Computer-Aided Electromyography and Expert Systems, edited by J.E. Desmedt
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CHAPTER 11

Crosstalk in surface electromyography

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DESCRIPTION OF PROBLEM

Myoelectric activity detected with surface electrodes above a given muscle may be considered as a summation of filtered signals generated by a number of concurrently active motor units. Surface detection is preferred to needle detection when 'global' information is desired about the time and/or intensity of muscle activation such as during gait analysis, biofeedback therapy, fatigue studies, prosthetic control, or other applications.

Unlike indwelling electrode techniques, surface detection may lack selectivity. Furthermore, current distribution and transfer function between signal source and detection point are poorly defined and strongly affected by local tissue properties and electrode position. As a consequence, a surface detected signal may contain contributions from muscles in the vicinity of the one over which the electrodes are placed. This may lead to erroneous conclusion of 'coactivation'. The problem has been identified and described by Denny-Brown (1949) who wrote " . . . if a muscle is the seat of an intense discharge its electrical activity can be recorded with ease from totally inactive or denervated muscles . . .". Further contributions came from Gath and Stålberg (1977) and from Gydikov et al. (1982). Evidence of apparent coactivation has been reported in a number of recent papers (Mangun et al., 1986; Nielsen et al., 1986; Hutton et al., 1988).

Recently, Morrenhof and Abbink (1985) measured the amplitude of signals detected with surface and wire electrodes respectively placed above and in the biceps femoris, the semitendinosus and the adductor magnus muscles in the human thigh. Eight pairs of surface electrodes equally spaced along an arc over the three muscles provided correlated signal showing a signal spreading over a surface area much larger than that associated with the individual muscle.

However, during the voluntary contractions in the Morrenhof and Abbink experiments the three muscles were simultaneously active, albeit to different degrees. This condition is less than ideal for crosstalk measurements although very difficult to avoid during voluntary contractions. The correlation coefficient between two surface detected signals has been used by these, as well as other authors, as an index of crosstalk. However, the correlation coefficient does not necessarily provide reliable information about the amplitude of the volume conducted signal for at least two reasons. As suggested by Broman et al. (1985), tissue filtering function, anisotropy and inhomogeneity may alter the phase relationship of the signal components changing the waveform and thus affecting the value of the correlation coefficient. Also, the common-drive control of synergistic or antagonist muscles, which has been shown by De Luca and Mambrito (1987), may lead to a falsely high value of correlation.

In a recent report, Etnyre and Abraham (1985) have shown that during voluntary contractions of the tibialis anterior muscle a myoelectric signal could be detected with surface electrodes located above the soleus muscle, whereas no signals were detected with wires inserted in the same muscle. This finding is consistent with the volume conduction theory. That is, if a source is modeled as a dipole, the potential would be inversely related to the square of the distance from the source. The differential potential between two closely spaced intramuscular electrodes may, therefore, be much smaller than that between two widely spaced electrodes on the skin.

Another related study by Perry et al. (1981) compared myoelectric signals obtained with surface electrodes to those obtained with intramuscular wire electrodes. Their results suggested that the surface myoelectric signal on the soleus or gastrocnemius muscles could be expressed as a weighted average of the intramuscular signals from these two muscles plus those from the tibialis posterior muscle. Again, the three muscles were voluntarily and simultaneously activated during the test. The model of linear signal combination provides an interpretation of the data which is not necessarily the best or the only one possible.

The problem of volume conduction and crosstalk is relevant in reflex measurements as well as in voluntary surface EMG detection. Some investigators have detected a response on tibialis anterior concomitant with the H reflex induced in the soleus by stimulation of the posterior tibial nerve (Gottlieb et al., 1982; Myklebust et al., 1982; Nielsen et al., 1986). This work has been recently reviewed by Hutton et al. (1988) who observed a concomitant reflex on both the soleus and tibialis anterior elicited by posterior tibial nerve stimulation in six normal subjects. The reflex observed on tibialis anterior could not be blocked by antidromic stimulation of the common peroneal nerve (collision technique) therefore supporting the hypothesis of its origin as a volume conducted signal from the soleus source. Nielsen et al. (1986) performed an experiment that provides unquestionable evidence of crosstalk (Fig. 1). On 14 cats myoelectric activity was elicited in both triceps surae and tibialis anterior by electric stimulation of either the posterior tibial nerve or of L7 or S1 dorsal roots. The signal on the tibialis anterior was still present after transection of the common peroneal nerve, showing that it was not due to activity of that muscle.

