The Contribution of the Acetabular Labrum to Hip Joint Stability: a Quantitative Analysis Using a Dynamic 3-D Robot Model

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Introduction

Increasing interest in the treatment of non-arthritic hip pathology, facilitated by the advent of hip arthroscopy and advancements in diagnostic imaging, has led to an improved understanding of hip joint pathoanatomy and disease progression. Acetabular labral tears are a known biomechanical source of hip-centric joint pain and are the leading indication for hip arthroscopy. Defining the role of the labrum in normal hip joint biomechanics is critical for understanding the pathology of labral injury. Cadaveric and simulation studies have shown that the labrum: (1) creates a seal that maintains negative intra-articular pressure, providing stability by resisting distraction of the femoral head; (2) resists synovial fluid extrusion from the central compartment during joint loading; (3) imparts mechanical resistance to femoral head subluxation and dislocation. The objective of the present study was to assess the contribution of the entire acetabular labrum to mechanical joint stability. We developed a novel "dislocation potential test" that utilizes a dynamic, cadaveric, robotic model that functions in real-time under load-control parameters to map the joint space for low-displacement determination of stability, and expressed this quantitatively using a stability index (SI).

Methods

- 5 fresh-frozen human cadaveric hips (all male, ages 58-79 years) without labral tears tested
- Hip mounted to a 6-degree-of-freedom (DOF) robotic manipulator (Rotopod R2000; Parallel Robotics Systems, Hampton, NH, USA)
- 6-DOF force-torque sensor (SI-2500-400, ATI Industrial Automation, Apex, NC, USA) used to evaluate force vectors required for dislocation
- Custom rotary stage used to recreate flexion and extension
- Joint coordinate system (JCS) defined according to International Society of Biomechanics standards
- MicroScribe G2L coordinate measuring machine (Immersion Corporation, San Jose, CA, USA) used to determine spatial orientation
- Coordinate transformations (JCS, robot motion, force sensor coordinate system) computed in real-time using LabVIEW (National Instruments, Austin, TX, USA)
- Hip positioned in 2 most provocative positions for dislocation
  - Full extension (0° flexion) with external rotation until impingement (i.e. anterior provocative position)
  - 90° flexion and 10° adduction with internal rotation until impingement (posterior provocative position)
- Dislocation potential tests were run in 15° intervals (new transverse or sweep plane), about the face of the acetabulum
- For each interval, a 100 N force vector was applied medially and swept laterally until dislocation occurred
- 3-D kinematic data with and without labrum were quantified using the SI (percentage of all directions constant force can be applied within given sweep plane while maintaining stable joint)
- Protocol performed 5 times each to precondition and reduce creep, with 5th run used for statistical analysis

Statistics

- For each sweep angle, curve of displacement with respect to increasing vector angle of the 3-D force was plotted and 1st-order derivatives were calculated to identify point of dislocation at threshold of 0.05 mm/degree (**Figure 3**)
- SI calculated as the percentage of all possible directions a constant force can be applied while maintaining a stable joint, evaluated globally (all 360°) and regionally (posterior provocative position from 30° superior of posterior axis to 15° anterior of the inferior axis; anterior provocative position from directly anterior to 30° posterior of superior axis) (**Figure 4**)
- Differences in SI analyzed using repeated measures mixed-models with pairwise comparisons on LS means with statistical significance set at $p \leq 0.05$

Figure 1. Experimental set-up (LOAD=6-axis load cell; MIC=MicroScribe; ROB=rotopod)

