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The influence of different pelvic technical marker sets upon hip kinematics during gait

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ABSTRACT

Background: The pelvis is commonly tracked during three-dimensional motion analysis using markers located on the anterior and posterior superior iliac spines. However, these markers are prone to soft tissue artefact and marker occlusion, highlighting the need for alternative technical marker sets.
Research question: How comparable are hip joint kinematics calculated using two alternative pelvic technical marker sets and a conventionally modelled pelvis?
Methods: Fourteen participants undertook 3D gait analysis, walking overground at a self-selected pace ($1.38 \pm 0.14\,m{\cdot}s^{-1}$), barefoot. Hip joint kinematics were compared using root mean square error (RMSE) between a conventionally tracked pelvis and two alternative technical marker sets; (1) posterior cluster and (2) additional iliac crest markers.
Results: The average RMSE in the sagittal, frontal and transverse planes was 2.5° ± 2.8°, 1.6° ± 0.4° and 0.8° ± 0.4°, respectively for the posterior cluster, and 1.3° ± 0.7°, 0.8° ± 0.3° and 1.4° ± 0.5° for the iliac crest marker set. The RMSE was significantly larger for the posterior cluster compared to the iliac crest model in the sagittal ($p = .05$, $d = .28$) and frontal planes ($p < .001$, $d = 7.65$). In contrast, the RMSE was significantly lower for the posterior cluster in the transverse plane ($p = .01$, $d = -2.85$).
Significance: The findings of this study suggest that either a posterior cluster or additional iliac crest markers offer means of accurately calculating hip joint kinematics within 3° of the conventional pelvic model. Therefore, either technical marker set offers a viable alternative to the conventional pelvic model for calculating hip joint kinematics.

1. Introduction

Three-dimensional (3D) motion analysis is common within both sporting and clinical settings. Kinematic models provide a representation of the skeletal system and are used during motion capture to calculate joint orientations [1]. While a plethora of kinematic models exist, it is becoming more common for models to utilise a mixture of anatomical and technical (tracking) markers, in line with the calibration anatomical system technique (CAST) [2]. Anatomical markers define the segmental coordinate system (SCS), with technical markers used to reconstruct the orientation of the SCS during dynamic trials. Technical markers may therefore be placed in arbitrary locations upon a segment, with marker visibility and soft tissue artefact (STA) often key considerations in marker placement [3].

The unique anatomical characteristics of the pelvis mean the anatomical markers commonly used to define this segment are located on the anterior and posterior proximal aspect of the segment. Kinematic models commonly use these anatomical markers to track the pelvis during dynamic trials [4]. However, adipose tissue around the anterior aspect of the pelvis can increase STA [5,6] and the visibility of markers located on the anterior aspect of the pelvis is often compromised during a number of functional movements, such as sit-stand tasks. To overcome this issue authors have advocated a number of solutions including posterior technical clusters [7] or the addition of iliac crest markers [8]. To-date limited work has explored the influence of these alternative technical marker sets upon hip joint kinematics. Therefore, the aim of this study was to compare hip joint kinematics calculated using a conventionally pelvis and two alternative technical clusters, during walking.

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2. Method

2.1. Participants

Fourteen adults (8 M;6 F, age: 44 ± 15 years; height: 1.70 ± 0.11 m; mass: 72 ± 12 kg; BMI: 24.7 ± 2.2) participated in this study. Inclusion criteria specified that the participants did not possess any medical issues which could influence gait. Institutional ethical approval was granted and written informed consent provided by participants prior to testing.

2.2. Procedures

Participants completed over ground walking trials along a 7 m walkway, barefoot at a self-selected velocity (1.38 ± 0.14 $m \cdot s^{-1}$). 3D kinematics were recorded using a 10 camera motion capture system (Oqus 3+, Qualisys, Sweden) operating at 200 Hz. The pelvis was modelled using the CODA pelvis option within Visual 3D (C Motion, Germantown, MD) [9], and defined by anatomical markers located bilaterally on the anterior and posterior superior iliac spines. The different pelvis technical marker configurations used within this study are detailed in Table 1. A composite marker set was used so that each technical marker set was attached simultaneously. The thigh was defined proximally using the hip joint centre and distally using the medial and lateral femoral epicondyles. A rigid cluster of four markers attached to the posterior-lateral aspect of the segment was used to track the thigh during dynamic trials. Segmental coordinate systems were oriented as follows; X-axis medial-lateral, Y-axis posterior-anterior, and Z-axis vertical. An XYZ cardan sequence of rotations was undertaken with positive angles interpreted as flexion, adduction and internal rotation.

