Clinical Biomechanics 32 (2016) 194–200

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

The effects of plane and arc of elevation on electromyography of shoulder musculature in patients with rotator cuff tears☆

Talia Alenabi [a,*], Fabien Dal Maso [a,c], Patrice Tétreault [b], Mickaël Begon [a,c]

[a] Laboratoire de simulation et de modélisation du mouvement (S2M), Département de kinésiologie, Université de Montréal, Laval, Canada
[b] Centre Hospitalier d'Université de Montréal (CHUM), Montréal, Canada
[c] Centre de Réadaptation Marie-Enfant-Centre Hospitalier d'Université Sainte Justine, Montréal, Canada

ARTICLE INFO

Article history:
Received 5 August 2015
Accepted 24 November 2015

Keywords:
Supraspinatus
Active arm elevation
Full can exercise
Shoulder rehabilitation
3D glenohumeral kinematics
Indwelling EMG

ABSTRACT

Background: Arm elevations in different planes are commonly assessed in clinics and are included in rehabilitation protocols for patients with rotator cuff pathology. The aim of this study was to quantify the effect of plane and angle of elevation on shoulder muscles activity in patients with symptomatic rotator cuff tear to be used for rehabilitation purposes.
Methods: Eight symptomatic patients with rotator cuff tears were assessed by using EMG (11 surface and 2 fine wire electrodes) synchronized with a motion analysis. The subjects completed five elevations in full can position (arm externally rotated and thumb up) in frontal, scapular and sagittal planes. Muscle activity in three elevation arcs of 20° (from 0° to 60°) was presented as the percentage of mean activity. Data were analyzed by mixed linear models ($\alpha = 0.003$), and Tuckey Post-hoc comparisons for significant effects ($\alpha = 0.05$).
Findings: The effect of plane was significant for supraspinatus, middle trapezius, anterior, middle, and posterior deltoid, triceps, and pectoralis major ($P < 0.001$). Supraspinatus was more active during abduction than scaption and flexion ($P < 0.05$), and its activity did not increase significantly after 40° of elevation ($P > 0.05$). Infraspinatus had similar activity pattern in the three planes of elevation ($P > 0.003$) with increasing trend in accordance with the elevation angle.
Interpretation: In any rehabilitation protocol, if less activity of supraspinatus is desired, active arm elevation should be directed toward flexion and scaption and postponed abduction to prevent high level of activity in this muscle.

1. Introduction

Rotator cuff disorders are among the most frequent causes of shoulder pain (Meislin et al., 2005), and many patients with rotator cuff tears are unable to use their affected limb efficiently (Bunker, 2002). Contribution of rotator cuff is essential for arm elevation not only to provide glenohumeral joint stability but also as arm movers in certain ranges of motion (Blache et al., 2015; Lee et al., 2000). Arm elevations are routinely used for clinical evaluation of shoulder dysfunction (Magee, 2014) and included in most of the upper-limb rehabilitation protocols (Lee et al., 2012; Wilk et al., 2002). There is not yet consensus on an ideal exercise program to treat patients with rotator cuff disease (Kuhn, 2009). Hence, a detailed examination of shoulder muscles activity during different tasks including arm elevation in patients with rotator cuff tear may help clinicians to design more specific shoulder rehabilitation programs (Escamilla et al., 2009).

Based on electromyographic (EMG) recordings of the shoulder musculature, several studies have proposed recommendations for shoulder rehabilitation exercises (Ellenbecker and Cools, 2010; Escamilla et al., 2009). For arm elevation exercises, "full can" position (arm externally rotated and thumb up) is preferred to "empty can" (arm internally rotated and thumb down) (Ellenbecker and Cools, 2010; Reinold et al., 2007) because internal rotation of the arm may decrease the width of subacromial space (De Wilde et al., 2003) and hence reproduce the symptoms (Hawkins and Kennedy, 1980). Among all planes in which an arm can elevate, "scaption", *i.e.*, elevation in the scapular plane, has been most investigated (Alpert et al., 2000; Johnston, 1937). However, patients are encouraged to exercise in all planes of elevation with large range of motion (Ellenbecker and Cools, 2010). While kinematics-based investigations have highlighted that planes of elevation alter rotations (Ludewig et al., 2009) and translations (Dal Maso et al., 2015) of the glenohumeral joint, little is known about changes in rotator cuff activation pattern induced by different planes of elevation. EMG studies on rotator cuff muscles have described the activation pattern for each of the abduction, scaption, and flexion planes separately (McMahon et al., 1996;

☆ The authors have no conflict of interest to disclose. The study was approved by the university research ethics committee (Comité d'éthique de la recherche en santé, certificate number CERSS # 2010-1013-P).

* Corresponding author at: Laboratoire de Simulation et Modélisation du Mouvement, Département de Kinésiologie, 1700 Rue Jacques Tétreault, Laval, QC H7N 0B6, Canada.
E-mail address: seyedeh.talia.alenabi@umontreal.ca (T. Alenabi).

http://dx.doi.org/10.1016/j.clinbiomech.2015.11.011
0268-0033/

Moseley et al., 1992; Wattanaprakornkul et al., 2011; Wickham et al., 2010). To our knowledge, only Reed et al. (in press) have directly compared the shoulder muscle activity patterns in three planes of elevation and reported significant main effect of plane on the activation level of supraspinatus, middle deltoid and upper trapezius muscles. However, their experiment was based only on healthy participants, which may not represent the patients with pathologic rotator cuff. Biomechanical studies have shown that glenohumeral kinematics differs between patients with shoulder pain and healthy individuals (Lawrence et al., 2014). These kinematic changes may also be accompanied with alteration in EMG activation pattern (Ludewig and Cook, 2000; McMahon et al., 1996; Reddy et al., 2000). For example, McMahon et al. (1996) reported lower EMG activity of supraspinatus in the shoulders with anterior joint instability than normal population between 30–60° of arm elevation in all the three planes of elevation. Such studies have not been performed on patients with rotator cuff tears. Therefore, the comparison of shoulder EMG in different planes and angles of elevation in cuff patients is essential to characterize muscle activation pattern following rotator cuff tear in order to better direct rehabilitation programs.

