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tA comprehensive dataset of *ex vivo* shoulder girdle kinematics during standardised humerus motions

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EXTENDED ABSTRACT

1 Introduction

The shoulder kinematic chain, namely the shoulder girdle, is often modelled as a multibody kinematic chain representing the relations between humerus, scapula, clavicle, and thorax [1]. Throughout this chain, the glenohumeral, scapulothoracic, acromioclavicular, and sternoclavicular joints can be observed. It is known that the choice of the kinematic constraints and degrees-of-freedom are crucial for bone kinematic estimation [2]. Still, these joints remain often modelled as spherical joints representing the whole shoulder girdle [3], or a set of joints independently [4]. This issue is partly due to the scarcity of validation datasets obtained from *in vivo* or *ex vivo* bone pins or fluoroscopy measurements [5]. In this study, a shoulder girdle kinematics dataset was constituted on 10 shoulders in an *ex vivo* protocol [6]. The bone kinematics of humerus, scapula, clavicle, and thorax were documented using an optoelectronic camera system during a set of standardised humerus motions induced by a robotic manipulator [6]. The aim of this study was to provide a comprehensive dataset of the shoulder girdle kinematics for joint model testing and validation purposes.

2 Material and Methods

Five fresh-frozen, unembalmed adult whole cadavers (77.4 ± 9.99 years) were obtained for the study. None of the 10 shoulders had a degenerative joint disease or previous ligamentous injury confirmed by direct inspection and radiographs before experiments. All specimens were acquired at the Anatomy Teaching Unit of the Geneva Faculty of Medicine. These specimens were all selected from the body donation program of the University of Geneva. The Cantonal Commission for Research Ethics approved this study (2020-00598). All procedures were performed in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and later amendments. Bone pins were inserted in the humerus, scapula, clavicle, and thorax, and clusters of reflective markers were secured on them. A 11-camera optoelectronic system sampled at 100 Hz (Oqus5, Qualisys, Sweden) was used to record marker trajectories. The whole shoulder girdle was mobilised by a robotic manipulator (KUKA LBR IIWA 14 R820, KUKA Robotics Corp, Germany). For that, the humerus was transected, potted in a custom 3D-printed cylinder by use of bone cement, and rigidly mounted via a custom fixture to the manipulator end-effector. All soft tissues (e.g. muscles, ligaments, joint capsules) were left intact along the whole shoulder girdle. A set of standardised humerus motions were applied by the manipulator using the embedded KUKA Sunrise.OS (1.10.0.8). These motions consisted in shoulder sagittal elevation, coronal elevation, internal-external rotation (at 0° of abduction), horizontal abduction, vertical traction, and horizontal compression. A CT scan was performed prior to the robotic procedure and after specimen preparation, documenting from above acromioclavicular joint to proximal third of the forearm, using a 16-row CT unit (CT LightSpeed VCT, GE Healthcare, USA). Segmentation of bones and reflective markers was obtained manually using Slicer 3D (4.10.2, https://www.slicer.org/). Bone coordinate systems were constructed by identifying, through virtual palpation, a set of anatomical landmarks according to the recommendations of the International Society of Biomechanics (ISB) [7]. Joint kinematics was computed using the 3D Kinematics and Inverse Dynamics toolbox proposed by Dumas and freely available on the MathWorks File Exchange (https://nl.mathworks.com/matlabcentral/fileexchange/58021-3d-kinematics-and-inverse-dynamics). Joint rotations of the glenohumeral, scapulothoracic, acromioclavicular, and sternoclavicular joints were decomposed using the Euler sequences proposed by the ISB [7]. Thoracohumeral rotations, describing the motions of the humerus relative to the thorax, were decomposed using the X-Z-Y order sequence [8].

