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Clinical Biomechanics xxx (2002) xxx–xxx
CLINICAL BIOMECHANICS
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Surface EMG electrodes do not accurately record from lumbar multifidus muscles

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Received 11 June 2002; accepted 4 October 2002

Abstract

Objective. This study investigated whether electromyographic signals recorded from the skin surface overlying the multifidus muscles could be used to quantify their activity.

Design. Comparison of electromyography signals recorded from electrodes on the back surface and from wire electrodes within four different slips of multifidus muscles of three human subjects performing isometric tasks that loaded the trunk from three different directions.

Background. It has been suggested that suitably placed surface electrodes can be used to record activity in the deep multifidus muscles.

Methods. We tested whether there was a stronger correlation and more consistent regression relationship between signals from electrodes overlying multifidus and longissimus muscles respectively than between signals from within multifidus and from the skin surface electrodes over multifidus.

Results. The findings provided consistent evidence that the surface electrodes placed over multifidus muscles were more sensitive to the adjacent longissimus muscles than to the underlying multifidus muscles. The R^2 for surface versus intra-muscular comparisons was 0.64, while the average R^2 for surface-multifidus versus surface-longissimus comparisons was 0.80. Also, the magnitude of the regression coefficients was less variable between different tasks for the longissimus versus surface multifidus comparisons.

Conclusions. Accurate measurement of multifidus muscle activity requires intra-muscular electrodes.

Relevance

EMG is the accepted technique to document the level of muscular activation, but its specificity to particular muscles depends on correct electrode placement. For multifidus, intra-muscular electrodes are required.

Keywords: Electromyography; Multifidus; Muscles; Lumbar spine

1. Introduction

Electromyography (EMG) provides a method to estimate the degree of muscular activation, by recording potentials from electrodes placed within or close to a selected muscle. For placement within the muscle, fine wires with uninsulated tips, or needles with electrodes built into them transduce these signals directly, but from a selected region of the muscle. Alternatively, electrodes (typically of a Ag–AgCl design) are adhered to the skin overlying the muscle to provide an indirect measure of muscle generated potentials. These two methods have relative advantages and disadvantages. The most salient advantages are the non-invasive nature of the surface electrodes, and the anatomical specificity of the intra-muscular electrodes. Indwelling electrodes sample from a small volume of muscle whereas surface electrodes sample a large volume (Basmajian and De Luca, 1985).

Surface electrodes may record from several muscles at the same time ('crosstalk'), and may move relative to these muscles as the subject performs a task. It is therefore important to know the sensitivity of each

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0268-0033/02/$ - see front matter © 2002 Published by Elsevier Science Ltd.
PII: S0268-0033(02)00140-7

surface electrode to the activity in each of the muscles close to it. This paper concerns the multifidus muscles in the human lumbar region. Recently, it has been proposed that the activity in the multifidi could be recorded by electrodes positioned on the skin overlying them. The evidence for this came from observed correlations in the range 0.88–0.95 ($n = 36$) between the amplitudes of the EMG signals recorded from intra-muscular electrodes placed within multifidi muscles at the L2 and L5 levels, compared to skin surface electrodes, 20 mm lateral to the midline (Arokoski et al., 1999). The signals were recorded from 11 healthy subjects who performed therapeutic exercises that activate the trunk muscles. These findings have subsequently been used to justify the use of surface electrodes to obtain measurements of the activation of the multifidus muscles (Ng et al., 2002a,b).

A difficulty in interpreting correlations between EMG signals is that such a correlation may result in part from crosstalk associated with coactivation of adjacent muscles. In the case of multifidus muscles, other muscles such as longissimus overlay the multifidi, so the signals recorded at the surface could be due to activation of longissimus in addition to activation of the more distant multifidi. If the EMG signals were recorded during an activity in which the superficial muscles were coactivated in proportion to the activation of the multifidus muscles, then the high correlation might result from the crosstalk phenomenon. However, in this situation it would not be possible to determine the source of the surface electrode signals precisely without additional information about the relative activation of all muscles contributing to the transduced signal.

