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ESTIMATION OF THE GLENO-HUMERAL ROTATION CENTER USING 3D FREEHAND ULTRASOUND

[1,2] Mathieu Lempereur, [3]Laurent Kostur, [1,2]Julien Leboucher, [1,2,4] Sylvain Brochard and [1,2,4] Olivier Rémy-Néris
[1]CHRU de Brest, Hôpital Morvan, service de médicine physique et de réadaptation, Brest, France
[2]Inserm, UMR_U1101, IFR148, Brest, France
[3]IFPEK, Rennes, France
[4]Université de Bretagne Occidentale, Brest, France
mathieu.lempereur@univ-brest.fr

SUMMARY

This paper describes the calibration process of a 3D freehand ultrasound (3D-US) using the Cambridge stylus and a motion analysis system (Vicon). The system was used to estimate the position of the gleno-humeral rotation center (GHRC). The accuracy of the 3D-US was then performed by computing the distance between the 3D positions of the GHRC determined by medical imaging EOS (method of reference) and 3D-US. The ultrasound system was also compared to 5 functional methods. In 10 healthy subjects, the 3D-US was the method the most accurate (13.93 mm from the GHRC estimated by EOS). Further developments may set the 3D-US as a valid and useful tool to identify anatomical landmarks in a motion lab.

INTRODUCTION

Imaging techniques such as magnetic resonance imaging or scanner could allow the estimation of the Gleno-Humeral Rotation Center (GHRC) by approximating the humeral head to a sphere using sphere fitting methods. However, it is not easy to include this data with those obtained by a motion analysis system. On the other hand, the 2D ultrasound scanning is a widely, non-invasive and less expensive system. Moreover, 3D freehand ultrasound (3D-US) involving combination of ultrasound scanning and 3D motion analysis provide a direct in vivo measurement of anatomical landmarks. The 3D-US has been already used simultaneously in motion analysis lab for locating hip joint center [1; 2]. However, no validation of the estimation of GHRC has been performed using 3D-US. Contrary to lateral and medial epicondyle which can be palpated and consequently adapted to each subject, GHRC is usually estimated with predictive or functional methods. While the predictive methods calculate the centre of rotation (CoR) from empirical relations between specific anatomical landmarks, the functional methods compute the CoR from the relative motion of adjacent body segments and are reported as accurate.

The objective of this study was to validate the use of 3D-US for estimating GHRC in comparison with functional methods and medical imaging.

METHODS

Ten subjects (23.3 ± 3.46 years, 169.2 ± 6.60 cm and 65.50 kg ± 12.88 kg) without upper extremity disorders took part in the experiments. All subjects read and signed a consent form prior to participation after being informed about the aims and procedures of the experiments. This study was approved by the local ethics committee.

The experimental protocol was divided into 3 parts: the calibration of the ultrasound system, estimation of the GHRC using ultrasound and functional methods and determination of GHRC using medical imaging.

The calibration of the ultrasound system consisted in determining the position and orientation of the probe's scan plane with respect to markers attached rigidly to the probe. The Cambridge stylus, composed of a marker cluster used to define its coordinate system, a rod with two inverse cones and a tip, is used. The shape formed by the 2 cones is easily recognizable in the US images. Calibration was performed in water moving the stylus target in different positions within the US image plane. The transformation, describing the position and orientation of the probe's scan with respect to markers attached to the probe (${}^{Probe}_{US\_img}T$), is found by minimizing the squared distance between points in US image and locations of the stylus target as described in [2]:

$$min \sum_{i=1}^{N} \left\| {}^{MAS}_{Probe}T_i \, {}^{Probe}_{US\_img}T \, {}^{US\_img}P_i - {}^{MAS}_{Stylus}T_i \, {}^{Stylus}P \right\|^2,$$

where N is the number of positions, ${}^{MAS}_{Probe}T_i$ the transformation between the coordinate system of the motion analysis system and the probe at the position i, ${}^{US\_img}P_i$ the position of the stylus target in the US image at the position i, ${}^{MAS}_{Stylus}T_i$ the transformation between the coordinate system of the motion analysis system and the stylus at the position I and ${}^{Stylus}P$ the position of the stylus target in the stylus coordinate system.

