Introduction

Background
• 3D motion capture using skin-mounted markers can be a tool to better understand hip pathology, such as femoracetabular impingement (FAI), as it relates to dynamic motions.
• However, motion capture is limited in accuracy due to the movement of skin relative to bone, known as soft tissue artifact, and errors in marker placement.
• Dynamic biplane radiography (DBR) evaluates in vivo hip kinematics during dynamic tasks with an accuracy of 0.3 mm and 0.8 degrees.
• Previous studies have evaluated the accuracy of motion capture to measure hip kinematics during gait, hip abduction, rotation, and loaded flexion by comparing motion capture with DBR and found errors up to 54 mm and 9.5 degrees.
• However, previous studies did not evaluate motion capture accuracy during deep hip flexion, which is an activity that elicits hip pain in FAI patients.
• Kinematic accuracy at the hip depends on accurately locating the hip joint center.

Purpose
• To determine the error in locating the hip joint center using motion capture compared to DBR during deep hip flexion.

Methods

Data Collection
• 12 unilateral FAI patients (9 female/3 male, average age: 31 ± 12 years, age range: 20-57 years, average BMI: 23.5 ± 4.0 kg/m²) participated in this IRB-approved study.
• Participants performed 2 trials of single-legged standing active hip flexion and 2 trials of single-legged standing active hip flexion combined with adduction and internal rotation with a target at 90° flexion (Figure 1).
• Motion capture (12-camera Vicon Vantage) and DBR data were captured simultaneously at 100 Hz and 30 Hz, respectively.

Data Processing
• For motion capture (Vicon), the hip joint landmarks were determined in Visual3D from a Coda pelvis and based on regression equations using the ASIS and PSIS marker locations (Figure 2).
• For DBR, the hip joint centers were based on fitting a sphere to the femoral head of a 3D model of the hip generated from a CT scan (Figure 3).
• DBR and Vicon hip center locations were filtered with 4th and 2nd order Butterworth filters with 3 and 12 Hz cutoffs, respectively.
• Hip joint center locations from motion capture were interpolated to match the frame rate of the DBR system and were transformed into the DBR coordinate system.

Data Analysis
• Root mean square (RMS) error was used to calculate the average difference in the medial-lateral (ML), anterior-posterior (AP), and superior-inferior (SI) positions of the hip joint centers between the synchronized Vicon and DBR systems.
• Differences between trials and sides were tested using paired samples t-tests, and repeatability of trials was assessed with Pearson’s correlations.

Results
• A total of 140 movement trials were included in this analysis. Average peak hip flexion angle across all trials was 92°.
• RMS errors ranged from 1 to 74 mm across subjects, trials, and anatomical directions.
• RMS errors were not significantly different between the symptomatic and asymptomatic legs or between the two trials (all p>0.05).
• The repeatability of error between trials of the same motion (neutral hip flexion or hip flexion with rotation) was high, with an average Pearson’s correlation of r=0.77, p=0.02.
• Although errors were fairly repeatable within subjects for a given flexion motion, RMS error varied between subjects and anatomical direction (Figure 4).
• The average RMS errors for all subjects and all trials were: ML: 11 ± 8 mm, AP: 26 ± 16 mm, SI: 17 ± 13 mm.
• Standard deviations of RMS errors ranged from σ=7 to 21 mm depending on the trial.

Discussion

• Our RMS error values are similar to, but slightly larger than those reported by Fiorentino et al. who found mean errors ranging from 3 to 54 mm during walking, hip abduction, and hip rotation.
• While Fiorentino et al. analyzed skin-mounted marker locations and not hip center locations, our AP and SI errors are higher than their findings of AP: 18 mm; SI: 12 mm, possibly due to the deep flexion movement we studied.
• Variability in error between subjects is reflected in the large range of standard deviations observed in RMS error values.
• Researchers should be aware that the error in identifying the hip joint center during deep flexion using motion capture is, on average, a factor of 60 times greater than DBR.

Significance
• Skin-mounted motion capture systems have error as high as 74 mm in identifying the hip joint center during deep hip flexion.
• The magnitude and patterns of error vary considerably between subjects, making it difficult to develop a single algorithm to correct for errors due to marker placement and skin motion artifact across many subjects.

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