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Assessing the validity of surface electromyography for recording muscle activation patterns from serratus anterior

Lucien Hackett [a], Darren Reed [b,*], Mark Halaki [a], Karen A. Ginn [b]

[a] Discipline of Exercise and Sport Science, Faculty of Health Sciences, The University of Sydney, Australia
[b] Discipline of Biomedical Science, Sydney Medical School, The University of Sydney, Australia

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ABSTRACT

Purpose: No direct evidence exists to support the validity of using surface electrodes to record muscle activity from serratus anterior, an important and commonly investigated shoulder muscle. The aims of this study were to determine the validity of examining muscle activation patterns in serratus anterior using surface electromyography and to determine whether intramuscular electromyography is representative of serratus anterior muscle activity.

Methods: Seven asymptomatic subjects performed dynamic and isometric shoulder flexion, extension, abduction, adduction and dynamic bench press plus tests. Surface electrodes were placed over serratus anterior and around intramuscular electrodes in serratus anterior. Load was ramped during isometric tests from 0% to 100% maximum load and dynamic tests were performed at 70% maximum load. EMG signals were normalised using five standard maximum voluntary contraction tests.

Results: Surface electrodes significantly underestimated serratus anterior muscle activity compared with the intramuscular electrodes during dynamic flexion, dynamic abduction, isometric flexion, isometric abduction and bench press plus tests. All other test conditions showed no significant differences including the flexion normalisation test where maximum activation was recorded from both electrode types. Low correlation between signals was recorded using surface and intramuscular electrodes during concentric phases of dynamic abduction and flexion.

Conclusions: It is not valid to use surface electromyography to assess muscle activation levels in serratus anterior during isometric exercises where the electrodes are not placed at the angle of testing and dynamic exercises. Intramuscular electrodes are as representative of the serratus anterior muscle activity as surface electrodes.

1. Introduction

Electromyography (EMG) is the most reliable tool that researchers have to understand the complex activation patterns of muscles during exercises and functional activities (Basmajian and De Luca, 1985). EMG can be recorded by intramuscular electrodes placed into the belly of the muscle or surface electrodes placed on the overlying skin.

Traditionally surface electrodes have been preferred for superficial muscles as they are non-invasive, easier to set up (Giroux and Lamontagne, 1989) and sample from a larger cross-section of the muscle than intramuscular electrodes (Basmajian and De Luca, 1985). However, surface electrodes may be susceptible to geometric displacement away from the target muscle (Oberg et al., 1992) and recording EMG signals from adjacent or underlying muscles, leading to contamination of signals, known as crosstalk (Johnson et al., 2011; Perry et al., 1981; Stokes et al., 2003).

Intramuscular electrodes are commonly used to record activity from deep muscles inaccessible to surface electrodes, but may also be the electrode of choice in some superficial muscles if cross talk or geometric displacement is a potential problem. They record activity from a smaller volume of muscle having more specificity than surface electrodes and therefore, are not susceptible to crosstalk (Basmajian and De Luca, 1985; Bouisset and Maton, 1972; Giroux and Lamontagne, 1989). However, studies suggest that they may not be representative of activity in the entire muscle (Giroux and Lamontagne, 1989; Yemm, 1977).

The shoulder region, with the humerus and scapula both moving through large ranges and multiple muscles with varying morphology lying in close proximity to each other, presents challenges in using surface electrodes on superficial shoulder muscles.

* Corresponding author. Address: Discipline of Biomedical Science, Sydney Medical School, Cumberland Campus C42, The University of Sydney, Lidcombe, NSW 1825, Australia. Tel.: +61 2 9351 9144; fax: +61 2 9351 9715.
E-mail address: darren.reed@sydney.edu.au (D. Reed).

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Previous research in the shoulder region has shown geometric displacement (Oberg et al., 1992) and crosstalk from adjacent muscles in isometric (Johnson et al., 2011; Waite et al., 2010) and dynamic exercises (Jaggi et al., 2009) may lead to invalid recordings from surface electrodes.

Serratus anterior is an important axioscapular muscle crucial to normal shoulder function. This large, flat muscular sheet attaches via individual digitations from the first 8 or 9 ribs to the medial border of the scapula (Palastanga et al., 2012). It is a major protractor of the scapula and the lower fibres co-ordinate with trapezius to upwardly rotate the scapula (Palastanga et al., 2012). EMG research investigating serratus anterior activity has predominantly used surface electromyography over the lower digitations of the muscle where it is most accessible and superficial (Cools et al., 2007; Decker et al., 1999; Ekstrom et al., 2003). However, glenohumeral joint movement results in the skin overlying the lower fibres of serratus anterior experiencing large degrees of shift during shoulder movement. There is also the possibility that surface electrode recordings from serratus anterior may be contaminated by potential cross-talk from adjacent muscles. To date, no studies have assessed the validity of using surface electrodes to record activity from serratus anterior. In addition, the issue of whether recording serratus anterior activity using intramuscular electrodes is representative of activity in the whole of this large muscle has not been investigated and is still unknown. Therefore, the aims of this experiment were to:

- Determine the validity of using surface electrodes to record muscle activity from the lower fibres of serratus anterior during dynamic and isometric contractions.
- In the test conditions where the validity of surface electrode recordings were confirmed, to determine the representativeness of intramuscular electrodes compared to surface electrodes for recording muscle activity from the lower fibres of serratus anterior.

