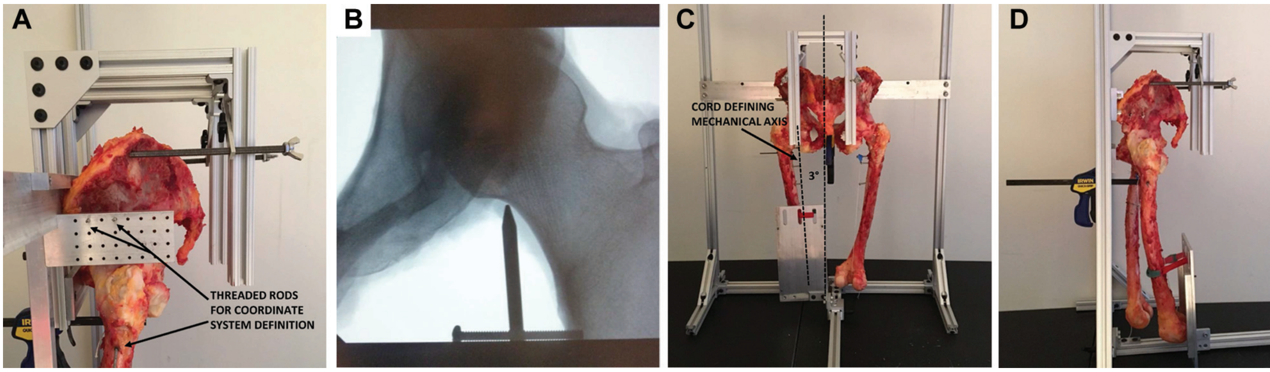

Figure 1. The pelvis was mounted in a custom apparatus in neutral alignment. (A) Neutral rotation of the pelvis in the sagittal plane was established by creating a vertical plane from each anterior superior iliac spine (ASIS) and the pubic symphysis. The line connecting each ASIS was used to define the mediolateral axis. (B) The center of the femoral head was radiographically determined by placing a metal rod over the hip capsule in line with a string connecting the distal femoral push pin. (C) Neutral alignment of the femur relative to the pelvis was defined with the mechanical axis oriented 3° valgus in the coronal plane and vertical in the sagittal plane. Neutral internal rotation and external rotation of the femur were established with the plane formed by the posterior condylar axis parallel to the pelvic coronal plane. (D) Each hip joint was manually brought into hyperextension on the alignment apparatus, while maintaining neutral femoral rotation.

threaded rods were placed lateral to medial in the acetabulum (Figure 1A). The 3 rods were used as landmarks for the coordinate system definition and as guides to reestablish hip neutral alignment on the day of mechanical testing. Each hip joint was then manually brought into hyperextension on the alignment apparatus, while maintaining neutral femoral rotation (Figure 1C). The hyperextension angle was recorded with a digital level.

The specimen was removed from the alignment apparatus. The femur was transected 150 mm distal to the greater trochanter, and the pelvis was cut outside of the capsule through a triple osteotomy of the ilium, pubis, and ischium to facilitate fixation in polymethylmethacrylate. The 2 screws inserted into the proximal femur were used as reference points, and the femur was potted with the mechanical axis coincident with an alignment rod on the potting block. The specimens were then stored in a −20°C freezer until the day of mechanical testing.

Mechanical testing was performed on an E10000 materials testing system fitted with a 10-KN/100-N·m biaxial load cell (Instron Corporation) (Figure 2). Neutral hip alignment was reestablished on the materials testing system by use of the alignment pins in the pelvis and femur along with a digital level. The femur was rigidly attached to the actuator of the test machine with the femoral mechanical axis coaxial with the test machine's rotatory axis. The acetabulum was attached to a custom fixture that allowed unrestricted motion in the axial plane during testing. The fixture incorporated a 3° angle plate to recreate the coronal plane angulation of the mechanical axis relative to the pelvic sagittal plane. The flexion-extension orientation of the hip was adjustable and was set by use of a digital level. A pulley system and counterbalances were used to offset the weight of the movable components on the setup during testing in positions of hip extension. Motion of the femoral head relative to the acetabulum was monitored throughout testing through use of custom rigid body trackers mounted on the femur

