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Short communication

The centre of rotation of the shoulder complex and the effect of normalisation

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ABSTRACT

Shoulder motions consist of a composite movement of three joints and one pseudo-joint, which together dictate the humerothoracic motion. The purpose of this work was to quantify the location of the centre of rotation (CoR) of the shoulder complex as a whole. Dynamic motion of 12 participants was recorded using optical motion tracking during coronal, scapular and sagittal plane elevation. The instantaneous CoR was found for each angle of elevation using helical axes projected onto the three planes of motion. The location of an average CoR for each plane was evaluated using digitised and anthropometric measures for normalisation. When conducting motion in the coronal, scapular, and sagittal planes, respectively, the coefficients for locating the CoRs of the shoulder complex are −61%, −61%, and −65% of the anterior–posterior dimension – the vector between the midpoint of the incisura jugularis and the xiphoid process and the midpoint of the seventh cervical vertebra and the eighth thoracic vertebra; 0%, −1%, and −2% of the superior–inferior dimension – the vector between the midpoint of the acromioclavicular joints and the midpoint of the anterior superior iliac spines; and 57%, 57%, and 78% of the medial–lateral dimension −0.129 times the height of the participant. Knowing the location of the CoR of the shoulder complex as a whole enables improved participant positioning for evaluation and rehabilitation activities that involve movement of the hand with a fixed radius, such as those that employ isokinetic dynamometers.

1. Introduction

The shoulder complex consists of four joints (glenohumeral, acromioclavicular, sternoclavicular, and scapulothoracic) that act together to enable its full range of motion (RoM). Previous research has focused primarily on the rotation of the glenohumeral joint alone (Campbell et al., 2009; Hill et al., 2007; Lempereur et al., 2010, 2011; Monnet et al., 2007; Stokdijk et al., 2000; Veeger, 2000). However, rotation of the humerus at the glenohumeral joint does not occur in isolation; in a pair of studies, Walmsley examined the movement of the position of the glenohumeral joint while using a dynamometer, relative to a laboratory reference frame, finding it to be of the order of several centimeters (Walmsley, 1993a, 1993b). Other groups have examined scapular kinematics in isolation (Matsuki et al., 2011) and the scapulohumeral rhythm (Yoshizaki et al., 2009), but none have quantified the location of the centre of rotation (CoR) of the entire shoulder complex.

The position of the joint CoR is important when considering subject positioning for evaluation and rehabilitation activities. For example, use of isokinetic dynamometers to assess strength at, and perform rehabilitation of a given joint, partly depends on the ability to align the dynamometer with the joint CoR, which may not be the same as the geometric centre of the joint. Incorrect alignment will result in pain and potential injury to the subject (Codine et al., 2005), as well as inaccurate outputs. Prior studies reported on the difficulty of aligning subjects due to the unknown location of the shoulder complex CoR relative to the thorax (Shklar and Dvir, 1995). Determining its location would facilitate more effective evaluation of the strength of the shoulder complex and improved positioning for rehabilitation. However, as the shoulder complex is not a single joint, the CoR cannot simply be estimated visually. Therefore, the aim of this work was to quantify the location of the CoR of the complete shoulder complex relative to the thorax.

Given the location of such a point, the objectives were to assess the inter- and intra-subject repeatability (S_{inter} and S_{intra}, respectively) of this point's position, determine the method of normalisation that best estimated the CoR of the shoulder complex for each plane of motion studied, and quantify how the error in locating this point varied during arm elevation.

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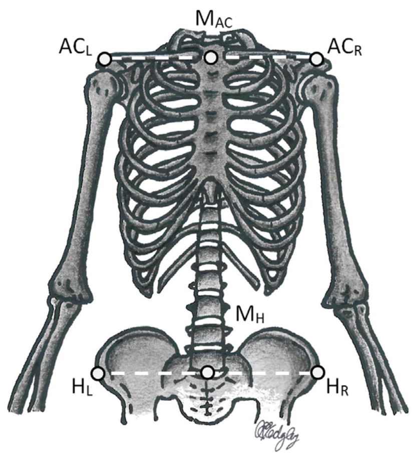

Fig. 1. Anatomic and derived landmarks used for the four methods of normalisation. These are the left acromioclavicular joint (AC_L), right acromioclavicular joint (AC_R), midpoint between AC_L and AC_R (M_{AC}), midpoint between the two anterior superior iliac spines (H_L and H_R) (M_H), midpoint between the incisura jugularis (IJ) and seventh cervical vertebra (C7) (M_1), midpoint between the xiphoid process (PX) and eighth thoracic vertebra (T8) (M_2), midpoint between IJ and PX (M_3), and midpoint between C7 and T8 (M_4).

Table 1
Distances used for the four methods of normalisation along the three anatomic axes (D_x, D_y, and D_z). These were calculated using the locations of the incisura jugularis (IJ), xiphoid process (PX), seventh cervical vertebra (C7), eighth thoracic vertebra (T8), midpoint between the IJ and C7 (M_1), midpoint between the PX and T8 (M_2), midpoint between IJ and PX (M_3), midpoint between C7 and T8 (M_4), left acromioclavicular joint (AC_L), right acromioclavicular joint (AC_R), midpoint between AC_L and AC_R (M_{AC}), midpoint between the two anterior superior iliac spines (M_H), height of the subject (H), the trigonum spinae scapulae (TS), the angulus inferior of the scapulae (AI), the angulus acromialis (AA).

