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Short communication

Evaluation of the accuracy of three popular regression equations for hip joint centre estimation using computerised tomography measurements for metal-on-metal hip resurfacing arthroplasty patients

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ABSTRACT

We investigated the accuracy of the regression equations by Bell et al., Davis III et al. and Harrington et al. for hip joint centre (HJC) estimation against the gold standard of computerised tomography (CT) measurements of HJC for 18 patients with metal-on-metal hip resurfacing arthroplasty (MoMHRA). The HJCs were estimated based on the position of the left and right Anterior Superior Iliac Spine (ASIS) and the left and right Posterior Superior Iliac Spine (PSIS) identified from a CT scan. Of the three tested regression equations, only those of Harrington et al. produced results that were not significantly different from the patient's 'true' HJCs as measured from the CT scan in all three directions when analysing left and right hips together for both resurfaced and native hips. When native and resurfaced hips were pooled and analysed for left and right, separately, the Harrington et al. regression equations showed significantly different results in the ML direction. Similar estimation errors were observed for native and resurfaced hips. Since none of the methods tested performed particularly well, we suggest using medical imaging if accurate estimates of HJCs are required.

1. Introduction

Motion capture is frequently used to assess the functional abilities of patients in clinical practices worldwide. For this, a model of the patient is used to estimate the kinematics and kinetics based on surface marker trajectories and ground reaction forces [1]. In this process, the hip is frequently modelled as a spherical joint with its joint centre (HJC) estimated using regression equations [2–4]. However, estimation inaccuracies of the HJCs have been shown to influence the resulting kinematics and kinetics [5,6].

Although conventional regression equations [2,3] were derived from the anthropometry of able-bodied adults, they are frequently applied to patients with musculoskeletal pathology. This raises the concern that the HJC estimation may be inaccurate for the patient group they are applied to, potentially leading to inaccurate estimations of the functional abilities of these patients. Recently, however, Harrington et al. [4] found no significant differences in the accuracy between adults, children and children with cerebral palsy using the regression equations of Bell et al. [2], those recommended by Ortho Trek (Motion Analysis Corp., USA) and the equations of Davis III et al. [3].

Metal-on-metal hip resurfacing arthroplasty (MoMHRA) is an alternative treatment option for young and active patients with osteoarthritis of the hip [7]. In addition to the differences in pelvis and femur geometry, arising from the resurfacing surgery, morphological features have been shown to be associated with the development of hip pathology [8]. This implies that geometric differences may exist between the normal and the pathological hip joint. Thus, the accuracy of applying the HJC regression equations to the MoMHRA patient group remains unknown and assessment of this accuracy for three popular regression equations for this patient group was the purpose of this study. Computerised tomography (CT) was used as a gold standard for estimation of the patients 'true' HJCs.

2. Methods

Eighteen MoMHRA patients (10 females, eight males, age 58 ± 10 years, height 1.70 ± 0.09 m, mass 73 ± 13 kg) participated in this IRB approved study. Sixteen subjects had MoMHRA implanted unilaterally whereas two had a total hip replacement (THR) on the contra-lateral limb. Eleven subjects had a Birmingham Hip resurfacing (Smith and

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Nephew, UK) and seven subjects had a Conserve Plus (Wright Medical Technology, USA) implanted.

For each patient, a CT scan was taken in the transverse plane using a high-resolution 64-slice CT scanner (Somatom, Siemens Medical Solutions, Inc., USA) with the patient in a supine position using a metal artefact reduction sequence.

From the CT scans, the Anterior Superior Iliac Spine (ASIS), Posterior Superior Iliac Spine (PSIS) bony landmarks and the 'true' HJCs were identified. The 'true' HJC of the implanted and the native hip were computed using two different methods. For the native hip, the 'true' HJC was found by segmenting the femoral head using Mimics v. 14.1 (Materialise, Belgium) and taking the centre of a sphere fitted to this 3D geometry using Geomagic Studio v. 11.0 (Geomagic, USA) (Fig. 1(A)). Sphere-fitting was impossible for the implanted hip due to metal artefacts, therefore the 'true' HJC for MoMHRA hips was estimated using six points on the edge of the acetabular component and defining a plane on the open face of the component. The average centre of circles fitted through combinations of three of the six points was found. The normal to the plane at this centre point was determined and the HJC estimated as a point projected along the normal based on each patient's component radius and coverage angle (Fig. 1(C)):

$$d_p = \frac{r_c}{\cos(\theta/2)} \quad (1)$$

d_p is the distance projected along the surface normal, r_c is the component radius and θ is the coverage angle.

