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SHOULDER COMPLEX JOINT LOCATION: AN IN-VIVO STUDY USING INTRACORTICAL PINS, IMAGING AND SKIN MARKERS

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SUMMARY

Joint centre locations can be determined using imaging, bony landmarks and functional methods. Using intracortical pins, CT-scan and skin markers, sternoclavicular (SC), acromioclavicular (AC) and glenohumeral (GH) joints were located and compared for four participants. The use of skin and pin markers led to inconsistent results for SC and AC joints, while bony landmarks and CT based locations gave more similar results. For the GH joint, all the approaches led to similar results, including functional location based on skin marker, a non-invasive way.

INTRODUCTION

In 3D human motion analysis based on experiment, the ball-and-socket (3 degrees-of-freedom in rotation, *dof*) joint kinematics are improved by functionally determined joint centers, even when skin movement artefacts affect bone kinematics [1]. CT-derived bone geometry and intracortical pins are often used as reference when locating anatomical joint centers and when tracking the actual bone kinematics, respectively. In line with studies about hip joint center [2], the comparison between these two approaches should be applied to the shoulder complex, namely sternoclavicular (SC), acromioclavicular (AC) and glenohumeral (GH) joints. Such comparisons provide insight about the nature of these joints and recommendations for an in-vivo determination of their location. The goal of this study was to compare SC, AC and GH centers of rotation (CoRs) locations determined using CT-scan and functional method with intracortical pins. Two additional clinical approaches were introduced into the comparison, namely the use of skin markers put on bony landmarks and a functionally located joint center based on skin markers. For the purpose of functional method, we hypothesized that the three shoulder joints can be considered as ball-and-sockets with a functional joint center located outside the intraarticular space.

METHODS

Four participants with healthy shoulder took part in the study. Each subject was taken to the surgical theatre for the insertion of a pin in the clavicle, scapula and humerus by an orthopedic surgeon. Clusters of 4, 4 and 5 markers respectively were then secured on these pins. No pin was inserted on the sternum because of the inability to safely obtain transcortical bone. Geometry of the clavicle, scapula and humerus were then acquired by CT-scan. Two anatomical (sternoclavicular and acromioclavicular joints) [2] and 19 technical [3] skin markers were put on the left upper limb of subjects. Participants performed large Star-Arc movements for each joint [4] in line with recommendation for functionally locating CoR. Marker trajectories were collected using an 18-cameras motion analysis system (Vicon, UK, at 300 Hz). Pins were removed within an hour after the insertion for all the subjects. The accuracy of bone position and orientation was estimated to 0.2 mm and 0.5° with the redundant pin markers.

SC and AC CoRs based on bony landmarks were derived from ISB recommendations [2]. Since, no bony landmark can be considered as the GH joint, the comparison between anatomical and functional methods was not feasible. The two functionally determined CoR using skin and pin markers were located using the SCoRE algorithm [1] under the assumption of a ball-and-socket joint. From the CT-scans (thickness 0.61 mm, 512x512 pixels), meshes were reconstructed. AC was defined as the most distal point of the clavicle and GH was defined as the average center of the sphere that fits the humeral head (n=15 estimates). Due to the size of the CT-scan, SC could not be geometrically determined, thus no comparison could be done. Qualitative comparisons consisted in describing relative position of CoRs and calculating the distance between CoRs for all the available conditions.

RESULTS AND DISCUSSION

Figure 1 shows meshes of bones for one subject where the joint center from the bony landmarks, CT, skin markers and pin markers are displayed in top and frontal views.

Sternoclavicular joint:

For the SC CoR, both bony landmarks and functional skin markers are located outside and in front of the clavicle. Bony landmarks locations are consistent with the fact that they are measured from a skin marker, which is obviously located outside the body. Using pins, the CoR was located inside the clavicle bone; its relative distance to the bony landmark ranged from 14 mm to 39 mm and from 26 mm to 36 mm to the functional CoR using skin markers. Functional method using skin markers was not more accurate than a single bony landmark when considering SC as a ball-and-socket joint. The anterior location of the CoR based on skin markers was unexpected. The difference with pin markers was only due to the experimental difficulty to track the clavicle under the skin using four markers [5]. Indeed the same markers were used for the thorax segment. The small range of motion of this joint also explains the inaccuracy of functional method SCoRE [6]. A predictive method starting from the SC bony landmark should be proposed to locate the joint center more inside the body.

