Chapter 4.2

Standards of instrumentation of EMG

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Introduction

Since instrumentation and technical factors can distort neurophysiological signals during acquisition and display resulting in changes which are identical to those seen in diseases, it is essential for the electromyographer to know these factors and to be aware of them during the investigation. Earlier reports on electromyographic instrumentation were published in Electroencephalography and Clinical Neurophysiology (Guld et al. 1970, 1974) and in Recommendations from IFSECN (Guld et al. 1983).

Instrumentation

In general, the set-up for electromyographic measurements consists of electrodes, amplifiers, filters, a display unit with some measurement and analysing facilities, a device for storage and a stimulator unit (Fig. 1). During the test, the recording system must accurately reproduce the potentials generated by muscle or nerve fibres under investigation. The potentials range in amplitude from less than 1 µV to several mV and contain frequency components from 2 Hz to more than 10 kHz (Table 1). They exist within an environment of electrical noise which may be several orders of magnitude larger than the potential under investigation.

After amplification the signals are between 1 and 10 V and can be shown on an oscilloscope (analogue display) or a video monitor after analogue to digital (A/D) conversion which is now implemented in most modern EMG machines.

Amplifier

An EMG amplifier must be able to multiply the amplitude within a sufficient frequency range, to reject common mode signals and to recover fast after overload. The gain of the amplifier is the ratio between the output voltage and the input voltage and is for an EMG amplifier usually adjustable between 1000 and 1 000 000.

To record a neurophysiological signal, two electrodes are placed within the electrical field of the tissue under investigation and they are connected to a differential amplifier (Fig. 2). This measures the difference between two inputs that are connected to
a pair of electrodes. Most systems display negative voltages upward. In such a system the electrode which is connected to the input that produces an upward deflection is called the active or recording (erroneously different) electrode. The other is called the reference (erroneously indifferent) electrode. Ordinarily the electrodes pick up the signal of interest together with noise. The actually recorded signal can be regarded as a superposition of some signals, a differential signal and a common mode signal (noise signal). The common mode signal which contaminates the signal of interest comes from different sources, as main interference (50 or 60 Hz) and distant physiological generators. Other noise sources are thermally generated noise in the electrodes or amplifier and electrochemical instability on the surface of the electrodes.

Common mode signals (sometimes called in-phase potentials) are signals with the same amplitude at both electrodes. Since the differential amplifier responds mainly to differences between signals those undesired common mode signals are not amplified, whereas the signal of interest is amplified because it causes a difference of voltages between the two electrodes (Fig. 2). A good differential amplifier has a high common mode rejection ratio (CMRR). This important parameter of an EMG machine is calculated as the amplification of differential signals divided by the amplification of common mode signals. The CMRR should be very high to reject the common mode signals, for modern EMG machines it is in the order of 1 000 000 or even more. It is often expressed in dB, calculated as 20 times the logarithmic value of the ratio. The CMRR is frequency dependant and is normally given at 50 (60) Hz, for example 90 dB at 50 Hz. The CMRR is normally reduced at higher frequencies.

Lower frequency limit for the amplifier is usually 2 Hz or less and upper frequency limit is 10 kHz or higher. Frequency limits can be seriously degraded by electrodes and electrode cables. The electrode impedance and the cable capacitance form a RC (low-pass) filter. Electrodes with small recording areas have a high impedance (high R values). This may decrease the high-frequency cut-off resulting in a distorted waveform. To avoid attenuation of the signal the input impedance of the amplifier should be at least 100 times greater than the electrode impedance as this reduces the influence of electrode impedance on amplitude accuracy as well as on CMRR. This requires for example that the cables to input stage are shielded.

Low noise of the amplifiers is essential and should preferentially be given as peak-to-peak voltage, but is often given as root mean square

<table>
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<tr>
<th>TABLE 1</th>
<th>APPROXIMATE AMPLITUDE RANGE OF THE SIGNAL, FILTER SETTING, MAXIMUM FREQUENCY OF THE SIGNAL AND FREQUENCY RANGE REQUIRED FOR SAMPLING</th>
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<tr>
<td>Amplitude range of the signal (µV)</td>
<td>Filter setting</td>
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<tr>
<td>EMG (MUAP)</td>
<td>50–30000</td>
</tr>
<tr>
<td>SFEMG</td>
<td>300–10000</td>
</tr>
<tr>
<td>CMAP</td>
<td>100–30000</td>
</tr>
<tr>
<td>SNAP</td>
<td>0.1–100</td>
</tr>
<tr>
<td>Surface muscle recording</td>
<td>10–1000</td>
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</table>
(RMS) values. The frequency band should always be stated; typical values are 3 μVpp or 0.7 μVRMS, 2 Hz–10 kHz.

