# Estimation of hip joint center from the external body shape: a preliminary study

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**KEYWORDS** Hip joint; biplanar X-rays; external predictors

## 1. Introduction

Human external shape model is becoming easily available using scanning technology, stereophotogrammetry, or Microsoft Kinect systems. However locating the internal skeleton from the external shape remains a challenging issue. Using low dose biplanar radiographs of the whole body, subject-specific 3D reconstructions of the bones and the surface envelope have been developed, providing data of both external body shape and internal skeleton (Dubousset et al. 2010). The basic idea of this research project was to explore the relationships between characteristics of internal skeleton and those of external body shape.

Hip joint center (HJC) prediction was considered in this preliminary study. Subject-specific HJC prediction is currently performed either using functional methods based on the relative motion of the femur and pelvis, or predictive methods relying on empirical regression equations using palpable femoral and pelvic landmarks as predictors. Yet functional methods may be ineffective when hip motion is limited. Different regressions between HJC and predictive landmarks were established based on direct measurements on pelvic and femoral bone specimen surface, using cadavers, medical imaging or 3D CT-scans (Peng et al. 2015). However, in most applications when medical imaging is not available, manual palpation over the skin of the bony predictors might increase the prediction error on HJC compared to cases where bone information is available directly (Sholukha et al. 2011, Sangeux et al. 2014).

In this paper, new predictors from external body shape were explored for HJC prediction.

## 2. Methods

A database of biplanar X-ray acquisitions (EOS Imaging, Paris, France) of the whole body of 40 volunteers (20 males, 20 females, average age: 33 ± 14 years), equally split into three BMI groups BMI < 21, 21 < BMI < 25 and BMI > 25Kg/m², was analyzed. From these two radiographs, 3D reconstruction of the pelvis, lower limbs and external envelope was performed.

HJC was identified as the centre of the femoral head by least square sphere fitting. Three sets of external parameters were considered in this exploratory approach: (1) Morphological parameters using the major, minor axes and centroid of ellipses fitted in a least square sense over the contour of body segments (Figure 1); (2) Barycentremetric parameters including the centers of mass (COM) of body segments which were calculated assuming homogeneous segment densities (Dempster 1955; Amabile et al. 2015); (3) Distances between anatomical landmarks on the skin surface. Anatomical bony landmarks were identified from the bone reconstructions and the closest point on the envelope was considered as the corresponding palpated landmark. Different statistical methods were implemented in order to find the best compromise between number of predictors and standard errors of estimate (multilinear regression, partial least square regressions, principal component regression). Leave- one-out cross validation (LOOCV) was used to test how each regression equation would perform on new input data. The existing data ($n$ = 40) were iteratively split into a training set of n-1data points and a validation set with one value. Using the regression equations established from the training sets, the HJC coordinates were predicted (Yestimated) and compared to the HJC coordinates of the validation set (Ytrue). The procedure was then repeated n times with each data point used once as the validation data.

95% confidence intervals (95% CI) around the true HJC location was calculated using 2 standard deviations (2SD) over the n residuals (Yestimated- Ytrue) obtained from the LOOCV. Results were compared to those obtained using the regression equation in Bell et al. (1989), widely used in

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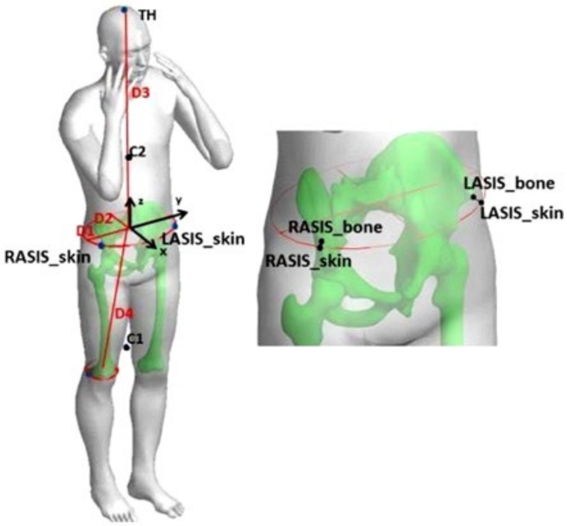


**Figure 1.** Morphological predictors used in the example regression: D1, D2: major and minor axes of ellipses fitted in a least square sense at the height of anterior superior iliac spines (ASIS), D3: distance between the top of the head and the centroid of the ellipse at the ASIS level. D4: Distance between the centroid of the ellipse at the ASIS level and the centroid of the ellipse at the height of the femoral epicondyles. Barycentremetric predictors: C1: COM of the lower limbs. C2: COM of the upper body. The local coordinate system is defined by the minor axis ($x$) and major axis ($y$) of the ASIS ellipse, with the $z$ vertical gravitational axis and origin at the intersection of the ellipse's axes.

clinical gait analysis. HJC coordinates were estimated from the pelvis width, defined as the distance between the two antero-superior iliac spines (ASIS), first using ASIS palpated on the skin surface (RASIS_skin, LASIS_skin), then using the ASIS identified on the pelvic bone (RASIS_bone, LASIS_bone) (Figure 1).

## 3. Results and discussion

Combining morphological and barycentremetric predictors helped improving the regression equations. As an example, one multiple regression is provided in Table 1 using the predictors defined in Figure 1. The regression allowed locating HJC with a 95% CI of 11.8 mm, which is similar to Bell's estimation when bone information is available directly (11.5 mm), while it was lower compared to Bell's estimation from external palpated landmarks (22.7 mm). This showed that soft tissue interposition around the pelvis might have affected Bell's prediction accuracy which relies on the identification of predictors from the direct bone surface, while building regression based on external body shape predictors as in the proposed regression method enabled to improve the estimate.

The best estimation method should be accurate (small 95% CI), reliable (with robust describing predictors) and include easily available predictors. As an example ellipse descriptors and barycentremetric parameters might provide more reproducible regressors compared to manually palpated landmarks. With that in mind, work is in progress to set the estimation that could provide the best compromise.

**Table 1.** Example of a regression equation obtained by combining morphological and barycentremetric predictors, and associated 95% CI of the distances around true HJC position (in three axes and 3D) using a LOOCV method. Results are compared to an existing regression using landmarks on the envelope surface (RASIS_skin, LASIS_skin), and landmarks on the pelvic surface (RASIS_bone, LASIS_bone)* as predictors to calculate pelvic width.

| Method | | Regression equation | 95% CI | |
|---|---|---|---|---|
| Current | $x$ | −0.17*D1 − 0.07*D2 + 0.45*C1 x + 56.91 | 10.4 | |
| | $y$ | −0.07*D3 − 0.70*C2y − 39.41 | 9.1 | |
| | $z$ | −0.28*D4 + 0.25*C2z + 5.10 | 8.6 | |
| | 3D | | 11.8 | |
| Bell et al. (1989) | $x$ | −0.22*PW | 13.5 | 13.7* |
| | $y$ | −0.30*PW | 21.4 | 9.8* |
| | $z$ | −0.14*PW | 13.7 | 11.6* |
| | 3D | | 22.7 | 11.5* |

## 4. Conclusions

We proposed a method for HJC estimation using a combination of morphological and barycentremetric parameters. This method was evaluated on a large panel of subjects with variable morphotypes and BMIs, and provided improved estimation with regard to existing ones.

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