Hip Stability after Total Hip Arthroplasty: Quantifying Capsule and Passive Muscle Contributions

Huizhou Yang[1], Kathryn Colone[1], Brian Haas[1], Casey A. Myers[1], Paul J. Rullkoetter[1], Chadd W. Clary[1]
[1]University of Denver, Denver, CO
Huizhou.yang@du.edu

Disclosures: Huizhou Yang (N), Kathryn Colone (N), Brian Haas (N), Casey Myers (3B,5-DePuy), Paul Rullkoetter (3B,5-DePuy), Chadd Clary (3B,5-DePuy)

INTRODUCTION: Dislocation remains a leading cause of revision following total hip arthroplasty (THA), with a substantial proportion occurring during passive or less weight-bearing movements. Understanding the primary contributors to hip passive stability is critical for assessing dislocation risk, optimizing implant design, refining surgical technique, and strengthening rehabilitation strategies. Previous studies have used finite element models to assess the capsule's contribution to hip stability. However, few have incorporated the role of periarticular musculature. Hence, this study aimed to develop and calibrate a computational model incorporating both the hip capsule and local muscles to identify their respective contributions to hip rotational stability mechanisms following THA. We hypothesize that hip muscles provide significant passive stability post-THA by resisting anterior and posterior dislocations.

METHODS: Three fresh-frozen pelvis-to-toe cadaveric specimens (six hips) underwent bilateral THA (CORAIL® total hip system, DePuy Synthes) via anterolateral approach. Pre-operative CT and post-operative optical scans were obtained to register bone and implant geometries. Specimens were secured to a Hana® table with pelvic positioning controlled by a custom fixture. Hip laxity was measured by applying 5Nm internal/external (IE) torques at flexion angles of -20°, 0°, 30°, 60°, and 90° (Condition-1: intact-THA), then repeated after transection of the gluteus medius and external rotators (piriformis, gemelli, obturators) (Condition-2: resected-THA). Hip kinematics were recorded using optical motion tracking (Fig.1-left). Torque-rotation curves were averaged, and ΔTorque was calculated as the difference between conditions. A representative finite element hip model was created from the specimen most closely matching a validated probabilistic capsule model. The capsule included iliofemoral, pubofemoral, and ischiofemoral ligaments modeled as non-linear springs embedded in hyperelastic membrane elements. Eighteen hip muscles were modeled with connector elements, with attachment sites determined from specimen anatomy (Fig.1-right). Muscle passive force-displacement properties were calculated using physiological cross-sectional areas and a nonlinear strain-stress relationship. Implants were rigidly fixed to the bone, with contact definitions for bone-implant and ligament wrapping interactions. Model calibration was conducted stepwise: first optimizing resected muscle properties against ΔTorque, then refining remaining ligaments and muscles to match intact-THA laxity. Verification was performed under resected-THA conditions to assess predictive capability. Individual structure contributions were quantified by systematically disabling each ligament and muscle. The calibrated model was further used to evaluate the effects of ±3 mm stem subsidence and ±5° version changes on laxity.

RESULTS: The calibrated model accurately reproduced experimental IE torque responses, with strong correlations ($r \geq 0.97$) and low root mean square errors (≤ 0.52 Nm) (Fig.2-left). Overall, muscles contributed 69.0% to resistive torque while the capsule provided 31.0%. During internal rotation, stability was dominated by muscles, particularly the quadratus femoris (up to 45% at 30° flexion) and ischiofemoral ligament (peak 21%). Other external rotators (gemelli, obturators) contributed 12~29%, while piriformis and gluteus medius provided moderate support. During external rotation, the iliofemoral ligament was the primary stabilizer in hyperextension and full extension (up to 81%), whereas the gluteus medius became dominant at mid-to-high flexion (peak 58% at 30°), with the gluteus minimus contributing about half as much (Fig.2-right). Superior stem alignment reduced laxity by 18.3% while inferior alignment increased it by 16.8%. Stem version effects were smaller, with retroversion increasing laxity by 6.5% and anteversion decreasing it by 6.3% at higher flexion angles.

