Journal of Biomechanics 47 (2014) 3771–3775

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Short communication

In vivo glenohumeral translation under anterior loading in an open-MRI set-up

Andrea Cereatti [a,*], Manuela Calderone [a], Dan M. Buckland [b], Anne Buettner [b], Ugo Della Croce [a], Claudio Rosso [b]

[a] Department of Information Engineering, Political Sciences and Communication Sciences, University of Sassari, Viale Mancini, 5, 07100 Sassari, Italy
[b] Orthopaedic Department, University Hospital Basel, University of Basel, Basel, Switzerland

ARTICLE INFO

Article history:
Accepted 17 September 2014

Keywords:
Glenohumeral translation
Humeral head
Shoulder laxity
Open MRI

ABSTRACT

The evaluation of the glenohumeral joint laxity requires the estimate of displacements of the humeral head centre (HHC) with respect to the glenoid. To the authors' knowledge, several studies have been conducted to estimate HHC translations *in vivo* but data under anterior loading conditions has not been collected yet. Aim of this study was to develop a non-invasive experimental methodology based on magnetic resonance (MR) imaging for the *in vivo* evaluation of the HHC translations due to an anteriorly directed force. Fourteen asymptomatic shoulders were acquired using a horizontal open MR scanner with the subjects in the supine position both at 15° and 90° of arm abduction with and without an anterior force of 20 N applied at the HHC level. When no load was applied, from 15° to 90° of arm abduction, the HHC moved, anteriorly (1.5 ± 1.3 mm) and superiorly (1.8 ± 1.3 mm) while smaller displacements were observed medio-laterally (0.4 ± 0.7 mm). Under the application of the anterior force the 3D displacement of the HHC with respect to the glenoid was 1.6 ± 1.2 mm and 1.3 ± 0.7 mm, respectively at 15° and 90° of arm abduction. The level of precision associated to the GHJ translation was less than 0.33 mm along all directions *i.e.* one order of magnitude smaller than the relevant translations. In conclusion, the MRI-based methodology allowed for the analysis of HHC displacements under conditions of anterior loads within an acceptable level of reliability.

1. Introduction

The *in vivo* assessment of glenohumeral joint (GHJ) instability is crucial in orthopaedic research because it is instrumental to understanding and thus preventing primary and repeated shoulder dislocations, over 90% of which are anterior (Mallon and Speer, 1995). The evaluation of the GHJ laxity requires the ability to accurately measure the linear displacement of the humeral head centre (HHC) with respect to the glenoid that results from shoulder movements and/or the application of external forces.

In vivo experiments for the assessment of shoulder laxity under the application of anterior forces have been proposed in the literature (Sauers et al., 2001; McQuade and Murthi, 2004). However, while the use of skin-mounted sensors might be acceptable for quantifying the relative changes in translation, such sensors cannot provide an accurate description of the HHC position. Indeed, the deformation of the soft tissues surrounding the scapula and humerus hampers the achievement of the level of accuracy required for the analysis of the small displacements involved (Anglin and Wyss, 2000; Hill et al., 2007; Veeger and van der Helm, 2007; Cereatti et al., 2014).

An alternative approach is the use of technologies based on ionizing radiation, such as computer tomography (CT) (Baeyens et al., 2001), biplanar X-rays (Lagacé et al., 2012), fluoroscopy (San Juan and Karduna, 2010) or a combination of dual-plane fluoroscopy and 3D bone models derived from CT or magnetic resonance imaging (MRI) (Bey et al., 2006; Nishinaka et al., 2008; Massimini et al., 2012). Major limitations of such techniques include image geometric distortion and radiation exposure. A further alternative, which might provide an acceptable level of accuracy and is innocuous for patients, is the use of MRI (von Eisenhart-Rothe et al., 2010). GHJ translations have been investigated both in healthy subjects (Rhoad et al., 1998; Graichen et al., 2000; Sahara et al., 2007) and patients (von Eisenhart-Rothe et al., 2002; Chhadia et al., 2010) using MRI. Very few studies have analysed GHJ translations under the action of gravity (Sahara et al., 2007) or with adducting loads of 10 N and isometric muscle activity (Graichen et al., 2000). However, no *in vivo* studies have analysed shoulder laxity in conditions of anterior loading. Conversely, extensive analyses of the biomechanical roles of soft tissues and articular surfaces as joint constraints under the application of anterior external forces have been conducted on

* Corresponding author at: Tel./fax: +39 079228340.
E-mail address: acereatti@uniss.it (A. Cereatti).

http://dx.doi.org/10.1016/j.jbiomech.2014.09.021
0021-9290/

cadavers (Alberta et al., 2006; Marquardt et al., 2006; Su et al., 2009). However, the translation of such *in vitro* results to the *in vivo* condition should be approached with caution due to the lack of tone in the involved mono- and bi-articular muscles.

The primary aim of this study was thus to propose an experimental MRI-based methodology for the *in vivo* evaluation of GHJ translation under conditions of anterior load. The secondary aim was to gather preliminary baseline data from healthy subjects to use for further comparison with patient populations.

2. Material and methods

2.1. Subjects

Fourteen shoulders of 11 healthy subjects (5 females; age 29.5 ± 3.7 years [mean ± standard deviation, SD]; height 1.76 ± 10.2 m; weight 68.3 ± 8.9 kg) with no previous shoulder injuries and no congenital joint laxity were analysed. The study was approved by the local Institutional Review Board of Basel, Switzerland, and an informed consent was obtained prior to enrolment.

