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Short communication

A comparison of acromion marker cluster calibration methods for estimating scapular kinematics during upper extremity ergometry

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Accurate measurement of joint kinematics is required to understand the musculoskeletal effects of a therapeutic intervention such as upper extremity (UE) ergometry. Traditional surface-based motion capture is effective for quantifying humerothoracic motion, but scapular kinematics are challenging to obtain. Methods for estimating scapular kinematics include the widely-reported acromion marker cluster (AMC) which utilizes a static calibration between the scapula and the AMC to estimate the orientation of the scapula during motion. Previous literature demonstrates that including additional calibration positions throughout the motion improves AMC accuracy for single plane motions; however this approach has not been assessed for the non-planar shoulder complex motion occurring during UE ergometry. The purpose of this study was to evaluate the accuracy of single, dual, and multiple AMC calibration methods during UE ergometry. The orientations of the UE segments of 13 healthy subjects were recorded with motion capture. Scapular landmarks were palpated at eight evenly-spaced static positions around the 360° cycle. The single AMC method utilized one static calibration position to estimate scapular kinematics for the entire cycle, while the dual and multiple AMC methods used two and four static calibration positions, respectively. Scapulothoracic angles estimated by the three AMC methods were compared with scapulothoracic angles determined by palpation. The multiple AMC method produced the smallest RMS errors and was not significantly different from palpation about any axis. We recommend the multiple AMC method as a practical and accurate way to estimate scapular kinematics during UE ergometry.

1. Introduction

This technical note is motivated by questions surrounding the clinical application of upper extremity (UE) ergometry as a rehabilitation modality in the spinal cord injury population. Upper extremity ergometry is recommended as an exercise intervention for these patients to improve cardiovascular function and muscle strength (Hasnan et al., 2013; Meyer et al., 2009; Valent et al., 2009), but the effect of this exercise on UE kinematics is unknown. Concerns exist about the impact of the exercise on the shoulder joint complex (Coupaud et al., 2008). Shoulder pain, impingement syndrome, and rotator cuff injuries are commonly associated with spinal cord injury (Jacobs and Nash, 2001), and it is unclear if kinematics associated with UE ergometry present subsequent risk for shoulder pain and injury.

Precise measurement of the shoulder joint complex is required to fully understand the potential kinematic changes, however reliable quantification of scapulothoracic (ST) motion is challenging to obtain (Illyés and Kiss, 2006; Uhl et al., 2009; van Andel et al., 2009). Currently, the acromion marker cluster (AMC) is the recommended method to estimate dynamic scapular orientation (Lempereur et al., 2014). While the AMC has been used to estimate scapular kinematics during functional motions (Lin et al., 2005; Roren et al., 2013), its accuracy has only been validated for single plane humeral elevation and internal/external rotation (Brochard et al., 2011a, 2011b; Duprey et al., 2015; Prinold et al., 2011; Shaheen et al., 2011; van Andel et al., 2009; Warner et al., 2012). Brochard et al. (2011b) and Cereatti et al. (2015) employed the AMC for humeral elevation and a throwing motion, respectively, using two static calibration positions – one with the shoulder at 0° elevation and one at full shoulder elevation (Brochard et al., 2011b; Cereatti et al., 2015). Similarly, Prinold et al. (2011) utilized the AMC with four static calibration positions throughout the range of shoulder elevation (Prinold et al., 2011). These studies indicate that

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the accuracy of the AMC improves with the use of more static calibration positions (Brochard et al., 2011b; Cereatti et al., 2015; Prinold et al., 2011). However, the multiple AMC calibration method requires more time to implement and may introduce additional errors from the multiple palpations (Lempereur et al., 2014). Considering that UE ergometry is a constrained cyclical motion, scapular kinematics may be adequately tracked using only the single or dual AMC calibration methods.

The purpose of this study was to compare the accuracy of the single, dual, and multiple AMC calibration methods for tracking scapular orientation during UE ergometry, in order to find the most appropriate measurement method for this application. As this investigation was constrained to static postures, palpation was used as a reference standard. We hypothesized that the multiple AMC calibration method would have the smallest root mean square errors (RMSEs) of the three methods and that the ST angles calculated with the multiple AMC calibration method would not be significantly different from palpated ST angles about any axis.

2. Methods

2.1. Subjects

A power analysis, conducted using GPower 3.1 (Faul et al., 2007) (α=0.05, power=0.80, correlation estimate=0.50), indicated a sample of 12 subjects would be sensitive to differences associated with a medium effect size (f=0.25) (Cohen, 1988). Thirteen healthy young adult subjects were recruited for this study (7 female, 6 male, ages 18–34). All subjects could sit upright and cycle continuously for 30 seconds without any difficulty. All subjects provided informed consent in accordance with the University of Delaware's human subjects review board.

Fig. 1. Cycle setup with markers and acromion marker cluster.