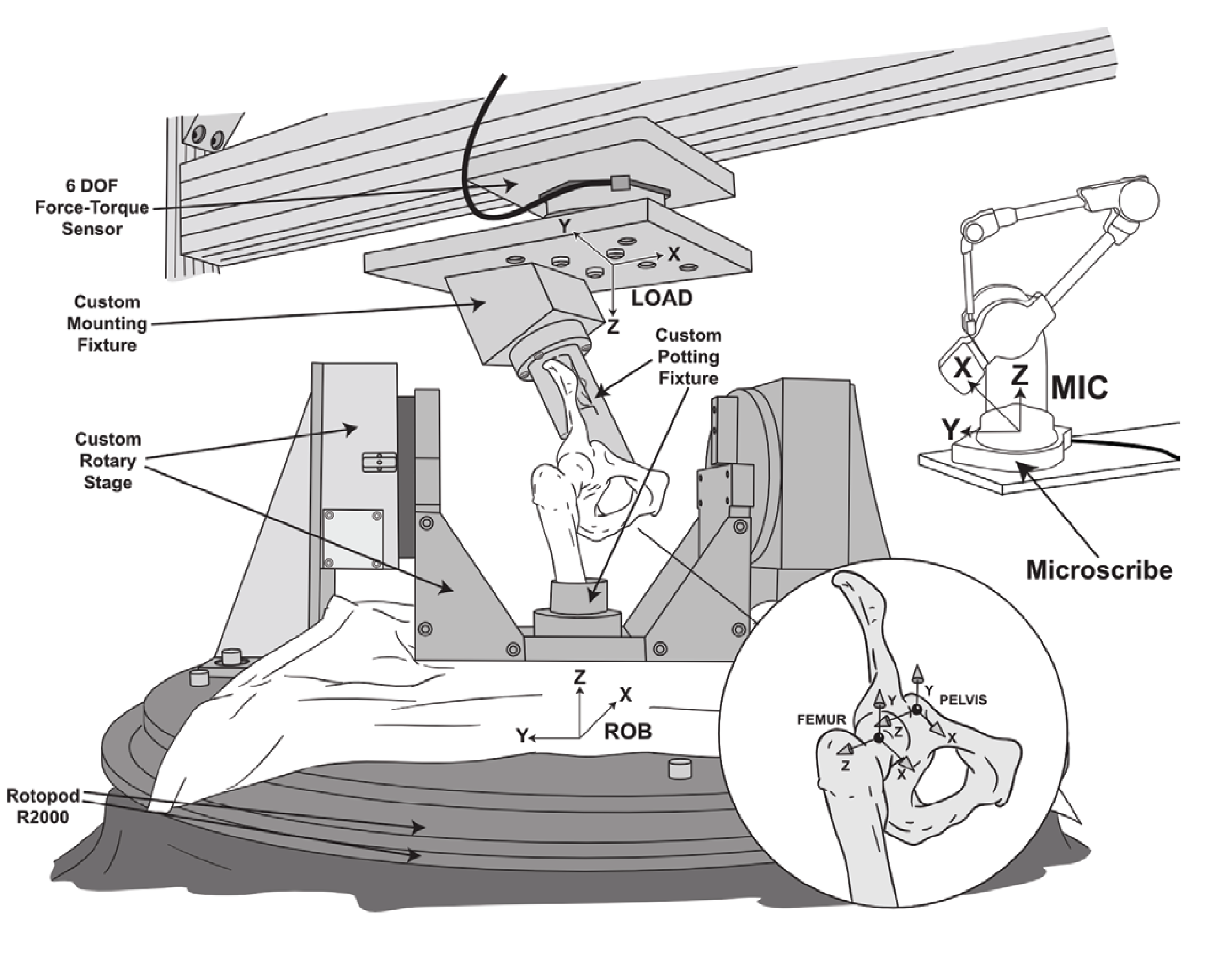


Figure 2. Dislocation potential test with a rotating, constant magnitude force vector

