An upper limb musculoskeletal model including acromioclavicular joint ligaments: preliminary results

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***Abstract*— Biomechanical models of the musculoskeletal systems are commonly used to estimate internal structural loads and muscle activation during body movements. Several musculoskeletal models developed in the last decade are used to evaluate upper limb movements in normal conditions. However only few studies are able to predict the influence of abnormal movements following injuries are available so far. An upper limb biomechanical model which includes strain-adjustable ligaments of the acromioclavicular joint was developed by using the OpenSim software. The model including 7 degrees of freedom is able to evaluate the movements of the shoulder, elbow and wrist. The ligaments strain can be adjusted in order to simulate different types of Rockwood acromioclavicular dislocation. Movements recorded from a healthy subject are used as preliminary assessment of the proposed model.**

***Keywords*— musculoskeletal model, upper limb biomechanics, shoulder, ligament injury.**

I. Introduction

UNDERSTANING internal structural loads and muscle activation is crucial for quantitative evaluation of human movements: unfortunately in vivo measurements are not immediate and easy. Hence, musculoskeletal models which provide meaningful noninvasive estimations of these variables can be used. During the last decade several upper limb musculoskeletal models have been developed, such as the Stanford VA upper limb model, the Garner model, the Delft shoulder and elbow model (DSEM), the Dickerson mathematical musculoskeletal shoulder model and the AnyBody shoulder model.

The musculoskeletal shoulder models are used to obtain a detailed biomechanical description. In addition they can be also used to predict the influence of injuries on movements. The Stanford VA upper limb model was used to perform simulations of surgical rotator cuff repair of the supraspinatus muscle–tendon unit [1]. Recently the impact of cuff tear arthropathy on the mechanics of the deltoid during elevation in the frontal, scapular and sagittal planes was simulated by using the AnyBody shoulder model [2]. The use of a musculoskeletal model for assessing the effects of a change in morphological structure is becoming rather common and may represent a promising reliable and valid approach.

The human shoulder joint can be considered as a group of joints which includes the sternoclavicular joint, the acromioclavicular (AC) joint, the glenohumeral joint and the scapulothoracic joint. AC joint injuries occur commonly in active and athletic persons. The injuries of the AC joint are graded according to the amount of injury on the acromioclavicular and coracoclavicular ligaments [3]. The Rockwood's classification divides AC injuries into six different types, from type I to type VI according to the severity of the joint dislocation.

The AC joint stability, which is maintained by a group of ligaments and muscles, is influenced by the specific dislocation injury. The analysis of the effects of abnormal ligament on upper limb movements is still an open issue. A biomechanical model which includes adjustable strain ligament can be used to predict the effects of ligaments injury on upper limb movements.

A biomechanical upper limb model including AC joint ligaments have been developed. Upper limb movements recorded on a healthy subject are presented and analysed. The ultimate goal of this biomechanical model is to estimate the motion kinematics of the shoulder according to different types of Rockwood AC dislocation and to provide a clinical support to the evaluation of functional recovery of the patient after a treatment.

Preliminary results from an upper limb musculoskeletal model including acromioclavicular joint ligaments are presented in this article.

II. Materials and Methods

A. *Musculoskeletal upper limb model*

The upper limb musculoskeletal model presented in this study was developed by using OpenSim platform version 3.3 (National Central for Simulation in Rehabilitation Research NCSRR, Stanford, CA, USA). The musculoskeletal model of the upper limb used in this study was developed from a previous upper limb model [4]. The model includes 7 degrees of freedom (DOF) such as shoulder rotation, shoulder elevation, elevation plane of the shoulder, elbow flexion, forearm rotation and wrist flexion. Fifty musculotendon actuators across these joints were also included. The model was based on the anthropometry and muscle force-generating characteristics of a 50th percentile adult male.

In addition, the trapezius muscle was added to control the moving, rotating, and stabilizing the scapula. The parameters of the trapezius muscle, including tendon slack length, optimal muscle-fiber length and peak isometric muscle force, are obtained from the DSEM [5]. This muscle was included in order to control the shoulder elevation.

B. *Acromioclavicular joint ligaments*

The AC joint is stabilized by a complex of three ligaments arranged around the joint: the coracoacromial ligament, the acromioclavicular ligament and the coracoclavicular ligament. The coracoclavicular ligament consists of the

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conoid ligament, which inserts into the inferior surface of the clavicle of the conoid tubercle near its posterior ridge, and the trapezoid ligament, which runs obliquely, superiorly, and then laterally toward the trapezoid ridge to the inferior surface of the clavicle [3].

