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Short Communication

On the implementation of predictive methods to locate the hip joint centres

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ABSTRACT

The purpose of this short communication is to discuss the relative benefits of various anthropometric parameters to drive predictive equations to locate the hip joint centres. The effect of soft tissue thickness over the anterior and posterior superior iliac spines on pelvic depth, pelvic width and leg length and position of the hip joint centres was discussed theoretically and experimentally, from a secondary analysis of previously published data.

Results highlighted that anthropometric measurements of pelvic width and leg length were similar when obtained from MRI images or during gait analysis whereas pelvic depth was different. The secondary analysis showed that Harrington et al. [5] equations using either only pelvic width or only leg length would lead to 3 mm improvement, in average over 164 limbs, over the equations using the best anthropometric predictors from MRI data.

1. Introduction

A lot of research effort is directed towards assessing and improving the accuracy of lower limb kinematic models. One joint, the hip, has received intense scrutiny from the gait community in recent years [1]. Our group was originally convinced that the functional hip joint centre offered key advantages such as subject specificity and independence from marker placement, and tested the accuracy of a range of functional calibration methods against 3D freehand ultrasound or low dose bi-planar X-ray (EOS) benchmarks [2–4]. The results from these studies highlighted the superiority of one of the functional calibration methods (sphere fitting), but only in healthy adults. Standardised marker placement and Harrington et al. [5] predictive equations were more accurate when subjects had movement restrictions and in pathological populations.

There was nonetheless some discrepancy between the accuracy of the predictive equation reported in [5] and the results from our studies. Harrington et al. reported leave-one-out cross-validation (LOOCV) prediction errors of 5 mm, 3 mm and 4 mm in the anterior–posterior (AP), medial–lateral (ML) and inferior–superior (IS) directions respectively. The LOOCV error in [5] is an estimate of the mean absolute error (MAE) for new samples. The MAE in our most recent study [4] was 6 mm (AP), 12 mm (ML) and 7 mm (IS). It was in agreement in the AP direction, about two times larger in the IS direction and three times larger in the ML direction.

Two sources of error may contribute to the difference in MAE, the measurement method of the anthropometric predictors and error in marker placement. In [5], anthropometric predictors and marker placement were derived from bony landmarks specified on MRI images whereas, in our studies, the anthropometric predictors were derived from palpation for pelvic width (PW, distance between the right and left anterior superior iliac spine, ASIS), leg length (LL, distance between the ASIS and the ipsilateral medial ankle malleolus passing through the medial knee epicondyle) and from marker positions for pelvic depth (PD, distance between the anterior and posterior superior iliac spines A/PSIS). It is important to note that soft tissue located between the ASIS and PSIS markers and the corresponding bony landmarks has a direct effect on PD and on the anterior–posterior position of the pelvis (Fig. 1) and we can approximate the relationship by $PD_{GAIT} = PD_{MRI} + \Delta F + \Delta B$ where PD_{GAIT} is the measure obtained from the A/PSIS markers, PD_{MRI} the measure obtained directly from the bony landmarks on MRI images and ΔF, ΔB the thickness of the soft tissues between the bone and the skin at the front and the back of the pelvis respectively. There is no obvious equivalent relationship for $PW_{GAIT/MRI}$ and $LL_{GAIT/MRI}$.

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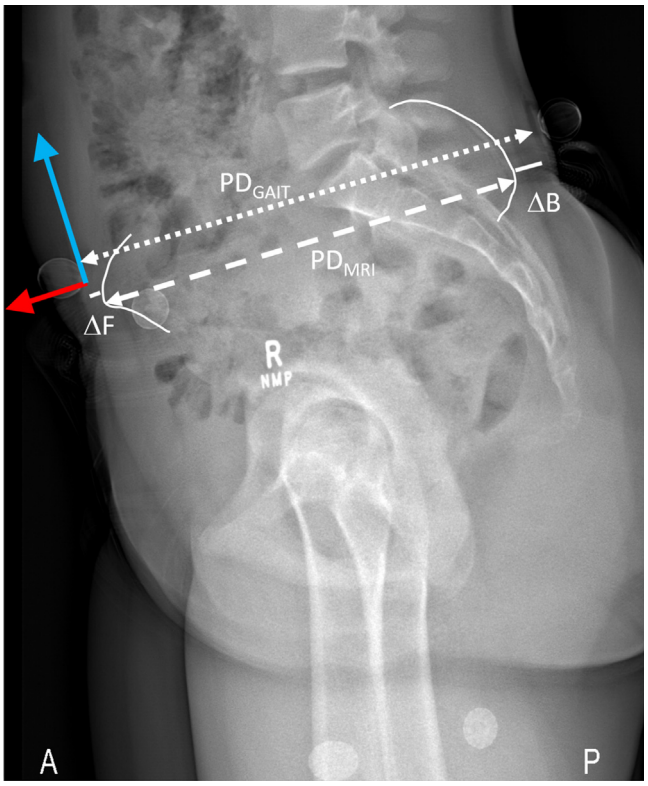

Fig. 1. Sagittal plane image from EOS [4] centred on the pelvis of one subject equipped with external markers for gait analysis. The red and blue arrows represent the anterior–posterior and superior–inferior axes of the pelvis as defined from external markers. The pelvic depth measured from the external markers position (PD_{GAIT}) and from the bony landmarks (PD_{MRI}, as it would have been measured from MRI images) are presented as well as ΔF and ΔB, the thickness of soft tissue in front and behind the bony landmarks.

