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Short communication

Methods for determining hip and lumbosacral joint centers in a seated position from external anatomical landmarks

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ABSTRACT

A global coordinate system (GCS) method is proposed to estimate hip and lumbosacral joint centers (HJC and LSJC) from at least three distances between joint center of interest and target anatomic landmarks (ALs). The distances from HJC and LSJC to relevant pelvis and femur ALs were analyzed with respect to usual pelvis and femur scaling dimensions. Forty six pelves and related pairs of femurs from a same sample of adult specimens were examined. The corresponding regression equations were obtained. These equations can be used to estimate HJC and LSJC in conditions where a very limited number of ALs are available: for example, during seated posture analysis as performed in the automotive industry. Compared to currently existing HJC and LSJC methods from ALs, the proposed method showed better results with an average error less than 11 mm.

1. Introduction

Locating joint centers from external anatomical landmarks (ALs) is frequently required for posture and motion analysis. In particular, the centers of the hip and lower lumbar spine (at L5/S1) joints are needed for studying seated postures for many applications, such as automotive packaging and seating comfort (Reed et al., 1999; Bush and Gutowski, 2003; Bulle et al., 2012) and wheelchair seating (Lalond et al., 2003). However, currently existing methods are not practical and even impossible to apply in a seated position due to the difficulty in locating ALs required for estimating joint centers. For hip joint center (HJC), two classes of methods were proposed in the past: functional method and regression method. The functional method (Piazza et al., 2001, 2004; Ehrig et al., 2006) locates the HJC by estimating the average center of rotation from the trajectories of the markers attached to the thigh when performing a hip circumduction movement. HJC can be expressed either in a pelvis or in a femur LCS. But due to soft tissue artefact (STA), it is almost impossible to define a reliable femur or pelvis LCS during a circumduction movement. The regression method relies on empirical regression equations between externally palpable bone landmarks and HJC, also requiring a definition of a pelvis local coordinate system (LCS). Different empirical regression equations were proposed in the past. Different pelvic dimensions were used as predictors. For example, Bell et al. (1990) used only pelvis width (PW=right and left anterior superior iliac spines RIAS–LIAS, see Fig. 1) as predictor to predict HJC in a pelvis LCS defined from the four superior iliac spines (RIAS, LIAS, RIPS and LIPS). Seidel et al. (1995) added pelvis depth (PD_1=distance from RIAS to RIPS) and pelvis height (PH=distance from pubic symphysis IPJ to RIAS–LIAS line) as two additional predictors. New equations were proposed in another pelvis LCS based on the right and left anterior superior iliac spines (RIAS, LIAS) and pubic symphysis (IPJ). It should be noted that the need of the palpation of the pubic symphysis makes Seidel's method not practical, especially outside clinical applications. Interestingly, Bush and Gutowski (2003) proposed a method to determine HJC in a global coordinate system (GCS) for seated postures by assuming the constant distances between HJC and two ALs (i.e., RIAS and femur lateral epicondyle) remain constant. Besides, HJC was assumed in the plane perpendicular to RIAS–LIAS with a known distance to RIAS. However, as no regression equations about these distances were available, these constants were estimated indirectly from HJC regression equations from Seidel et al. (1995). For seated automobile drivers, Brodeur et al. (1996) suggested using the right and left ischial tuberosities (RIIT and LIIT), estimated as the center of pressure under these ALs, in addition to RIAS and LIAS. HJC was assumed in the plane by LIAS, RIAS and RIIT for the right side (or LIIT for the left side). The projection of HJC on the line RIAS–RIIT was first predicted as function of the distance RIAS–RIIT. The

