

# THREE-DIMENSIONAL KINEMATICS OF THE SHOULDER .

Evaluation and reproducibility of a technique using optoelectronic stereophotogrammetry

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**Abstract**— The aim of this paper is to develop and to test the reproducibility of a quantified analysis of shoulder complex motion using optoelectronic stereophotogrammetry and an acromial cluster to track dynamically the scapula. The standardization proposal of the Shoulder Group of International Society of Biomechanics was used to communicate the results.

**Keywords** -shoulder joint complex; skin-based technique; ISB recommendations; motion analysis

## I. INTRODUCTION

Alterations of scapula motion are associated with shoulder disorders, such as impingement syndrome, instability, adhesive capsulitis or frozen shoulder. The knowledge of the relative contribution of gleno humeral and scapulothoracic mobility may be helpful for physical examination and rehabilitation.

During arm elevation, the humerus rotates in the glenoid of the scapula and the scapula moves on the thorax resulting in a coupled movement described as the scapulohumeral rhythm [1]. The quantification of this complex synchronisation may be useful to help clinical decision before surgery or rehabilitation.

In parallel, the use of three-dimensional motion measurement system to quantify shoulder movement dynamically [2] or discretely [3,4,5] is increasingly reported.

These techniques use an electromagnetic tracking system and scapulator to record shoulder movements. Skin-based methods are sometimes considered poorly reproducible to acquire scapular kinematics due to the position of the scapula covert by the skin (Ceci veut dire collé dans la peau. Je ne pense pas que ce soit approprié, anatomiquement parlant).

In order to overcome the difficulties related to dynamic scapula motion tracking, the present investigation developed a quantified method of shoulder complex motion analysis using an acromial cluster and optoelectronic stereophotogrammetry. The reproducibility analysis of this technique is also reported. The standardization proposal of the Shoulder Group of International Society of Biomechanics (ISB) was used to communicate the results.

## II. METHODS.

### A. Study sample

Nine young subjects (5 men, 4 women) with a mean age of 25.2 years (range 21 to 28 years) without shoulder pathologies were evaluated by two experimenters. The mean body mass index was 21.9 kg/m<sup>2</sup> (range 18.8 to 24.1 kg/m<sup>2</sup>) . All subjects were right-hand dominant.

### B. Measurement system

Thorax, head, scapula, and upper arm motions were measured with a 3D motion-capture system [VICON 612, 8 cameras CCD, 120 Hz]. The calibrated volume was the same as during typical gait analysis.

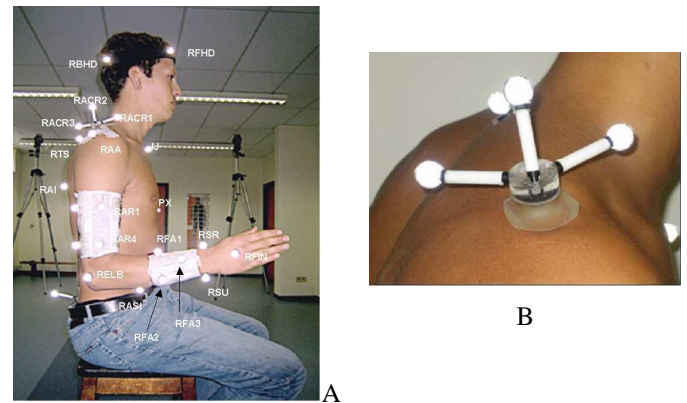


Figure 1. A. Location of anatomical and technical markers B. Acromial cluster

### C. Placement of markers

Landmarks were placed on the upper limb, scapula, thorax, head and pelvis using the anatomical definitions suggested by the Shoulder Group of the International Society of Biomechanics [6]. The placement and labeling of bony landmarks are shown in Figure 1-A.

A CAST-like method was also used to locate these bony landmarks closer to the real position of these landmarks [7].

Movement tracking of the arm and scapula was performed using technical clusters attached on both segments. The arm cluster was fixed laterally on the upper arm and consisted in four-markers. The scapula cluster was a tripod with three reflective markers located on the flat part of the acromion (Figure 1-B).