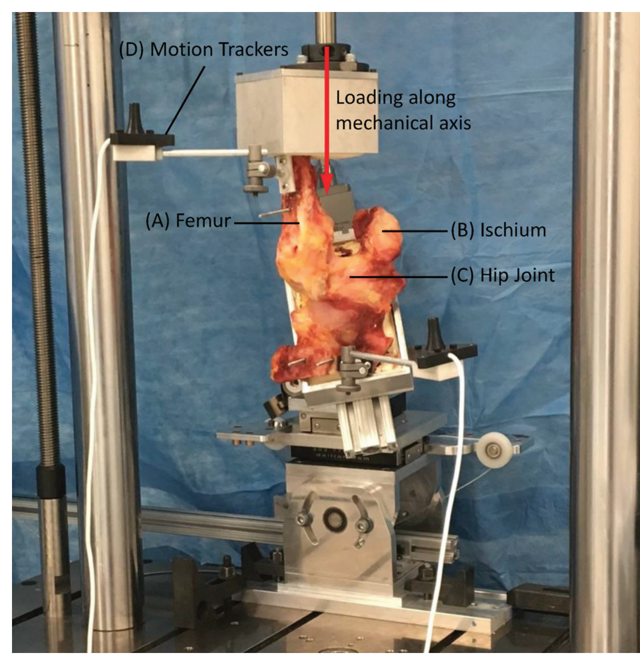

Figure 2. Experimental setup for 5 degree of freedom testing of hip joints. The femur (*A*) was rigidly attached to the actuator of the test machine with the femoral mechanical axis coaxial with the test machine rotatory axis. The pelvis (*B* and *C*) was attached to a custom fixture that allowed unrestricted motion in the axial plane during testing. The fixture incorporated a 3° angle plate to recreate the coronal plane angulation of the mechanical axis relative to the pelvic sagittal plane. Motion trackers (*D*) allowed for motion capture analysis during testing.

and pelvis (3D Creator; Boulder Innovation Group). The position and rotational accuracies of the trackers have been estimated by our laboratory to be 0.1 mm and 0.1°, respectively (root-mean-square error).

Specimens were initially preconditioned in neutral hip alignment for 10 cycles to 5 N·m IR-ER torque at a rate of 5 deg/s while maintaining a constant axial compressive load of 10 N. Specimens were then subjected to 4 loading conditions with the hip oriented in both neutral and hyperextension: IR-ER arc of rotation, mediolateral (ML) translation, AP translation, and superoinferior (SI) translation. The femur was first rotated about the mechanical axis to 5 N·m IR-ER torque at a rate of 5 deg/s for 3 cycles. A 5 N·m torque limit has been used in previous studies and was estimated by the senior author (M.R.S.) of this study to be the torque used during clinical examination.[2,17-19] Specimens were then subjected to SI-directed forces of 50 N with a displacement rate of 0.1 mm/s for 3 cycles. Finally, a 50-N force was manually applied independently in ML and AP directions by use of constant force springs. A constant superiorly directed compressive load of 10 N was maintained during IR-ER, ML, and AP tests. Data collected from the third cycle for each loading condition were used for analysis, to account for any viscoelastic effects. Data not reported were consistent between the 3 trials.

Translation tests were performed with the IR-ER fixed in 2 positions: (1) anatomic neutral, with the plane formed by the posterior condylar axis oriented parallel to the pelvic coronal plane, and (2) biomechanical neutral, with the IR-ER fixed at zero torque, defined as the midpoint of the neutral zone during rotation from 5 N·m IR to 5 N·m ER. The biomechanical neutral position was determined for both neutral hip flexion-extension and maximal hip extension. The authors thought that collecting and reporting data from both positions was important, as this would detail the interactions and strain of the capsule at each hip position, which is dependent on IR and ER of the femur. Prior studies measured only 1 rotational variable,[1,9,12,17] and this modification allows for a better understanding of the role of hip rotation in femoral head motion during flexion-extension of the hip.