Sometimes the amplifier is overloaded, e.g. due to a stimulus artefact or a movement. It is important that the amplifier recovers before the signal of interest appears. Much modern EMG equipment has some kind of built-in protection against overload.

### Filters

The basic principle of a neurophysiological recording system is that the amplification of the signal must be linear in amplitude as well as in phase over the whole frequency band of the signal of interest. The system should reproduce the signal of interest as exactly as possible and it should reject other signals as much as possible. Filtering is an integral step in processing neurophysiological signals. Main functions of filters are: (i) noise reduction; (ii) suppression of artefacts and interfering potentials by reduction of the band pass to such a degree that the interesting part of the wave is not distorted – noise attenuation improves quality of the signal of interest and makes its interpretation easier; (iii) revealing information in a signal that may not be intuitive under ordinary conditions (e.g. single fibre action potentials).

The interesting frequency band is usually between 2 Hz and 10 kHz, but in special cases the upper or lower cut-off frequencies must be changed (Table 1). The frequency range of the system (bandwidth), i.e. the range between the low-frequency limit and the high-frequency limit, should be chosen to be as wide as necessary for undistorted recording and as narrow as possible for the reduction of unwanted signals. If the baseline is unstable, it may be necessary to increase the lower frequency limit. If much high-frequency noise is present, decreasing the upper limit may improve the quality of the recording. If the frequency band is limited, one must be aware that the signal may be distorted (Fig. 3). Filters may attenuate the amplitude of the signal and change the phase proportional to the relative deviation from the cut-off frequency (Barry 1991). The simplest analogue filter, a single order 20 dB/decade filter, attenuates signals by 30% (3 dB) and changes the phase by 90° at the cut-off frequency. One octave away from the cut-off frequency inside the band-pass attenuation is still 11% (1 dB) and phase shift still is 6°. One octave outside the band pass the attenuation is 60% (8 dB). As it can be seen, filters are not ideal. Even inside the band pass there are some attenuation and phase shift, and outside the band pass the attenuation is not 100% (Fig. 3). Therefore, it is essential to be careful when using filters. The effects of filters may be evaluated by comparing action potentials.
recorded with the total bandwidth (2 Hz–10 kHz) with the same signal recorded with reduced bandwidth (Fig. 3). Distortion may be significant using recording instruments with limited bandwidths (paper recorder, magnetic tape recorder).

Low-frequency filters (LFF; high pass filters) attenuate slowly changing components of a waveform. An increase in the low-frequency cut-off causes initial amplitude loss of slowly changing signals, waveform distortion, but more important it also decreases the latency to the peak of the waveform and introduces artefacts (i.e. a tail of the motor unit action potential). Recording motor unit action potentials (MUAP) the duration as well as the amplitude decreases when the cut-off is increased up to 500 Hz (Fig. 3). Using a 500 Hz cut-off the contribution from distant muscle fibres is lost because of the soft tissue itself acts as a high-frequency filter. Ideally the low limiting frequency should be one decade lower than the lowest frequency of the signal, to make sure that no phase shift will affect latencies. In that case, phase shift is only 1°. Movement artefacts contain slow frequencies. In some cases the only way to remove this artefact is to increase the lower limiting frequency. This is usually done for surface EMG recording of movements (e.g. tremor recordings).

High-frequency filters (HFF; low pass filters) attenuate high frequencies. A decrease in the high-frequency cut-off reduces the amplitude and rise time. Using too low high-frequency cut-off the system is not able to record the rise of the potential (containing the highest frequencies of the signal) adequately and possibly (i) lowers the amplitude, (ii) reduces the number of phases and (iii) prolongs the duration of the main peak component of the signal. Inadequate HFF can also affect the measurement of onset latency of a potential. It will be prolonged because the abrupt decline from the baseline is missed and more time elapses before the start of the potential can be noticed.

