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Electromyographic assessment of muscle fatigue in massive rotator cuff tear

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ABSTRACT

Shoulder muscle fatigue has not been assessed in massive rotator cuff tear (MRCT). This study used EMG to measure fatigability of 13 shoulder muscles in 14 healthy controls and 11 patients with MRCT. A hand grip protocol was applied to minimise artifacts due to pain experience during measurement. The fatigue index (median frequency slope) was significantly non-zero (negative) for anterior, middle, and posterior parts of deltoid, supraspinatus and subscapularis muscles in the controls, and for anterior, middle, and posterior parts of deltoid, and pectoralis major in patients ($p \leqslant 0.001$). Fatigue was significantly greater in patients compared to the controls for anterior and middle parts of deltoid and pectoralis major ($p \leqslant 0.001$).

A submaximal grip task provided a feasible way to assess shoulder muscle fatigue in MRCT patients, however with some limitations. The results suggest increased activation of deltoid is required to compensate for lost supraspinatus abduction torque. Increased pectoralis major fatigue in patients (adduction torque) likely reflected strategy to stabilise the humeral head against superior subluxing force of the deltoid. Considering physiotherapy as a primary or adjunct intervention for the management of MRCT, the findings of this study generate a base for future clinical studies aiming at the development of evidence-based protocols.

1. Introduction

Effective shoulder function is essential for many activities of daily living. Coordinated synchronous activity of shoulder girdle muscles is required to limit translation of the humeral head on the shallow glenoid fossa (Bey et al., 2008; Poppen and Walker, 1978). Rotator cuff muscle activity plays a fundamental role in maintaining glenohumeral joint (GHJ) stability (Burkhart, 1991; Inman et al., 1944; Yanagawa et al., 2008), 'stiffening' the GHJ to establish a stable fulcrum (David et al., 2000).

Rotator cuff tears are prevalent in the elderly (Sher et al., 1995; Tempelhof et al., 1999). A tear larger than 5 cm or involving 2 or more rotator cuff tendons is defined as a 'massive rotator cuff tear' (MRCT) (Cofield, 1981; Gerber et al., 2000). An MRCT often has significant impact on quality of life due to impaired shoulder strength and range of movement, and consequently reduced ability to perform essential daily activities. A MRCT disrupts the glenohumeral fulcrum, leading to abnormal superior translation of the humeral head on the glenoid fossa during arm elevation as the destabilising force generated by the deltoid muscle is unopposed (Terrier et al., 2007; Yamaguchi et al., 2000). The altered joint mechanics results in a disabling condition which can impact on functional capacity and quality of life. However, despite this anatomical deficit, some patients with a MRCT are able to maintain function. This has led to the hypothesis that alternative muscle activation strategies can compensate for the deficient rotator cuff to establish a stable glenohumeral fulcrum for arm movement (Hansen et al., 2008; Steenbrink et al., 2006, 2009).

The outcome of surgical interventions for MRCT depends on several factors such as age, activity level, joint stability, and associated degenerative changes (Dines et al., 2006; Gerber et al., 2011). High rates of re-tear follow rotator cuff repair (Galatz et al., 2004) and tendon transfer or shoulder arthroplasty are the main options when the tear is irreparable (Boes et al., 2006). Physiotherapy has

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been suggested as a key alternative intervention in the management of MRCT when tear is irreparable and symptomatic (Ainsworth and Lewis, 2007). However, evidence is lacking to support the development of effective rehabilitation protocols which target compensatory muscle activation strategies and fatigue-susceptible muscles. While a few studies have investigated the activation pattern of shoulder girdle muscles in MRCT, their fatigability not been studied. Identification of potentially fatigable muscles in the upper limb kinetic chain is needed to support the development of tailored rehabilitation protocols.

Muscular fatigue is a time-dependent process occurring during muscular contraction, resulting in manifestations such as tremor, pain and inability to achieve a desired force output (De Luca, 1984). Its importance in MRCT is that altered muscle force generation caused by deficient rotator cuff function may contribute to decreased GHJ stability. Shoulder muscle fatigue has been studied using electromyography (EMG) in healthy subjects during isometric arm elevation tasks, in which the greatest fatigue is observed in the deltoid and rotator cuff muscles (Minning et al., 2007; Nieminen et al., 1995). However, appropriate measurement of muscle fatigue in painful conditions such as MRCT presents a significant challenge.

Shoulder pain directly alters muscle activation strategies, partly to protect painful structures (Diederichsen et al., 2009) and partly as movement avoidance due to fear of pain (Alizadehkhaiyat et al., 2007). These factors complicate comparisons with healthy controls, so an alternative approach is required. Hand grip tasks activate key shoulder girdle muscles by exploiting the principles of the kinetic chain (Alizadehkhaiyat et al., 2011; Sporrong et al., 1995, 1996, 1998). This can provide a practical way of studying shoulder muscle fatigue, albeit only in a particular position, in patients with MRCT while limiting pain and potential sources of confounding.