After testing in the intact state, specimens were vented by use of an 18-gauge needle under 100-N inferiorly directed (distractive) and 50-N laterally directed loads. The needle was introduced through the inferior portion of the capsule until it was felt to be between the femoral head and the acetabulum, and then air was allowed to flow inside the joint by removing the needle stylet. To create capsular laxity, specimens were oriented in maximal extension and externally rotated in torque control from the end point of laxity (defined as 0.2 N·m) to 30 N·m torque for 100 cycles at 0.5 Hz. Specimens were then loaded in ER by use of a rotation controlled test for 1000 cycles at 0.5 Hz, with the rotation endpoints of cycle 100 of the initial cyclic test. A constant superiorly directed compressive load of 10 N was maintained during the cyclic stretching protocol. A 15-minute rest period was observed after the stretching protocol. Measured testing states were baseline testing in the intact state, after venting, and capsular laxity (after stretching).

Points on the threaded rods inserted into the pelvis and femur, along with a point on the mechanical axis, were acquired with a probe. A spherical fit of surface points on the femoral head was used to determine the center of the femoral head, which was used to measure the displacement of the femoral head. Post hoc measurement of the femoral neck with a protractor was used to determine femoral anteversion. Information on femoral version is not available for the first 2 specimens because this measurement was included later in the study. Acetabular version was determined by projecting a vector normal to a plane created from 4 points on the acetabular rim onto the pelvic axial plane. The McKibbin index was determined by the addition of the femoral and acetabular version values.[16]

Motion of the femoral head was reported relative to the pelvic coordinate system. IR-ER rotations and displacements were reported as the net motion along the axis of loading. A mixed-effects linear model was fitted to the data, with testing condition as a fixed effect and specimen as a random effect. Tukey contrasts for multiple comparisons of means were used to examine the differences between testing conditions. Significance was set at $P < .05$.

RESULTS

Of the 7 hips included in the study, femoral version was available for 5 of 7 specimens (mean, 17° ± 5°; range, 11° to 25°). Acetabular version was available for all 7 specimens (mean, 28° ± 6°; range, 23° to 40°). The average McKibbin index for available specimens was 47° ± 8° and ranged from 35° to 55°. The average maximum hip extension was 10° ± 3° and ranged from 7° to 14°. On average, the biomechanical neutral femoral IR-ER alignment was internally rotated relative to the anatomic neutral IR-ER alignment for hip neutral (mean, 3° ± 11°; range, –11° to 20°) and hip hyperextension (mean, 5° ± 12°; range, –6° to 22°).

IR-ER Range of Motion

With the hip in neutral alignment, IR-ER range of motion increased significantly after venting (P = .042) and capsular stretching ($P < .001$) (Figure 3; Appendices 1 and 2, available online). A 4.5° ± 1.7° increase in rotation, corresponding to an 8.2% ± 3.7% increase in rotation, was observed in the capsular laxity state compared with the vented state. With the hip in hyperextension, IR-ER range of motion increased significantly compared with the intact state only after capsular stretching ($P < .001$). A 7.4° ± 1.6° increase in rotation, corresponding to an 18.7% ± 7.2% increase in rotation, was observed in the capsular laxity state compared with the vented state.

Femoral Head Displacement: Anatomic Neutral Femoral Alignment

With the hip in neutral alignment, femoral head displacements increased in magnitude after venting; however, a significant change was observed only in ML displacement (P = .003) (Figure 4A; Appendices 1 and 2). Relative to the vented state, capsular laxity resulted in significantly greater mean