D_x	M_3M_4	IJC7		
D_y	M_1M_2	$M_{AC}M_H$	0.288*H	TSAI
D_z	M_1AC_R	AC_LAC_R	0.129*H	TSAA

2. Materials and methods

2.1. Participants

Twelve volunteers (four women, eight men; age 26.4 ± 5.6 years old; height 1.76 ± 0.11 m; weight 71.4 ± 10.7 kg; BMI 22.8 ± 2.1 kg/m^2) participated in the study that was approved by the institutional ethics committee. All participants gave informed written consent prior to testing and were screened to ensure they had no previous surgery, injury or chronic pain in either shoulder. Laterality was assessed with a modified Edinburgh Inventory Handedness Score (Milenkovic and Dragovic, 2013).

2.2. Experimental protocol

A nine-camera optical motion tracking system (Vicon, Oxford, United Kingdom) was used to obtain kinematic data. Retro-reflective markers (14 mm diameter) were secured to the skin on the incisura jugularis (IJ), xiphoid process (PX), seventh cervical vertebra (C7), and eighth thoracic vertebra (T8) (Fig. 1). Clusters of three markers were affixed over the spine of the scapula (Prinold et al., 2011) and on the upper arm, just below the insertion of the deltoid, on the dominant side. Coordinate frames for the thorax, scapula, and upper arm were defined as recommended by the International Society of Biomechanics (Wu et al., 2005). The coordinate frame of the scapula was established with the arms at 90° of elevation in the coronal plane (Shaheen et al., 2011). Additional markers were placed on the shoulders and hands, providing participants with visual feedback from the motion capture system to assist them in performing each planar movement.

Participants performed maximal elevation and depression in the coronal, scapular, and sagittal planes with both arms simultaneously, using a metronome to maintain an average velocity of approximately 160°/s. Participants were instructed to perform each motion with wrist in a neutral position and the thumb pointing superiorly. Participants were permitted to practise the movements before recording the kinematics. Between six and eight repetitions were performed and five consecutive cycles from the middle of the trial were selected for analysis.

2.3. Data analysis

Raw data were twice filtered with a second-order Butterworth filter (Thigpen et al., 2010; Winter et al., 1974) and, following a frequency analysis (Angeloni et al., 1994), filtered with a cut-off of 5 Hz. The glenohumeral joint CoR was calculated with the Gamage and Lasenby (2002) algorithm using the clusters of markers on the scapula and upper arm. The shoulder complex CoR was determined by finding the instantaneous helical axis (IHA) (Reichl and Auzinger, 2012; Woltring et al., 1985) in the thorax technical coordinate system (TCS) using custom-written code (MATLAB, MathWorks, Natick,

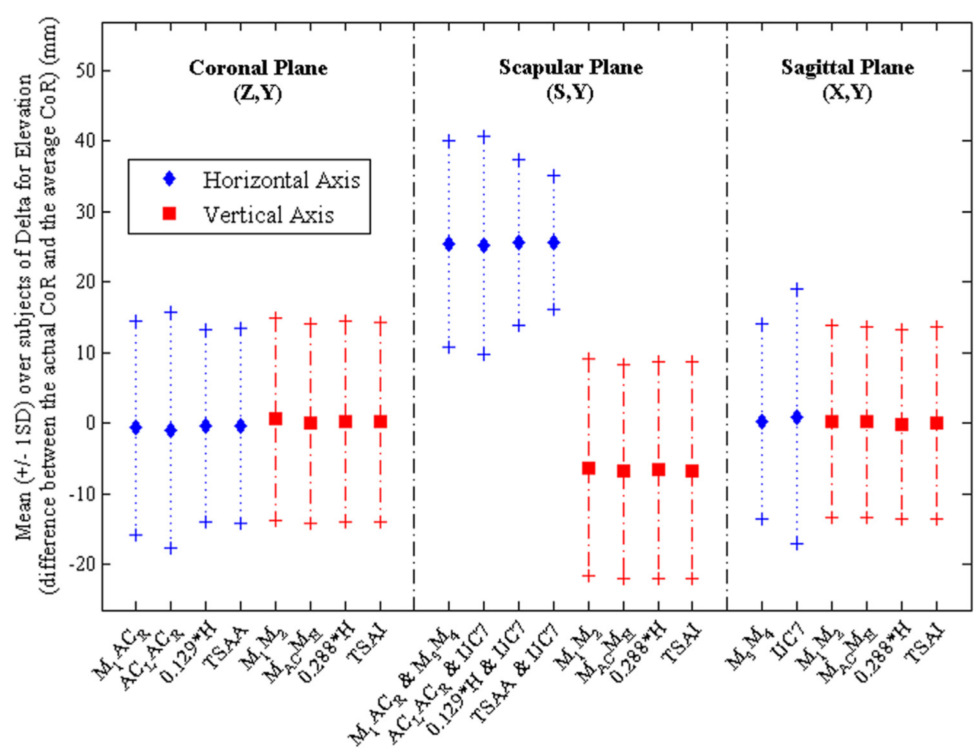

Fig. 2. Mean (± 1SD) of the distance (Delta) between the mean CoR and the instantaneous CoR, for the three planes of elevation, for the elevation phase, using the methods of normalisation described in Table 1.

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