Predicting the 3D Hip Centre of Rotation Using Contralateral Pelvic Anatomy

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Introduction: Current methods to determine the true hip Centre of Rotation (hCoR) utilize plain radiographs and thus have an inherent degree of inaccuracy; as radiographs are a two-dimensional representation of a three dimensional structure. We propose two methods to determine the true hCoR and replace missing anatomy, within commercially available 3D processing software, using Digital Imaging and Communications in Medicine (DICOM) files obtained from Computed Tomography (CT). In addition, we evaluated the ability/accuracy of each method to: 1) predict the hCoR and 2) replace missing anatomy.

Methods: We investigated two methods to predict the hCoR and virtually replicate missing anatomy using the contralateral pelvic anatomy.
Method 1 involved centering the pelvis in the anterior pelvic plane and mirroring the contralateral hemipelvis half way along the X-axis (See Figure 1). Method 2 involved isolating and mirroring the contralateral innominate bone; the isolated/mirrored innominate bone was then non-rigidly aligned to the pelvis, using an “Iterative Closest Point Alignment” algorithm. The pelvis was then realigned using the anterior pelvic plane, allowing comparison of results. The two methods were performed using 10 patient (5 Male and 5 Female) CT DICOM files and the accuracy of each method was evaluated.
To evaluate the accuracy of each method at determining hCoR a sphere matching technique was used. A sphere was matched to the predicted and actual acetabulum (See Figure 1); the sphere’s CoR Coordinates were recorded for each and compared using Intraclass Correlation Coefficients and Paired T-tests (P-Value of <0.05 was considered to indicate significance).
To determine the error in the prediction of bone geometry a “One-Sided Hausdorff distance” algorithm was performed. The: 1) One-Sided Hausdorff distance, 2) mean minimum distance between the predicted and actual anatomy, and 3) the root mean square were all recorded. In addition, red green blue color maps depicting the location of error in predicting bone geometry were generated (See Figure 2).
Figure 1. Method 1, three-dimensional model of whole pelvis (Cream) and mirrored right hemipelvis (Grey). A sphere matching technique has been used to determine the predicted hCoR (Yellow sphere) and the actual hCoR (Orange sphere).

Results: Applying method 1 we were able to predict the hCoR in all axes with excellent agreement (ICC > 0.9) to actual values. In addition, there were no systemic errors in the prediction of hCoR in the medial (P = 0.933, Mean = 0.039, 95% CI -1.006, 1.086), distal (P = 0.368, Mean = 1.084, 95% CI -1.504, 3.672) and posterior (P = 0.219, Mean = -1.246, 95% CI -3.382, 0.889) direction.

Using method 2 we were able to predict hCoR with excellent agreement (ICC > 0.9) to actual values. There were no systemic errors in the prediction of hCoR in the medial (P = 0.616, Mean = 0.177, 95% CI -0.596, 0.951), distal (P = 0.671, Mean = -0.133, 95% CI -0.820, 0.553) and posterior (P = 0.427, Mean = -0.391, 95% CI -1.452, 0.671) direction.

The mean One-Sided Hausdorff distance between bone geometry predicted using method 1 and actual bone geometry was 13.217mm (SD = 3.722). The mean distance between the closest corresponding points on the models of predicted and actual bone geometry was 1.835mm (SD = 0.831). The mean root mean square of this difference for all patients was 2.570mm (SD = 1.276).

The mean One-Sided Hausdorff distance between bone geometry predicted using method 2 and actual bone geometry was 9.389mm (SD = 2.585). The mean distance between the closest corresponding points on the models of predicted and actual bone geometry was 1.473mm (SD = 0.726). The mean root mean square of this difference for all patients was 1.064mm (SD = 0.491).

Color maps were generated to determine the location of greatest error (See Figure 2). From the color maps it was determined that the area of greatest error tended to be the iliac crest while the ischium and acetabulum had lower levels of error for both methods.
Figure 2. Lateral and Anterior-Posterior views of two Red-Green-Blue maps depicting the location of error on the same mirrored contralateral innominate bone. **Figure 2A:** shows that the Hausdorff distance is susceptible to artifact as no regions of blue are seen on the innominate bone. **Figure 2B:** shows that the majority of the innominate bone has a low amount of error (<5mm).

**Discussion:** We applied two methods that were able to predict the hCoR in subjects with normal pelvic anatomy. Using Method 2 we predicted the hCoR within the acceptable +/- 5mm range in all axes (1). Alterations of the hCoR within this range are minimal in terms of increased hip load and loosening of implants (1).

Compared to previous methods, which utilize plain radiographs, the two proposed techniques are also able to determine the hCoR in the anterior-posterior axis. This is advantageous as deviations in this axis lead to an anterior-posterior laxity and increased risk of dislocation (2).

The mean difference between the predicted anatomy and actual anatomy was 1.835mm for method 1 and 1.473mm for method 2. The two methods could be used to plan reconstruction of unilateral defects in patients allowing a mean restoration of anatomy within 1.835mm and 1.473mm of normal anatomy.
**Significance:** In clinical practice the planning of total hip arthroplasty in patients with pelvic deformities such as perthes is challenging. The proposed methods may be useful in the preoperative planning of these patients, who have unilateral defects.

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