2.2. Data collection

Prior to data collection, the seat of a Cybex Upper Body Ergometer Arm Bike (Cybex International, Inc., Medway, MA, USA) was adjusted for each subject. Seat height was altered so that the rotational axis of the cycle crank was just below each subject's shoulders. Seat position was then adjusted so that subjects could reach the fully extended crank arm configuration without locking their elbows, while their trunks remained upright against the back of the seat. The crank arm moved in a circle, primarily in the subject's sagittal plane. However, only the subject's hands stayed on the grips of the crank arm, allowing for motion of the elbow and shoulder outside of the sagittal plane.

The AMC consisted of a group of three 6 mm, retroreflective, 3D markers placed on the acromion process (Fig. 1). Each marker cluster was attached so the central marker was positioned directly over each acromion process with the remaining cluster markers oriented posteriorly. Additional markers were placed on the spinous processes of T1 and T4, the sternal notch, bilaterally on the medial and lateral epicondyles, and the posterior surfaces of the humeri. Six markers were positioned bilaterally on the body, pivots, and crank arms of the cycle (Fig. 1).

Subjects were placed in eight static positions corresponding to the orientation of cycle crank arm (0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°). Low-profile retroflective markers were placed on the trigonum spinae and the inferior angle of each of the scapulae. Both landmarks corresponding to these low-profile markers were re-palpated at each of the eight different static positions by a researcher formally trained in palpation. For all trials, 3D positions of all the markers were recorded at 60 Hz by a nine camera system (Motion Analysis Corp., Santa Rosa, CA).

2.3. Data processing

Three dimensional marker positions were used to define rigid bodies for the trunk, scapula, and humerus. Coordinate systems for the trunk and humeri were created in line with the International Society of Biomechanics recommendations (Wu et al., 2005). The coordinate system for the scapulae was created similarly to ISB recommendations (Wu et al., 2005), however the central AMC marker (acromion process) was used in place of the angulus acromialis. Without knowing the axis associated with the greatest amount of scapular motion during UE ergometry, we elected to use an order-independent helical approach (Woltring et al., 1985) to calculate 3D ST joint angles. The ST helical angles (θ) were then decomposed into their respective X, Y, Z components (θ_X, θ_Y, θ_Z) for analysis. Additionally, markers positioned on the cycle were used to determine crank angle.

In each static calibration position (0°, 90°, 180°, 270° crank angles) (Fig. 2), the relationship (i.e. transformation matrix, $[R]$) was established between the 3D orientation of the scapula, as determined by palpation, and the 3D orientation of the AMC. This relationship was then used to estimate scapular orientation at the four static test positions (45°, 135°, 225°, 315° crank angles) based on the 3D orientation of the AMC. This technique has been described in previous literature (Brochard et al., 2011b; Karduna et al., 2001; Meskers et al., 2007; van Andel et al., 2009). For the single AMC calibration method, the transformation matrix from the AMC to the scapula in the 180° static calibration position was used to estimate scapular orientation at the four static test positions. For the dual AMC calibration method, the transformation matrix from the AMC to the scapula was linearly interpolated from the matrices at the 0° and 180° static calibration positions (Eq. (1)). Interpolation weights (w_H, w_L) were determined from the crank angle in the test position (α) and the crank angle in the static calibration positions (θ_H, θ_L) using Eqs. (2) and (3),

$$[R]_\alpha = w_L[R]_{\theta_L} + w_H[R]_{\theta_H} \quad (1)$$

$$w_H = \frac{\alpha - \theta_L}{\theta_H - \theta_L} \quad (2)$$

$$w_L = 1 - w_H \quad (3)$$

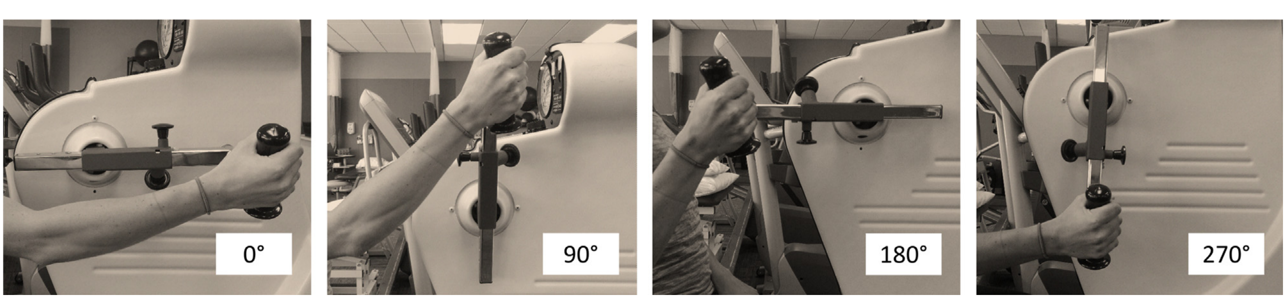

Fig. 2. Calibration cycle positions and corresponding crank angles.