In Vivo Hip Kinematics During Clinical Exams Using Dual Fluoroscopy and Model-Based Tracking: Application to the Study of Femoroacetabular Impingement

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Introduction: Femoroacetabular impingement (FAI), a reduction in clearance between the femoral head and acetabulum, causes hip pain and may initiate hip osteoarthritis. Clinical exams, including the impingement exam, FABER exam, and rotational profile test for functional impairments in patients with radiographic signs of FAI. However, because pain is subjective, and kinematics are measured with a goniometer or estimated visually, there is limited biomechanical understanding of how abnormal anatomy influences clinical exam findings.

Accurate quantification of hip kinematics during clinical exams could provide objective diagnostic criterion, explain damage patterns, and be used for preoperative planning. Unfortunately, marker motion artifact and inaccuracies in estimation of the hip joint center preclude the use of skin marker motion tracking technique to study intricate impingement biomechanics. Computer modeling has been used for this purpose, but models employ unrealistic assumptions (generic/inaccurate kinematics, fixed center of rotation, stationary pelvis, and/or direct bone-bone contact) [1-3].

We have shown that dual fluoroscopy and model-based tracking can directly quantify hip kinematics during clinical exams in cadaver hips to an error less than 1 mm and 1° [4]. In this study, we applied this technique to asymptomatic subjects and three patients with varying presentations of FAI.

Methods: With IRB approval, 6 asymptomatic subjects without a history of hip pain and normal anteroposterior radiographs were enrolled (2 females, age 25.5 ± 3.7 years, height: 177 ± 11.9 cm, weight: 64.9 ± 9.00 kg, alpha angle 45 ± 2.6°, lateral center edge angle 34 ± 5.8°). Three patients with hip pain and radiographic signs of FAI were enrolled. Patient 1: pistol-grip cam deformity, male, 25 years, 180 cm, 85.3 kg. Patient 2: protrusio and large pincer groove on the femur, female, 23 years, 168 cm, 63.5 kg. Patient 3: acetabular overcoverage and femoral head asphericity, female, 26 years, 173 cm, 56.7 kg. CT arthrograms were acquired and bones were segmented from the images [5]. Following a validated protocol, dual fluoroscopy video was acquired at 100 Hz as an orthopaedic surgeon manipulated each subject’s hip through three supine exams: Impingement, FABER, rotational profile (neutral hip flexion). Total fluoroscopy time for each subject, including positioning and two trials per exam, averaged 28.4 ± 3.88 s. Average tube voltage and current were 79 ± 7.0 kVp, 3.0 ± 0.37 mA, respectively. The position and orientation of the pelvis and femur for each frame was calculated with model-based tracking software [6].

From the 3D reconstructions, the femoral and pelvic joint centers, mediolateral axis of the femur, and midpoint of the knee were calculated automatically using principal curvature and sphere/cylinder fitting. The posterior superior iliac spines and anterior superior iliac spines were found semiautomatically using principal curvature. Anatomical coordinate systems were defined using these landmarks, which were then used to calculate joint angles with the Grood-Suntay convention [7]. Joint angles were normalized in time. Joint translation in each anatomical direction was defined as the vector from the pelvic joint center preclude the use of skin marker motion tracking technique to study intricate impingement biomechanics. Computer modeling has been used for this purpose, but models employ unrealistic assumptions (generic/inaccurate kinematics, fixed center of rotation, stationary pelvis, and/or direct bone-bone contact) [1-3].

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Results: During the impingement exam, patients achieved less internal rotation and adduction than normal subjects (Figure 1); the pelvis tilted ~10° during flexion in all subjects (not shown). At the terminal position of this exam, impingement generally occurred between the anteroinferior femoral head-neck and the anterosuperior acetabulum at 9-11 o’clock (Figure 2). Bones did not collide at the terminal position (minimum bone-bone distance = 2.93 ± 0.58 mm [all subjects]), or any other exam. Normal subjects achieved 34.7 ± 6.43° internal and 36.4 ± 8.17° external rotation during the rotational profile (not shown). Only Patient 2 demonstrated substantially decreased range of motion during this exam (13.4° int, 7.86° ext). Patient 1 had mildly decreased ext rot (27.6°). During the FABER test, all three patients had less external rotation (Pt 1- 36.5°, Pt 2 - 23.2°, Pt 3 - 41.6°) than the normal subjects (48.3 ± 7.41°). Bones did not collide during either exam. The greatest translation occurred during the FABER exam (Figure 3). Translations were similar between groups, except increased for Patient 1 during the FABER exam (Figure 3).

Discussion: As the first application of dual fluoroscopy and model-based tracking in a cohort of live subjects, our results demonstrate joint articulation to be a highly complex process in all hips analyzed. As the impingement exam is used to recreate pain, it was interesting to note the minimum bone-bone distance at the terminal position was located on the anteroinferior femoral head-neck junction in both groups, not at the anterosuperior region where most cam lesions (including patient 1 and 3’s) occur. Though preliminary, it is possible that the dynamic path of hip articulation,
rather than the terminal position, is responsible for pain during the impingement exam. Femoral head translation was apparent in all of the subjects, especially during the FABER and impingement exams. As the femur reached its limit during the impingement exam, it pivoted about the acetabular rim, and in some cases, was displaced posteriorly. Such posterior displacement has been coined the ‘counter-coup effect’, but until now, it had yet to be witnessed outside of surgery.

In the absence of direct bone-bone contact, our results suggest soft tissue interference is involved during ‘impingement’. Further, our data clearly demonstrate that the femur translates and the pelvis is dynamically involved when determining the final position of the femur. As such, by ignoring the true complexities of hip joint articulation, previous computer simulations may substantially overestimate range of motion and may yield inaccurate predictions of the impingement site. In summary, our chosen technique to measure hip motions provides the most accurate data collected on hip articulation during clinical exams. Normal subject data provide critical baseline results for future studies. Further, data collected in this study could validate computer simulations of impingement, guide pre-operative planning, and serve as boundary conditions in finite element models investigating labrum and cartilage mechanics.

Significance: Using dual fluoroscopy and model-based tracking, limitations in range of motion and the locations of impingement during clinical exams were identified in FAI patients relative to normal subjects.

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Figure 3. Range of joint translations in each anatomical direction during three clinical exams. Bars represent mean ± standard deviation for normal subjects. Patient results plotted individually.