3 Results

The resulting dataset is composed of the 6-DOF kinematics for each joint of the shoulder girdle, and that for each humeral motion assessed in this study. This dataset is freely available on an open repository. Specific point displacement computation is also made available thanks to the bone segmentation data. For example, the 3D displacement of the most dorsal point on the acromioclavicular joint, useful to define acromioclavicular joint dislocation, is reported in Figure 1 for one arbitrarily selected shoulder, together with the 3D rotation of this joint, during humerus coronal plane elevation.

4 Discussion

Measured glenohumeral, scapulothoracic, acromioclavicular, and sternoclavicular joint kinematics are consistent with previous studies [9]. However, unlike most of these studies focusing on a limited number of degrees-of-freedom and/or humeral motions, the present study provides a comprehensive dataset of the shoulder girdle kinematics during standardised humerus motions.

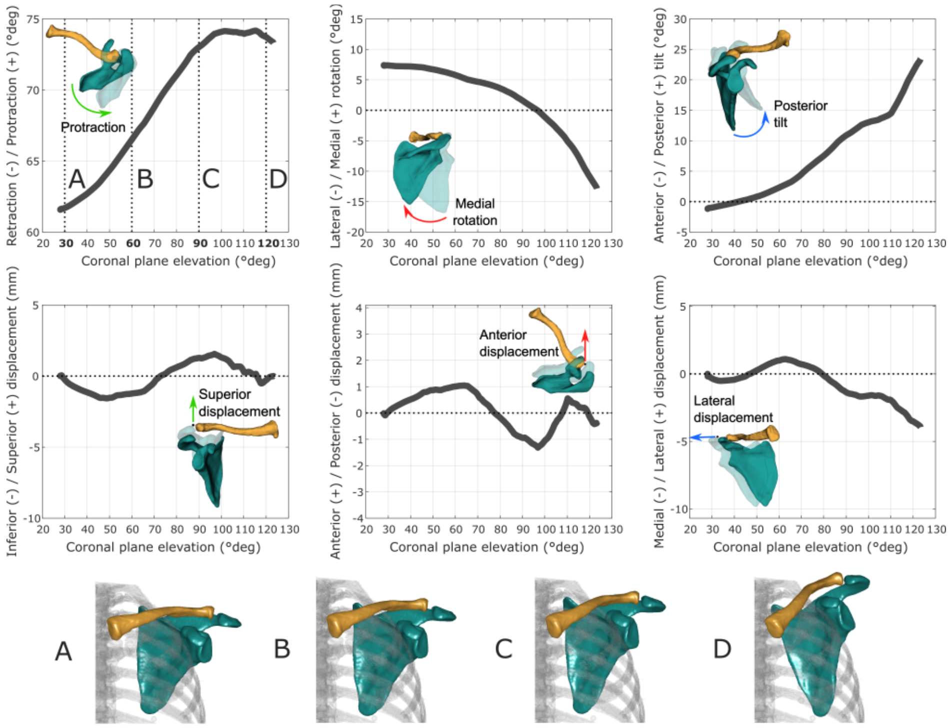

Figure 1: Acromioclavicular joint 3D rotation and 3D displacement of the most dorsal point on the joint of one arbitrarily selected shoulder during humerus coronal plane elevation

This study has several limitations. First, a reduced number of shoulders was included in the study. This is mainly due to limited access to cadaveric specimens and preparation time. Second, the humeral motions induced by the robotic manipulator was not randomised. The impact of tissue drying may thus have impacted the same motions for each shoulder. Third, it must be noticed that the interpretation of the present results is restrained to *ex vivo* or intraoperative conditions with complete muscle relaxation. Indeed, *in vivo* conditions would introduce muscular contraction inducing another scapula positioning.

5 Conclusion

The present study, based on the fusion between motion capture and imaging data, opens new opportunities for testing and validating joint kinematic models, but also to compare joint coordinate systems (e.g. the scapula coordinate system if often described with bony landmarks accessible by palpation, as for the ISB recommendations, and glenoid landmarks, as for surgery navigation systems).

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