2.3. Processing and analysis

Marker trajectories were reconstructed, labelled and cropped to a single gait cycle within Qualisys Track Manager (Version 2.17, Qualisys, Sweden). Five trials (per participant) were exported to Visual 3D. Marker trajectories were low pass filtered at 6 Hz and time normalised to stance duration. Hip joint kinematics were calculated using each technical marker set. The root mean square error (RMSE) was calculated between the conventional pelvic model and each alternative technical marker set. The RMSE associated with each technical marker set was compared statistically using paired t-tests or Wilcoxon match pairs analysis within SPSS version 23 (IBM, Armonk, NY, USA). Cohen's d was calculated to estimate effect sizes and interpreted as follows; .2–.49 = small, .5–.79 = medium and > .8 = large [10]. The level of significant was set at $p \leq .05$.

3. Results

Fig. 1 displays assembled average hip joint kinematics in the sagittal, frontal and transverse planes for each tracking marker set. In the sagittal plane. the RMSE was significantly ($p = .05$, $d = .28$) larger for the posterior cluster (2.5° ± 2.8°) compared to the iliac crest model (1.3° ± 0.7°) (Fig. 2A). Similarly, the RMSE was significantly ($p < .001$, $d = 7.65$) larger for the posterior cluster (1.6° ± 0.4°) compared to the iliac crest model (0.8° ± 0.3°) in the frontal plane (Fig. 2B). In contrast, the RMSE was significantly ($p = .01$, $d = -2.85$) lower for the posterior cluster (0.8° ± 0.4°) compared to iliac crest model (1.4° ± 0.5°) in the transverse plane (Fig. 2C). Pelvic kinematics are displayed in the Fig. A1 in Appendix A.

Table 1
Bilateral tracking marker configurations used to define the pelvis for the three models utilised within this study.

	ASIS	PSIS	Distal PSIS	Iliac crest
Conventional pelvic model	X	X		
Posterior cluster model		X	X	
Iliac crest model		X		X

Note: Distal PSIS marker placed ≈ 2 cm below the PSIS marker. The posterior cluster model did not use tracking markers attached to a rigid cluster, instead all four markers were attached directly to the skin.

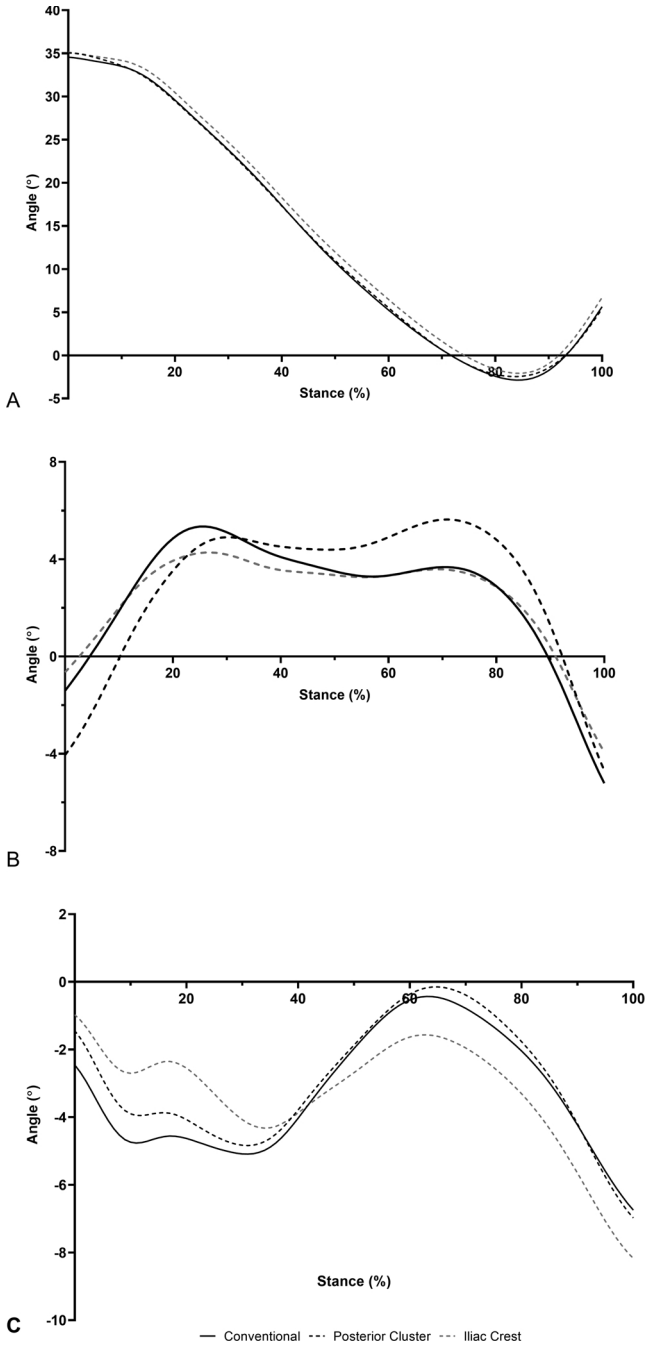

Fig. 1. (A) Sagittal, (B) frontal and (C) transverse plane hip joint kinematics calculated using the conventional pelvic model (solid black line), posterior cluster (dashed black line) and iliac crest model (dashed grey line).