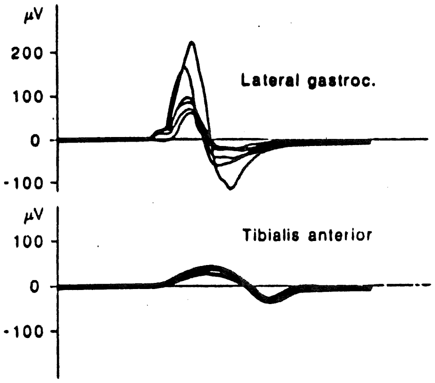

Fig. 1. Surface-detected reflex activity induced in cat's lateral gastrocnemius by stimulation of dorsal roots at L7 – S1 level and signal detected on the denervated tibialis anterior showing volume conduction. (Provided by R.P. Nielsen)

Presence of myoelectric signal in denervated muscles of cats and salamanders was also demonstrated by Mangun et al. (1986). These authors chronically implanted stainless steel electrodes in the popliteal fat pad, in the plantaris and in the medial gastrocnemius muscles of cats. During walking of the experimental animal, signals were detected from these locations following denervation of the implanted muscles. Such signals were associated to the activation of the biceps femoris and semitendinosus muscles. The signal detected in the popliteal fat pad had an amplitude in the order of 6 – 10% of that detected in the semitendinosus and 10 – 14% of that detected in the biceps femoris. Results from this work are mostly qualitative.

QUANTITATIVE ANALYSIS

Quantification of crosstalk due to volume conduction in humans is not trivial. An ideal paradigm would consist of activating one muscle at a time while measuring the volume conducted signals on the nearby muscles. While this task cannot be performed voluntarily it can be obtained with electrical stimulation as described by De Luca and Merletti (1988). In our experiments the main motor point of the tibialis anterior was stimulated in 12 healthy subjects using a monopolar technique with a 3 cm × 4 cm sponge electrode placed on the main motor point of the tibialis anterior muscle and an 8 cm × 12 cm sponge electrode on the gastrocnemius muscle. Current pulses of 0.2 ms duration and 20 Hz frequency were applied to elicit maximal M waves in the tibialis anterior.

Crosstalk measurements require the ability to discriminate between a volume-conducted signal propagating along the muscle fiber below the detection electrode. The necessary discrimination was obtained with the double differential technique described by Broman et al. (1985). The four-bar electrode used in this technique was placed on the lower part of the tibialis anterior muscle below the lowest motor point, to ensure the detection of a well-defined M wave generated by motor unit action potentials travelling in the same direction. The electrode was then moved around the leg on the soleus and peroneus brevis muscles and on the flat face of the tibial bone as described in Fig. 2. Single differential (SDMES) and double differential (DDMES) myoelectric signals were recorded on FM magnetic tape. A moist floating ground strap was applied between the stimulation and the detection electrodes whose circuitry were fully isolated. A number of precautionary expedients were applied in order to minimize amplitude and duration of the stimulation artefact. The details of the technique are described by Knaflitz and Merletti (1988). Residual artefacts were later removed by time-windowing the playback signal before processing.

Volume-conducted signals were identified as those generating output on the SDMES channel and no output on the DDMES channels. Three amplitude parameters were defined for the SDMES channels and employed as crosstalk indices. They were: normalized peak-to-peak amplitude, normalized average rectified values, and normalized root mean square values. All of the values were computed by averaging 60 M waves detected in a 3 s interval. The values recorded on the tibial bone, and on the peroneus brevis and soleus muscles were divided by the values corresponding to the maximal M wave recorded on the tibialis anterior muscle.

Fig. 3 (*A, B, C*) presents samples of SDMES recorded above the tibial bone, the peroneus brevis muscle and the soleus muscle as compared to that on tibialis anterior. The residual artefact (removed before processing) is evident. Fig. 3 (*D, E, F*) shows the single and double differential myoelectric signal present on the three detection sites. A low-amplitude DDMES is evident only on the tibial bone site due to its nearness to the source.