The aims of this letter were (1) to discuss the effect of soft tissue thickness over the A/PSIS on the position of the hip joint centre and (2) to estimate the accuracy of alternative predictive equations derived from Harrington et al. data and based on a secondary analysis of the data in [2–4].

2. Material and methods

2.1. The effect of soft tissue thickness over the A/PSIS on the position of the hip joint centre

Pelvic depth was the best predictor and used in the predictive equations for the anterior–posterior and medial–lateral positions of the Hip Joint Centres (HJC) in [5]. The true anterior position of the HJC from Harrington et al. equations (HJC_x) and in gait (HJC_x^{GAIT}) is given by:

$$HJC_x = -9.9 - 0.24 \times PD_{MRI} + \epsilon_{\text{marker placement}}$$

$$HJC_x^{GAIT} = -9.9 - 0.24 \times PD_{GAIT}$$

where $\varepsilon_{\text{marker placement}}$ is the error due to marker placement over the ASIS, the origin of the pelvic coordinate system. If we consider that $\varepsilon_{\text{marker placement}}$ is solely due to soft tissue between the markers and the bony landmark (i.e. assuming no error due to pelvic tilt) $\varepsilon_{\text{marker placement}} = -\Delta F$ (cf. Fig. 1) and with $PD_{GAIT} = PD_{MRI} + \Delta F + \Delta B$, the difference between HJC_x^{GAIT} and HJC_x becomes:

$$HJC_x^{GAIT} - HJC_x = (1 - 0.24)\Delta F - 0.24\Delta B$$

and $HJC_x^{GAIT} - HJC_x = 0$ when $\frac{\Delta F}{\Delta B} = \frac{0.24}{1 - 0.24} \approx 0.3$

The error due to soft tissue in estimating PD compensates exactly for marker placement error when the thickness of soft tissue in front of the ASIS is approximately a third of that behind the PSIS.

The true lateral position of the hip joint centres from Harrington et al. equations (HJC_y) and in gait (HJC_y^{GAIT}) are given by:

$$HJC_y = 7.9 + 0.28 \times PD_{MRI} + 0.16 \times PW_{MRI} + \epsilon_{\text{marker placement}}$$

$$HJC_y^{GAIT} = 7.9 + 0.28 \times PD_{GAIT} + 0.16 \times PW_{GAIT}$$

In the medio-lateral direction we expect $\varepsilon_{\text{marker placement}}$ to remain small in average. With $PW_{MRI} = PW_{GAIT}$ and $PD_{GAIT} = PW_{MRI} + \Delta F + \Delta B$ the difference between HJC_y^{GAIT} and HJC_y becomes:

$$HJC_y^{GAIT} - HJC_y = 0.28 \times (\Delta B + \Delta F)$$

Therefore the thicker the soft tissues over the A/PSIS landmarks the more lateral the predicted HJC will be from its true location.

3. Accuracy of alternative predictive equations derived from Harrington et al. data

Predictive equations for the HJC using one predictor only (PD, PW or LL) were derived from the data published in Harrington et al. [5]. These equations were then applied to predict the position of the HJC in data from [2–4] to maximise generalizability of the findings. We also compared the values for PD, PW and LL from these studies and the raw data in [5]. It is worth noting that data from [2,3] were obtained in different populations but in the same laboratory with the same personnel and using the same reference

Table 1
Results of the secondary analysis on alternative predictive equations we derived from the data published in Harrington et al. using the same methodology [5]. All predictive equations were applied to data in [2–4]. For each direction (anterior–posterior AP, medial–lateral ML, and inferior–superior IS) we provide the regression equations derived from the data in [5], the leave-one-out cross-validation (LOOCV) error on the regression data in [5] and the mean absolute error (MAE) on the data in [2–4]. Results on the linear distance (L3D) are also provided. *Paired *t*-test for differences in MAE for L3D showed a significant difference ($p < 0.001$) between the equations using the best predictors and the equations with a single predictor (PW or LL, not different between them).

		Best predictors in [5]	Pelvic width only	Leg length only
AP	Equation [5]	$X = -0.239PD - 9.9$	$X = -0.138PW - 10.4$	$X = -0.041LL - 6.3$
	LOOCV (mm) [5]	5.2	5.8	5.4
	MAE (mm) [2–4]	9	8	8
ML	Equation [5]	$Y = 0.28PD + 0.16PW + 7.9$	$Y = 0.33PW + 7.3$	$Y = 0.0874LL + 5.4$
	LOOCV (mm) [5]	3.2	3.8	4.5
	MAE (mm) [2–4]	11	7	8
IS	Equation [5]	$Z = -0.16PW - 0.04LL - 7.1$	$Z = -0.305PW - 10.9$	$Z = -0.083LL - 7.9$
	LOOCV (mm) [5]	3.6	3.8	3.8
	MAE (mm) [2–4]	7	8	7
L3D	MAE (mm) [2–4]	18*	15	15