2.2. Experimental set-up

A horizontal open-MRI scanner (Philips Panorama HFO, 1 T) was used to acquire image of subjects in the supine position between the two gantries with their hands facing up (Fig. 1). The trunk of the subject was fixed to the table of the scanner using belts to limit movement. The thoraco-humeral angle was adjusted using a goniometer, which allowed the positioning of the forearm of the subject *via* a velcro strap (Fig. 1). A force of 20 N that was aligned with gravity and anteriorly directed was applied at the HHC level. The structural load was generated using a custom-built carbon lever; the extremity of this lever was attached to the proximal portion of the arm as close as possible to the GHJ *via* a velcro strap (Fig. 2). For both the loaded and unloaded conditions, the weight of the arm was neutralized (De Leva, 1996) (for a detailed description of the force diagram please refer to the Supplementary material).

Fig. 1. Details of the experimental set-up employed to apply the anterior force to the subject's humerus in the MRI scanner. The scans were performed using 3D T2-W turbo spin echo imaging sequences (TR 1.4 s; TE 50 ms; flip angle 90°; number of excitations NEX=2; 1.5 mm slice thickness, contiguous slices, FOV 180 mm with a 256 × 225 acquisition matrix and a 0.7 mm × 0.8 mm pixel size).

The following acquisitions were collected while the subject was asked to relax as much as possible to prevent significant muscle activity:

- 15° of arm abduction without external load (15-w/o);
- 15° of arm abduction with the external load (15-w);
- 90° of arm abduction without external load (90-w/o);
- 90° of arm abduction with the external load (90-w).

The acquisition time for each scan was approximately 6 min.

2.3. Estimation of the GHJ displacements

From each MR acquisition, 3D scapula and humerus models were obtained with semiautomatic segmentations that were performed by a single skilled operator using the software AMIRA (FEI Visualization Sciences Group, Oregon, USA.). The scapula and humerus anatomical coordinate systems (ACSs) were defined according to the definitions proposed by Calderone et al. (2014). Following the latter guidelines, the humeral ACS origin coincides with the HHC and is determined as the centre of the sphere that best fits the spherical portion of the humeral head (Veeger, 2000). For each shoulder, four distinct pairs of humerus and scapula models of the same bones were obtained for the acquisitions (15-w/o, 90-w/o, 15-w, and 90-w).

To minimize repeatability errors associated with the ACSs identification, the following procedure was implemented. First, the ACSs were defined by the same operator on humerus and scapula bones templates reconstructed for an arbitrary acquisition (15-w/o); then, the templates with the ACSs were optimally registered to the remaining scapula and humerus models of the same shoulder using the iterative closest points technique (Besl and McKay, 1992) and the ACSs were transferred to the models.

For each acquisition, the position of the HHC with respect to the relevant scapula ACS was estimated. The GHJ translational components were computed as the HHC displacements in the following conditions: (1) between 15-w/o and 15-w, (2) between 90-w/o and 90-w and (3) between 15-w/o and 90-w/o. From the anterior–posterior (A–P), the superior–inferior (S–I) and the medio-lateral (M-L) components, both the 3D and 2D displacements (A–P, S–I plane) were computed.

2.4. Repeatability assessment

To assess the level of precision associated with the GHJ translation estimates, the MR images were segmented and processed relative to two arbitrarily selected shoulders (one right male and one left female shoulder) by the same operator four times on four separate days. The repeated estimates of the GHJ translations in the different conditions (15-w/o and 15-w, 90-w/o and 90-w, 15-w/o and 90-w/o) were calculated, and the SD values were computed.

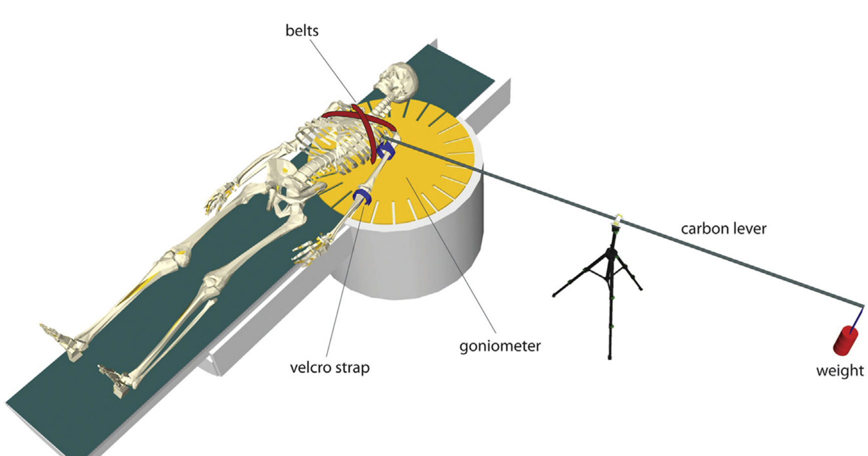

Fig. 2. Schematic overview of the experimental set-up employed for the acquisitions. The upper gantry is not depicted for illustrative purposes. The weight (red) was adjusted by changing the quantity of water contained in a deformable receptacle. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)