The objective was to determine, using regression analysis, whether EMG signals from surface electrodes over the multifidi provided a signal that corresponded more closely with the signal from the wire electrodes within the multifidi at L2 and L4 levels, than with the signals from more lateral surface electrodes overlying longissimus muscles. We tested the hypothesis that there was a greater correlation between signals from the two surface locations (overlying multifidus and longissimus) than between signals from the surface electrodes overlying multifidus muscles and the underlying wire electrodes. Also, we hypothesized that there would be a less variability in the regression coefficient for different tasks in the surface–surface electrode relationships than in the surface–wire EMG electrode relationships.

2. Methods

Three male subjects (18, 24, 24 years old; bodymass 74, 76, 76 kg respectively) were studied with Institutional Review Board approval and informed consent. EMG signals were recorded as each subject performed ramped isometric efforts up to a voluntary maximum while standing in an apparatus that immobilized the pelvis. The resistance was provided by a harness around the thorax connected to a cable that was attached to each of a series of three anchor points on the walls to the right of the subject. This produced an angle of pull at either 0°, 45° or 90° to the anterior direction. Tests were also performed at 135°, but at this angle the muscle activation of the dorsal muscles was too little to provide EMG signals that could subsequently be analyzed. A load cell in the cable recorded the force generated. The support frame had pads pressing on both anterior superior iliac spines and sacrum to minimize motion of the pelvis (Stokes et al., 2000). At each angle, the subject performed the pulling task three times, with a brief rest period between trials.

Intra-muscular wire electrodes recorded EMG signals from four locations within the multifidus muscles at symmetrical (right and left) locations at the levels of L2 and L4. Surface EMG electrodes (Delsys Inc. Type DE-02.3, Boston, MA USA) were placed immediately cephalad to each of the insertion points of the intra-muscular electrodes. In addition, surface electrodes were positioned bilaterally over the longissimus, 30 mm lateral to the L3 spinous process. The intra-muscular electrodes were called ‘intra-multifidus’. The surface electrodes overlying the intra-muscular electrodes were called ‘surface multifidus’. The lateral surface electrodes were called ‘surface longissimus’. A reference ground electrode was placed over the lateral epicondyle of the left elbow. The surface electrodes have 10 mm × 1 mm silver bar electrodes with 10 mm spacing; their single differential amplifiers have a nominal gain of 1000, bandwidth 20 Hz to 450 kHz, 92 dB (typical) common mode rejection ratio, and 10^{12} Ω input impedance.

The intra-muscular electrodes were made with nylon-insulated twisted wire pairs connected to Motion Control Inc., Type 3030001 (Salt Lake City, UT USA) differential preamplifiers taped to the adjacent skin. These preamplifiers have a nominal gain of 3000, 10 Hz to 24 kHz bandwidth, >100 dB common mode rejection ratio and 10^{11} Ω input impedance. The intra-muscular electrodes were fabricated from 50 μm gauge nickel alloy wire, with a 2 mm long uninsulated section at the ends. These ends were bent to make a ‘hook’, with setback 2 mm on one wire and 4 mm on the other. The twisted wire pairs were threaded through a 26 gauge hypodermic needle that was used to insert the wires, and subsequently withdrawn to leave the wires in place. Previously, ultrasound imaging with the subject in the prone position was used to locate an entry point for each needle and a depth for insertion. The electrode insertion point was 10 mm lateral to the midpoint of the L4 or L2 spinous process. The depth was calculated as the distance from the skin to the vertebral lamina (as measured from the ultrasound image), less 5 mm. This placed the uninsulated sections of the two wires at a nominal distance of 9 mm from the lamina, which was considered to be the middle of the deepest fascicle of the multifidus muscles (Haig et al., 1991).