**D. Movements tested**

The movements tested were ab-adduction, flexion-extension, axial rotation at 0 ° and 90° of abduction, internal rotation and "hand-head", free elevation and circumductions of the shoulder.

**E. Validation of the Euler rotation sequence**

Shoulder kinematics consists of large rotations about the three axes. Euler angles sequences of 2 or 3 axes are used to calculate arm motion. It is well known that, on a rotation matrix  $R(\phi, \theta, \psi)$  if  $\theta$  is null, only the sum or the difference of  $\phi$  and  $\psi$  are defined.

To verify the possible singularities, a validation of these Euler rotation sequences was performed using a modified theodolite with 3 degrees of freedom (Figure 2). This theodolite allowed simulating elevation of the arm in terms of plane of elevation, elevation and axial rotation. Motion combined ranges of -15 to 90 ° of elevation plane, 0 to 160° of elevation and -90° to 90° of axial rotation. The results are shown in table 1.

TABLE I. DIFFERENCES BETWEEN IMPOSED AND MEASURED ROTATION

	Elevation plane	Elevation	Axial Rotation
Mean difference (°)	1.1	0.1	1.0
Absolute mean difference (°)	2.1	1.6	1.8

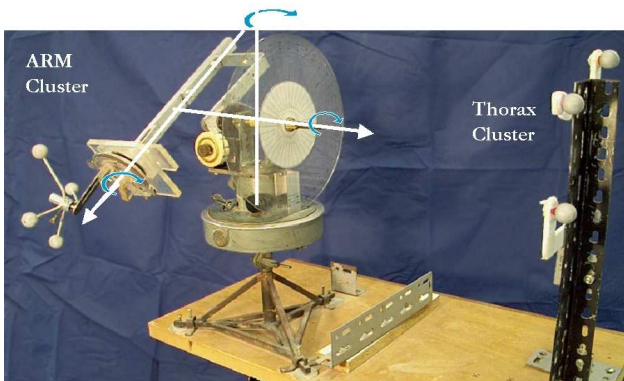


Figure 2. Calibration of rotation sequences

**F. Experimental protocol**

**1) Neutral position**

To express the results in clinical terms, a measurement in a neutral position was realized. As shown in figure 1-A, the arm hung vertically along the thorax with the medial and lateral

epicondyles aligned in the frontal plane, the elbow flexed at 90°, the forearm in neutral rotation.

In this position, a C3d file acquired the anatomical and technical marker positions necessary to build anatomical transformations.

At this stage, a palpation-like CAST technique may be also added to improve the quality of the anatomical transformations.

**2) Motion analysis**

From this neutral position, the subject moved the upper limb maximally through the range in the plane of the requested movements. Two trials were realized. All the markers were left on the subject when it was possible. For each trial, descriptive statistics were calculated. To describe the motion pattern of the group, data at five-degree increments were linearly interpolated relative to humeral elevation.

**G. Data processing**

Arm and scapular kinematics were expressed relative to the thorax. Glenohumeral kinematics was then expressed relative to the scapula. The scapulo-humeral rhythm was also calculated during the movement. The position of the glenohumeral joint centre was estimated by using the regression equations of Murray [8]. Different techniques of joint centre estimation (regression and functional) were also performed for a further usage.

The joint coordinate systems followed the proposal of Wu *et al.* [9] expressing humeral movement in terms of plane of elevation (Y), elevation (X) and axial rotation (Y) with positive X pointing forwards, positive Y upwards and positive Z to the right. Scapular kinematics was expressed in terms of lateral medial rotation (X), re-protraction (Y) and antero-posterior tilt (Z). All the transformations were considered rigid [10].

Data are expressed as mean (SD). Pearson correlation analysis and paired t-test were computed for the assessment of reproducibility.

**III. RESULTS**

A good reproducibility was observed (Figure 3).