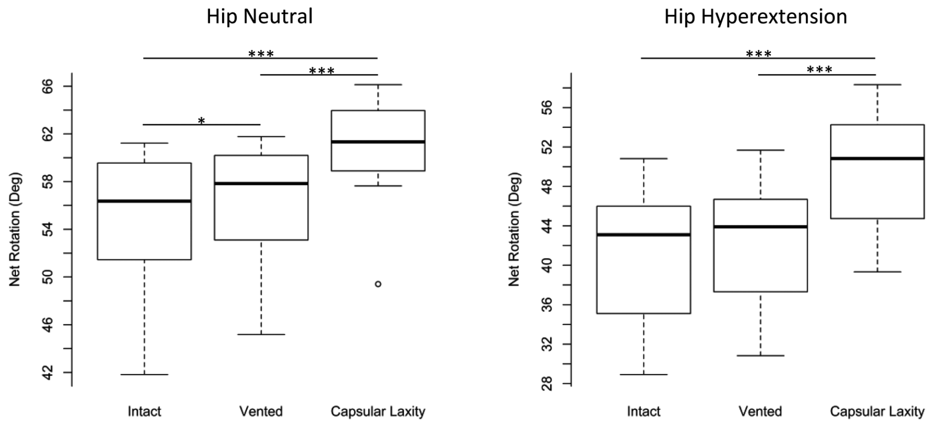

Figure 3. Net femoral internal and external rotation with the hip positioned in neutral and hyperextension. The midline represents the median, with the upper and lower limits of the box denoting the third and first quartiles, respectively. The whiskers extend to 1.5 times the interquartile range from the top (bottom) of the box to the farthest datum within that distance. The small circle located below one of the boxes represents an individual point that is beyond that distance and may be a possible outlier. *$P < .05$, ***$P < .001$.

displacements in the AP (0.6 ± 0.5 mm, $P = .013$), ML (1.2 ± 0.8 mm, $P < .001$), and SI (0.5 ± 0.7 mm, $P = .036$) directions.

With the hip in hyperextension, no significant increases in femoral head displacements were observed after venting (Figure 4B). SI displacement significantly increased after capsular stretching compared with the vented state ($P = .041$); however, the mean increase of SI displacement was only 0.2 ± 0.2 mm.

Femoral Head Displacement: Biomechanical Neutral Femoral Alignment

With the hip in neutral alignment, ML displacement of the femoral head increased after venting ($P < .001$) (Figure 5A, Appendices 1 and 2). Relative to the vented state, capsular laxity resulted in significantly greater AP displacement (0.9 ± 0.8 mm, $P = .012$); however, ML (0.9 ± 1.1 mm, $P = .058$) and SI (0.5 ± 0.9 mm, $P = .147$) displacements were not significantly increased by capsular stretching.

With the hip in hyperextension, no significant increases in femoral head displacements were observed after venting (Figure 5B). Relative to the vented state, displacements increased significantly in the ML (0.3 ± 0.3 mm, $P = .012$) and SI (0.2 ± 0.1 mm, $P < .001$) directions after capsular stretching.

Mean displacements and rotations for all test configurations along with P values for all group comparisons are presented as separate appendices (available online).

DISCUSSION

The current study describes a novel model of hip microinstability. Unlike prior static testing models, capsular laxity was created via a controlled cyclic stretching protocol after venting of the joint, and this protocol caused a significant increase in femoral rotation and femoral head displacement. Our hypothesis was proven correct, in that the capsule is important in controlling femoral head rotation and displacement and that a novel model is able to recreate this state.

The hip joint is believed to be a stable joint because of the acetabular depth, congruity, and strong ligaments. Hip instability may come from bony insufficiency, capsular insufficiency, or labral insufficiency.[20,21,26] It is widely accepted that a dysplastic hip is unstable because of bony insufficiency. However, microinstability in the setting of a normal osseous anatomic state is becoming increasingly recognized as a source of pathologic characteristics in the young patient due to laxity in the capsuloligamentous structures of the hip joint.

The goal of the instability model described in this study is to simulate hip instability in a physiologic manner. Hip microinstability is believed to occur because of repetitive loading in extension and ER as seen in dancers and gymnasts.[7,13] Therefore, our model replicates this pathologic state with cyclic loading in extension and ER to target the iliofemoral ligament. Previously described models used static techniques where the anterior capsule was stretched by placing and holding the hip in extension for 1 hour in neutral rotation or by pie crusting all capsular ligaments.[10,12] Although both models achieved increased range of motion with their technique, we believe the current model may be more physiologically accurate because forces are dynamically and cyclically applied, which, in theory, has been considered the pathologic mechanism for hip microinstability. Further, our custom jig allows for acetabular motion during testing using low-friction linear slides. Small movement of the acetabulum during femoral head rotation allowed for a more physiologic rotation cycle, where the capsule interacted with the osseous anatomic feature similar to hip movement in a less controlled setting. These specifications make this model the most physiologically accurate to date, and the authors believe it best replicates the pathologic state of microinstability.

