Impingement Free Range of Motion and Dislocation Potential in Total Hip Arthroplasty versus Femoral Head Resurfacing Using a Novel Cadaveric Robotics Model

+4Bottros, J J; 1Greeson, C B; 1Colbrunn, R; 1van den Bogert, A; 1Barsoum, W K
+Cleveland Clinic Foundation, Cleveland, OH

bottroj@ccf.org

Abstract Introduction:
Hip Impingement is a dynamic process that is difficult to identify from static, plain radiographs or clinical evaluation. It is a known cause of instability and accelerated wear that is influenced by prosthetic design, component position, patient variables and biomechanical factors. Much controversy surrounds the resurgence of femoral head resurfacing (FHR) and its biomechanical implications of retaining the femoral neck, particularly its head-neck ratio. We have developed a dynamic cadaveric robotics model that functions in real time under load-control parameters to recreate in vivo hip mechanics. This study specifically identifies and compares the impingent-free ROM and direction of force vectors required for dislocation in the native hip, femoral head resurfacing and total hip replacement (size 28, 36mm femoral heads).

Methods:
Five cadaveric hip specimens (male, age 58-79) were utilized. Randomly chosen, the right hip or left hip was randomly chosen and disarticulated with all soft tissues removed. The specimen (cut femur and hemipelvis) was secured to a custom holding fixture and mounted to a robotic manipulator (Rotopod R2000, Parallel Robotics Systems) which is capable of manipulating in six degrees of freedom (6 DOF). A 6 DOF force-torque sensor (SI-2500-400, ATI Industrial Automation, Apex, NC) was used to evaluate force vectors required for dislocation. A standard joint coordinate system (JCS) was created and defined, corresponding to standard clinical definitions. The coordinate transformations between the JCS, robot motion, and force sensor coordinate system were done in real time in the Labview program, which controls the robot (figure 1).

Based on earlier studies, the hip was positioned in two provocative positions, including (1) full extension with external rotation, and (2) 90° of flexion and 10° of abduction with internal rotation. The load controller was programmed to generate a 3D force vector that corresponds to a representative in vivo hip joint force at each position.

With the load held constant, the femur was externally (position 1) or internally (position 2) rotated until impingement occurred. Impingement was detected and recorded for each condition (i.e., native hip, FHR, THA) as a sudden increase in the reaction moment with respect to the center of the hip. The hip reaction moment occurred when the contact force was transmitted via the neck on the acetabular rim or other bony impingement. At this point, rotation was stopped and the joint angles were kept constant. Impingement was found in position 2, with internal rotation rather than external rotation

Once impingement occurred, 3D force vectors were applied medially and swept laterally at increasing angles (magnitude held constant) until dislocation was achieved. This was repeated circumferentially in 15 degree increments.

The hemi-pelvis of each specimen was tested in four conditions: (1) native hip, (2) FHR, (3) THA 28mm head, and (4) THA 36mm head. Once the native hip testing was completed, the same hip underwent a FHR with a Stryker Corin Hip Resurfacing system under standard guidelines. Finally, after completion of the FHR testing the hip underwent a THA with a cemented Stryker Exeter Stem and Crossfire polyethylene cup. The coordinate system was used to verify and recreate cup positioning within 5° of adduction with internal rotation. The load controller was programmed to generate a 3D force vector that corresponds to a representative in vivo hip joint force at each position.

With the load held constant, the femur was externally (position 1) or internally (position 2) rotated until impingement occurred. Impingement was detected and recorded for each condition (i.e., native hip, FHR, THA) as a sudden increase in the reaction moment with respect to the center of the hip. The hip reaction moment occurred when the contact force was transmitted via the neck on the acetabular rim or other bony impingement. At this point, rotation was stopped and the joint angles were kept constant. Impingement was found in position 2, with internal rotation rather than external rotation

Results Section:
Each of the five specimens was tested under the aforementioned conditions in provocative positions (1) and (2). A statistical analysis evaluating impingement was done utilizing ANOVA with significance set at a p-value of <0.05. The effect on impingement-free ROM was significant statistically in position (2) (p=0.0024) and post hoc tests revealed that differences existed between FHR and 36mm THA (P=.0064) as well as native hip and 36mm THA (P=.0083) (Figure 1).

Stability Envelope - Position 2

Discussion:
Hip resurfacing has been marketed as a more stable, bone preserving alternative to THA. This study is the first known application of a 6 DOF Robot in the evaluation of hip dislocation and stability in a cadaveric model. It allows for the evaluation of prosthetic geometry and highlights their critical effects. Our findings underscore the importance of implant geometry with respect to the head-neck ratio. The impingement free ROM for the THA 36mm head was significantly larger than the FHR. Also, the stability envelopes for both the 36mm head and 28mm THA were significantly found to be 5% larger than the FHR. Perhaps just as important, the impingement profiles of hip resurfacing were essentially all neck-on-cup impingement, whereas the total hip arthroplasty had a heterogenous impingement profile. Historically, hip resurfacing has underperformed relative to conventional total hip arthroplasty, primarily due to aseptic loosening. Our findings of a smaller stability envelope and predominance of neck-on-cup impingement suggest that component loosening may be a consequence. This may be concerning given the targeted young, active patient population that are undergoing hip resurfacing.