Recent progress in the diagnostic use of surface EMG for neurological diseases

Machiel J. Zwarts a, b,*, Gea Drost a, b, Dick F. Stegeman a, b, c

a Department of Clinical Neurophysiology, Institute of Neurology, University Hospital Nijmegen, PO Box 9101, 6500 HB Nijmegen, The Netherlands
b Institute for Fundamental and Clinical Human Movement Sciences, The Netherlands
c Motor Research Group, Institute of Pathological Physiology, Friedrich-Schiller University, Germany

Abstract

The different techniques to measure and analyze surface EMG are summarized with an emphasis on the clinician’s point of view. The application of surface EMG in neurological disease is hampered by many inherent problems, especially the difficulties in extracting features of single motor units. However, the evolution of surface EMG from single bipolar recordings via a linear array of multiple electrodes to densely packed, multi-channel electrode arrays could in principle solve this problem. The added value of using multiple channels (up to 128) with an interelectrode distance of a few millimetres to obtain more spatial information is emphasized. At least for some muscles it is now possible to extract information from the surface EMG, conventionally thought to belong to the domain of needle EMG (for example the “electrical size” of motor units). The use of analysis techniques such as the estimation of muscle fiber conduction velocity has already proven to be of diagnostic value in several myopathies characterized by a disturbed membrane function and in metabolic myopathies with abnormal fatigue profiles. Future research should be directed at the development of analysis techniques enabling the extraction of more relevant motor unit variables from surface EMG signals. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

In a recent technology assessment study of Haig et al. [4] issued by the American Association of Electrodiagnostic Medicine (AAEM) after a computer literature search from 1964 to 1994 and the analysis of 2600 manuscripts regarding clinical applications of surface EMG (SEMG), the following was concluded: “There is in fact almost no literature to support the use of SEMG in the clinical diagnosis and management of nerve or muscle disease”. Of course, such a disappointing conclusion challenges workers in the field of surface EMG to develop better, more useful techniques in the diagnosis and follow-up of neuromuscular disease. Furthermore, since this assessment study deliberately excluded the estimation of muscle fiber conduction velocity (MFCV) and applications during fatigue it can be argued if the above conclusion is fully justified. The electrophysiological determinants of (pathological) muscle fatigue have already shown to be the exclusive domain of SEMG [8–10,15,16]. Comparing SEMG with needle EMG information content as a golden standard will degrade the former. More important seems to be the issue of what SEMG can add to needle EMG information and vice versa. A major obstacle in applying SEMG is the impossibility of measuring the spontaneous activity of denervated muscle fibers, which is so important in conventional needle EMG. Noninvasive measurement of motor unit activity with SEMG is used now both in the central and peripheral nervous system (see Table 1). Although it can only be used on a small set of suitable muscles, the study of propagation and other topographical aspects of voluntary activated motor unit potentials (MUPs) along an array of electrodes [1,11,13] potentially uncovers otherwise inaccessible physiological information.

* Corresponding author.
Table 1
SEMGG applications in neurology

<table>
<thead>
<tr>
<th>Central nervous system</th>
<th>Peripheral nervous system</th>
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<tbody>
<tr>
<td>Timing</td>
<td>Evoked activity</td>
</tr>
<tr>
<td>Movement patterns</td>
<td>CMAP (amplitude/area)</td>
</tr>
<tr>
<td>Amount of activity/central drive</td>
<td>Voluntary activity</td>
</tr>
<tr>
<td>Involuntary movements</td>
<td>Amplitude/frequency</td>
</tr>
<tr>
<td>Central fatigue</td>
<td>Fatigue</td>
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<tr>
<td>Tremor</td>
<td>Endplate localization</td>
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</table>

2. Applications

2.1. Central nervous system

Due to the high (theoretically unlimited) temporal resolution of electrophysiological measurements, SEMG has long been used in the assessment of central nervous system activation of muscles. Applications are the measurement of timing and duration of CNS output, for example, in movement disorders such as dystonia and tremor. The same kind of analysis can be applied on complicated movement patterns such as gait and gait disorders. The combination of multiple SEMG derivations combined with for example an accelerometer gives a good visual representation of difficult movement disorders. In orthostatic tremor, for example, this kind of measurement is essential for diagnosis [14]. Due to the high tremor frequency (around 16 Hz) the mechanical output of the muscle is almost fused, which makes it virtually impossible for the clinician to recognize the tremor component. With SEMG measurements this specific tremor is easy to diagnose.