DISCUSSION: This study quantified hip capsule and muscle contributions to passive stability after THA. Muscles provided consistent resistance across the entire motion range, eliminating the "free rotation" range observed in capsule-only models. The quadratus femoris and ischiofemoral ligament were dominant stabilizers during internal rotation, supporting posterior stability, while the iliofemoral ligament and gluteus medius were key contributors to external rotation, particularly in extension and mid-flexion, protecting against anterior dislocation. Together, these four structures (iliofemoral ligament, ischiofemoral ligament, gluteus medius, and quadratus femoris) collectively accounted for approximately 75% of anterior and 64% of posterior dislocation resistance. Superior stem alignment increased resistance but also tightened soft tissues. Changes in stem version had smaller effects, with retroversion linked to earlier impingement.

SIGNIFICANCE: The iliofemoral and ischiofemoral ligaments, along with the gluteus medius and quadratus femoris, are the primary passive stabilizers after THA, highlighting their preservation as critical for reducing dislocation risk.

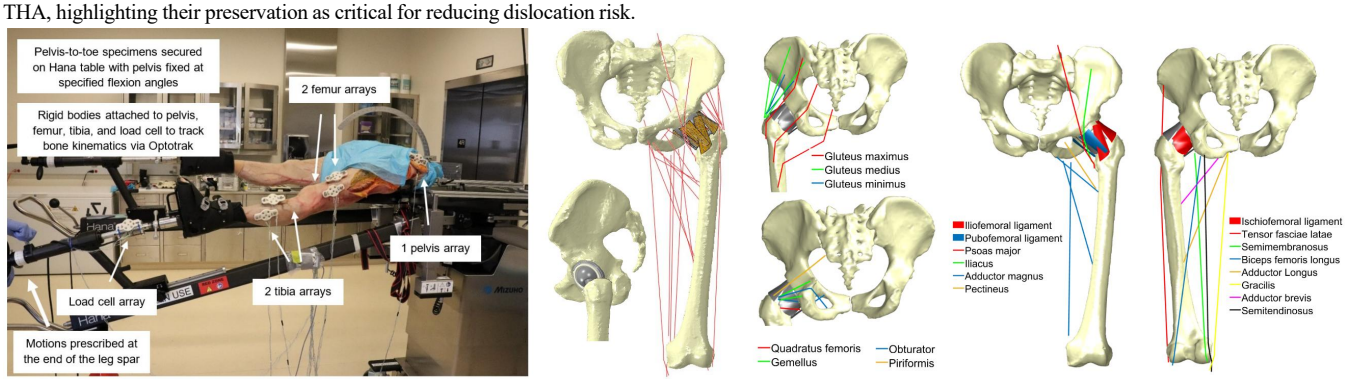

Fig. 1. (Left) Diagram of experimental configuration. **(Right)** Representative hip model with ligament and muscle configurations.

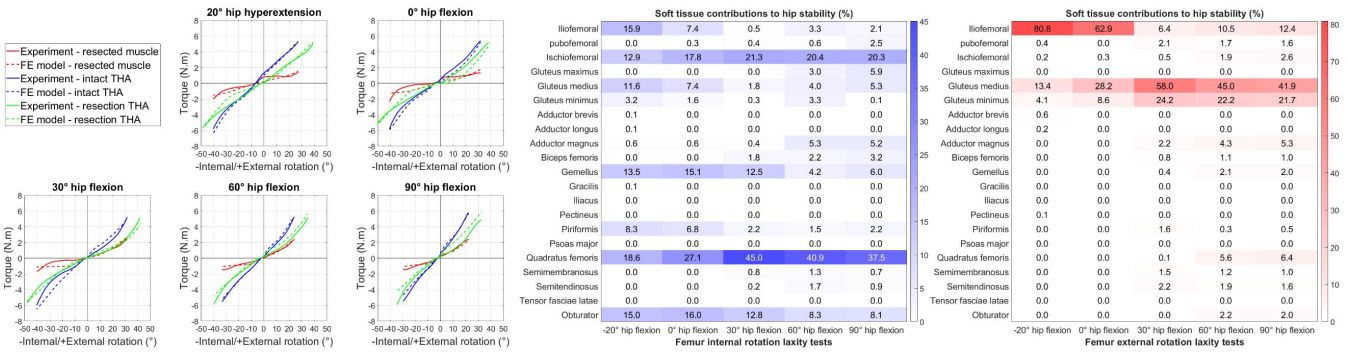

Fig. 2. (Left) Calibration and verification results. **(Right)** Heatmap of capsule/muscle contributions (%) to hip stability during femur IE rotation laxity tests.