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Comparison of the SCoRE and HA methods for locating *in vivo* the glenohumeral joint centre

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Abstract

A recent paper has described a new functional method, the symmetrical centre of rotation (SCoRE), for locating joint centre position [Ehrig, R.M., Taylor, W.R., Duda, G.N., Heller, M.O., 2006. A survey of formal methods for determining the centre of rotation of ball joints. Journal of Biomechanics 39 (15), 2798–2809]. For *in vitro* analyses, the SCoRE method showed better precision than helical axis (HA) or sphere fitting methods. Despites HA determination is very sensitive to small angular velocity, the International Society of Biomechanics has recommended to use HA for locating the glenohumeral joint centre. This paper aims at comparing the SCoRE method with the HA method for locating *in vivo* the glenohumeral joint centre according to the movement characteristics.

Nine subjects performed 10 cycles of three different movements at two different velocities. For each test (combination of movements) the location of the centre of rotation was estimated with both methods (SCoRE and HA). Analyses focused on the 3D location of the glenohumeral joint centre and on the repeatability of location (standard deviation). This study showed that SCoRE and HA methods yielded the same GH location. Nevertheless, with SCoRE method, the location of the glenohumeral joint centre was different according to the test. This study evidenced that the SCoRE method was more precise than HA method (error of 3 mm versus 4.6 mm) and that the GH location with the SCoRE method was not affected by movements with slow velocities.

Keywords: Glenohumeral; Functional method; Rotation centre

1. Introduction

An accurate location of the joint centre is of primary importance for biomechanical applications. The glenohumeral joint centre (GH) location is of many interests, especially because it is required to compute the local humeral coordinate system (CS) (Wu et al., 2005). GH can be determined with either functional (Chèze et al., 1996; Veeger et al., 1997; Stokdijk et al., 2000; Gamage and Lasenby, 2002) or predictive approaches (Meskers et al., 1998). The predictive approach, which is based on regression equations of the scapula geometry, is mainly affected by errors on landmarks calibration and the regression uncertainty.

Despite 1 mm of translation during arm elevation (Graichen et al., 2000), GH is described as a perfect ball-and-socket joint since the work of Poppen and Walker (1976). This assumption has been corroborated by several 3D cadaver studies (Harryman et al., 1990; Hogfors et al., 1987; Veeger, 2000). Hence, using a functional approach is valid for locating GH. Among the functional approaches, the helical axis (HA) method is preferred for locating GH and recommended by the International Society of Biomechanics (ISB) (Wu et al., 2005). This method determines the centre of rotation as the point closest to all the instantaneous helical axis (IHA) (Woltring, 1990; Veeger et al., 1996; Stokdijk et al., 2000). Recently a new method appeared, the Symmetrical Centre of Rotation Estimation (SCoRE) (Ehrig et al., 2006). To our knowledge, it was not compared yet *in vivo* with other methods. Various papers were published concerning the comparison of the different functional methods (Veeger, 2000; Stokdijk et al., 2000;

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Ehrig et al., 2006). A sphere fitting method was compared with the HA method *in vivo* by Stokdijk et al. (2000). This study concluded that these two methods are reliable for locating GH. Stokdijk et al. (2000) preferred the HA method, because calculation time is shorter. Nevertheless, HA method is very sensitive to low angular velocities (Woltring et al., 1985; Stokdijk et al., 2000; Ehrig et al., 2006).

With a functional approach, additional tests with specific movements must be carried out for locating the centre of rotation (Piazza et al., 2004). Some papers evidenced that the movement characteristics (type of movements, range of motion) have an effect on the location of the joint centre (Begon et al., 2007; Hicks and Richards, 2005). Both studies showed the interest to combine different types of movements (i.e. flexion/extension, abduction/adduction and circumduction). Moreover, it is better to use a large range of motion for tests involving a single cycle (Begon et al., 2007). These results were obtained with a sphere fitting approach and for simulated movements with a model of noise.

There is no recommendation concerning HA or SCoRE methods for locating GH *in vivo*. Previous papers have presented a functional method similar to the SCoRE (Schwartz and Rozumalski, 2005; Siston and Delp, 2006). But the final form of SCoRE method with proximal and distal segments moving simultaneously was presented in Ehrig et al. (2006). It consists in explaining the joint centre in local CSs of both segments. For computer simulation, Ehrig et al. (2006) found that SCoRE method produced smaller errors than HA or sphere fitting methods. These results were analog to the ones of Siston and Delp (2006) with a mechanical linkage.