Once the probe was calibrated, subjects were sitting with the arm in external rotation. Markers were attached to thorax, right arm and flat part of the acromion to create local coordinate system. Different positions of the probe resulting in ultrasound images of the humeral head and markers were simultaneously recorded. Outlines of the humeral head were manually digitalized for all images and then transformed in the scapula coordinate system using the transformation between the probe's scan and the probe and the scapula coordinate system. Least squared sphere fitting method was used to estimate the GHRC from outlines.

Then, subjects were instructed to perform upper arm movements continuously: three flexions/extensions, three abductions/adductions and three circumductions. The arm elevation was between 0° and 60°. Four markers were fixed on the upper arm as far as possible from the deltoid in order to reduce the errors caused by skin movement artifacts. The estimation of GHRC was computed from the 3D trajectories of the 4 technical markers of upper arm with respect to the scapula coordinate system. The functional methods to estimate GHRC were the algorithm of Gamage and Lasenby [3] (Gamage), the bias compensated method of Halvorsen [4] (Hal), the SCoRE method [5] (SCoRE), the Normalization Method [6] (NM) and the Helical Axis [7] (HA).

Immediately after the motion capture and keeping all the markers at their location, an imaging of their scapula and arm were performed using a low-dose stereoradiographic imaging (EOS) (EOS imaging, France). This technique produces simultaneously frontal and lateral X-rays of the whole body in a standing position with a very low exposure to radiations.
The 3D position of the GHAC and the anatomical markers were determined from the 2 planar images using circle fitting to approximate the humeral head. GHAC was then defined with respect to the coordinate system of the scapula.

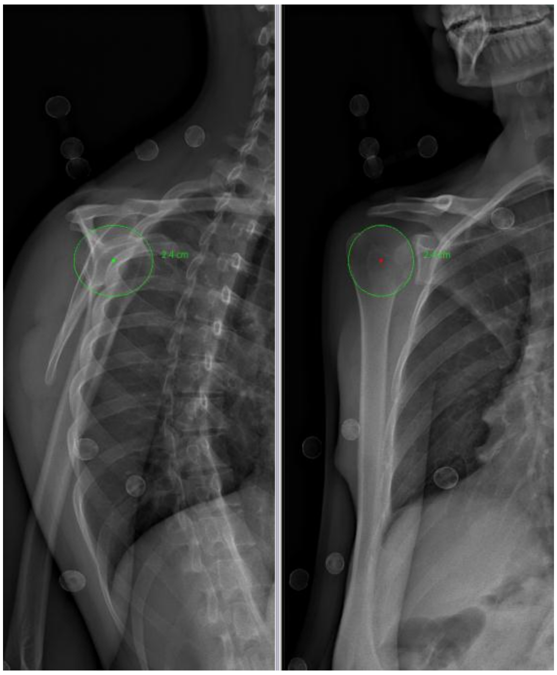

Figure 1: Frontal and lateral view of the scapula and humeral head using the EOS system.

The Euclidian distance between GHAC and GHRC determined by 3D-US and functional methods was computed for each subject.

RESULTS AND DISCUSSION

The table 1 presents the mean and standard deviation of the Euclidian distances according to the ultrasound system and functional methods.
The results of one-way ANOVA show that there was a significant difference between the methods ($p=0.0006$). A post hoc test shows that there was no significant difference between 3D-US, Gamage ($p=0.36$), SCoRE ($p=0.08$) and HA ($p=0.63$). However, the minimal mean distance (13.93 mm) was obtained with the 3D-US.
The magnitude of the error remains relatively large regarding at the humeral head diameter (around 25 mm).
For a mislocation error of 15 mm, Lempereur et al. [8] show that the gleno-humeral kinematics error is between 4° and 6° thus minimizing the consequences of such an error. However, there is no study about the mislocation of GHRC on shoulder joint kinetics.

CONCLUSIONS

The GHRC was estimated using the 3D-US and 5 functional methods in comparison with a reference position obtained using a low dose biplanar X-Rays. The preliminary results on 10 subjects showed that the most accurate method is the combination of the ultrasound and motion analysis system. These results must be confirmed with more subjects. Further developments may set the 3D-US as a valid and useful tool to identify anatomical landmarks in a motion lab.

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Table 1: Mean and standard deviation of Euclidian distance between GHAC and GHRC.

	3D-US	Gamage	SCoRE	NM	Hal	HA
Distance (mm)	13.93 (6.35)	18.44 (7.29)	22.73 (3.87)	29.62 (15.59)	33.85 (18.47)	16.31 (4.98)