Notch filter is a special type of band stop filter. In electrophysiology it is normally designed to reduce power line interference (50 Hz or 60 eps). But in
Fig. 4. Analogue to digital conversion. The analogue signal is sampled at discrete time intervals and the amplitude is converted to a digital value. The number of horizontal points depends on the sampling rate. The signal can be reconstructed the better the higher the sampling is. The amplitude resolution depends on the number of bits of the A/D converter. Here, the situation for a 4 bit A/D converter is shown. It is obvious that the amplitude resolution is better when the whole range of the converter is used.

In general it should normally not be used as most neurophysiological signals contain significant components at this frequency. As notch filters are designed to attenuate these frequencies it may hide interesting components. In addition, the phase changes abruptly back and forth around the notch frequency and may distort the waveform.

Digital instrumentation

Modern EMG equipment uses digital computers for data sampling (analogue to digital (A/D) conversion) and for signal processing. Following amplification and filtering the amplitude of a neurophysiological signal is converted to a digital value and is sampled at discrete time intervals (Fig. 4). This offers the possibility to post-process the signals (using delay lines, making averages, changing display sensitivity and sweep speed, capturing waveforms) and allows the calculation of various waveform parameters.

The sampling rate is determined by the highest frequency component in the signal and the required time resolution (Table 1). Using appropriate algorithms it is possible to reconstruct the waveform in detail if the sampling rate is more than twice the highest frequency component of the waveform (Nyquist theorem). The reconstruction of a waveform from the Nyquist sampling rate would slow down the computer due to the high number of calculations necessary. Thus, to reproduce the signal by drawing straight lines between the sampling points a sampling frequency of at least 5–10 times the highest frequency component of the signal is required (Fig. 5). Therefore, the choice of the sampling frequency depends on the frequency characteristic of the signal (Table 1). Before A/D conversion the signal must be filtered (anti-aliasing filter) to remove the high-frequency components. Cut-off frequency should be chosen so that frequencies higher than half the sampling frequency are sufficiently attenuated. If signal components with frequencies higher than half the sampling frequency enters the A/D converter, spurious signals of lower frequency will be generated (aliasing effect) and the original signal will be distorted (Fig. 5).

The resolution of the amplitude depends on the

Fig. 5. Effect of the sampling rate on a signal (sine wave). Sampling rate of > 2 times the highest signal frequency (best 5–10 times) results in an exact reproduction of the waveform. When sampling is below the theoretical limit (Nyquist theorem, twice the signal frequency) a low-frequency distortion may occur (aliasing effect).
amplification of the signal and the resolution of the A/D converter (Fig. 4). Twelve-bit converters with a resolution of 4096 discrete levels are commonly used, but 16 bits or more are becoming increasingly popular. It is important to adjust the amplification so that the actual signal swing uses as much of the input range of the A/D converter as possible. In most cases the resolution of the data storage is better than the resolution of the monitor. Thus, special algorithms (first order data reconstruction, interpolation and fitting procedures) are used when displaying a signal on the video (computer) monitor which represents the original signal.

The relative error increases when the signal swing is only a part of the range of the A/D converter, e.g. if the signal covers one-quarter of the range of the amplitude the error increases 4 times.

**Instrumentation settings**

In visual marker placement sweep speed setting (horizontal) and sensitivity setting (vertical) influence the decision and thereby the resulting latency and duration measurements. High sensitivity (gain) setting reveals the deflection of the signal from the baseline earlier than using lower sensitivities resulting in shorter onset latencies and longer duration of the signals. Thus, in manual (visual) potential assessment, measurement should always be done using a standardised gain setting. Likewise, sweep setting should be standardised although the effect of sweep speed on latency is less pronounced.

Using video (computer) monitors, the number of horizontal points (pixels) limits the time resolution. Thus the minimal time interval that can be measured is the time given by a single horizontal pixel. Therefore, the accuracy of the visually marked latency increases with fast sweep settings. In practice algorithms for automatic cursor placement are implemented in digital EMG machines. In this case, the full internal unscaled amplitude as well as time resolution given by the sampling rate is used for cursor placement. It is independent of the screen display and results in a better time and amplitude resolution. With correct algorithms the accuracy of the automatic cursor placement is usually better than the manual placement. A correction of cursor placement should only be done when the automatic placement is obviously incorrect (e.g. due to an artefact).