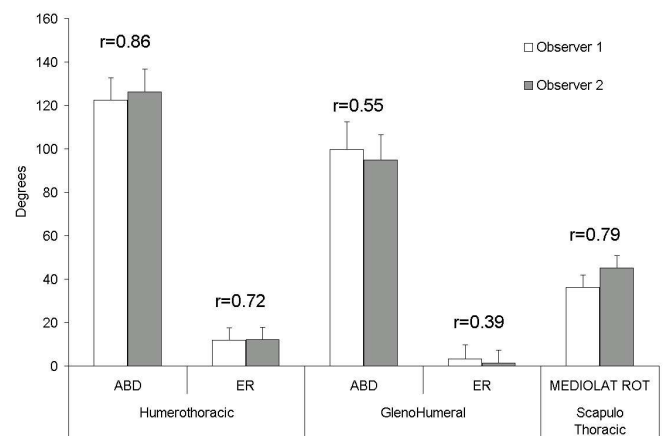


Figure 3. Abduction reproducibility (2 observers and 2 trials)

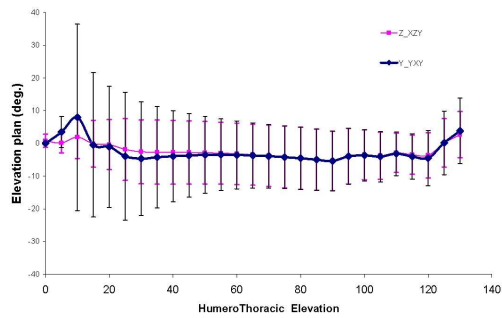


Figure 4. Effect of Euler sequence on elevation plane.

A comparison between Euler sequences was also performed to determine the level of agreement between some proposed sequences with 2 axes [6] or 3 axes [3] (Figure 4).

Averaged curves and standard deviation sticks are shown for 9 subjects during humeral abduction in figure 5 for the plane of elevation and axial rotation. During abduction, on average, the humerus rotated externally in a plane oriented posteriorly.

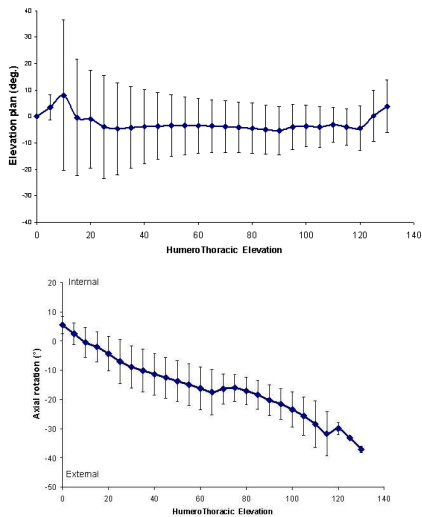
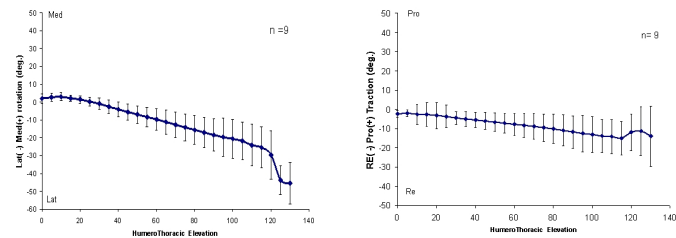


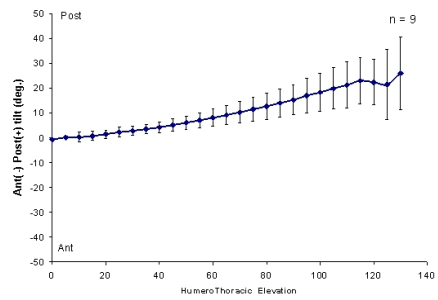
Figure 5. Abduction. Associated movement of the humerus relative to thorax during humeral elevation

During abduction, on average, the scapula rotated laterally, slightly retracted and tilted posteriorly (Figure 6).