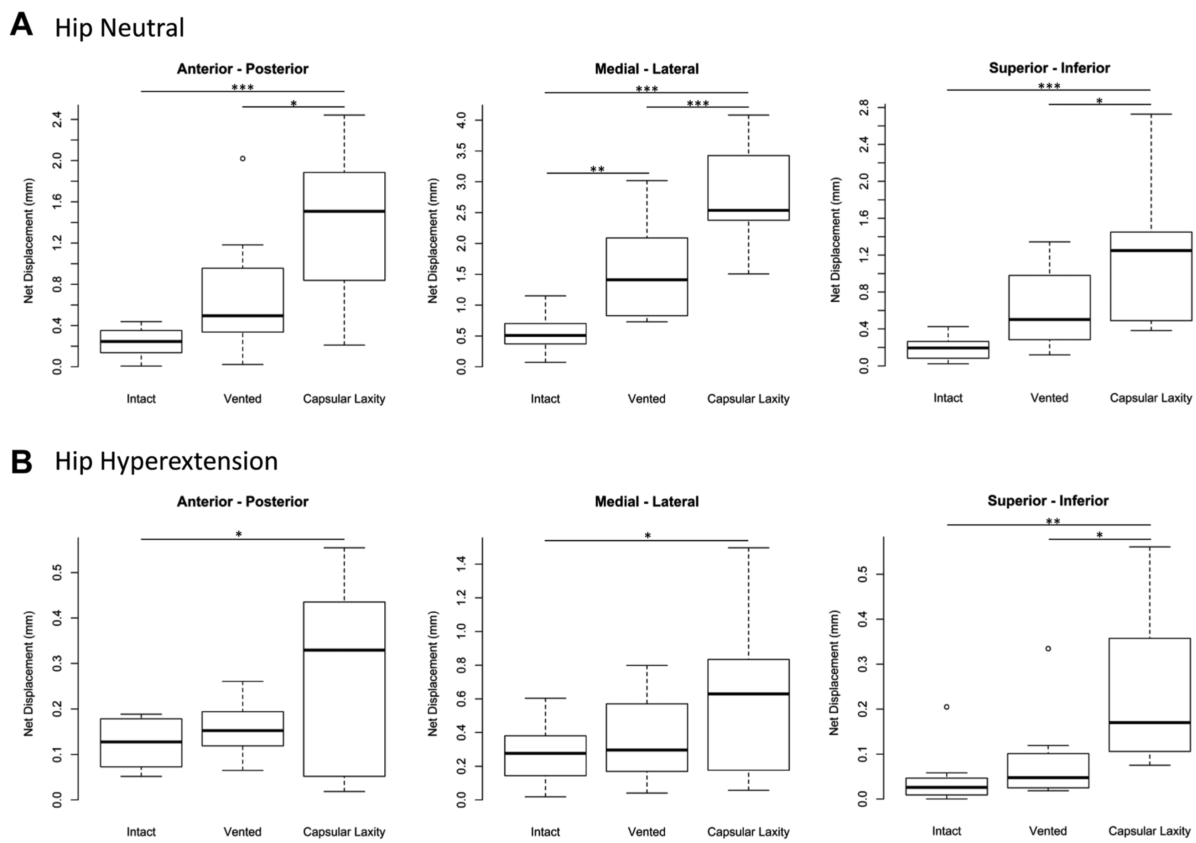

Figure 4. Femoral head displacements with the hip in (A) neutral and (B) hyperextension during translation tests with the femoral internal and external rotation fixed in anatomic neutral alignment. Net motion is reported along the axis of the applied loads. The midline represents the median, with the upper and lower limits of the box denoting the third and first quartiles, respectively. The whiskers extend to 1.5 times the interquartile range from the top (bottom) of the box to the farthest datum within that distance. The small circles located above some of the boxes represent individual points that are beyond that distance and may be possible outliers. **P* < .05, ***P* < .01, ****P* < .001.

Jackson et al[12] also compared the vented state versus the laxity state, saying that "venting was performed to control for effects seen with the loss of negative pressure found in the hip capsule." In a biomechanical model, increased motion and rotation could be seen if a small inadvertent puncture of the capsule happened during dissection or stretching of the capsule. By demonstrating differences between the vented and laxity states, this model shows that the observed results are due to the stretching of the capsule. Furthermore, this model can be applied in future research regarding surgical techniques used in the treatment of hip microinstability. If the vented state was to not be tested, one may argue that differences between conditions studied in future tests may be due to loss of the negative pressure inside the joint (eg, capsulotomy and/or capsular plication) and not because of the capsular stretching or technique evaluated.

