IMPACT OF STRENGTHENING EXERCICES ON THE SHOULDER JOINT

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Strengthening of shoulder muscles in rehabilitation protocols and sport practice can be achieved by a wide range of different exercises. Very limited objective data is at disposal to emit recommendations for design of a training protocol that aims at minimizing subacromial impingement, stress on the articular cartilages or labrum and excessive tendon elongation of the rotator cuff. The purpose of this study was to evaluate the impact of shoulder rehabilitation exercises on the shoulder joint using motion capture and computer simulations of patient-specific anatomical joint structures.

KEY WORDS: rehabilitation, impingements, rotator cuff, computer simulations.

INTRODUCTION: Strengthening of shoulder muscles in rehabilitation protocols and sport practice can be achieved by a wide range of different exercises and several types of technique. In presence of a rotator cuff lesion, articular cartilage pathology or instability, recommendations for design of a shoulder strength training protocol aim at avoiding or minimizing subacromial impingement, stress on the articular cartilages or labrum and excessive tendon elongation of the rotator cuff. Unfortunately, very limited objective data is at disposal to emit such recommendations. Our goal was to study the impact of the most common shoulder rehabilitation exercises on: subacromial space height, articular cartilages and labrum compression and rotator cuff elongation.

METHODS: One healthy male volunteer (28 years old) underwent MRI arthrography and motion capture of the shoulder. Based on the MR images, patient-specific 3D models of the shoulder bones, articular cartilages and labrum were reconstructed using Mimics software. The rotator cuff muscles (infraspinatus, supraspinatus, teres minor, and the superior/inferior bundles of the subscapularis) were also modeled using 3D splines. Attachment sites and trajectories were identified on the MR images.
Kinematic data from the volunteer was recorded using a Vicon system (24x MXT40S) during 31 rehabilitation exercises targeting 11 most frequently trained shoulder muscles or muscle groups and using up to four different techniques when available: cable bar machine, dumbbell, body weight and TheraBand™. Glenohumeral kinematics was computed from the markers trajectories using a validated biomechanical model (Charbonnier et al., 2014; Charbonnier et al., 2015) which accounted for skin motion artifacts. The model was based on a patient-specific kinematic chain using the shoulder 3D models reconstructed from MRI data and a global optimization algorithm with loose constraints on joint translations (accuracy: translational error < 3mm, rotational error < 4°). As a result, the subject's shoulder 3D models could be visualized at each point of the movement (Fig. 1A).
Subacromial space height was assessed by measuring the minimum distance between the inferior acromial surface and the humeral head surface (Charbonnier et al., 2015)(Fig. 1B). Cartilages and labrum contacts were evaluated using a collision detection algorithm (Charbonnier et al., 2015). Maximal surface-to-surface distance (i.e., penetration depth) between humeral, glenoid cartilages and labrum surfaces were computed to quantify the topographic extent of compression on each structure (Fig. 1C). Muscles were simulated using a position-based dynamics approach (Müller et al., 2007). The splines were discretized into a set of connected particles with a straight-forward distance constraint which attempts to keep the distance between two particles equal to a specified rest-length. To prevent

interpenetration between the 3D bone models and the splines, continuous collision detection was performed. The muscle simulation technique was validated and used to compute maximal muscles lengths, expressed as muscle length variation (ratio of current length with respect to the neutral position in %). All aforementionned measures were acquired on the entire range of motion during motion simulation.

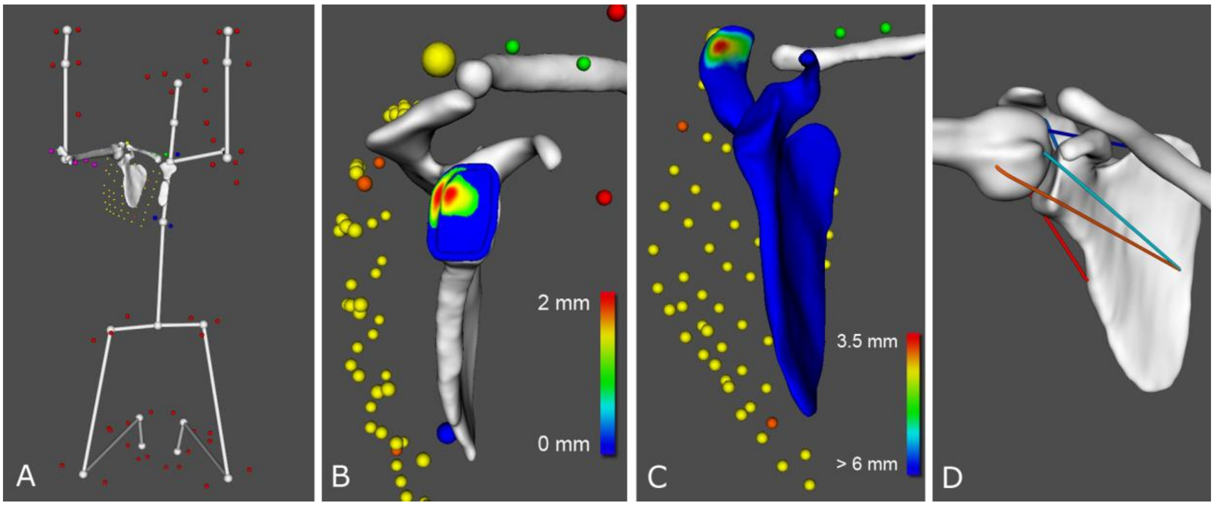

Figure 1: A) Example of a computed posture (chin-up exercise). B) Visualization of the humero-acromial distance during motion (red color = minimum distance). C) Visualization of the penetration depth distribution (red color = maximum penetration). D) Rotator cuff simulation (warm colors = elongation, cold colors = compression).

RESULTS: Minimal subacromial height varied up to 14.1-fold for targeted muscles exercises according to the training technique used. Cartilages compression varied up to 6.6-fold and labral compression up to 5.7-fold. Contacts were all located between the antero- and postero-superior sectors of the glenoid. Least favorable target muscles training with respect to cartilages and labrum compression were biceps brachii, pectoralis major and supraspinatus. Overhead strength training resulted in significant decrease (p=0.001) of subacromial space height. Maximal muscle length variations ranged between 81% and 138% during the different exercises. The teres minor and the inferior bundle of the subscapularis were the most solicited. Least favorable target muscles training with respect to rotator cuff elongation were deltoid, pectoralis major and serratus.

CONCLUSION: According to the type of strengthening exercise, important variations in subacromial space height, cartilages and labrum compression and tendon elongation were observed. The simulations confirmed the decrease of subacromial space height in overhead strength training, as expected. To our knowledge, this study represents the first screening of shoulder strengthening exercises to identify potential deleterious effects on the shoulder joint using a patient-specific measurement method coupling motion capture and medical imaging.

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