**Temporary storage, trigger and delay line**

Trigger and delay lines are used to isolate and display potentials that occur irregularly or at relatively long intervals as it is the case with individual MUAPs, single-fibre action potentials or some types of spontaneous activity. Successful recording of consecutive potentials is possible by triggering each sweep by the potential itself. Different triggering criteria can be used: amplitude level trigger, window trigger, edge trigger and combinations of them. To display the initial part of the potential it is continuously stored in a temporary memory. In this way, parts of the signal that occur before the trigger event can also be displayed (so-called delay line). The signal is displayed so that the trigger event is placed (time-locked) in an appropriate position on the screen relative to the start of the sweep. Thus the important part of the signal is displayed in a stable position which makes it easier to assess it quantitatively and/or qualitatively (duration, amplitude, number of phases/turns, stability, blocking, satellite potentials).

The advances of modern signal processing techniques has made it possible to develop EMG machines with more or less automatic quantitative methods. For example, various automatic algorithms are used to extract MUAPs from a low to moderate interference pattern and to automate the quantification. This makes the quantification of EMG easier, but comparison studies are missing to assess their value (for details see Chapter 4.3).

**Signal averager and artefact rejection**

Many electrophysiological signals have low amplitudes and are therefore masked by noise. Often the noise has a higher amplitude than the signal itself. When the signal can be evoked many times averaging can extract the signal from the randomly occurring (not time-locked) noise and therefore improve the signal-to-noise ratio (SNR).
(Fig. 6). This method is used especially when neurophysiological signals are of low amplitudes (e.g. SNAPs) or when an event-related potential shall be extracted from background noise or other interfering signals (macro-EMG). The SNR improves by factor square root of \( n \) where \( n \) is the number of averaged sweeps. To use the averaging process the signal must be related to a fixed event, e.g. a stimulation or must be locked by a trigger criterion (see above). The signals are mathematically summed, averaged and then displayed. The validity of the signal displayed should be checked for example by doing at least two consecutive runs. If they are equal, i.e. if they have the same latency and peak amplitude, the SNR is sufficient and the signal is valid. It should be possible on line as well as off line to amplify or attenuate the signals and to change the time scale on screen with preserved accuracy.

During the averaging process it is essential that the signal is within the active range of the system (amplifier and A/D converter). An overloaded part of the signal contains no signal information and therefore decreases the validity of the resulting average.

One way to improve the quality of the averaged signal is to use a sweep rejection method, the so called automatic artefact rejection. Here, sweeps are rejected if they contain overloaded parts (e.g. a movement artefact when recording SNAPs). The incoming signal is rejected when it exceeds a predetermined (amplitude) value, usually expressed as a percentage of the input range of the amplifier or A/D converter over a certain time. There should be no automatic artefact rejection during the first part of the sweep where the stimulus artefact appears. Otherwise most of the sweeps will be rejected due to the high amplitude of the stimulus artefact.

### Storage of data

The use of personal computer technology makes storage of waveforms and measured data easy using hard discs or other storage media. After A/D conversion the complete waveform is stored. This means that further distortions created by the storage procedures are not possible. For certain conditions (e.g. long-term recordings) magnetic tape recording is used. Frequency modulated tape recorders normally have recording speeds which provide a flat frequency response from 0 to 10 kHz. This allows shape analysis of most neurophysiological signals. Due to phase distortion overshoot may occur at certain recording speeds. It is recommended to check the system by comparing the waveform of a test signal before and after storing on tape. Recently the development of digital tape

![Image of waveform and artefact rejection](image)

Fig. 6. Averaging of a time looked signal produce a better signal to noise ratio (SNR). Not time-locked signals (e.g. EEG, noise, interferences, movement artefacts, muscle contractions) can be attenuated after summation of a certain number of sweeps. The SNR is increased by increasing the number of sweeps.
recorders (DAT) and large hard disks have made recording of long epochs much easier.