2. Methods

2.1. Subjects

Seven asymptomatic subjects (six male, one female, aged 19–23) volunteered to participate in this investigation. To be eligible to participate subjects must have had no pain in their dominant shoulder in the previous two years and had never been treated for shoulder pain. Prior to the experiment, shoulder strength and range of motion tests were conducted by an experienced physiotherapist to verify normal pain free functioning of the dominant shoulder and subjects gave their informed consent. Ethics approval was granted by The University of Sydney's Human Research Ethics Committee (approval number 04-2011/13610).

2.2. Instrumentation

Electromyographic data were collected simultaneously from the lower fibres of serratus anterior using both surface and intramuscular electrodes. Intramuscular electrodes were manufactured in the Shoulder Laboratory, Sydney Medical School, using the technique developed by Basmajian and De Luca (1985) and comprised of two insulated wires of 0.14 mm diameter made of Teflon coated stainless steel. The two wires were bent back to form barbs at 2 mm and 4 mm respectively from the terminal end. This terminal end was de-insulated for a length of 1 mm for both wires. Using a sterile technique, the wires were inserted via a hypodermic needle acting as a cannula into the digitation of serratus anterior over rib 7 (Geiringer, 1994). Wires were looped to allow for adequate movement, and then taped to the skin to prevent inadvertent removal.

A pair of 3.2 mm diameter silver/sliver chloride surface electrodes (Red Dot, 2258, 3M, Sydney, Australia) was used to detect muscle activity from serratus anterior (Ekstrom et al., 2004). With the subject side-lying and the arm in 60° abduction, the surface electrodes for serratus anterior were placed at a distance of approximately 25 mm apart over the seventh rib (Ekstrom et al., 2005; Hardwick et al., 2006), in line with the muscle fibres and around the intramuscular electrodes (Giroux and Lamontagne, 1989; Johnson et al., 2011). A large ground electrode (Universal Electrosurgical Pad: Split, 9160F, 3M, Sydney, Australia) was placed on the spine and acromion of the contralateral scapula. Resistances were measured between surface electrodes (Dick Smith Electronics Q-1450) and were <5 kΩ.

Both the intramuscular and surface electrodes were then connected to amplifiers (Iso-DAM8-8 amplifiers, World Precision Instruments, Sarasota, FL; gain = 100) via a junction box. Data was recorded on a personal computer using SPIKE 2 software (Version 4.0 Cambridge Electronics Design, Cambridge, UK) and a 16 channel analogue to digital converter (CED2701, CED Ltd., Cambridge, UK) at a sample rate of 3125 Hz.

Maximum voluntary contractions (MVCs) were then performed using five standardised shoulder normalisation tests (Boettcher et al., 2008; Ginn et al., 2011) known to have a high likelihood of producing maximum activity in serratus anterior. These normalisation tests were performed in random order and consisted of manually resisted shoulder flexion with the shoulder at 125° flexion, internal rotation at 90° shoulder abduction, shoulder extension at 30° abduction, abduction with the shoulder abducted 90° and internally rotated and self-resisted horizontal adduction at 90° shoulder flexion.

2.3. Test positions

Isometric and dynamic tests of shoulder flexion, extension, abduction, adduction and a dynamic bench press plus exercise (seated chest press to a point where the elbows are fully extended, followed by shoulder protraction) were performed. These tests were selected as they include tasks expected to elicit high serratus anterior activity (flexion and abduction, bench press plus) (Decker et al., 1999; Ludewig et al., 2004), as well as ones in which it would be expected to be less active (extension, adduction). The order of the isometric and dynamic tests was block randomised. During the abduction, adduction, flexion and extension tests the subject stood with their feet placed shoulder width apart and their contralateral hand placed on the corresponding hip in order to prevent unwanted trunk movement. For the flexion test, the contralateral foot was brought two feet-lengths forward, and for the extension test, the ipsilateral foot was brought two feet-lengths forward. The bench press plus exercise was performed on gym equipment (Hyper Extension Gym 50036, 150lbs).

Prior to testing and electrode placement, the maximum isometric load (100% load) for shoulder abduction, flexion, adduction, and extension was measured using a load cell (XTRAN load cell S1W, Applied Measurement Australia PTY LTD, Melbourne, Australia), with resistance maintained for three seconds. Maximum tests were repeated twice, with at least a 30 s rest in between each repetition. The maximum load was used as the ramped isometric target load, and to calculate the 70% maximum load used during dynamic testing. The one repetition maximum (1RM) for the dynamic bench press plus exercise was calculated by the Bryzcki equation, using the number of repetitions a subject was able to perform sub-maximally to determine their 1RM (Bryzcki, 1995). The testing order of these maximal load tests was randomised.

Dynamic tests included shoulder flexion, extension, abduction, adduction and bench press plus. The bench press plus, was performed seated and through range from 20° shoulder extension to 90° shoulder flexion, followed by full range scapular protraction