TABLE I
LIGAMENTS PARAMETERS

Ligament	*Length (m)*	*Stiffness (N/m)*
Acromioclavicular	0.0150 [6]	N/A
Coracoacromial	0.0369 [7]	51600 [7]
Conoid	0.0112 [8]	70000 [8]
Trapezoid	0.0096 [8]	83000 [8]

N/A: Not available.

The ligaments were modelled in OpenSim by means of two parameters: physiological cross-sectional area and resting length, the length at which the ligament has no strain and no force is produced. The length and stiffness of ligaments in normal condition are reported in Table I.

III. RESULTS

The developed musculoskeletal upper limb model is shown in Fig. 1. To demonstrate how this model works based on the inverse kinematics problem by using experimental data, an able-bodied subject was asked to perform right upper limb movements.

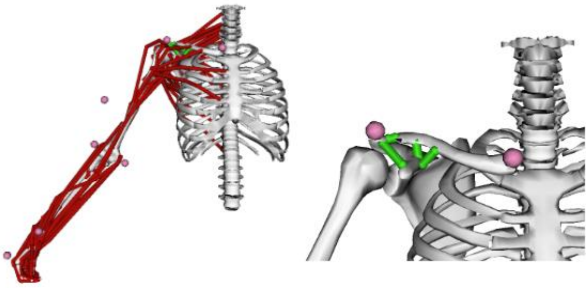

Fig. 1. Upper limb model in an anterior view (left) and acromioclavicular joint (right) where ligaments are represented as green bars.

The movements were recorded by a motion capture system (SMART-DT, BTS Bioengineering Corp., Milano, Italy) which is capable of recording 3D movements. The body landmarks to be recorded were: acromion, clavicular, C7, bicep front, elbow lateral, elbow medial, wrist lateral, wrist medial and hand. A reflective marker was attached to each body landmark. The subject performed a "hand to mouth" movement five times with a self-paced velocity (e.g., 4 seconds for bringing the hand towards the mouth and 4 seconds for returning to the original position).

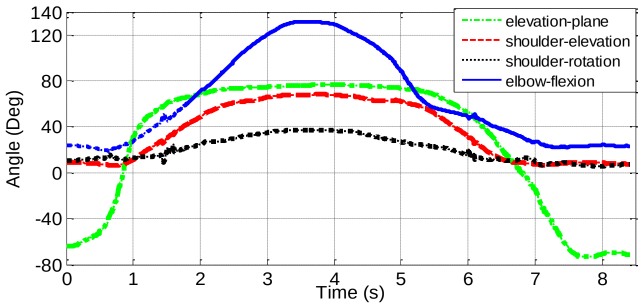

Fig. 2. Trajectories of DOFs angles during a representative trial.

Based on the marker positions recorded during an experimental trial, anatomical scaling, inverse kinematics and dynamics were performed. Scaling was used to match the anthropometric values of the generic model to the characteristics of the subject. Then the joints angles of each DOF of the model were obtained by means of the Inverse Kinematics OpenSim Tool. Finally inverse dynamics is used to estimate the forces and moments that cause the motion.

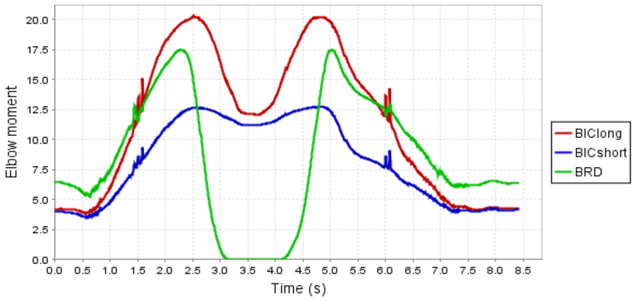

Fig. 3. Contribution of muscles to elbow moment (BIClong: biceps brachii long head, BICshort: biceps brachii short head, BRD: brachioradialis).

Fig. 2 shows the joint angles corresponding to elevation plane of the shoulder, shoulder rotation, shoulder elevation, elbow flexion during a representative trial. The angles obtained are in agreement with the literature [9]. The contribution of biceps brachii and brachioradialis muscles to elbow moment are presented in Fig. 3.

IV. CONCLUSION

The developed model was tested in order to evaluate upper limb movement kinematics by means of experimental data. The influence of different types of Rockwood AC dislocations can be evaluated by means of this biomechanical model. Further analysis will be performed in order to study the effects of ligaments strain on shoulder movements.

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