Hip microinstability is more prevalent in young patients.[6,13] Accordingly, the current study used only specimens less than age 50. When one is attempting to replicate disease in a biomechanical model, it is important to use specimens of the same age, to best match the capsular integrity. Prior studies used older specimens; the average age of donors was 60.4 years in the Myers et al[17] study and 58.5 years in the Jackson et al[12] study. Authors of both of these studies described impingement of the greater trochanter and the ischium in some specimens during testing. In the current investigation the average age was 31 years, and no cases of greater trochanteric impingement occurred. For a cadaveric mechanical model to resemble the clinical scenario of hip microinstability, older specimens must not be included in the research.

Prior studies on hip microinstability reached similar findings. Jackson et al[12] reported an increase of ER from 26.3° to 30.9° after the creation of the model. Interestingly, Jackson et al[12] did not demonstrate a difference for hip distraction when comparing the venting state with the laxity state, demonstrating the importance of evaluating the vented state, as it can lead to instability by itself. Han et al[9] reported an overall increase of 4.1° in ER and 3.1° in IR in all positions of flexion examined. Those authors also found an increase in femoral head translation, with the largest occurring during IR, with 0.9 mm of additional medial translation in full extension and 0.95 mm of lateral

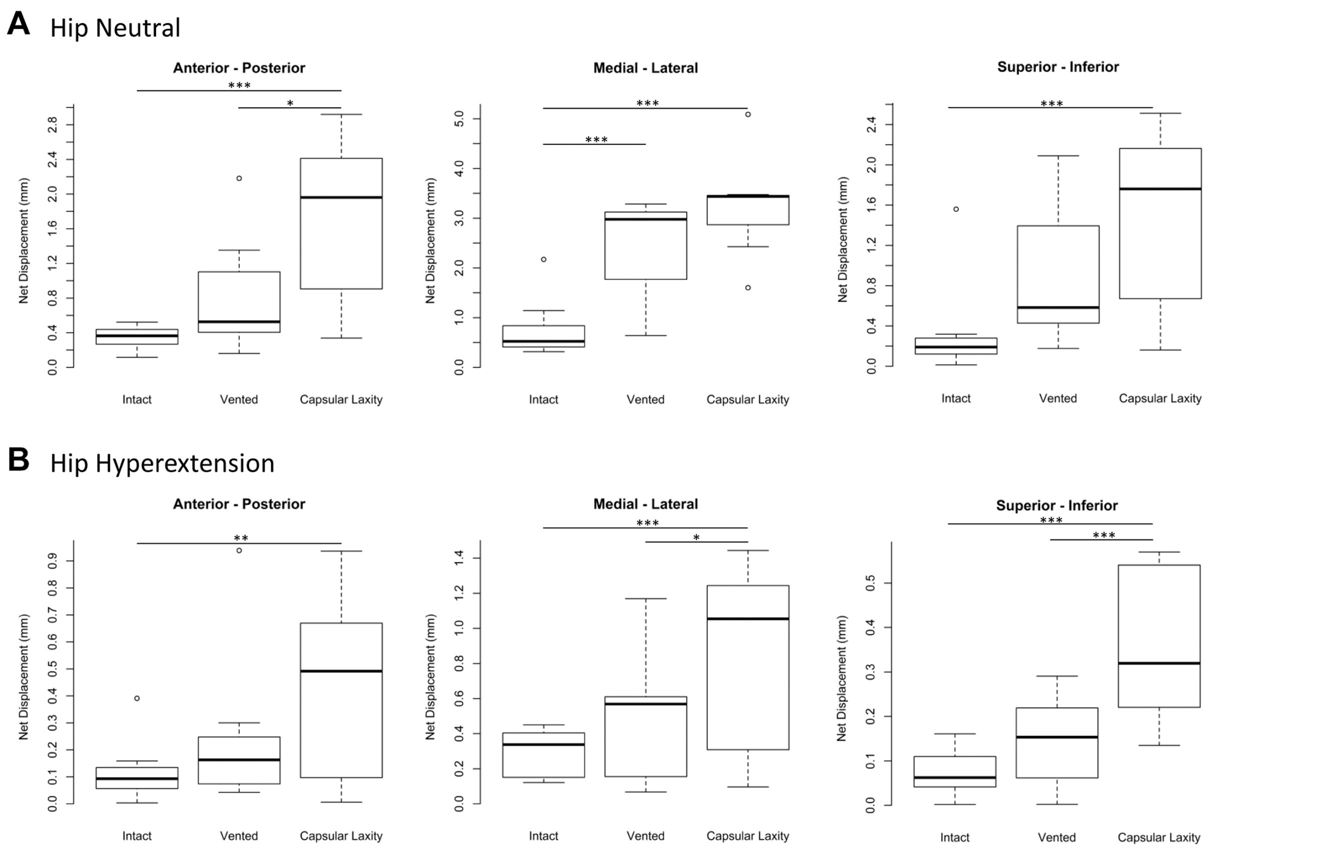

Figure 5. Femoral head displacements with the hip in (A) neutral and (B) hyperextension during translation tests with the femoral internal and external rotation fixed in biomechanical neutral alignment. Net motion is reported along the axis of the applied loads. The midline represents the median, with the upper and lower limits of the box denoting the third and first quartiles, respectively. The whiskers extend to 1.5 times the interquartile range from the top (bottom) of the box to the farthest datum within that distance. The small circles located above or below some of the boxes represent individual points that are beyond that distance and may be possible outliers. *$P < .05$, **$P < .01$, ***$P < .001$.

translation in 90° of flexion. The present study found an increase of 4.5° in rotation in the 0° flexion condition and an increase of 7.4° in rotation in the hyperextension condition when comparing the laxity state with the vented state. Moreover, femoral head displacement increased in the laxity state compared with the vented state.

The axis of rotation throughout testing is important in replicating physiologic motion. The current study determined the proper position of the pelvis in relation to the sagittal plane by determining the anterior pelvic plane alignment by means of a custom jig, as previously described.[12] The jig also determined the neutral rotation of the femur by a plane formed by both posterior femoral condyles and 3° of valgus angulation between the pelvic plane and the mechanical axis.