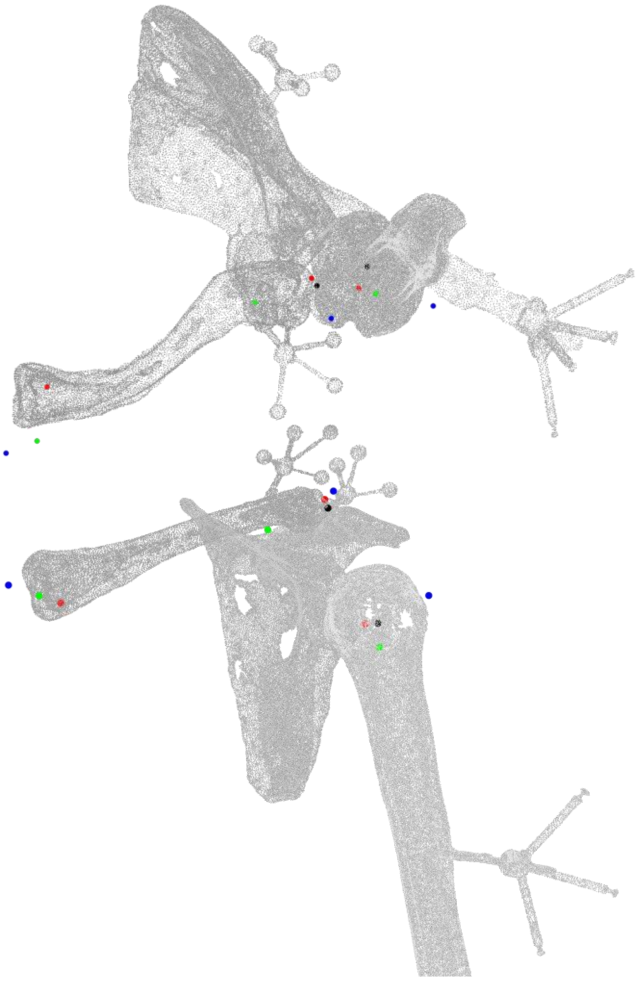

Figure 1: Representation of CoRs locations by functional skin (green) and pin (red) markers, bony landmarks (blue) and CT-scan (black) approaches for one subject.

Acromioclavicular joint:
The AC joint showed the most variability in location between the subjects and the methods. The bony landmark was always anterior and upward to the CT but varied in distance, ranging from 13 mm to 19 mm. The functionally determined locations did not show any easy pattern to describe. The locations varied all over the flat distal end of the clavicle with the pin markers always posterior to the location obtain using the skin markers. While the CoR was not expected in the intraarticular space between the clavicle and scapula, the discrepancy of location between pin and skin based markers highlights the experimental difficulty of tracking both bones. Consequently skin movement artefact effect should be quantified on each bone. Analysis of the kinematics (data not reported here) showed that scapula with respect to the clavicle has up to 6 mm of translation and a range of rotation of 30°. Such translations for a small amount of rotation may invalidate the assumption that AC joint should be modeled as a ball-and-socket joint and the use of the SCoRE method based on skin or pin markers. Since a 6 *dof* joint requires accurate bone tracking, a 3 *dof* model is still recommended. The location determined with pin markers is the optimal position when modeling a 3 *dof* joint. Further studies should assess the error propagation according to the chosen AC CoR location.

Glenohumeral joint:
Finally, the GH joint showed the least variability within subjects. CT locations were close to functional CoR based on pin markers (Euclidean distance between 4 mm and 13 mm). They were systematically more distal and inferior. The inaccuracy between the 15 repetitions of sphere fittings on the CT-scan was about 1 mm, while 6 mm of glenohumeral head translation have been reported in the literature [7]. Due to the large range of motion at this joint compared to AC joint, the functional and geometrical locations were consistent. Whereas no approach can be considered as a gold standard, the maximal distance between the two locations (13 mm) could be considered as a criterion of accuracy. Locations found with skin markers were always inferior to functional pin markers of 13 mm to 16 mm. In our point of view, these differences in the CoRs estimation, when considering the humerus length and the total range of motion, appear to be clinically acceptable.

CoRs do not correspond to bony landmarks or intraarticular space (anatomic joint). In fact, CoRs are more likely located inside a bone (e.g. GH). Moreover, there is no consensus in the literature on the number of degrees of freedom best describing SC, AC and GH joints, especially for clinical studies. Therefore, even techniques of imaging such as CT-Scan should be interpreted with care. While further investigations are necessary, our recommendations are that functional approaches should be improved for SC and AC joints and bony landmarks or predictive approaches should be preferred when CT-scan are unavailable. However, for the GH, functional location based on skin markers appeared to be a good estimate in comparison to both functional pin markers and CT-scan based approaches.

CONCLUSIONS
This study provides a better understanding of differences between anatomical and functional approaches when locating CoRs for the shoulder joint complex. Functional SC and AC CoRs using skin and pin markers led to inconsistent results while bony landmarks and CT based locations gave more similar results. On the other hand, for the GH joint, all the tested approaches led to similar results, including functional skin marker method which provides a non-invasive way to locate the center of the head.

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