EMG signals were digitized at 2048 Hz and recorded. Subsequently the recorded signals were bandpass filtered (10–100 Hz by a Chebyshev type II no-lag filter) and then rectified and further filtered by a 293 ms root-mean-square filter. This filtration eliminated high frequency components of the signal, to provide a signal whose variance was primarily associated with the changing force, as shown in the sample in Fig. 1. Linear regression analysis between pairs of signals from a specific trial provided the coefficient of determination (R^2) and the regression coefficients (intercept and slope).

Statistical methods were used to test two hypotheses:

(1) That the correlation coefficients between the surface-multifidus and intra-multifidus recordings would be less than the correlations between the surface-multifidus and the surface-longissimus recordings. This hypothesis was examined by a two-tailed paired *t*-test comparing R^2 values for the surface–surface signal correlations with the wire–surface signal correlations.

(2) That the linear regression slopes would be less variable between recordings from different load angles for the intra-multifidus versus surface-longissimus signal regressions than the intra-multifidus versus surface-multifidus signal regressions. This hypothesis tested whether the relationship was more consistent for signals from electrodes that were detecting the same EMG signal. Differences were examined by comparing confidence intervals for the coefficient of variation (CV), calculated by the method of Wong and Wu (in press).

3. Results

Correlations were higher for the surface–surface electrode regressions than for the surface–wire electrode regressions. In all 12 cases (four multifidus sites, at each of the three force direction angles) the mean differences between R^2 values were positive, indicating that the correlations were greater for the surface–surface comparison than the wire–surface comparison. The differences were statistically significant in paired *t*-test comparisons ($P < 0.05$) for 8 of the 12 comparisons (Table 1).

In 7 of 10 cases, the regression coefficients were observed to be less variable in the surface–surface electrode regression relationships than in the surface–wire electrode regression relationships, based on the CVs of these coefficients (Table 2). In three of these 10 comparisons there was no overlap of the 95% confidence intervals for the CVs, indicating that the differences were statistically significant.

Because of technical problems with electrodes, one of the three subjects only provided data from the muscles on his left side.

4. Discussion

The findings of this study provide consistent evidence in support of the hypothesis that the surface electrodes placed over multifidus muscles were more sensitive to

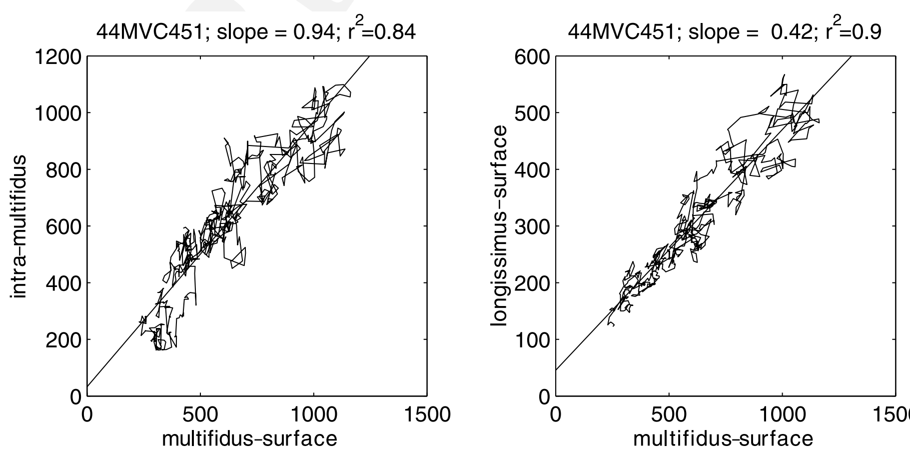

Fig. 1. Example of a regression analysis comparing EMG signals, here the intra-multifidus muscle signal (left panel) and that from the surface electrode over the longissimus muscle (right panel), both plotted against the surface-multifidus signal. The multifidus signals were recorded at L4 (left side) for an angle of pull of 45°. The straight lines indicate the linear regression relationship. The coefficient of determination (R^2) was used to test whether the association between signals from surface electrodes (right panel) was stronger than that between the indwelling and surface electrode (left panel). The slope of the regression relationship was used to test whether the relationships were consistent for different angles of pull.

