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IN VIVO GLENOHUMERAL TRANSLATION UNDER EXTERNAL LOADING IN AN OPEN-MRI SETUP

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SUMMARY

Understanding the mechanism underlying glenohumeral joint stability is crucial in orthopaedic surgery. The development of a non-invasive methodology for in vivo assessment of glenohumeral joint translation, when selected loads are applied, would contribute to the advancement of the state of art. Seven patients were acquired using a horizontal MRI scanner while an anterior load of 20 N was applied for different shoulder configurations. Both accuracy and precision were satisfactory (< 0.3 mm). The estimated translations in loaded conditions were lower than $1.4 \text{ mm} \pm 0.6 \text{ mm}$ and, due to muscular tone differences, smaller than those previously observed on cadavers.

INTRODUCTION

Traumatic joint dislocations represent a frequent and important problem in orthopaedic surgery and sports medicine. The most frequently dislocated joint is by far the shoulder, or the glenohumeral joint (GHJ), the joint with the widest range of motion in humans and with very limited coverage of the humeral head by the joint socket. The incidence of GHJ dislocations is about 11.2 per 100'000 per year (90 % of which are anterior) and a high number of recurrences after the first dislocation have been reported. Investigating the physiological and pathological GHJ kinematics (joint stability, rotations and translations), has been crucial in orthopaedic research since it is instrumental in understanding and thus preventing primary and repeated shoulder dislocations. The primary aim of this study was to develop a magnetic resonance imaging (MRI) based methodology for in vivo evaluation of the glenohumeral translation under the application of external loading. The secondary aim was to gather normative data on healthy shoulders.

METHODS

Seven patients (3 females, 30 ± 3 y) with no previous shoulder injury and no congenital joint laxity were analyzed. General MRI exclusion criteria were applied. A horizontal open-MRI scanner (Philips Panorama HFO, 1 Tesla, FOV = 180 mm) was used. Recordings were performed with the subject in the supine position, with the hand facing up (90° of external rotation), between the two gantries of the MRI system. An anterior load of 20 N plus the weight of the arm was applied to the proximal portion

of the arm of the subject through a specifically designed lever built of carbonium. (Figure 1). The mass of the arm was estimated as percentage of the whole body mass [1]. The following shoulder configurations were tested:

- 15 deg no load - humerus at 15 deg of abduction, 0 N;
- 15 deg load - humerus at 15 deg of abduction, loaded;
- 90 deg no load - humerus at 15 deg of abduction, 0 N;
- 90 deg load - humerus at 15 deg of abduction, loaded.

Acquisitions were performed using a 3D sequence T2 weighted (inter slice gap: 1.5 mm; slice thickness: 3 mm). The following procedure for the estimate of GHJ displacements was adopted. From each MR images, 3D reconstruction of the scapula and humerus segments was obtained through a semiautomatic segmentation performed by a single operator using the software AMIRA (v.5, Visage Imaging Inc., San Diego, CA, USA). The glenoid cavity surface and the humeral head were manually extracted from the 3D models. The scapula reference system (ACS) was defined on the glenoid model according to the definitions proposed in a previous work [2]. The centre of the humeral head (GHJC) was determined as the centre of the best fitting sphere. For each shoulder, four distinct glenoid models of the same bone were obtained for the different experimental conditions (15 deg no load, 15 deg load, 90 deg no load, 90 deg load). To minimize the repeatability errors associated to the scapula ACS identification, the ACS was defined on an arbitrary selected glenoid model (template). The template carrying the ACS was then optimally registered to the corresponding glenoid models by means of the iterative closest points technique and the ACS transferred.

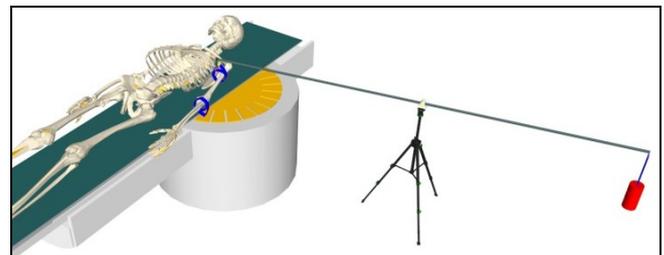


Figure 1: Experimental set-up employed to apply external anterior load to the subject shoulder in the MRI scanner.