The absence of double differential signals indicates that the single differential signal was simultaneously present on all electrode pairs and

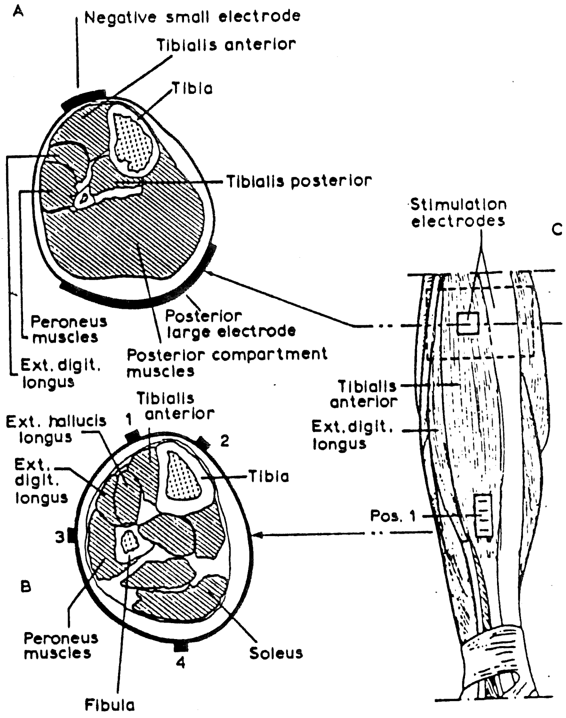

Fig. 2. Location of stimulation and detection electrodes. *A*: leg section at the stimulation electrode level; *B*: leg section at the detection level (1, 2, 3, 4 are the detection locations); *C*: front view of the leg.

therefore was volume conducted from a distant source and was not due to action potentials generated in the vicinity of the detection electrodes.

The average values and the standard deviations of the three crosstalk indices for the twelve subjects are presented in Table 1. The relationship between each crosstalk index and the leg circumference for the three detection locations is presented in Fig. 4. The slopes of the regression lines for the soleus and peroneus muscles are not significantly different from zero. The relationship between the crosstalk indices and the detection location are presented in Fig. 5, where they are plotted in order of increasing distance from the tibialis anterior muscle area.

The signals detected above the tibial bone are not crosstalk signals in the usual sense. Their presence indicates that the field generated by muscle action potentials is volume-conducted through the bone and the subcutaneous tissue. The large spread of values obtained in the tibial region (see Figs. 4 and 5) are likely due to variations in the thickness of such tissue layers in different subjects.

The lack of correlation between crosstalk and leg size also indicates the existence of a compensatory relationship between the source intensity and the tissue filter attenuation. Such compensa-