The aim of this study was to assess the effect of plane, *i.e.,* abduction, scaption, and flexion and arc of elevation, *i.e.,* 0–20°, 20–40°, and 40–60° of glenohumeral angles, during full can elevations on the EMG of shoulder musculature in patients with rotator cuff tears. Glenohumeral angle was selected for investigation as its movement requires more precise rotator cuff activity and the rotator cuff tear is associated with disruption of normal glenohumeral kinematics (Yamaguchi et al., 2000). We hypothesized that plane of elevation as well as elevation angle significantly affect the EMG pattern of torn rotator cuff and should be considered in different phases of rehabilitation protocols.

2. Methods

2.1. Participants

Eight symptomatic patients with full thickness rotator cuff tears affecting one or two tendons were chosen for this study. The patients' information is detailed in Table 1. All tears were confirmed by MRI and the patients were waiting for surgery for more than six months after their diagnosis. Any patient with coexisting musculoskeletal disorder affecting the upper limb or previous surgery was excluded from the experiment. Written informed consent was obtained from all participants before the experiment. All patients were then asked to complete quick-DASH (Hudak et al., 1996) and Constant (Constant and Murley, 1987) questionnaires by aid of the same experimenter. The research was approved by the ethics committee of the local university (CÉRSS-2010-1013-P).

2.2. Recordings

EMG signals were recorded from 13 shoulder muscles of the affected limb of the patients using 2 fine-wire electrodes and 11 surface electrodes. Fine-wire intramuscular electrodes (30 mm, 27 gauge; CareFusion, San Diego, CA, USA) were inserted into the supraspinatus and infraspinatus as explained by Perotto (Perotto, 2005). After suitable skin preparation, circular silver–silver chloride bipolar surface electrodes (20 mm inter-electrode distance; CareFusion, San Diego, CA, USA) were placed over 11 muscles, namely the long heads of triceps and biceps, anterior, middle, and posterior deltoid, latissimus dorsi, sternal part of pectoralis major, serratus anterior and upper, middle, and lower trapezius by standard placement techniques (Boettcher et al., 2008; Ekstrom et al., 2005; SENIAM, 2006). The ground electrode was placed on the opposite clavicle. Proper electrode placement was confirmed by checking the signals during sub-maximum isometric contractions, which were performed in specific positions expected to generate high EMG activity (Alenabi et al., 2013). The EMG signals were acquired at 1000 Hz and passed through an amplifier (model 15A54; Grass Technology, West Warick, RI, USA) with 10 to 1000 Hz bandwidth detection (common mode rejection ratio > 90 dB; input impedance > 20 MΩ; noise, 10 mV peak to peak).

For kinematic analysis, the patients were setup with 29 reflective markers on the trunk and the affected arm as described by Robert-Lachaine et al. (2015). Marker trajectories were tracked using an 18-camera motion analysis system (Vicon Motion System, Oxford Metrics Ltd., Oxford, UK) at 150 Hz. EMG and kinematic data were synchronized online using the Nexus 1.8.5 software (Vicon Motion System).

2.3. Experimental procedure

Patients were standing in an anatomic posture and maintained the trunk as stable as possible. Each movement started with the arm relaxed at the side. Patients executed three repetitions of arm elevations in different planes, shoulder rolls, shrugs, and circumductions, along with five elbow flexion-extension to locate joints centers and axes of rotation (Monnet et al., 2007). Then, they were asked to perform 5 arm elevations in frontal, scapular and sagittal planes (abduction, scaption, and flexion) at their maximum range of motion with the thumb pointing toward the ceiling (full can position). One examiner was checking the exact plane of scapula for each patient and then adjusted the other two planes accordingly. Moderate self-controlled speed was maintained throughout elevations as application of metronome was not feasible due to different maximal elevation angle for each patient. Five trials were recorded in each plane of elevation and the order of planes was randomly assigned for each patient.

2.4. Data processing

2.4.1. Kinematics

For joint kinematic analysis, the positions of the center of rotation of the sternoclavicular, acromicoclavicular, and glenohumeral joints were personalized. This personalization was performed in accordance to the recent recommendations based on a gold standard kinematics measurements performed in our lab (Michaud et al., submitted for publication). Secondly, to improve the accuracy of kinematic reconstruction, the displacement of the scapula was constrained to follow an ellipsoid

Table 1
Demographic variables and functional scores.

Patients	Age	Gender	BMI	Injured side	Q-DASH	Constant	Tendon torn	Tear size	Symptomatic (year)
P1	64	M	29.7	R	64	25	SS	1–3 cm	3–5
P2	55	M	30.1	L	35	57	SS	1–3 cm	1–3
P3	41	F	26.8	R	65	26	SS	<1 cm	3–5
P4	69	F	28.4	L	75	38	SS + IS	1–3 cm	3–5
P5	68	M	30.7	L	67	50	SS	1–3 cm	3–5
P6	64	F	33.6	R	44	46	SS + IS	3–5 cm	1–3
P7	49	F	27.6	R	91	18	SS + IS	3–5 cm	1–3
P8	57	F	24	R	93	13	SS	1–3 cm	1–3
Mean	58.38		28.86		66.75	34.12			
(SD)	(9.8)		(2.87)		(20.28)	(15.97)			

M = male, F = female, R = right, L = left, SS = supraspinatus, IS = infraspinatus, SD = standard deviation.