Our study used the mechanical axis of rotation while determining 2 different center points for rotation. A significant difference between the "anatomic neutral" and the "biomechanical neutral" IR-ER arc of rotation was found, highlighting the importance of both variables. However, it is still unclear what this difference means and whether it is clinically relevant. Most previous hip biomechanical studies used pelvic specimens with the femurs cut on their shafts.[1,9,12,17] Philippon et al[19] also used whole femurs as study specimens; however, those authors also described hip rotation as the "biomechanical neutral." Most previous models seem to rotate about the axis of the femur, which is not a physiologically accurate motion for the hip, and do not address the anatomic neutral position. We determined the axis for each specimen to best replicate physiologic motion during testing and capsular stretching. Further, during a clinical examination, the physician uses the anatomic neutral as the center point for determining hip motion. Therefore, this method of establishing the IR-ER arc of rotation better resembles our clinical evaluation as orthopaedic surgeons.

Limitations of this study include the inherent concerns related to cadaveric work. Specimens were tested in a skeletonized manner, and it is expected that in vivo forces may be different because of patterns of muscle activation surrounding the hip joint. The pelvic position was determined through use of anatomic landmarks to create a vertical plane from each ASIS and the pubic symphysis. Conditions such as an altered relationship between the spine and the pelvis (eg, increased lordosis or scoliosis) and differences in leg length may alter the pelvic tilt and consequently hip biomechanics but could not be addressed in the current research. Testing was completed with a 10-N axial load, as has been used in other studies.[19] This load was used to provide a constant force to keep the femoral head seated in the acetabulum during motion. Further, 50-N forces were used in each direction when femoral head motion was tested. However, the cumulative forces from weightbearing, muscular contraction, and gravity are not fully understood and may be different than the forces applied in our study. Last, the extension torque was determined before stretching as a firm endpoint but was not quantified. Our positioning and load frame device did not allow for objective measurement of the extension torque after capsular stretching, and this remains an area for future study.

In conclusion, we describe a novel model for hip microinstability. Capsular laxity increased hip IR-ER range of motion and femoral head displacement. This biomechanical model may be used in future research investigating the pathomechanics of hip microinstability and surgical techniques used in its treatment.

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