Shoulder muscle fatigue has not been measured before in MRCT. Hence, the central aim of the present study was to determine and compare the fatigability of key shoulder girdle muscles in groups of MRCT patients and healthy controls during a pain-free task representative of daily activities. We further aimed to evaluate the functional impact of MRCT on patients' quality of life using validated scores. The combined results are intended to provide a base of knowledge for future clinical studies aiming to compare current rehabilitation protocols and promote the development of effective evidence-based programmes.

2. Methods

2.1. Participants

The control group (CG) comprised 14 healthy subjects with no history of upper limb painful conditions or surgery, and normal upper limb clinical examination. The mean (±SD) age was 36 ± 15 year, height 175 ± 10 cm and mass 77 ± 15 kg. The arm tested was randomly selected. The MRCT group (MRCTG) including 12 patients were recruited from a specialised Upper Limb Unit in a major orthopaedic centre during 2009–2011. Patients typically presented with shoulder pain and loss of both strength and range of motion. A MRCT was diagnosed following ultrasound or magnetic resonance imaging, which confirmed a two-tendon full thickness tear of the rotator cuff. Patients were excluded if they had a coexisting musculoskeletal disorder affecting the upper limb. Mean age was 74 ± 7 year, height 166 ± 8 cm, and weight 78 ± 14 kg. Six patients had a tear of supraspinatus and infraspinatus, 5 of supraspinatus, infraspinatus and subscapularis, and 1 of supraspinatus and subscapularis. The study had Local Research Ethics Committee approval and written informed consent was obtained from all participants. Repeatability was assessed by retesting 4 subjects from CG 2–8 weeks after their first visit. Study groups were the same as those reported in an earlier study of muscle activation and coordination in MRCT (Hawkes et al., 2011).

2.2. EMG measurement

EMG was recorded from 13 shoulder muscles during the hand grip protocol described below. A TeleMyo 2400 G2 Telemetry System (Noraxon Inc., Arizona, USA) was used for signal acquisition. Recorded signals were analysed off-line using MyoResearch XP software (Noraxon Inc., Arizona, USA). Signals were differentially amplified (common mode rejection ratio >100 dB; input impedance >100 Mohm; gain 500 dB), digitised at a sampling rate of 3000 Hz and band-pass filtered in accordance with international guidance ([10–500]Hz for surface electrodes and [10–1500]Hz for fine wire electrodes) (ISEK, 1996). ECG contamination was removed from affected signals using an adaptive cancellation algorithm.

Disposable, self-adhesive pre-gelled Ag/AgCl bipolar electrodes with conducting area of 10 mm diameter and inter-electrode distance of 20 mm (Noraxon Inc., Arizon, USA) were used to record the EMG from anterior, middle, and posterior deltoid (AD, MD, PD), pectoralis major (PM), upper trapezius (UT), serratus anterior (SA), latissimus dorsi (LD), teres major (TM), brachioradialis (BR) and biceps brachii (BB) according to guidelines (Caldwell et al., 1993; Gartsman, 1997; Kadaba et al., 1992; SENIAM). Skin preparation involved shaving and the application of abrasive paste (Nuprep, Weaver and Company, Aurora, USA). Crosstalk was limited by the judicious placement of appropriately sized electrodes, parallel to the muscle fibres and according to accepted anatomical criteria (Basmajian and De Luca, 1985). Fine wire electrodes were used to record signals from the supraspinatus (SSP), infraspinatus (ISP) and subscapularis (SUBS). Bipolar disposable hook wire electrodes (Nicolet Biomedical, Division of VIASYS, Madison, USA) were inserted aseptically using the accepted technique (Basmajian and De Luca, 1985). Signals were reviewed and excluded if of low signal-to-noise ratio or if manual muscle testing indicated incorrect electrode placement.

2.3. Hand grip testing protocol

Grip strength was measured using a Jamar dynamometer (Biometrics Ltd., E-LINK, Gwent, UK). Subjects were tested seated on a chair with their hips and knees flexed to 90°; wrist and forearm in neutral position, elbow extended to 180°, and the shoulder in neutral rotation and elevated to 30° in the scapular plane (Fig. 1). A goniometer ensured the correct angle of arm elevation and a guidance pole was positioned to maintain the testing position. Subjects were instructed to squeeze the dynamometer maximally (build gradually to the maximal exertion) during a 3-s trial. Three trials were performed and the average was taken as maximum voluntary contraction (MVC) (Mathiowetz et al., 1984). Verbal encouragement was provided, participants being encouraged to exceed each previous measurement (Baratta et al., 1998).

An isometric task is considered most appropriate for studying muscle fatigue (Merletti et al., 1991; Viitasalo and Komi, 1975). Typically, shoulder fatigue is studied in isometric contraction at a predefined fraction of the MVC. This approach will not work where pain significantly affects measurement of true MVC: all that can be determined is the 'acceptable maximal effort', which can show marked day-to-day variability (Graven-Nielsen et al., 2002). Comparisons with normal controls can also be undermined by fear-related movement avoidance and pain-related alterations in muscle activation (Alizadehkhaiyat et al., 2007; Diederichsen et al., 2009). Thus fatiguing EMG signals were recorded during sustained