2.2. Peripheral nervous system

Initially, for the peripheral nervous system, clinical applications of surface EMG have been cumbersome. However, there has been an evolution in electrode design which has made it possible to derive increasingly basic information from the SEMG (see Fig. 1). Using a mono- or bipolar EMG derivation it is possible to measure amplitude and frequency content of voluntary contractions. Examples of extreme neurogenic conditions measured with bipolar SEMG are given by Hermens et al. [5]. However, in general this is of very limited value from a clinical point of view. Adding a second electrode pair and aligning these parallel to the muscle fibers made it possible to measure the MFCV with a surface technique.

2.2.1. Abnormal fiber conduction velocity

In two myopathies characterized by membrane disturbances, hypokalemic periodic paralysis (HOPP) and myotonia congenita (MC) severe disturbances of MFCV were found [7,15,16], enabling the detection of asymptomatic carriers in the HOPP family (Fig. 2). The conventional needle EMG findings in these patients were not of diagnostic value. Coupled to the MFCV, a significantly lowered median frequency \( F_{\text{med}} \) was also found in these patients (Fig. 3). However, the variability of the frequency parameters was clearly larger than that of MFCV estimation and the latter was obviously superior in detecting affected relatives.

In ALS we found a significantly increased MFCV (4.9 m/s versus 4.2 for controls). However, the \( F_{\text{med}} \) was lowered in this ALS group (72 versus 80 Hz for controls). These results were compared with an invasive technique for measuring the MFCV of single muscle fibers. The invasive MFCV results were clearly lower in the ALS group [6] as compared with the SEMG results. The differences between these techniques are probably due to the fact that with SEMG only MUPs of surviving motor units are measured. These motor units try to compensate for the force loss and part of this adaptation is an increased muscle fiber diameter with higher conduction velocities as a consequence. The invasive technique also measures the conduction of denervated muscle fibers. It is interesting to note in connection with the introductory remarks that in that study invasive EMG and surface EMG give complementary information: the invasive EMG shows the drop out of fibers while the SEMG shows the physiological adaptation of surviving motor units (MUs).

2.2.2. Pathological fatigue

Abnormal behaviour of MFCV during fatigue tests in McArdle’s disease and type I fiber dominance was shown by Linssen et al. [8,9]. In a patient with carnitine deficiency, an abnormal increase in median power frequency of SEMG of the vastus lateralis was shown [2]. In recessive myotonia congenita an abnormal lowering of MFCV, median frequency and amplitude of SEMG [16] accompanied a fast decline in force.

2.3. Topographical changes

The last step in the development of electrode design (Fig. 1) is the multi-channel high density electrode. With such arrays it is possible to obtain information from the SEMG with regard to the topography of MUPs. Masuda and Sadoyama [11] have shown that endplate detection is possible in this way. More elaborate analysis with a multielectrode grid has shown the possibility of estimating the position, and direction of the MUP, endplate zone and muscle–tendon transition. The amplitude decline perpendicular to the MU indicates the depth of the MU [3,12,13].
electrode type | illustration | possibilities/perspectives
---|---|---
High density multielectrode grid | | -motor unit recognition
Long array (cross) | -Endplate detection
Small linear array | -Motor unit parameters: depth and amplitude
Monopolar | -Muscle fiber conduction
| | -Amplitude
| | -Frequency content
| | -Timing

Fig. 1. The development of increasingly complex electrode arrays for surface EMG is shown from bottom to top. For each electrode configuration the added physiological information is summarized in the right column. (From Refs. [13,18,5], respectively, with permission.)

3. Methodology

As is also true for a conventional electrodiagnostic study in neuromuscular diseases, application of a standard SEMG protocol is in general not useful. The measurements and especially the protocol of muscle activation should be chosen in relation to the clinical differential diagnosis and questions posed.

Until now, noninvasive measurement of MFCV has proven to be the most valuable tool in SEMG [1]. The method is especially useful in a limited number of myopathies characterized by a disturbed membrane function. It is interesting to note that profound and global reduction in conduction velocities of the muscle membrane are not detected with standard needle examinations but SEMG measurements resulted in clear abnormalities [15].

The MFCV is usually measured by calculating the time delay between two or more bipolar electrodes in a linear array (Fig. 1). Due to the small time differences between the two signals a high sample rate is necessary (in combination with linear interpolation) for a reliable estimate. Alternatively, the MFCV can be calculated by phase shifting in the frequency domain, this makes the time resolution as high as necessary, independent of the sampling rate [8–10].

A limitation of this technique is the fact that, until now, only a small number of muscles permit these measurements. The muscle must have a clearly delineated endplate zone and a parallel course of muscle fibers. Mostly, the biceps brachii, brachioradialis, vasti and distal parts of the tibialis anterior have been used.