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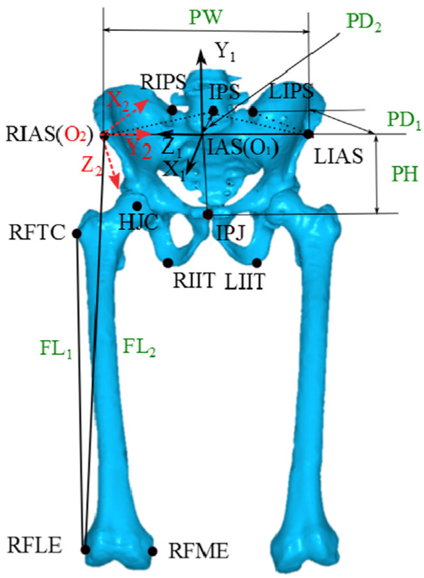

Fig. 1. Pelvis and femur anatomical landmarks (ALs) and definition of two pelvis local coordinate systems (LCS). LCS1 follows the ISB recommendation (Wu et al., 2002), with the origin at the mid-point (IAS) between the two anterior superior iliac spines (RIAS and LIAS), and Y_1 being normal to the plane RIAS–LIAS–IPS. IPS is the mid-point between the two posterior superior iliac spines (RIPS and LIPS). LCS2 is centered at the anterior superior spine, the media-lateral axis Y_2 is defined by the line LIAS–RIAS pointing medially, X_2 perpendicular to the frontal plane defined by RIAS, LIAS and the pubic symphysis IPJ.

direction RIAS–HJC with respect to RIAS–RIIT was assumed to be constant depending on gender. Compared to the methods requiring a pelvis LCS like those proposed by Seidel et al. and Bell et al., the GCS approach requires a smaller number of ALs. In case of the method proposed by Bush and Gutowski, only two target ALs are needed. However, to our knowledge, there are no regression equations to predict the distances from HJC to different ALs. Compared to hip joint center, fewer studies were published to locate the lumbosacral joint (LSJ) at L5/S1 from externally palpable ALs. LSJ is an important joint required for posture/motion analysis implying the trunk and upper body. Reed et al. (1999) proposed a solution using scaling relationships with respect to pelvis width (PW), pelvis depth (PD_1) and pelvis height (PH) (see Fig. 1 for their definitions). They were calculated from the average values of three pelvis types representing small female, midsize male and large male from the data collected by Reynolds et al. (1982) to estimate LSJC in a pelvis LCS. Recently, Murphy et al. (2011) proposed regression equations to locate LSJC using the four superior iliac spines from 16 CT pelvis scans. In addition to the small sample size, no regression equations for predicting the distances from LSJC to other ALs were provided if a GCS method is used. Table 1 summarizes the existing methods for locating HJC and LSJC from external ALs. The ALs and parameters used as predictors are illustrated in Fig. 1.

In summary, there is a need to establish the relationships between joint center of interest (HJC and LSJC) and various easily accessible ALs so that a GCS method can be used. In case of automobile seated posture or other situations with a seat back, only two anterior superior iliac spines of the pelvis (RIAS, LIAS) and two knee epicondyles (RFLE and LFLE) can be easily palpated. Therefore, the main objective of this study was to propose the relationships between HJC/LSJC and these easily palpated ALs for seated posture analysis.

2. Methods

Forty six bodies from donators were obtained from the Body Donation program of the Université Libre de Bruxelles. X-ray control ensured that selected bodies did not show bone deformities or surgical materials that could create methodological artefacts. All available bodies were processed by medical imaging (computed tomography or CT) in order to produce 3D models that were eventually available to build the database used for regression building in this study. For each donator, CT datasets were obtained in a supine position from above the iliac crests until below the joint space of both knees (CT system and imaging sequences used in this study were Siemens SOMATOM, helical mode, slice thickness: 1 mm for the pelvis area and both femoral epiphyses, and 10 mm for the femoral diaphysis). After segmentation (Van Sint Jan et al., 2002), 3D models of the specimen pelvis and two femoral bones were obtained. Gender information was not available. All ALs of interest were virtually palpated from the reconstructed 3D pelvis and femoral models. Their definitions are detailed in the book by Van Sint Jan (2007) and shown in Fig. 1. The coordinates of the left side ALs of each pelvis and left femur were symmetrically transferred to the right according to the sagittal plane to increase the database. The HJC was approximated as the center of the femoral head at each side by sphere fitting. The lumbosacral joint center (LSJC) was considered as the joint between the fifth lumbar vertebra and first sacral vertebra by neglecting the motions within the sacroiliac joint (Goode et al., 2008), shown as in Fig. 2.