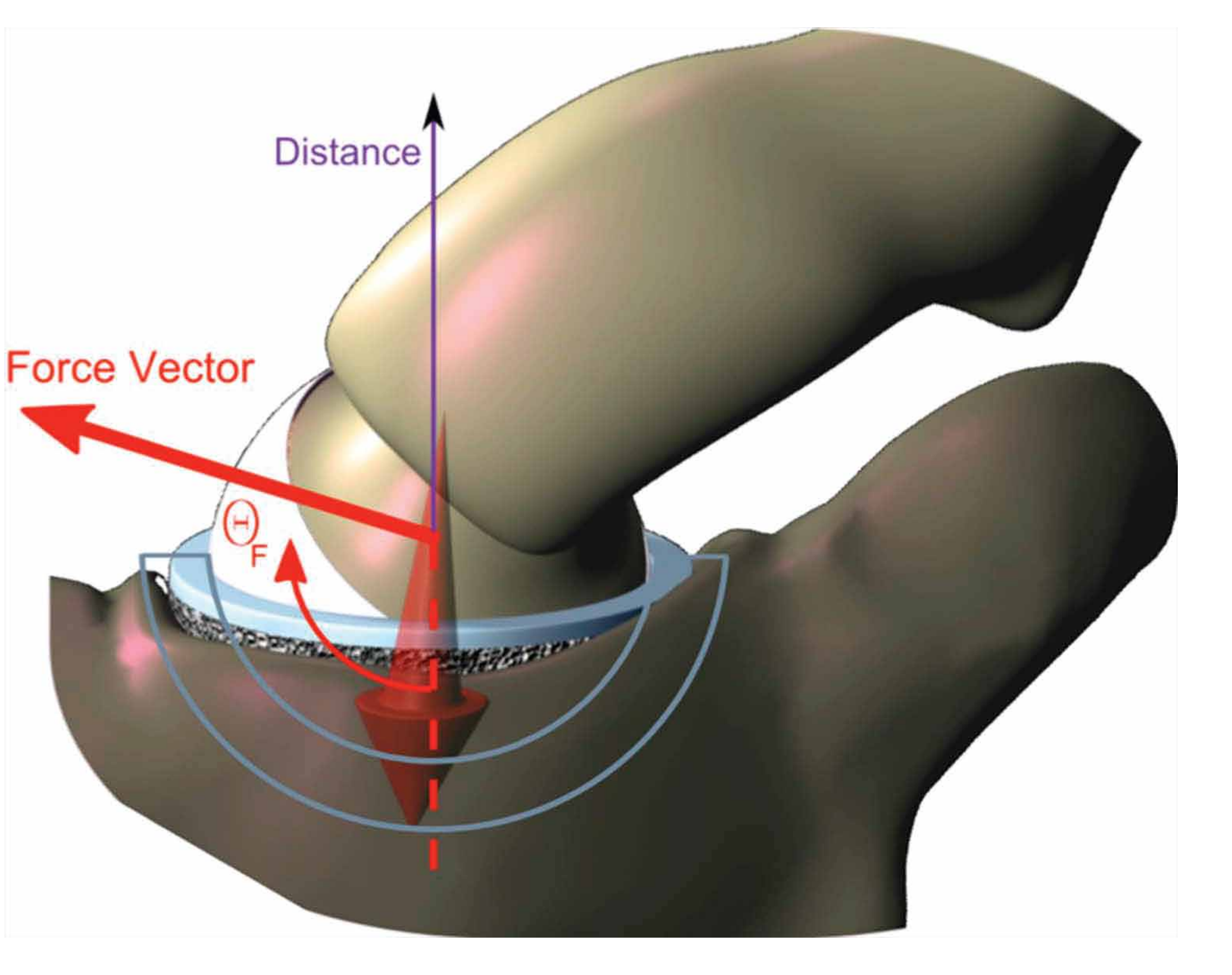


Figure 3. Defining point of dislocation, force and displacement versus vector angle