Databases, report generators and telecommunication

During the last 10 years many EMG companies have incorporated databases in the EMG machine. With a database it is possible to perform automatic calculation of deviation from normal, to obtain automatic report generation, to perform statistical analyses using third party programs and to reduce the amount of human typing errors. The development in medical informatics has moreover made telecommunication possible. Unfortunately, no international standard for storage, retrieval and exchanges of EMG data exists. Different types of EMG machines even from the same company have different data formats, different databases and different report generators.

An international standard format for EMG data would make it possible that data from one EMG machine can be read by other EMG machines. With such a standard it would be possible to integrate the EMG machine, the database, the report generator, a hospital information system (HIS), an electronic patient report and communication links to others laboratories. This would give several advances.

(I) With a common standard for EMG data the laboratories need only one EMG database and one report generator independent of the type of EMG machine. In this way the report will be the same even if the EMG examinations are performed on different types of EMG machines or if a new type of an EMG machine is introduced in the laboratory.

(II) Telecommunication within the hospital may be possible with links or interfaces to a HIS or to an electronic patient record.

(III) Telecommunication between laboratories based on an international standard for EMG data may make it possible to exchange patient studies between laboratories. This may be used for (i) consulting service, (ii) research on multicentre databases (e.g. research on special techniques or on seldom disorders and evaluation of reference values), and (iii) conduction of multicentre quality development projects (e.g. medical audit electronic conferences and development of standards and guidelines for EMG practice). Moreover, dissemination of standards and guidelines for EMG practice may be possible.

An international standard for EMG data requires the following. (i) A common EMG terminology (e.g. the AAEM glossary (1987) and the IFCN terminology (see Chapter 4.1). (ii) A common EMG dataset structure, which covers and harmonises all information from different EMG schools. The dataset identifies, codes and relates anatomical structures, techniques, measured data (optimally also signals), deviations from reference material, pathophysiological states of examined structures and diagnoses (Johnsen et al. 1994). (iii) A common communication protocol for exchange of EMG data which defines how to send data (Johnsen et al. 1994).

To explore the possibilities of medical informatics within EMG one has to take into consideration the techniques of local area network (LAN), wide-area network (WAN), analogue telephone modems, digital modems (ISDN) and the use of internet. The legal aspects of electronic communication which may differ from country to country should be considered.

Interfaces

For interfacing of EMG equipment with computers the IEEE 488 (IEC2) has been used. It has sufficient data transmission capacity for on-line requirement. For less demanding data transmission RS 232 has been the most common standard. Since most modern EMG equipment includes a computer, network connections are becoming more and more used. It enables the use of a common storage device and thereby a common database and the possibility to access data from any point of a network (e.g. in a department).

Electrodes

To evaluate electrical activity of muscle or nerve tissue a measurement between two electrodes is
done. Surface and needle electrodes are used which are manufactured in a variety of shapes and from a variety of materials. The following materials are usually accepted: platinum, stainless steel and chlorided silver. Copper and unchlorided silver should not be used. Whenever possible electrodes of identical materials should be used for the electrodes connected to both inputs of an amplifier. The electrode impedance can vary from one to several hundred kΩ.

The contact of a metal with an electrolyte (electrolyte paste or tissue fluid) creates a galvanic cell like a small battery. This potential which has an amplitude between 100 and 600 mV is called the electrode polarisation potential. Movement of an electrode within the tissue may change electrolyte concentration locally and thereby create changes in galvanic cell voltage for a short period of time. This gives rise to false spike potentials, causes baseline movement artefacts and sometimes saturates and blocks the amplifier. Electrode problems like contamination, corrosion or damage to the coating (monopolar electrodes) may cause chemical reactions on the surface of the electrode. This makes the polarisation potential unstable and creates artefacts which occasionally resemble abnormal membrane potentials.

The total impedance of an electrode is composed of the capacitance and the resistance of the electrode surface, the electrolytes and the tissue. The impedance increases as electrode area decreases and decreases as frequencies increases.

The choice of electrodes depends on the aim of the investigation (Table 2). It depends on the number of fibres which are to be recorded, on the number of fibres which are active and on their spatial distribution. In so called unipolar recordings the recording electrode is very close to the fibre(s) under investigation while the reference electrode is remote and is expected to receive minimal contributions from active fibres. In bipolar recordings both electrodes are close to the active fibre(s).