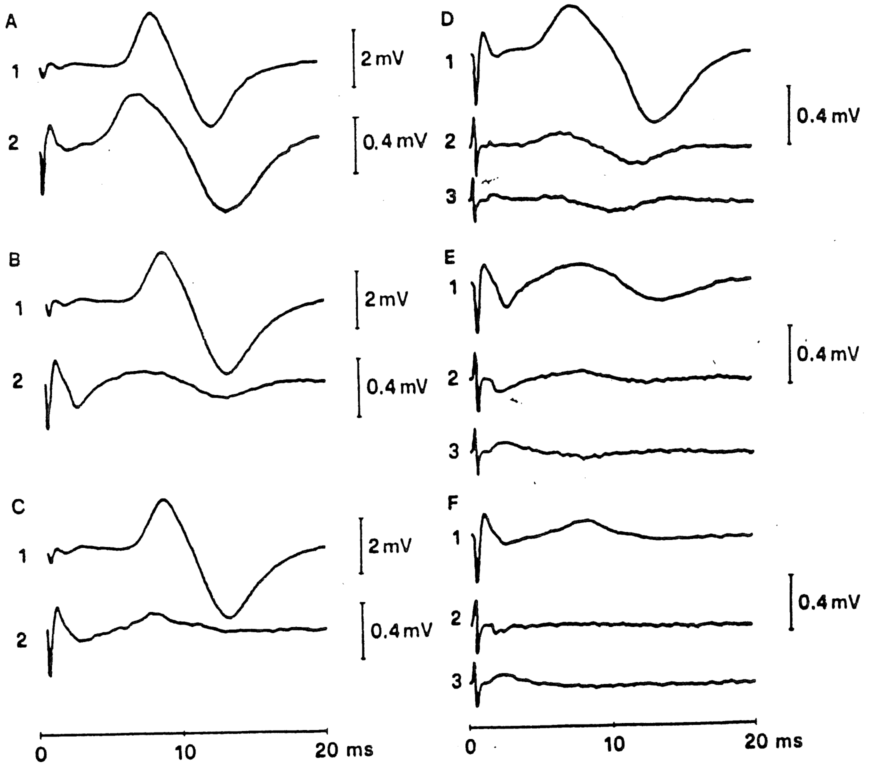

Fig. 3. Responses to supramaximal stimulation of the main motor point of the tibialis anterior muscle (0.2 ms and 20 Hz). *A1, B1, C1:* maximal single differential M wave elicited on the tibialis anterior muscle (repeated for comparison with *A2, B2, C2*). *A2, B2, C2:* single differential signals (volume conducted) on the tibial bone, on the peroneus brevis and soleus muscles. *D1, E1, F1:* single differential signals detected on the tibial bone, on the peroneus brevis and soleus muscles (as *A2, B2, C2,* repeated for comparison with *D2, D3, E2, E3, F2, F3*). *D2, D3:* double differential signals on the tibial bone. *E2, E3:* double differential signals on the peroneus brevis muscle. *F2, F3:* double differential signals on the soleus muscle. The absence of double differential signal in the peroneus and soleus muscles shows that the single differential signal is volume conducted.

tion is less evident in the tibial bone area due to the proximity of the source and the relatively low level of conductivity of the bone. Predictably, larger legs with greater amounts of tissue over the bone yield higher signals in the tibial bone area. The smallest leg, with only skin over the bone, shows a tibial signal even smaller than that on the peroneus brevis area (Fig. 5). The SDMES on the tibial bone was approximately five times smaller than the one on the tibialis anterior muscle (Table 1); while the

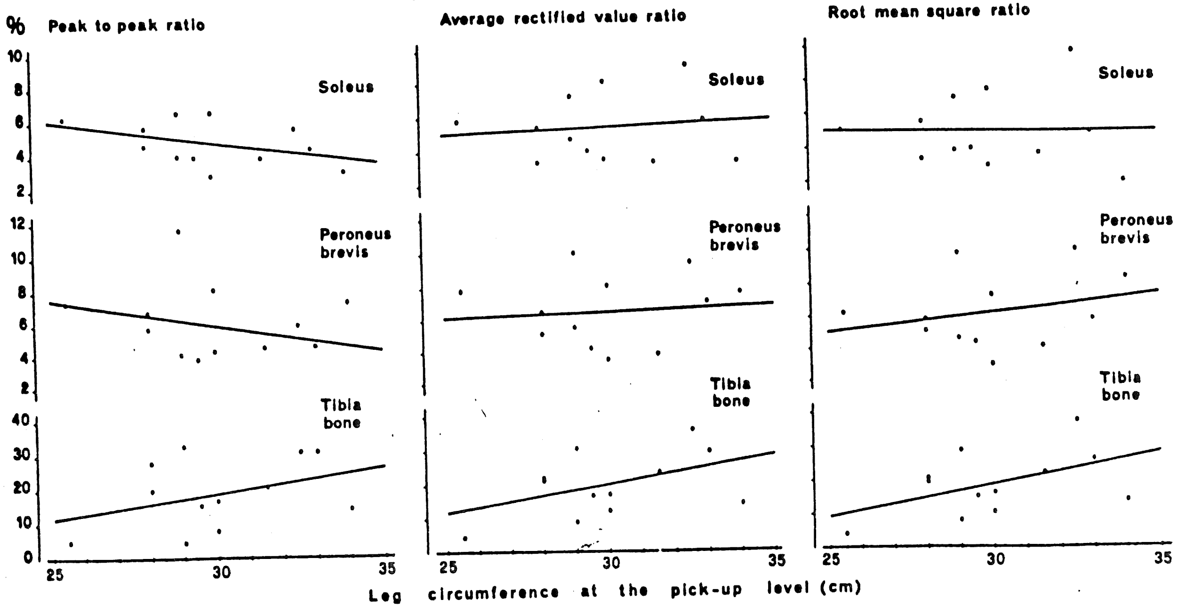

Fig. 4. Correlation between each crosstalk index and leg circumference at the detection level.