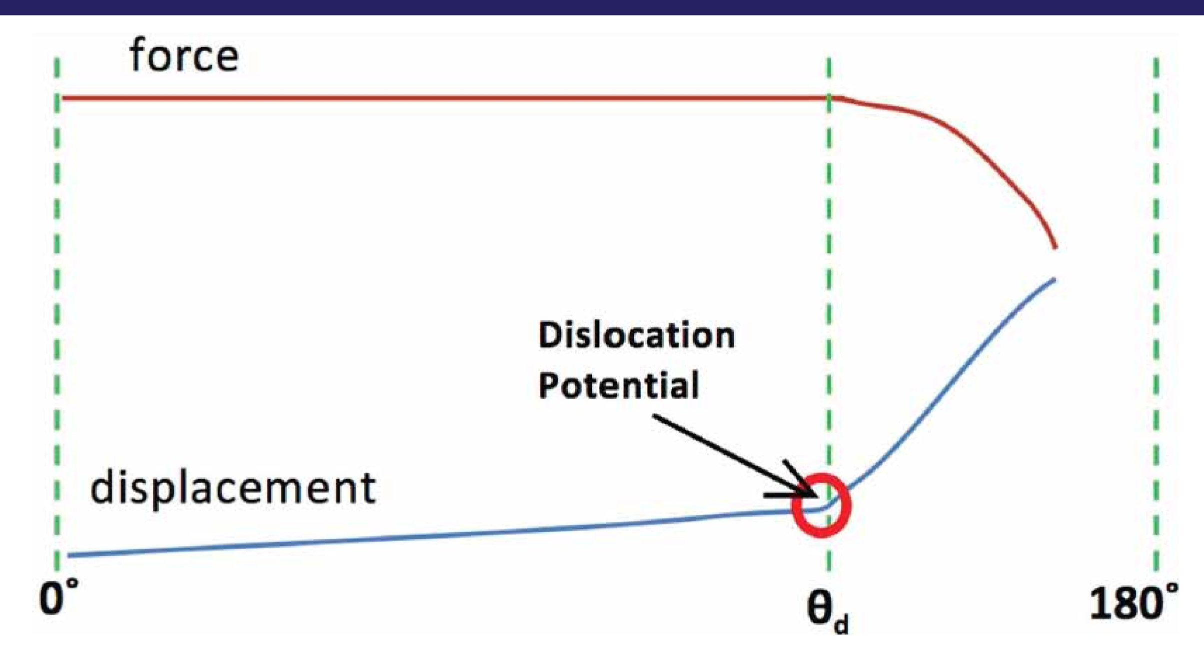
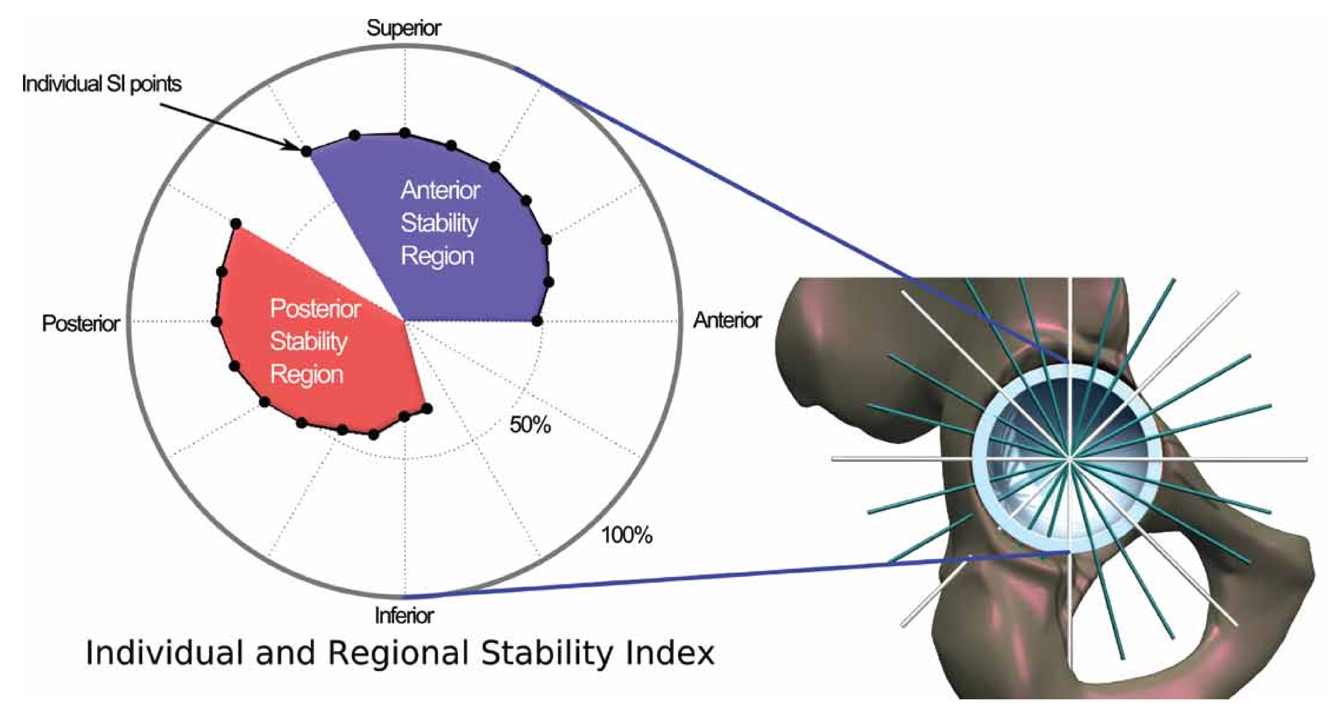


