Determining Cup Position, Leg Length and Offset using Intraoperative 3D/2D Registration in Direct Anterior Approach Total Hip Arthroplasty

Eric Michael Slotkin, Jacob Haynes, Jevan Arulampalam, Moritz Franz Ehlke[1], Christopher Plaskos[2], Jim Pierrepont[2], Nicholas Michael Brown, Arjun Saxena
[1]Corin Group, [2]Corin

INTRODUCTION: Intraoperative 2D fluoroscopy has well documented variable accuracy when measuring acetabular position, leg length and offset in total hip arthroplasty (THA). We evaluated the accuracy of a new 3D/2D registration software for intraoperative measurement of THA parameters.

METHODS:

We developed software (apolloHipX, Corin Ltd, UK) to register 3D models of the pelvis and femur determined from pre-operative CT scans and 3D models of acetabular and femoral head components to 2D intraoperative fluoroscopic images using an intensity-based matching algorithm (Figure 1). This allows for the calculation of component position, leg length, and offset in the 3D model workspace after registration for improved accuracy. The intraoperative registration steps entail selecting six predefined pelvis and femur landmark points on the 2D images for initial registration (Figure 2). The software then automatically registers the 3D models to the 2D images using the intensity-based matching algorithm (figure 3), after which users can adjust the registration for improved fit. We evaluated the accuracy of this software in two experiments using A) simulated images and B) human cadavers.

Experiment A: Four users made a total of 128 measurements on 96 unique digital reconstructed radiographs (DRRs). DDRs were generated to simulate intraoperative 2D fluoroscopic images from preoperative CT scans of 8 THA patients with virtually positioned implants. Images were simulated for the following surgical stages: cup insertion, femoral trialing, final implants. For each stage, different views were simulated by rotating the image intensifier by ±5° about the mediolateral and superior-inferior axes. Each user then performed the registration on a set of randomly selected images using a test version of the software and were blinded to the virtually planned component positions. Accuracy was determined as the mean absolute error (MAE) for the initial auto- and final user-adjusted registration relative to the ground truth values (ie the known implant positions, leg length and offset values from the virtual 3D planning).

Experiment B: Six direct anterior approach (DAA) THAs were performed on three bilateral pelvis-to-toe cadavers by six surgeons. 3D planning of the acetabular and femoral components was performed on preoperative CT scans. Intraoperatively, 2D fluoroscopic images were taken to capture trial and final positioned implants. Preoperative 3D models of the pelvis, cup, femur and femoral head were registered to the 2D fluoroscopic images intraoperatively using the 3D/2D registration software. Accuracy was determined as the MAE of the final user-adjusted registration of the final implants relative to ground truth values as measured on postop CT. Ground truth values were determined by 3D/3D registration of the preop and postop CT models to establish a common coordinate system.

RESULTS:

Experiment A (DRRs): Cup inclination, anteversion and medialization/superiorization MAE was within 1° and 1 mm across all users for both the initial auto- registration and the final user-adjusted registration, with maximum errors of 1.6 degrees and 1.9mm, Figure 4. Leg length and offset MAE with trials were 1.5 and 2.4 mm initially, and 1.4 and 2.1 mm after adjustment. With implants, leg length and offset were within 2.9 and 2.5 initially and 2.4 and 2.1 after adjustment, with final maximum errors of 7.2 and 4.7 mm. Inter-user differences in accuracy were within 1 mm.

Experiment B (cadaver): Cup anteversion and inclination MAE was 1.3° and 1.8°, respectively (maximum error: 2.5° and 3.1°). Maximum cup mediolateral and superoinferior errors were ≤1.6 mm. Leg length and offset MAE was 2.5 and 2.0 mm, respectively (maximum error: 4.8 and 3.4 mm). Mean combined convergence time of the 3D/2D registration algorithm was 13.6 seconds for the pelvis and cup (15s maximum) and 12s for the femur and femoral head (14s maximum).

DISCUSSION AND CONCLUSION: This study demonstrated high accuracy and efficiency of 3D/2D registration for determining cup position, length leg and offset in DAA THA in both simulated images and cadavers. 3D/2D registration methods have the potential to overcome some of the accuracy limitations associated with using 2D intraoperative imaging on its own.

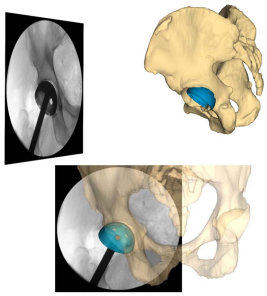

Figure 1 3D/2D registration of 3D CT and cup model to 2D fluoroscopic image