4. Discussion

The aim of the study was to compare hip joint kinematics calculated using a conventional pelvis and two alternative technical marker sets. The findings of this study demonstrate that hip joint kinematics are generally comparable, with small RMSE between each technical marker

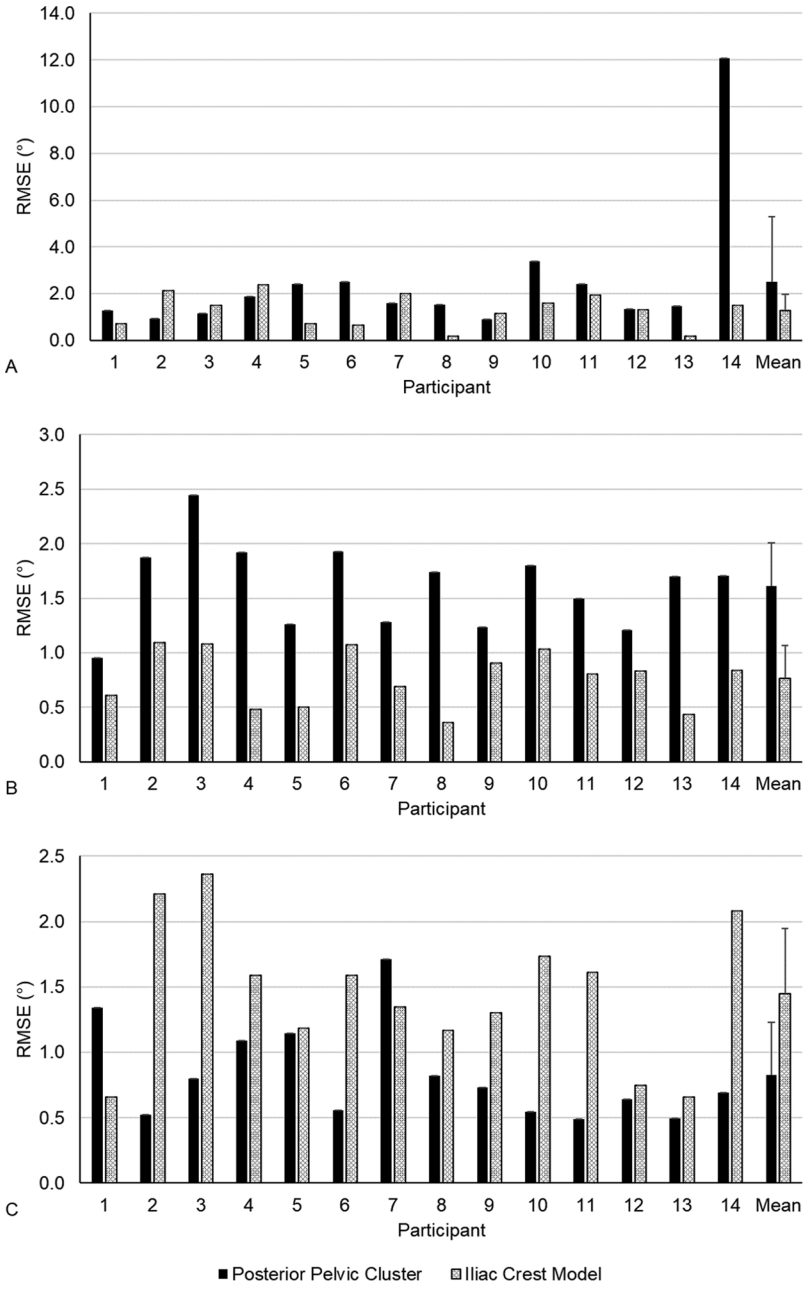

Fig. 2. Root measure square error (RMSE) for (A) sagittal, (B) frontal and (C) transverse plane hip kinematics calculated using the posterior cluster (solid black bars) and iliac crest model (patterned grey bars).

set and the conventional pelvic model. Both the posterior cluster and iliac crest marker sets offer means of accurately calculating hip joint kinematics within 3° of the conventional pelvic model. RMSE of this magnitude is lower than the 5° threshold suggested by McGinley et al., [11] for concern in relation to data interpretation.

The iliac crest marker set appears to be superior to the posterior pelvic cluster when assessing sagittal and frontal plane kinematic waveforms, evidenced by the reduced RMSE (Fig. 2). As such if sagittal and frontal plane kinematics are of interest a technical marker set including iliac crest markers are preferable. In contrast, the pelvic cluster has a reduced RMSE compared to the iliac crest marker set in the transverse plane and may therefore be preferable if hip internal/external rotation is of interest.