The ISB has recommended to use HA method for locating GH *in vivo* (Wu et al., 2005). However, this method is not accurate for small angular velocity. The SCoRE method is reliable and theoretically not affected by small velocity. Nevertheless, SCoRE method has never been used for locating GH *in vivo*. Furthermore, the characteristics of the movements were not tested with this method. The purpose of this paper is to show *in vivo* that SCoRE method yields the same GH location as the reference method (HA) and that SCoRE method is more precise and can be used for slow movements.

2. Methods

2.1. Experimental design

Nine men having an average age of 27.9 ±1.05 years without known upper extremity disorders volunteered. Subjects were instructed to perform three types of upper arm movements composed of 10 cycles: flexion–extension (FE), abduction–adduction (AbAd) and circumduction (Cir). Elevation of arm during any movement did not exceed the shoulder height. Each movement was repeated for two different velocities: slow (one cycle every 8 s) and medium (one cycle every 4 s).

A *Saga3*^{RT} motion analysis system (Biogesta, Valenciennes, France) was used to collect kinematical data with six infrared cameras (50 Hz)

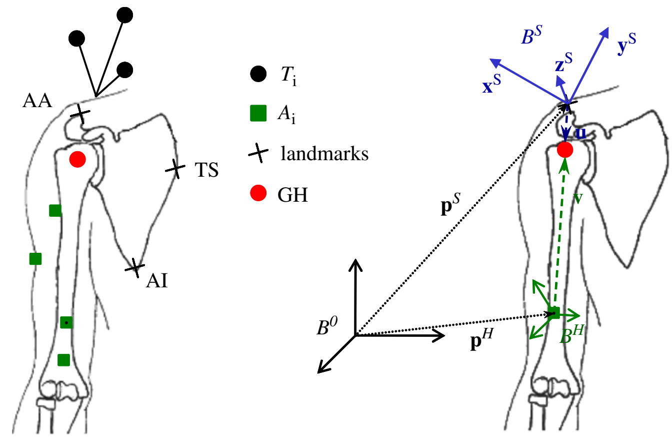

Fig. 1. Markers positions and vectors used in the SCoRE method. **u** is the position of GH wrt B^S and **v** is the position of GH wrt B^H.

inside a calibrated volume of 2 m × 1 m × 1 m. Seven markers were placed on the body as illustrated in Fig. 1(a). Four markers were fixed on the upper arm ($A_i, i = 1, \ldots, 4$) as far as possible from large muscles. The elbow was kept straight to limit the errors caused by skin movements artefact. A rigid triad composed of three markers was fixed to the acromion ($T_i, i = 1, \ldots, 3$). Karduna et al. (2001) showed that the average scapula motion pattern recorded with a skin-based measurement of the acromion was similar to an invasive technique. The rigid triad allowed to perform an anatomic calibration (Cappozzo et al., 1995) of three specific landmarks of the scapula (Fig. 1(a)): angulus acromialis (AA), trigonum spinae (TS), angulus inferior (AI). These points were defined with respect to (wrt) the acromion CS using the markers on the acromion triad in a static trial. Then, they were reconstructed during the actual movement trials based on the position of the acromion CS.

These landmarks were used to define the scapula CS (B^S) centred in AA, as proposed in Stokdijk et al. (2000):

$$\mathbf{x}_s = \frac{AA - TS}{|AA - TS|}, \quad \mathbf{z}_s = \mathbf{x}_s \times \frac{AA - AI}{|AA - AI|}, \quad \mathbf{y}_s = \mathbf{z}_s \times \mathbf{x}_s.$$

The humeral CS (B^H) was defined with the four markers A_i.

In line with the recommendations of Begon et al. (2007), 10 trials of three different tests were extracted from the experimental kinematics:

- [Cir] composed of one cycle of Cir,
- [FE/AbAd] composed of one cycle of FE and one cycle of AbAd,
- [FE/AbAd/Cir] composed of one cycle of FE, one cycle of AbAd and one cycle of Cir.

For HA method, GH location was calculated wrt B^S for the trials with the medium velocity. For SCoRE method, GH location was calculated for all the trials (slow and medium velocities).

2.2. Functional methods

2.2.1. HA

IHAs were calculated from the position of the upper arm markers wrt B^S (Woltring et al., 1985; Woltring, 1990; Veeger et al., 1997; Stokdijk et al., 1999; Ehrig et al., 2006). The position vector **s** of the IHA was calculated from $\boldsymbol{\omega}$ which corresponds to the angular velocity vector of B^H wrt B^S and from **p** which corresponds to the position vector of B^H wrt B^S by:

$$\mathbf{s} = \mathbf{p} + \boldsymbol{\omega} \times \frac{\dot{\mathbf{p}}}{\sqrt{\boldsymbol{\omega}^{\mathrm{T}}\boldsymbol{\omega}}}.$$

Then, the centre of rotation corresponds to the point closest to all the position vector of the IHA in a least squared sense (Woltring, 1990; Veeger