The acetabular component in MoMHRA is not a complete hemisphere. The coverage angle for the Conserve Plus hip resurfacing was assumed to be 170°. For Birmingham Hip resurfacing, the coverage angle varied with component size [9].

Subsequently, the HJCs were estimated based on the identified bony landmarks using the regression equations of Bell et al. [2], Davis III et al. [3] and Harrington et al. [4]. All HJCs were computed in a common reference frame defined by the identified bony landmarks; the origin was located midway between the ASIS bony landmarks with the medial–lateral (ML) axis from the left to the right ASIS bony landmark. The anterior–posterior (AP) axis was constructed as the line orthogonal to the ML-axis from the midpoint of the two PSIS bony landmarks. The superior–inferior (SI) axis was constructed as the cross product between the AP- and ML-axis (Fig. 1(B)).

Mann–Whitney U statistical tests were performed on the vector difference and distance between the estimated HJC and the 'true' HJC. Finally, the above analysis was repeated for native and resurfaced hips, separately with the left and right hips pooled to obtain larger populations. Symmetry between left and right were assumed and the ML coordinates for the left hips were multiplied by minus one before being pooled with the right hips.

3. Results and discussion

When comparing the estimations for the resurfaced and native hips pooled together, the regression equations of Bell et al. [2] and Davis III et al. [3] showed significant differences for two out of the four tested variables, bilaterally (Fig. 2). The regression equations of Harrington et al. [4] showed no significant differences for the right hips, but a significantly different result in the ML direction for the left hips.

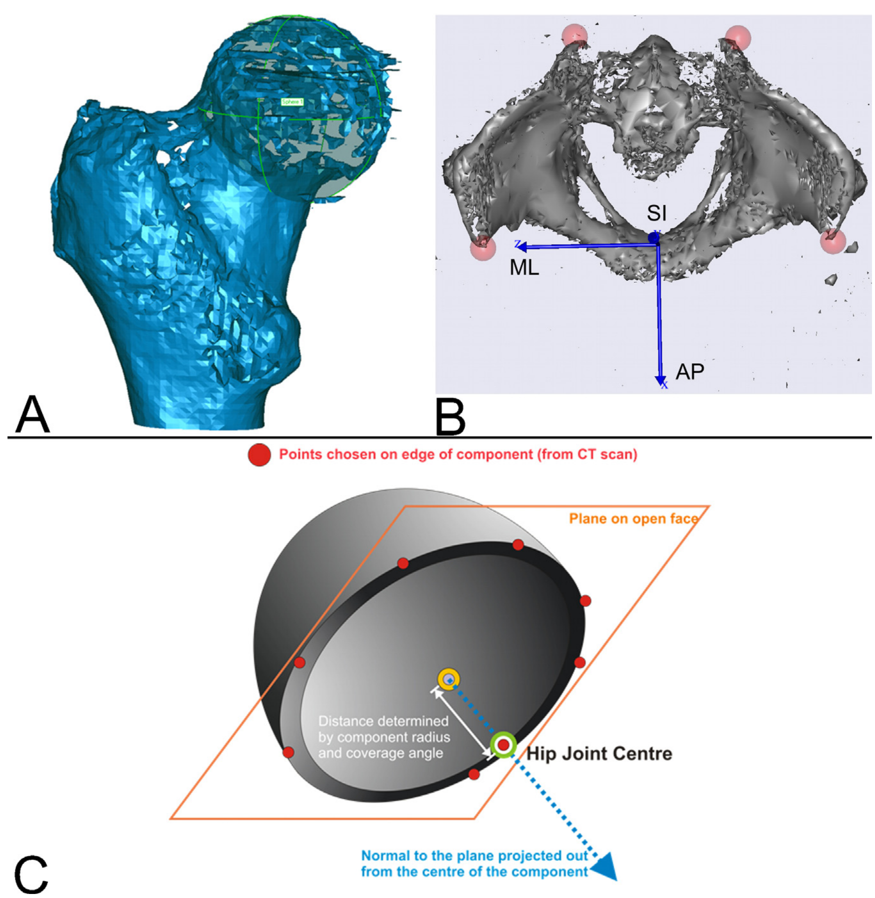

Fig. 1. (A) The HJC for the native hips were determined by segmenting the patient's femur and fitting a sphere to the femoral head; (B) top view of a scanned pelvis including the defined reference frame in blue. The transparent red spheres show the identified bony landmarks; and (C) the method employed to estimate the HJC for the resurfaced hip. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)