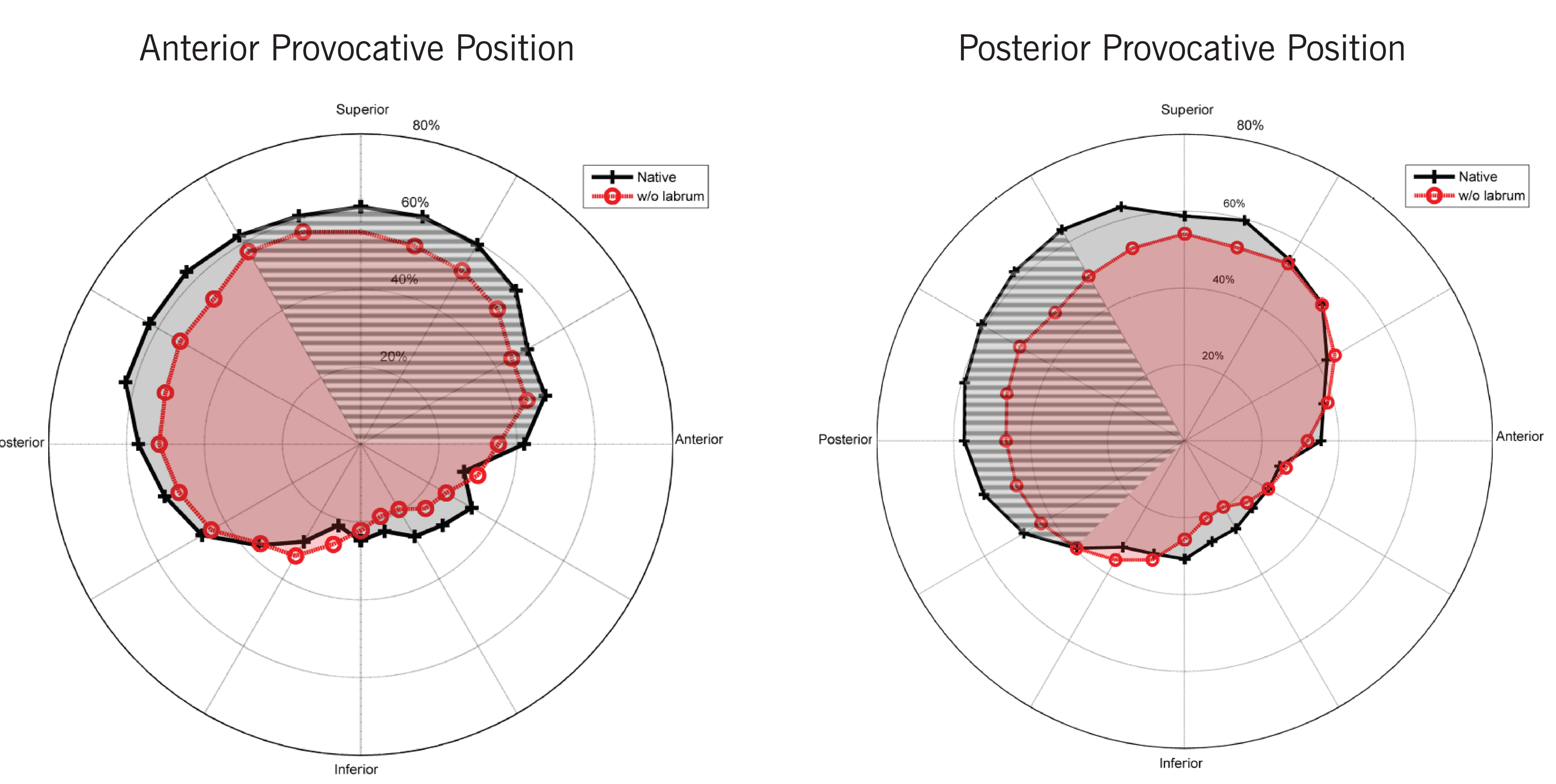
Figure 4.