An especially useful application with good prospects for the future is the electrophysiological study of pathological fatigue in myopathies. SEMG changes in normal fatigue are extensively described [17–19]. Abnormal changes in MFCV induced by fatigue are an important tool, especially due to the possibility of measuring MFCV during all kinds of voluntary contraction and at all levels of effort. It is important to choose the protocol according to the clinical situation. For example, in myotonia congenita an abnormal decline in force (and EMG amplitude and MFCV) is only demonstrated after a period of rest and within the first seconds of the contraction [16]. After repeated contraction these abnormalities subside. By the same token, it is necessary to apply prolonged, submaximal exercise in patients with carnitine deficiency to show an abnormal increase in median
Fig. 2. Examples of the normal (a) and reduced (b) MFCV in a family with hypokalemic periodic paralysis. The calculated MFCV values are 4.4 and 2.8 m s$^{-2}$, the cross-correlation coefficients are 0.95 and 0.97, respectively. The vertical calibration is 0.24 mV/div. Note the much lower frequency content of the signals from the patient (adapted from [15]).

Fig. 3. The power spectra of the same measurements as in Fig. 2. The median frequency of spectrum (a) corresponding to Fig. 2a is 86 Hz, the $F_{med}$ of spectrum b is 44 Hz. The horizontal calibration is 24.4 Hz, the vertical calibration is in arbitrary units (adapted from [15]).

The high temporal resolution of SEMG makes it an ideal tool to measure the motor output of the central nervous system in a variety of disorders and facilitates the analysis of complicated movement patterns. With respect to the peripheral nervous system, promising results have been obtained by the measurement of MFCV in myopathies characterized by membrane abnormalities and the changes in SEMG in pathological muscle fatigue.

The last decade has shown a development of increasingly complex SEMG array designs. The first results indicate that with these (two-dimensional) electrode configurations it is now possible to obtain information from the surface EMG regarding MUP variables, which originally was thought to belong to the domain of needle EMG.

**4. Conclusion**

The high temporal resolution of SEMG makes it an ideal tool to measure the motor output of the central nervous system in a variety of disorders and facilitates the analysis of complicated movement patterns. With respect to the peripheral nervous system, promising results have been obtained by the measurement of MFCV in myopathies characterized by membrane abnormalities and the changes in SEMG in pathological muscle fatigue.

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The power frequency of SEMG of the vastus lateralis [2]. During this kind of exercise, the muscle depends on lipid oxidation, which is disturbed in carnitine deficiency.

Recent developments in the analysis of MUP variables with SEMG using a multielectrode grid and the application of volume conduction theory promise new possibilities. Several properties of MUPs, until now assumed to belong to the domain of needle EMG, can be measured with SEMG [3,12,13]. Most importantly, the amplitude of MUPs as detected with a multichannel grid show high correlations with amplitude measurements of macro EMG recordings of the same MUPs [12]. This indicates that important parameters of the MUP can also be deduced from SEMG. In addition, with this technique, SEMG provides details concerning MU location, direction of fibers, endplate position and fibre–tendon transition, which are not accessible with conventional needle EMG.

A comparison between needle and SEMG limitations and benefits is provided in Table 2. As can be seen, needle EMG is versatile, quick and gives a unique opportunity to measure membrane instability. SEMG, on the other hand, provides unique spatial information besides conventional MUP variables such as amplitude. Being noninvasive and patient friendly, the application of SEMG in neurology certainly deserves further research.

### Table 2

Comparison between surface and needle EMG

<table>
<thead>
<tr>
<th></th>
<th>Needle EMG</th>
<th>Surface EMG</th>
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<tbody>
<tr>
<td><strong>General</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of muscles</td>
<td>Many</td>
<td>Limited</td>
</tr>
<tr>
<td>Analysis time</td>
<td>Short</td>
<td>Moderate</td>
</tr>
<tr>
<td>Quantitative data</td>
<td>Usually not, although possible</td>
<td>Generally</td>
</tr>
<tr>
<td>Patient acceptance</td>
<td>Limited due to pain</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Motor unit variables</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MUP amplitude</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Recruitment pattern</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>Spontaneous activity</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>Muscle fiber conduction</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td><strong>Spatial variables</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endplate position, fiber length</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>MUP position</td>
<td>Depth</td>
<td>Depth/direction</td>
</tr>
</tbody>
</table>
References


Dick Stegeman was born in Enschede, The Netherlands on 9 March 1951. He received the MSc degree in electrical engineering from the University of Twente, Enschede. In 1977 he joined the Laboratory of Medical Physics and Biophysics, University of Nijmegen. He worked on model studies of electrical nerve activity. In 1981 he received his PhD degree from the University of Nijmegen. In 1984 he was appointed as head of the physics group at the Department of Clinical Neurophysiology, Institute of Neurology, University of Nijmegen. In 1997 he was appointed part-time to work on the research program “Moving systems” at the Friedrich-Schiller University in Jena, Germany. His research interests include the physics of neurophysiological processes, the quantitative analysis and source characterization from the topography of EMG and brain activity.