ON THE APPROPRIATENESS OF ESTIMATING INTRAMUSCULAR MYOELECTRIC SIGNALS FROM SURFACE ELECTRODES FOR THE ROTATOR CUFF

[1]Rebecca L. Brookham, [1]Danielle L. Waite and [1*]Clark R. Dickerson
[1]University of Waterloo, Waterloo, Ontario, Canada
*email: cdickers@uwaterloo.ca

INTRODUCTION

Surface electrodes are commonly used in recording electromyographic (EMG) signals as surrogates of muscle force. Surface electrodes are inexpensive, easy to use and non-invasive; but are only useful for monitoring superficial muscles, and their large (non-specific) pick-up volume can result in frequent signal cross-contamination. Intramuscular (fine wire) electrodes are less commonly used due to their cost, required insertion-expertise, and invasiveness to participants. Due to the small size and depth of the rotator cuff musculature, their accessibility for surface recordings is difficult, and in the case of the subscapularis, impossible. Previous studies have compared simultaneous signals from surface and intramuscular recordings to determine if surface electrodes approximate the activity of deep muscles [1-5]. To our knowledge, no reported data exists that systematically compares surface and indwelling EMG activity levels for the rotator cuff musculature. Thus, the purpose of this study was to quantify the nature of the relationship between surface and intramuscular recordings of the rotator cuff muscles (excluding subscapularis), in order to assess if the surface electrodes can be used to predict intramuscular electrode activity. It was hypothesized that surface measurements would overestimate intramuscular values, and that the identified relationships would depend on exertion type and arm posture.

METHODS

12 right-hand dominant males [mean: 20.7 years, 76.7 kg] participated after providing informed consent. Exclusion criteria included a history of upper limb or low back injury in the past 6 months, or known neuromuscular, cardiovascular or metabolic conditions. Bipolar intramuscular electrodes (27 gauge needles, 44 gauge wires) were inserted into the supraspinatus, infraspinatus and teres minor [6]. Bipolar Ag/AgCl surface electrodes were placed on the skin surface over the supraspinatus and infraspinatus. Subjects performed two maximal voluntary contractions (MVCs) specific to each of the recorded muscles, followed by 20 maximal isometric exertions: shoulder flexion and abduction at 45º and 90˚ elevation, and a reference position (0º elevation - arm at side), with force being directed from the hand on the palmar and dorsal aspects of the hand and radial and ulnar aspects wrist. These 20 exertions were organized into groups based on hand *force direction* (palmar, dorsal, radial, ulnar) and *posture* (neutral, 45° and 90° humeral flexion, 45° and 90° humeral abduction). Exertion duration was 6 seconds, with 2 minutes rest between exertions. EMG was linear enveloped (single pass, low-pass Butterworth filter, 3 Hz cutoff), and normalized for each subject and each muscle (Figure 1). Mean normalized EMG was then calculated during a 2 second window (time 2 - 4 seconds). Linear least squares best fit regressions (unconstrained, and constrained with zero intercept) were used to compare: supraspinatus intramuscular and surface signals; infraspinatus intramuscular and surface signals; and intramuscular teres minor and surface infraspinatus signals. The intramuscular signals were considered the true representation of muscle activity. Variance explanation (r^2) was calculated to determine how linearly related the

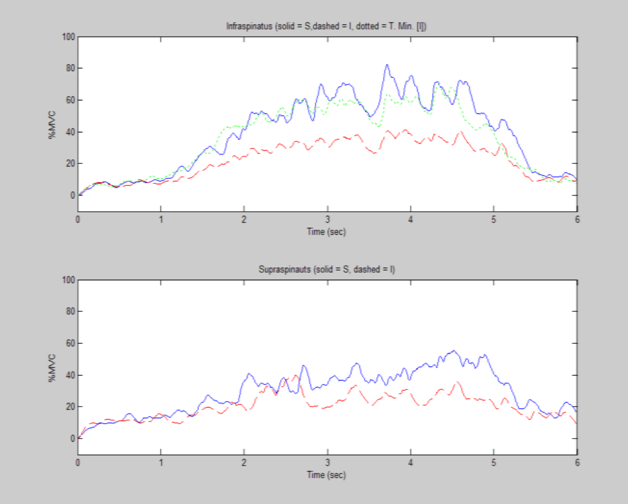

Figure 1: Normalized EMG: [Top] surface infraspinatus (solid), intramuscular infraspinatus (dashed), intramuscular teres minor (dotted); [Bottom] surface supraspinatus (solid) and intramuscular supraspinatus (dashed).

signals were. These relationships were further examined using *force direction* and *posture* as additional model effects in the linear regression; post hoc analysis (Student's t test) indicated significant differences between variables within groups. Trials containing signal artifact (identified visually) were excluded from analyses.