A

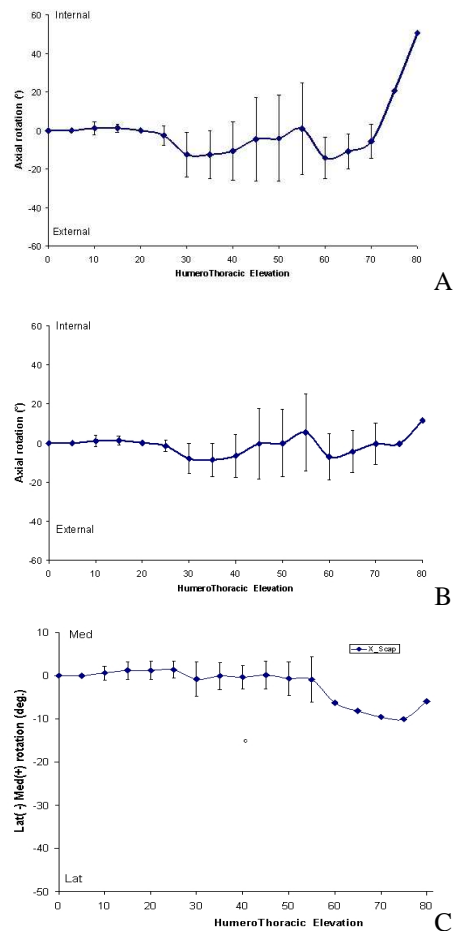
B



C

Figure 6. Abduction. Scapular motions A: Latero-medial rotation; B: Re-Pro-retraction; C: Antero posterior tilt relative to thorax

During internal rotation (needed for perineal care), internal rotation was observed after 60 ° of humeral elevation. Note the difference between humeral rotation if seen relative to the thorax (Figure 7-A) or the scapula (Figure 7-B) stressing the contribution of the scapula (Figure 7-C).



A

B

C

Figure 7. Internal rotation in the humero-thoracic coordinate system (A); in the glenohumeral joint (B) and in the scapulo-thoracic coordinate system (C)

#### IV. DISCUSSION

In this study, a new technique for the measurement of scapula motion was developed using a tripod with 3 reflective

markers. The innovative use of an acromial cluster to track dynamically the scapula seems promising. In parallel, the reproducibility of the data confirms the suitability of a 3D motion-capture system.

Agreement with the literature was found for scapular kinematics with Mc Clure [11] and with Baillon [12], Meskers [4], and Van der Helm [5] for humeral movements.

The singularities observed at the poles but also in the first 30 degrees of humeral elevation, inherent to the Euler methods, could be relatively limited. Indeed, we developed conditions on the sum or difference of  $\phi$  and  $\psi$  in YXY sequence suggested by the ISB. Validation of these procedures must be performed before automation. The use of a calibration system of the Euler sequences (Figure 2) should permit to simulate a maximum of conditions pertinent to the real range of shoulder joint.

Some limitations must be underlined. Deltoid contraction can induce an artifact. For that reason, we performed movements without load.

In this model, kinematics was calculated relative to the thorax. The thoracic landmarks can deform and thus involve errors on humeral and scapular kinematics. One could suggest a bilateral elevation in order to minimize the deformation of the thorax cluster as done by Van der Helm [5].

Another minimization of cluster-related errors should be performed on humeral cluster. However, we placed two of the cluster markers on the lateral intermuscular septum to limit the effect of brachialis and biceps brachii contraction. The inter-marker distance is also a point of discussion that will be addressed for future developments of the method.

Estimation of the glenohumeral centre of rotation must be validated. Different regression methods [8,13] proposed use bony landmarks such as the coracoid process as a reference. The use of functional methods should also be validated relative to the most recent observations published in the literature [14,15,16]

## V. CONCLUSIONS

A protocol has been developed to evaluate dynamically the movements of the shoulder complex using a 3D motion-capture based technique and the standard proposal of the ISB. Clinical perspectives of this proposal include the quantification of dynamic ROM deficits in patients, or pathological scapulo-humeral rhythm in patient with a “frozen shoulder”, or the effects of botulinic toxin in spastic patients.

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