



Short communication

Evaluation of alternative technical markers for the pelvic coordinate system

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ABSTRACT

In this study, we evaluated alternative technical markers for the motion analysis of the pelvic segment. Thirteen subjects walked eight times while tri-dimensional kinematics were recorded for one stride of each trial. Five marker sets were evaluated, and we compared the tilt, obliquity, and rotation angles of the pelvis segment: (1) standard: markers at the anterior and posterior superior iliac spines (ASIS and PSIS); (2) markers at the PSIS and at the hip joint centers, HJCs (estimated by a functional method and described with clusters of markers at the thighs); (3) markers at the PSIS and HJCs (estimated by a predictive method and described with clusters of markers at the thighs); (4) markers at the PSIS and HJCs (estimated by a predictive method and described with skin-mounted markers at the thighs based on the Helen-Hayes marker set); (5) markers at the PSIS and at the iliac spines. Concerning the pelvic angles, evaluation of the alternative technical marker sets evinced that all marker sets demonstrated similar precision across trials (about 1°) but different accuracies (ranging from 1° to 3°) in comparison to the standard marker set. We suggest that all the investigated marker sets are reliable alternatives to the standard pelvic marker set.

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1. Introduction

In human movement analysis, describing the movement of the pelvis is accomplished through a pelvic anatomical coordinate system most commonly defined by use of surface markers placed on the right and left anterior superior iliac spines (RASIS and LASIS) and on the right and left posterior superior iliac spines (RPSIS and LPSIS). The pelvic anatomical coordinate system can be described as the origin at the midpoint between RASIS and LASIS, the Z-axis points from the origin to the RASIS, the X-axis lies in the plane defined by the RASIS, LASIS, and the midpoint of the RPSIS and LPSIS markers and points ventrally orthogonal to the Z-axis, and the Y-axis is orthogonal to these two axes (Wu et al., 2002), as shown in Fig. 1. This marker placement has been the de facto standard for human movement analysis of the pelvis segment.

Given the difficulty of measuring the position of the RASIS and LASIS markers due to occlusion by the arms or by skin tissue from the abdominal area during movement, alternative technical markers have been used during motion trials. In order to use these technical markers, a static trial, where the subject stands still with both anatomical and technical markers on the pelvis, must be performed first. After that, the RASIS and LASIS markers can be removed; hence, the position of these markers can be

expressed in relation to a technical coordinate system (TCS) created using the technical markers. A common solution is to place technical markers at the right and left lateral iliac crests (RIC and LIC). However, the markers at the RIC and LIC still might be occluded by the arms and might not produce reliable results given that they are placed on the lateral of the waist, where a good amount of fat and skin tissue may be present. We are unaware of any work that has evaluated the reliability of using the RIC and LIC markers. Another alternative to solve the problems listed above is to use the right and left hip joint centers described in the TCS of the right and left thighs, together with the RPSIS and LPSIS markers, as technical markers for tracking the pelvis movement. Here, we report a kinematic evaluation of these alternative technical markers for the motion analysis of the pelvic segment.

2. Methods

Thirteen healthy adults (mean \pm SD age, height, and mass of 27.8 ± 5.7 yr, 1.71 ± 0.08 m, and 69.3 ± 12.3 kg) participated in this study. This study was approved by the ethics committee of Instituto Vita.

To test the alternative pelvic technical markers, we kept the standard pelvic anatomical coordinate system described earlier and the following pelvic technical marker sets were evaluated: (a) RASIS, LASIS, RPSIS, and LPSIS (the standard); (b) right and left hip joint centers (RHJC and LHJC) described in the thigh TCS, RPSIS, and LPSIS; and (c) RIC, LIC, RPSIS, and LPSIS.

The type of marker set used to describe the motion of the thigh may affect the second pelvic marker set. In order to investigate this effect, two marker sets were investigated: the Helen-Hayes marker set (Kadaba et al., 1990) and a marker set composed of rigid clusters to define the segmental TCS (Cappozzo et al., 1995). For the Helen-Hayes marker set, an extra non-collinear marker was placed on each thigh to compose a TCS in each segment. For the cluster marker set, each cluster was formed by

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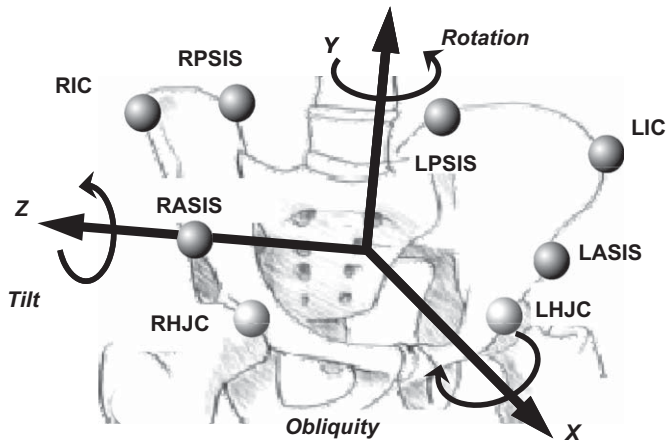


Fig. 1. Bony landmarks and axes convention for the pelvis segment.

four markers placed on elastic bands fastened to each thigh. These two marker sets were simultaneously worn by the subjects. In addition, the pelvic marker set composed of the HJCs might also be dependent upon the accuracy of the estimation of the HJC (Leardini et al., 1999). To consider this possibility, the HJCs were estimated using a predictive method based on regression equations (Bell et al., 1990) and based on a functional method using motion trials (Schwartz and Rozumalski, 2005).