Visual comparisons of the assembled average curves (Fig. 1) provide insight into the variations in RMSE between models. Peak hip adduction occurs considerably later in the stance phase when using the posterior cluster, thus explaining the increased RMSE for this marker set in the frontal plane. Whereas, the iliac crest marker set displays reduced range of motion throughout the first 80% of the stance phase in the transverse plane. The larger RMSE in the sagittal plane for the posterior pelvic cluster is largely due to the 12.1° RMSE reported for participant 14. Exploration of this individuals' data reveals a large offset between the conventional pelvic model and the posterior cluster. Interestingly, this participant does not have the highest BMI; however, they may have had increased adipose tissue around the posterior aspect of the pelvis in turn increasing STA in this region.

The findings of this study need to be interpreted with some caution. The recruitment of a healthy participant cohort and the lack of any participants classified as obese are potential limitations of the study. Gait kinematics have been shown to be influenced by pathological conditions [12], and STA increases with increased BMI. The ability to extrapolate the findings pathological groups or obese individuals, and

beyond walking, may therefore be limited.

In conclusion, either a posterior cluster or additional iliac crest markers provide alternative means of accurately calculating hip joint kinematics during 3D gait analysis. As such clinicians/researchers may use either technical marker set as a viable alternative to the conventional pelvic model.

Conflict of interest

None.

Acknowledgement

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Appendix A

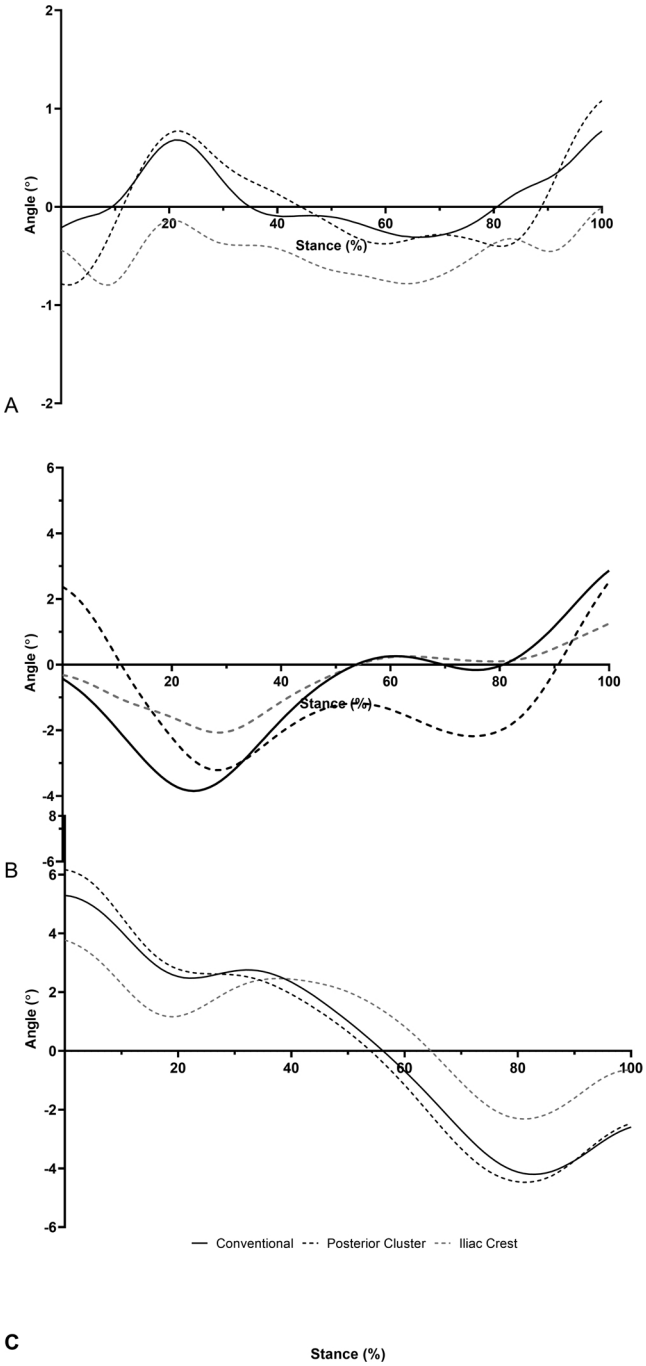

Fig. A1. Assembled average pelvic kinematics in (A) sagittal, (B) frontal and (C) transverse planes calculated using the conventional pelvic model (solid black line), posterior cluster (dashed black line) and iliac crest model (dashed grey line).

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