Similar to the GCS method proposed by Bush and Gutowski (2003), we propose using at least three target ALs ($\boldsymbol{T}_i$, $i = 1:n$, $n \geq 3$) to locate a joint center ($\boldsymbol{C}$) by assuming that their distances are known and remain constant. $\boldsymbol{C}$ can be considered as the point which gives the shortest distance to the spheres centered at the target ALs with corresponding distances d_i as radius:

$$minimize\ f(\boldsymbol{C}) = \sum_{i=1}^{n} \left(\sqrt{\boldsymbol{C} - \boldsymbol{T}_i} - d_i \right)^2$$

In the present study, the usual pelvis scaling dimensions as those used by Seidel et al. (1995) and Reed et al. (1999) are considered as predictors (Fig. 1): pelvis width (PW), pelvis height (PH) and pelvis depth (PD_1). As the distance (PD_2) between IAS (mid-point of the two anterior superior iliac spines) and IPS (mid-point of the two posterior superior iliac spines) was used by Murphy et al. (2011) for locating LSJC, PD_2 is included as an alternative to PD_1. For the femur, the distance (FL_1) between the great trochanter and the lateral knee epicondyle is used as the principal variable for predicting the distances from HJC to the three easily palpable femur ALs (great trochanter and two knee epicondyles). Considering the difficulty in palpating the greater trochanter, particularly on overweight individuals, the distance (FL_2) between the anterior superior iliac spines (RIAS) and lateral knee epicondyle (RFLE) in a supine or standing position is also proposed. As RIAS and RFLE are not on the same segment, their distance varies when changing the femur position with respect to the pelvis. A test with a subject showed its variation was quite small, less than 10 mm when rotating the femur 10° around the axes Z_1 and X_1 passing through HJC from the scanned supine position. PW, PH, PD_1, PD_2, FL_1 and FL_2 are illustrated in Fig. 1.

Multiple regressions with backward stepwise selection procedure (p-Value$=0.05$) were performed to predict the distances between joint center of interest (HJC/LSJC) and target ALs. PW, PH and PD_1 (or PD_2) were used as predictors for the pelvis ALs. In case that PH was retained as predictor, the equations without PH were also proposed in case that the pubic symphysis (IPJ) is not available. For the distances defined by femur ALs, only FL_1 or FL_2 was used as predictor.

3. Results and discussion

The regression equations for predicting the distances between HJC/LSJC and different target ALs are summarized in Table 2. Different combinations of target ALs for predicting HJC and LSJC were tested using the proposed GCS method and compared with real joint centers. Results are shown in Table 3. In Table 1, the revised coefficients from the data of the current study are also provided as well as the errors. Note that the scaling factors for HJC from the current study are very close to those proposed in Seidel's method, suggesting that our data is comparable to those by Seidel et al. As for LSJC, the scaling factors from the current study are very close to those proposed in Reed's method based on the data of 85 pelves by Reynolds et al. (1982). However, they are quite different from those proposed by Murphy et al. (2011). Compared with the LSJC predicted by the scaling coefficients from the present data, LSJC predicted by Murphy et al. is located at 18.0 mm more inferior (y-axis of the pelvis LCS1) and 18.9 mm more posterior (x-axis of the pelvis LCS1) for an average pelvis with PW$=239.9$ mm. These differences might be due to the difference in AL palpation. Actually, the location of ALs was not described in an accurate way in the paper by Murphy et al., while this new study used strict palpation guidelines for reproducibility reasons. Different sample sizes (16 and 46 specimens for Murphy's study and this study, respectively) might also explain the differences in results.