The Influence of Hip Motion on the Functional Centre of Rotation

INTRODUCTION

A functional centre of rotation (CoR) is often required in biomechanical analysis of the hip and as a landmark in computer guided surgery. The hip is moved through a prescribed motion while tracking the femur and a CoR is determined by a mathematical fit of the motion data. It is important that the motion is not confined to a single plane and typical motions include circumduction and ‘star’ (flexion-extension and abduction-adduction) patterns. It was previously shown that circumduction motions predict a CoR that is inferior and lateral to the geometric centre of the hip bearing surfaces. It is therefore necessary to establish the best method for determining the CoR to improve surgical planning. The objective of this study was to compare the predicted CoR from circumduction and star motions, and to compare these to the geometric centre of the joint.

MATERIALS AND METHODS

Eight cadaveric hips from four cadavers were tested. The study was approved by the Institutional Review Board. Prior to testing, CT scans of the cadavers were made from the iliac crest to the tibial plateau; the alpha angle for all hips was less than 50° so all hips were considered ‘normal’. Reflective marker arrays were rigidly mounted on the femoral diaphysis and iliac spine using 4mm Steinman pins. A five-camera Vicon system (Oxford, UK) was used to track the motions of the arrays during manipulation of the lower limb. To determine the functional hip centre, trials consisting of five cycles each of circumduction, flexion-extension and abduction-adduction were performed on each lower limb; three trials of each motion were performed. The range of motion (ROM) was approximately 45° in the coronal and sagittal planes. For the ‘star’ motion, the flexion-extension and abduction-adduction trial data were combined. Following the trials the hip was dissected to expose the articular surfaces of the femoral head and acetabulum. These surfaces were traced using a pointer equipped with reflective markers to determine the geometric centre.

To calculate the functional centre, the 3D coordinates of the markers were used to construct a local-to-global 3D transform for each frame throughout the trial. These transforms were used in the symmetric centre of rotation technique (SCoRE) to determine the functional centre in the local coordinate system of the femur and acetabulum. The geometric centre was calculated using a least-squares sphere fit (Gauss-Newton) of the trace data, calculated in the respective local coordinate systems. The coordinates of the functional centres were then transformed to an anatomic coordinate system, using the geometric centre as the origin. All calculations were performed using Matlab (Mathworks, Inc, MA, USA). A t-test was performed in each anatomic direction to detect differences in CoR predicted by the two motions.

RESULTS

Both the circumduction and star motions resulted in a similar CoR (Figure 1). Differences were 0.41±2.25mm in the anterior-posterior direction; 0.09±0.72mm in the superior-inferior direction; and 0.21±0.82mm in the medial-lateral direction, none of which were significant (p>0.5). The overall mean distance between the CoR predicted by the two motions was 2.0±1.3mm.

Figure 1 also shows that the functional centre was lateral and inferior to the geometric centre (origin of each graph), and was consistent for each motion. Results for the acetabulum showed similar trends.

DISCUSSION

This study has shown that circumduction and star motions are equivalent in predicting the hip functional CoR; differences were small compared to the dimensions involved in studies such as gait analyses. However, both motions predicted a CoR that was inferior and lateral to the spherical centre of the femoral head, suggesting that the hip does not act as a true ball-and-socket joint with congruent spherical bearing surfaces. It has been suggested previously that the hip joint surfaces are mathematically described as a revolved conchoid. This may explain the offset between the CoR and geometric (spherical) centre, but requires further investigation.

Potential errors in the calculations arise from measurement of marker 3D coordinates and performing a best-fit of the sphere. The uncertainty in the Vicon coordinate measurements was 0.4mm; however, the SCoRE technique is accurate to within 2mm for a ROM of 45° with 1mm of random error in the coordinate data. The uncertainty in the geometric centre location was less than 0.15mm. The data from the acetabular side had higher uncertainty, partly due to the bearing surface presenting a smaller portion of a sphere for tracing (the fossa and transverse ligament regions were excluded).

Testing was performed within a small ROM. Changes in the functional hip centre at the extremes of the ROM may be more critical in biomechanical analyses of pathological joints, but requires further analysis.

The CoR predicted by circumduction and star motions can be considered equivalent for larger scale studies such as gait analysis. The consequences for computer assisted surgery depend on the specific application and may significantly affect the quality of registration. Interestingly, both techniques showed a CoR that was generally inferior, lateral and anterior to the geometric centre. This may have important consequences in studies at the scale of the hip joint, especially for pathological conditions such as femoroacetabular impingement.

REFERENCES

1. Speirs et al., 55th ORS, 2009

Poster No. 2027 • 56th Annual Meeting of the Orthopaedic Research Society