INTRODUCTION

Femoro-acetabular impingement (FAI) is associated with early development of hip osteoarthritis. Impingement between the femur and acetabulum has been proposed as the most likely mechanism leading to cartilage damage, based on surgical observations and bony abnormalities identified from static imaging. However, impingement as a dynamic phenomenon, occurring during every-day movements, has yet to be demonstrated, due to the absence of high-quality *in vivo* data.

We have previously described a technique combining high-speed biplane radiography and model-based tracking, which has been validated for the glenohumeral1 and tibiofemoral2 joints. The hip poses special challenges for dynamic radiographic imaging, due to the greater amount of soft tissue and bone overlap. We proposed that the combination of a unique high-resolution biplane radiographic system (utilizing fast sample rates and short, high-intensity x-ray pulses) with volumetric model-based tracking could lead to accurate hip motion tracking during functional activities. The purpose of this study was to determine the real-world accuracy of this system for evaluating *in vivo* hip function, and evaluate novel variables that may be valuable for relating arthrotokinematics to the development of OA at the hip joint.

METHODS

Testing was performed using both hips from two unpreserved human lower torsos (including all bone and soft tissue from sacrum to mid-femur), during simulated activities of daily living. Four 2 mm chrome beads were implanted into each bone. Ropes were attached bilaterally to the distal femurs and the anterior and posterior iliac wings. To simulate gait, the pelvises were suspended and the distal femurs were pulled from 70 degrees of flexion to extension. To simulate rising from a chair (chair ascent), the pelvises were “seated” on a wood platform and then lifted by the ropes tied to the hemi-pelvises, for a range of about 60 to 110 degrees of flexion. Motions were performed with a period of 1 s or less, approximating typical in vivo movement speeds for the simulated activities. Biplane radiographic images were acquired at 100 frames/s approximating typical in vivo movement speeds for the simulated activities. Biplane radiographic images were acquired at 100 frames/s with 1 ms pulsed x-ray exposures (80 kVp, 250 mA, 25 mAs per trial, 180 cm SID). Imaging angles (Figure 1) were oblique (± 25 degrees from AP), either in the horizontal plane (“gait” trials) or angled down 15° anterior to posterior (“chair ascent” trials). CT scans were acquired for building 3D bone models, defining anatomical coordinate systems and locating implanted beads relative to the skeletal anatomy.

Reference 3D motion of the femur and pelvis was determined using the implanted beads and radiostereophotogrammetric analysis (RSA)3. The model-based tracking method, as previously described1, does not use implanted markers or identifiable landmarks. As shown in Figure 2, it automatically matches biplane radiographs to ray-traced projections through a 3D volumetric model. Though far more computationally intense than commonly used edge-based approaches4, this technique provides a much richer information set for object matching, especially in the presence of overlapping bone and dense soft tissues.

To examine potential application for detecting FAI, joint space was mapped in 3D by determining bone-to-bone distances over the entire articulating surfaces. Total area on the antero-superior portion of the acetabulum with bone-to-bone distance less than 3 mm was calculated.

Model-based tracking performance was evaluated relative to RSA. *Bias* was calculated as the mean difference between RSA and model-based kinematics and joint space. *Precision* was calculated as the standard deviation of the difference between the two tracking results.

DISCUSSION

Accuracy of the model-based approach was similar to that of the RSA technique, with precisions better than 0.25 mm. Joint space area estimates were within 3% of RSA-estimated values. These results show that model-based tracking can be an excellent tool for analyzing hip kinematics during functional activities, as well as assessing pathologies where dynamic joint space changes may be important, such as FAI. An *in vivo* FAI study is currently underway using this technique.

REFERENCES


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