Table 1
Mean squared correlation coefficients (R^2) between signals from pairs of electrodes, and mean paired differences between coefficients for wire–surface and for surface–surface regression relationships

Angle	Location	R^2 for intra-multifidus versus surface multifidus	R^2 for surface-multifidus versus surface-longissimus	Difference between R^2 values (* indicates $P < 0.05$)	SE of difference
0°	L2 left	0.871	0.948	0.077*	0.032
	L4 left	0.794	0.896	0.101*	0.023
	L2 right	0.892	0.927	0.035*	0.008
	L4 right	0.907	0.953	0.047*	0.011
45°	L2 left	0.820	0.922	0.102*	0.038
	L4 left	0.872	0.923	0.051*	0.019
	L2 right	0.442	0.610	0.168	0.101
	L4 right	0.677	0.865	0.188*	0.044
90°	L2 left	0.444	0.479	0.034	0.073
	L4 left	0.364	0.676	0.311*	0.134
	L2 right	0.131	0.592	0.460	0.183
	L4 right	0.451	0.773	0.323	0.131

In all cases the mean coefficient is greater in magnitude for the surface–surface correlations than for the surface wire correlations.
Wire–surface = correlation of intra-multifidus signal versus surface-multifidus signal.
Surface–surface = correlation of surface-multifidus signal versus longissimus signal.

Table 2
CV (standard deviation/mean) of the regression slopes

	L2 left	L2 right	L4 left	L4 right
Subject 1				
Wire/surface	0.65	1.39	0.14	1.44
Surface/surface	0.26	0.98	0.29	0.28
Difference	0.39	0.41	−0.15	1.16*
Subject 2				
Wire/surface	1.27	–	0.20	–
Surface/surface	0.22	–	0.36	–
Difference	1.05*	–	−0.16	–
Subject 3				
Wire/surface	0.56	1.31	0.78	2.40
Surface/surface	0.64	0.47	0.34	0.44
Difference	−0.08	0.84	0.44	1.96*

Values in each cell correspond to three angles and three trials. Values were not available for Subject 2, right side. Positive differences indicate that the regression slopes between surface multifidus and wire multifidus signals were more variable than the regression slopes between surface multifidus and surface longissimus signals.
* Difference significant ($P < 0.05$).

activity in the adjacent longissimus than to activity in the underlying multifidus muscles.

The report by Arokoski et al. (1999) suggested that surface electrodes were sensitive to multifidus muscle activity, based on the high correlations that were observed between mean and maximum signals from surface and wire electrodes. The authors noted in their discussion that these correlations might have been a consequence, at least in part, of coactivaton of adjacent muscles, and the present study would support that inference.

Here, the correlations were observed to be lower when the angle of pull was 90° (i.e. when the subject pulls to the left). This may be due to low signal amplitudes, since at this angle the right-side muscles were considered to be antagonistic, and their EMG signals were of small magnitude. For wire electrodes the signals were about 1% of that at 0°, and about 4% of that at 45°; for surface electrodes 40% and 65% of the 0° and 45° values. However, this explanation for the lower correlations would not apply on the left side, as the level of activation observed from both surface and indwelling electrodes was substantial at all three angles. Instead we suspect that the lower correlation results from 'crosstalk' between surface electrodes, and their specific pattern of coactivation.

It is likely that the coactivation of multiple dorsal trunk muscles, combined with 'crosstalk' between signals from adjacent muscles can give a misleading impression that surface electrodes are sensitive to activity of deep muscles. The present study suggests that accurate measurement of multifidus muscle activity requires intra-muscular electrodes.

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