For each experimental condition, the position of the GHJC with respect to the relevant scapula ACS was estimated. The following GHJC translations were computed: case (a)

between 15 deg no load and 15 deg load; case (b) between 90 deg no load and 90 deg load; case (c) between 15 deg no load and 90 deg no load. To assess the reliability and the overall resolution of the methodology used, the MR images, relative to a single shoulder for an arbitrary selected experimental condition, were processed by the same operator four times and the GHJC translations estimated. Since in absence of errors, the translations would be zero, the standard error (SE) provided an indication of the measurement uncertainty.

RESULTS AND DISCUSSION

Data relative to a subject are shown as an example in Figure 2.

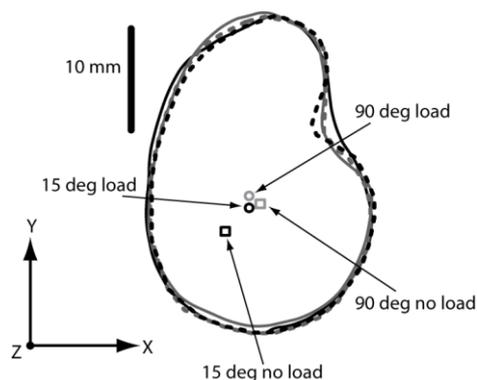


Figure 2: Projections, onto the x-y plane, of the glenoid cavity contours and the GHJC positions (O, □) in the four conditions analyzed.

In Table 1, the GHJC translations expressed in the scapula ACS and averaged across subjects, are reported.

	15 deg (un – lo)	90 deg (un – lo)	15 - 90 deg (un)
x [mm]	1.1 (1.6)	0.1 (0.9)	1.7 (1.7)
Y [mm]	0.8 (1.5)	0.4 (0.4)	0.9 (1.9)
Z [mm]	0.4 (0.2)	0.0 (0.9)	1.2 (0.9)
3D [mm]	1.4 (0.6)	1.2 (0.5)	3.1 (1.4)

Table 1: Mean (and std) values for the GHJC translations for case (a), (b) and (c). Unloaded (un), loaded (lo).

Regarding the resolution of the methodology, SE values were 0.3 mm, 0.2 mm, 0 mm and 0.1 mm for x, y, z and 3d, respectively. These results suggested that the level of the measurement uncertainty, associated to the present methodology, is expected to be of one order of magnitude smaller than the estimates of the GHJC translations.

The assessment of GHJC translations in vivo and under specific loaded condition is very difficult due to the deformation of the soft tissues surrounding the bones and the small displacements involved. Several studies have used bone-embedded sensors (pins drilled into the bone) on cadavers [3] but could not take into account the role of muscular tone. An alternative approach is to use dual-plane fluoroscopy [4]. Major limitations of such techniques are the image geometric distortion and the

radiation exposure, which makes the approach invasive. An alternative which could ensure an acceptable level of accuracy and that is innocuous for patients, is provided by open MRI. To authors' knowledge, only few studies have been conducted using open MRI to estimate GHJC translations [5] but no data about GHJC translations under loading condition, different from gravity loading, has been collected so far. In this study, a MRI based methodology, which included a carbonium leverage for the application of an external anterior load, has been developed and tested. The GHJC 3D displacements observed between 15 deg and 90 deg of shoulder abduction in unloaded conditions ($3.1 \text{ mm} \pm 1.4 \text{ mm}$) were of the same order of magnitude of those reported in previous studies [5]. Translations observed in vivo under an anterior load of 20 N were smaller than those observed in cadavers studies [6]. This discrepancy can be ascribed to the differences in muscular tone between in vivo and in vitro conditions (for instance the rotator cuff which acts as secondary shoulder passive stabilizer). No significant differences in the total GHJ laxity (3D values) were observed for the different abduction angles analyzed. The smallest translations, under anterior load application, were observed as expected along the z direction. A relatively high inter-subject variability was observed for all GHJC translations components. When interpreting the GHJC translation components, it is important to keep in mind that the load direction (anteriorly) does not necessarily coincide with the direction of the scapula x-axis.

Based on prior data, the sample size needed to assess significant differences between healthy and pathological shoulder ($P = 80\%$, $\alpha = 5\%$) is expected to be 14 subjects. Experiments to increase the number of subjects are planned.

CONCLUSIONS

The present MRI based methodology allowed to analyze shoulder translation under loaded conditions with an acceptable level of repeatability and accuracy. As future work, patients with a history of shoulder dislocations will be analyzed.

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