RESULTS

These comparisons resulted in the equations listed in Table 1, and indicated the following for traditional and zero intercept fit lines, respectively:

- Surface supraspinatus electrode overestimated the intramuscular electrode by 88.7% MVC (+ bias), and 81.8% MVC (eq'ns 1-2; Figure 2).
- Surface infraspinatus electrode overestimated the intramuscular electrode by 185.7% MVC (+ bias), and 156.4% MVC (eq'ns 3-4).
- Surface infraspinatus electrode overestimated the intramuscular teres minor electrode by 270.4% MVC (+ bias), and 244.8% MVC (eq'ns 5-6).

Post hoc analysis indicated there was a significant difference between *force direction* for supraspinatus ($p < 0.01$) and infraspinatus ($p < 0.01$) signals, however, as inclusion of this model effect only improved the explained variance by 3%, a more parsimonious model (without this model effect) was preferred. There was no significant difference found between *postures* in any comparisons.

Table 1: Linear least squares best fit regressions

	Regression Equations	**r^2**
1	$EMG_{S,FW} = 20.32 + 0.53*EMG_{S,SF}$	0.73
2	$EMG_{S,FW} = 0.55* EMG_{S,SF}$	0.73
3	$EMG_{I,FW} = 18.33 + 0.35* EMG_{I,SF}$	0.40
4	$EMG_{I,FW} = 0.39* EMG_{I,SF}$	0.40
5	$EMG_{TM,FW} = 21.01 + 0.27* EMG_{I,SF}$	0.61
6	$EMG_{TM,FW} = 0.29* EMG_{I,SF}$	0.61

Note: S = supraspinatus, I = infraspinatus, TM = teres minor, FW = fine wire, SF = surface

DISCUSSION

Quantifying the relationship between rotator cuff surface and intramuscular electrodes proved our first hypothesis to be correct: surface electrodes overestimated their respective intramuscular electrode signals during maximal exertions. However, explanation of these relationships did not markedly change when *posture* was considered, and was only minimally altered when *force direction* of task was considered. Explanations of variance for supraspinatus and teres minor intramuscular predictions were good (greater than 60%), suggesting that these surface electrodes may be used for estimating intramuscular activations in these muscles, albeit with an sizeable offset as defined by multiplicative coefficients (Table 1) to correct for overestimations. Conversely, explanation of variance was low for infraspinatus intramuscular predictions (perhaps due to differences in recorded fiber orientations), suggesting that the use of surface infraspinatus electrodes to estimate intramuscular signals may be problematic. Past works have shown good agreement between surface and intramuscular signals [1-3], while others have shown slightly better agreement between adjacent (rather than underlying) muscles ($r^2 = 0.8$ vs. $r^2 = 0.6$) [4]. Further research is needed to test these relationships for the shoulder in other force directions and postures, and during submaximal exertions, which are partly responsible for the large offsets in our equations. These findings could potentially simplify experimental measurement of shoulder muscle activity, at least for supraspinatus and teres minor.

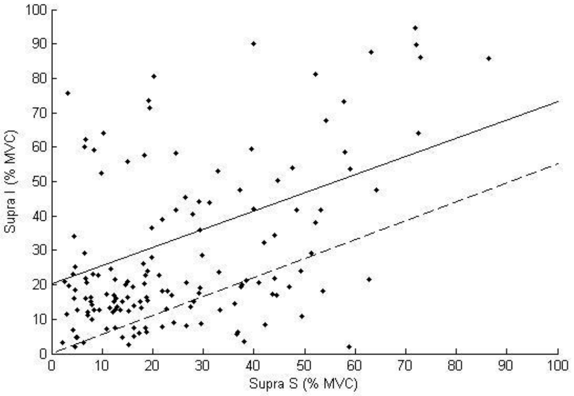

Figure 2: Prediction of supraspinatus intramuscular via surface electrode. [Best fit line (solid) and forced-zero intercept line (dotted)]

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