**Needle electrodes**

In electromyography concentric or monopolar needle electrodes are most often used. As the recording surface of these electrodes is large relative to the diameter of a muscle fibre they record form many active muscle fibres of a motor unit. The motor unit action potential itself represents a summation of the electrical activity of a number of muscle fibres belonging to the same motor unit.

The concentric needle electrode consists of a fine (platinum) wire electrode which is insulated and housed in a steel cannula. The surface area of the wire electrode depends on the diameter and cutting angle and is usually between 0.01 and 0.09 mm², typically 0.07 mm². The recording is done between the inner wire and the cannula shaft which acts as reference electrode. The main spike component of the MUAP is generated by approximately 2–12 fibres within a pick-up area of about 0.5–1 mm around the tip of the needle. More fibres contribute to the initial and late parts of the potential which define the duration of the MUAP. Due to the proximity of both electrodes the reference electrode records almost the same potential as the active electrode but in an attenuated and smoothed version due to the large surface area. Due to the short distance between the electrodes, signals that appear as common mode signals will be detected better and rejected by the amplifiers than when monopolar and surface electrodes are used.

The monopolar needles are usually constructed from a stainless steel needle which are coated with Teflon except for its tip of 1–5 mm. The recording area is approximately 0.03–0.34 mm². The potential difference is measured between the bare tip of the needle and a reference electrode which may be a similar needle electrode placed subcutaneously or a surface electrode at some distance from the active electrode. The reference electrode should be placed over an electrically silent area, a tendon or a bone. However, background potentials of the muscle under investigation or signals from other muscles which are simultaneously activated may influence the signal. An other source of artefacts is the impedance difference between the needle electrode and the surface reference electrode, the impedance of which may be 10-fold lower than the impedance of the needle. This may result in 50 Hz (60 cps) interference. The shape of the recorded MUAP varies with the geometry and
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<th>Description</th>
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<th>Reference electrode</th>
<th>Measured parameter</th>
<th>Electrode impedance (kΩ)</th>
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</thead>
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<td>25 μm diameter</td>
<td>Needle shaft</td>
<td>Single muscle fibre</td>
<td>100</td>
</tr>
<tr>
<td>Routine EMG</td>
<td>Coaxial needle</td>
<td>0.07 mm² area</td>
<td>Needle shaft</td>
<td>Motor unit action potential</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Monopolar needle</td>
<td>0.12 mm² area</td>
<td>Surface electrode or other needle</td>
<td>Motor unit action potential</td>
<td>5</td>
</tr>
<tr>
<td>Firing pattern</td>
<td>Bipolar coaxial needle</td>
<td>0.015 mm² area</td>
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<tr>
<td>Macro-EMG</td>
<td>Modified single fibre needle</td>
<td>15 mm tip; 25 μm side port electrode</td>
<td>Surface needle; cannula</td>
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<td>1–5; 100</td>
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<tr>
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</tr>
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<td>Sensory nerve surface</td>
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<td>1–2</td>
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<tr>
<td>Ground electrode</td>
<td>Metal electrode</td>
<td>&gt;100 mm² area</td>
<td>–</td>
<td>–</td>
<td>0.4–1</td>
</tr>
</tbody>
</table>
dimension of the leading-off area. Monopolar needles produce larger amplitude and greater phasicity compared with concentric needle electrodes, whereas duration is comparable. This is due to the slightly greater recording area of the monopolar needle and the attenuation of the potential due to the vicinity of recording and reference electrodes in concentric needle electrodes. Therefore, reference values are to be worked out for each type of electrode separately. The use of both types within a laboratory is discouraged.

Monopolar needles (2–8 μm uninsulated at the tip) are sometimes used as recording electrodes for sensory nerve action potentials in the near nerve technique and as stimulation electrodes (e.g. stimulated SFEMG).

When selective recording is required the recording electrode should be of the same order as that of the structure investigated. For single-fibre EMG the recording surface consists of a platinum wire normally 25 μm in diameter exposed in a side port of a steel cannula (Stålberg and Trontell 1994. Within the pick-up range (a semicircle with a radius of 300 μm, pick-up area 0.0005 mm²) in healthy muscles there are usually 1 or 2 fibres, seldom there are up to 3. The cannula acts as reference electrode.