Results

	Position	SI With Labrum	SI Without Labrum	p-value
Global	Anterior Provocative	46% ± 15%	40% ± 13%	0.02
	Posterior Provocative	45% ± 14%	40% ± 11%	<0.001
Regional	Anterior Pro	56% ± 7%	49% ± 7%	<0.001
	Posterior Provocative	56% ± 8%	46% ± 3%	<0.001

Figure 4. Radial plot of global SI values to compare stability of the native and labrum-deficient skeletonized conditions.



Conclusions

This is the first known application of a 6-degree-of-freedom robot to recreate mechanical hip impingement and dislocation to elucidate the functional stabilizing role of the labrum. It is known that the labrum comprises on average 22% to 27% of articular surface area and 30% to 33% of acetabular volume. The present study found that completely removing the labrum decreases stability, as reflected by the global SI (considering all sweep angles), by approximately 5% for both "at risk" positions.

Regional analyses according to where the femoral head engages the labrum for a given "at risk" position may offer a more clinically meaningful measure. In the posterior provocative position there was a 10% difference in the posterior region-based stability index in favor of the intact condition and only a 5% difference globally. In the anterior provocative position, the increase in regional SI was only 1% larger than its global counterpart. One explanation for these findings is that in the anterior provocative position, the labrum still affords resistance to dislocation in other regions, whereas in the posterior provocative position its stabilizing role is limited to the posterior region. Osseous acetabular coverage likely differs for each "at risk" position. Consequently, differences in the point at which the femoral head engages the labrum and the relative contributions of bone and labrum to blocking dislocation could offer further explanation of these position-based stability variances. In other words, joint position influences which labral region will be engaged as well as certain mechanical properties of that particular region.

The dislocation potential test, and its measurable outcome of Stability Index (SI), offers a novel methodology for biomechanical researchers to understand hip joint stability and to test labral preservation techniques. Although this study does not replicate the true *in vivo* condition, it provides insight into the labrum's role in preventing dislocation through a new, objective measure of stability. At least in extreme positions, the labrum imparts significant overall mechanical resistance to hip dislocation. Regional stability contributions appear to vary according to "at risk" joint orientation.

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