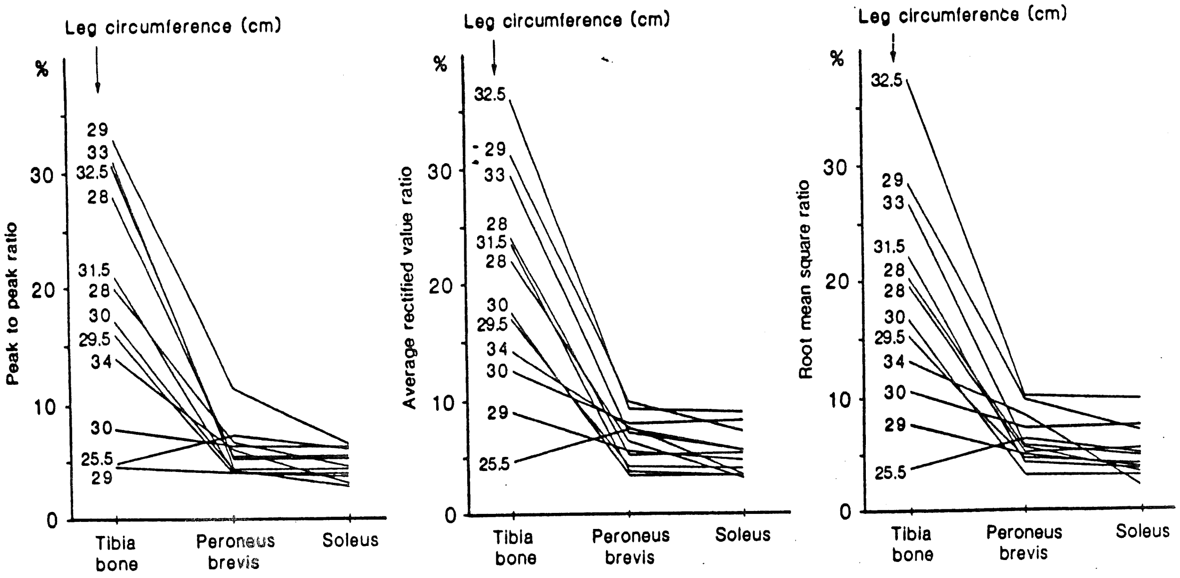

Fig. 5. Correlation between each crosstalk index and the detection point.

TABLE 1

Crosstalk indices – average values and standard deviation (in brackets) of 12 subjects

Detection electrode location	Peak-to-peak ratio (PP)	Average rectified value (ARV)	Root mean square value ratio (rms)
Tibialis anterior	100%	100%	100%
Tibial bone area	19.4% (9.4)	19.9% (8.8)	18.4% (9.0)
Peroneus brevis	7.0% (4.2)	6.5% (2.0)	6.2% (2.1)
Soleus	5.0% (1.5)	5.4% (1.9)	5.0% (23.1)

DDMES was more than 15 times smaller. On the peroneus brevis and soleus muscles the DDMES was at noise level (Fig. 3). As expected, the DDMES decreases with distance much faster than the SDMES measurements since the three SDMES obtained from the first set of amplifiers become more similar and less delayed as the source becomes more distant.

RESEARCH PERSPECTIVE AND CLINICAL APPLICATIONS

The technique proposed by De Luca and Merletti (1988) is being applied to other muscle groups of the limbs to provide a table of crosstalk indices between muscle couples. Such a table should be valuable to clinicians and researchers in establishing the reliability of surface myoelectric signal readings, particularly during multichannel detection such as in gait measurements and back muscles analysis.

Preliminary results concerning crosstalk among muscles of the thigh have been reported by Emley et al. (1987) and by Knaflitz et al. (1988) who used the technique described above. These authors found that during supramaximal stimulation of the vastus medialis, signals of up to 10.7% could be detected on the vastus lateralis while smaller signals were detected on the rectus femoris and on the hamstrings. Stimulation of the vastus lateralis generated a crosstalk signal of up to 18.2% in the rectus femoris while smaller signals were detected on the vastus medialis and on the hamstrings.

A second line of research deals with modeling aspects of the volume conduction phenomena with the purpose of estimating crosstalk originating from deep muscles that could not be easily stimulated with the required selectivity.

From the clinical stand point it is emphasized that particular caution should be exercised in interpreting surface myoelectric signals or surface detected reflex activities when nearby muscles may be activated. It is suggested that whenever there is reason to suspect muscle coactivation or concomitant reflexes, the myoelectric signal should be detected with the double differential technique. A low DDMES (5 – 10 times lower than the SDMES) would indicate that the single differential signal is volume conducted and is not representative of activity of the muscle below the electrode. Caution should be exercised, however, about the proper positioning of the four electrode probe with respect to the motor points of the muscle since the double differential signals are highly sensitive to action potentials travelling in opposite directions.

ACKNOWLEDGEMENTS

The cooperation of Dr. Marco Knaflitz is greatly appreciated.

We gratefully acknowledge the support provided for this work by Liberty Mutual Insurance Company and by the Ministry of Public Education of Italy through the Department of Electronics of the Politecnico di Torino, Italy.