The different pelvic marker sets were evaluated in a standard gait analysis procedure. Each subject walked eight times at a comfortable speed for approximately 10 m while the tri-dimensional kinematics were recorded for one stride of each trial using a six-camera motion analysis system operating at 120 Hz (Vicon 460, Oxford Metrics, UK).

2.1. Data analysis

The data for one stride (the dataset between two successive right-heel strikes) of each trial were normalized in time from 0% to 100% in increments of 1%. Only the results for the pelvic segment will be shown here, because it is the only segment directly affected by the alternative pelvic TCS. To use the HJCs as technical markers for the pelvic segment during the motion trials, the HJCs were first expressed in the pelvic TCS and then transformed to the thigh TCS. The pelvic angles were calculated using a ZXY Cardan rotation sequence (tilt, obliquity, and rotation).

To evaluate the error of the alternative pelvic TCS, we estimated the precision (repeatability) and accuracy (in relation to the standard marker set) of the pelvic segment angles using such TCS. The precision of the pelvic angles for each subject and for each technical marker set was defined as the mean across the standard deviation for each instant (% of the stride) of the eight trials. The accuracy of the pelvic angles for each subject was defined as the mean across the root-mean-square of the difference of the pelvic angles for each alternative pelvic TCS and the respective angles calculated using the standard pelvic marker set for each instant (% of the stride) of the eight trials.

Since our goal was only to evaluate the alternative pelvic TCS, we did not compare the data across different kinematic models, nor across the different methods of estimation of the HJCs (for these comparisons, see Cappozzo et al., 1997; Cereatti et al., 2009; Leardini et al., 1999). Data analysis was performed using the software Visual3D (version 3.0, C-motion Inc., USA) and Matlab (version 7.0, Mathworks Inc., USA). Repeated-measure ANOVAs were employed to determine the effect of the different pelvic TCS on precision and accuracy for each angle separately and the Sidak test was employed for the post-hoc comparisons. A significance level of 0.05 was adopted for all statistical tests performed.

3. Results

The time series of the three pelvic angles for the five pelvic TCS are shown in the supplementary material accompanying this article. All five marker sets demonstrated similar precision, with mean values across angles ranging from 1.0° to 1.1° (Fig. 2A). In regard to the accuracy (Fig. 2B), the pelvic TCS based on the HJCs at the thigh TCS and the Helen-Hayes marker set was the least accurate of the four marker sets (the mean accuracy across angles of the Helen-Hayes marker set was 3.0° versus 2.0° for both marker sets based on HJC and clusters, and 1.2° for the marker set based on the RIC and LIC markers). The post-hoc comparisons evinced that the Helen-

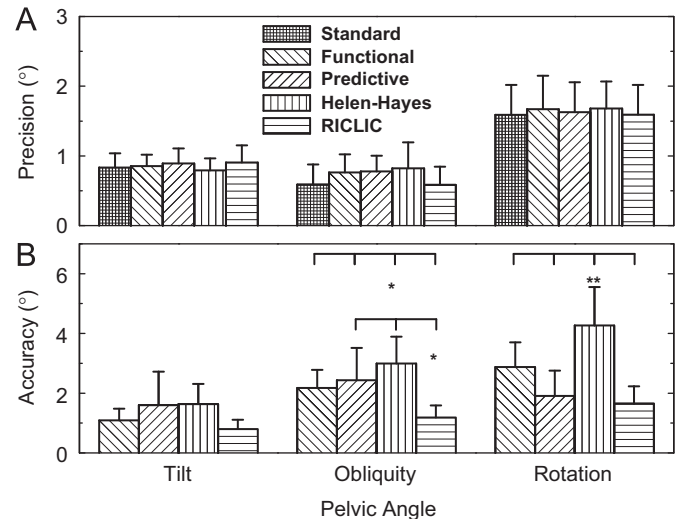


Fig. 2. (A) Mean and standard deviation across subjects of the precision of the three pelvic angles obtained with the five pelvic technical coordinate systems (TCS). (B) Mean and standard deviation across subjects of the accuracy of the three pelvic angles obtained with four TCS in relation to the standard pelvic coordinate system. Significant differences between the pelvic TCS (* $p < 0.05$ and ** $p < 0.001$).

Hayes marker set presented significantly lower accuracy for the pelvic obliquity ($p=0.04$) and rotation ($p < 0.001$) than the other three marker sets. The marker set based on the RIC and LIC markers was significantly more accurate than both marker sets based on HJC and clusters for the pelvic obliquity ($p=0.01$).

4. Discussion

The evaluation of the alternative technical marker sets for the pelvis evinced that all marker sets presented similar precision across trials (about 1°) but different accuracies (ranging from 1° to 3°) in comparison to the standard marker set. Although, the marker set based on the HJCs estimated by the predictive method and described using the Helen-Hayes marker set was statistically the least accurate of the pelvic marker sets, the values for all marker sets were in the range of the accepted precision and accuracy of current state of the art kinematic gait analysis based on surface markers and commercial equipment (Della Croce et al., 2005; Schwartz et al., 2004). The slightly lower accuracy of the Helen-Hayes marker set is most probably explained by the fact that this marker set is composed of markers directly on the skin, which may have introduced an artifact due to skin movement.

We suggest that all the investigated marker sets are reliable alternatives to the standard pelvic marker set. In particular, if clusters for the thighs are already being used, the adoption of the pelvic technical marker set based on the HJCs described at the thigh TCS using clusters gives the advantage of needing two markers less than other pelvic marker sets and, in our experience, solves the problem with marker recognition due to the upper arms, abdominal tissue, or excessive hip flexion blocking the view of the markers on the pelvis.

Statement of conflict of interest

We declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

Appendix A. Supporting material

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.jbiomech.2009.09.050](https://doi.org/10.1016/j.jbiomech.2009.09.050).

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