For microneurography insulated tungsten electrodes, exposed for 5–10 μm at the tip are used. Other needles with two (bipolar) or more (multipolar) electrodes which are close together are used for special purposes, e.g. for MUAP analysis during strong effort (bipolar electrodes), for volume conduction studies, for the measurement of the propagation velocity along a muscle fibre (multipolar electrodes) or for determination of the territory of a motor unit (multipolar electrodes).

To record from as many muscle fibres of a motor unit as possible, a special macro EMG electrode is used. This is a modified single fibre electrode. The single fibre action potential which is picked up by a platinum wire coming out at a side port 7 mm apart from the tip of the needle is used to trigger the sweep. The distal 15 mm of the recording needle electrode is uninsulated whereas the rest of the needle is insulated. The actual macro EMG potential is recorded between the distal part of the cannula and a remote reference electrode, a surface electrode or a subcutaneously placed monopolar needle electrode. Several potentials are obtained with the cannula and are averaged to produce the average macro-MUAP.

Due to the risk of transmission of infectious diseases (e.g. hepatitis, AIDS, Jakob-Creutzfeld disease), disposable needles should be used for needle EMG investigation whenever possible. This also overcomes the problems with maintenance of reusable electrodes, e.g. sharpening, removing hooks of the tip, check for defects due to long-time use, electrolytic treatment and others.

**Surface electrodes**

Surface electrodes are often used for nerve conduction studies, for recording of periodic movements, as reference electrodes for monopolar needle EMG, for macro EMG and for ground electrodes. Surface electrodes are small round or square metal disks (Table 2) or ring electrodes for the digits. Some kind of adhesive keeps the electrode in place. A new type of stick-on electrodes uses a conductive adhesive that reduces artefacts due to a loose contact. The electrode impedance for surface electrodes is initially very high without special treatment of the skin. It is often >300 kΩ and has therefore to be reduced to obtain satisfactory recordings. This is achieved by applying the electrodes firmly to the skin, by using electrode gel and sometimes by preparing the skin by cleaning with water, soap or alcohol, by abrading the skin or by doing both.

Any potential is measured as the difference between two electrodes. For motor nerve conduction studies the recording electrode is placed over the motor point (usually the middle of the muscle belly); the reference electrode is placed over a silent area, i.e. over the distal tendon or further away. Ideally, the potential captured by the reference electrode should be zero. This is frequently not the case resulting in a disturbed waveform. Due to the use of a differential amplifier the potential will be the smaller the nearer the electrodes are located together. For recording SNAP both electrodes are placed on the skin over the nerve or over the corresponding skin area with an interelectrode distance of approximately 4 cm.
Ground electrode

A third electrode, the ground electrode serves as a zero-voltage reference for the amplifiers. It also serves to short-circuit the current from the power line interference. The lower the ground impedance is the lower is the interference voltage. For grounding a plate or strip electrode is the most useful and it should be placed on the extremity under investigation. For sensory nerve conduction studies it is appropriate to place the ground electrode between the recording electrode and stimulating electrode.

Stimulation

For nerve conduction studies and stimulated SFEMG an electrical stimulus is applied to the nerve. Standard stimulation techniques use surface or less often needle electrodes. Usually two surface electrodes are placed over the nerve with an inter-electrode distance of 2–3 cm with the cathode placed closest to the recording electrode. Inversion of the polarity of the stimulation electrodes will affect the point of stimulation and thereby the onset latency and nerve conduction velocity. The duration of the stimulus is usually between 0.1 and 1 ms. In routine, short duration stimulus pulses are preferred in order (i) to minimise patient’s discomfort, (ii) to ensure the site of stimulation which may spread distally using longer duration pulses (as well as too high intensity) and (iii) to reduce the stimulus artefact. The stimuli can be applied as single pulses or as trains with repetition frequencies between 0.5/s and 50/s. A train duration control should be implemented in the system to stop the train of a given stimulation frequency after the designated duration or number of stimuli.

Two types of stimulators are used. The constant voltage stimulator delivers a constant voltage between 0 and 300 V. The disadvantage of this type of stimulator is that the resultant current is not constant because of the fluctuations of the electrode/tissue impedance. It may change between two stimuli or even during the stimulus itself. Constant current stimulators deliver a constant and stable current usually between 0 and 100 mA. Stimulus current is independent of electrode/skin impedance as long as the stimulator is not overloaded. Constant current stimulation is therefore preferred by most physicians. Due to technical limitations magnetic stimulators which are routinely used for transcranial stimulation are until now not useful for peripheral nerve investigations.

Supramaximal stimulation is required in most situations to depolarise all neurons at the same time. Too-high stimulus currents may result in a spread of the stimulation site and thus cause a shorter onset latency and stimulation of nearby nerves.

Artifacts

The stimulus artefact is generated by the stimulus itself. It is caused by volume conduction of the stimulating current or by capacitive coupling due to the relatively high voltages that are required to drive a depolarising current through the stimulating electrodes. It is a spike of short duration with an exponentially decaying tail. When recording signals with low amplitudes the artefact makes the determination of onset latency and configuration difficult. To minimise the stimulus artefact it is useful to: (i) use stimuli of short duration and of the lowest strength that is appropriate for supramaximal stimulation; (ii) to decrease stimulator-skin impedance (e.g. by cleaning the skin or eventually abrading it or both); (iii) to avoid fluid bridges between the electrodes; (iv) to place the ground electrode between the recording and stimulating sites; (v) to rotate the stimulating electrodes by 45–90° keeping the cathode above the nerve; (vi) to use short and shielded cables; and (vii) to keep recording and stimulating cables widely separated from each other.

Power line artefacts (50 Hz/60 cps) are mostly due to problems of high and/or unequal electrode impedances or bad grounding, but can occasionally be due to an excessive power line noise. To get rid of power line artefacts it is useful to check the lab environment, never to use fluorescent lamps, to unplug other electrical apparatus within the laboratory, to isolate the EMG machine from other electrical circuits and to check the grounding of the EMG machine. Most often the reason for power line artefacts are high electrode impedances (reasons and methods to reduce it see above) or
defects of the cables. Low impedances are essential, particularly for the grounding electrode. Sometimes the examiner is a source of power line artefact. In this case the artefact starts or increases when the examiner touches the patient or the EMG needle. To reduce this type of artefact the examiner should apply a ground electrode to himself.

**Radio-frequency** energy can cause artefacts. By demodulation in the EMG amplifier the investigation may be disturbed by speech or music that can be heard from the loudspeaker and seen as interfering potentials on the screen. This kind of artefact should be removed by built-in radio-frequency rejection circuits in modern EMG amplifiers. Even though it is sometimes present and difficult to eliminate, but fortunately it is usually short lasting. Shielded rooms eliminate such problems.

**Cardiac pacemakers** produce regularly firing artefacts mimicking spontaneous activity.

**Electrical safety**

For electrical safety it is required that the EMG equipment is insulated from the power line and that any accessible part of the instrument is connected to the ground. The electrical hazard for the patient is generally caused by faults in the grounding system. A leakage current of sufficient intensity through the cardiac region may cause ventricular fibrillation. In modern EMG machines isolated amplifiers are used. Here, all patient connections are electrically isolated from the power line and ground connections which makes a dangerous leakage current extremely unlikely. Mainly optical isolation is used in which the neurophysiological voltages are converted into an optical signal, transmitted across the isolation barrier and then reconverted to voltage. ICE 601-1 (International Electrotechnical Commission 1988) recommends that the maximum current which leaks to earth should not exceed 10 μA at 50 Hz in normal circumstances. The leakage current should be checked and recorded at regular intervals by authorised persons.

Any contact between a second power-line-operated apparatus and a patient connected to the EMG machine should be avoided for safety reasons and also for reduction of noise and artefacts.

The grounding system should be arranged such that all ground sockets used for the recording instrument are connected to a single point within the laboratory. This point is connected to the installation ground lead and is called the equipotential reference point (ERP). It must be a part of the installation and therefore it cannot be disconnected. No other ground terminals should be used (e.g. water pipes). The ERP is also the terminal to which all other equipment and other exposed metal work (e.g. beds) in the vicinity of the patient must be ultimately connected.

Needle EMG and conventional nerve conduction studies utilising percutaneous nerve stimulation may be performed with little risk in patients who have cardiac pacemakers (LaBan et al. 1988).

Although many countries have adopted the standards developed by the International Electrotechnical Commission for Medical Equipment (IEC 513 and IEC 601-1) national regulations have to be observed.

**References**


