MOTOR UNIT ACTION POTENTIAL QUANTITATION

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Workshop handouts are prepared as background didactic material to complement a hands-on workshop session. This workshop handout was originally prepared in September 1994 and revised in October 2001. The idea and opinions in this publication are solely those of the author(s) and do not necessarily represent those of the AANEM.
Motor Unit Action Potential Quantitation

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“Since the measuring device has been constructed by the observer...We have to remember that what we observe is not nature itself but nature exposed to our method of questioning.”
Werner Karl Heisenberg
(Physics and Philosophy, 1958)

INTRODUCTION

This workshop will focus on motor unit action potential (MUAP) quantitation. It is assumed that the participant is familiar with the basic, routine needle electromyography (EMG) examination. The goal of this workshop is to enhance his/her ability to maximize the data they acquire in routine needle EMG. This will be achieved in 3 general steps: review of basic MUAP features (refer to references 24, 25, 31 and 35 for detailed reviews), demonstration of acquisition techniques, and analysis of the MUAPs that are acquired.

Even basic contemporary electromyographs offer many options in instrumentation, yet many electrodiagnostic medicine (EDX) consultants have an aversion to touching the machine during needle EMG signal acquisition except to turn the preamplifier on and off. The general trend in what might be termed ‘subjective’ needle EMG is a passive process of watching the screen with minimal to no interference from the operator. MUAP assessments are made on general impression (particularly amplitude) and the only movement is when the needle electrode is displaced to a different recording site. At the other extreme is computer-assisted MUAP quantitation where a great deal of operator input is required. This approach requires training, takes time, and is not indicated in most studies.\(^{25,31,36}\)

There is a middle ground, however, which we have called ‘objective-interactive’ needle EMG.\(^{8}\) This disciplines the EDX consultant to truly monitor the signals being acquired on the screen and to make ongoing semi-quantitative or ‘objective’ assessments of amplitude, duration, complexity, area, and stability. But these assessments are usually not achieved with a single instrumentation setting (i.e., a single sensitivity, sweep speed, and fixed filters). Hence the operator must constantly ‘interact’ with his/her electromyograph and manipulate settings as needed to acquire the information desired. Combining these two concepts yields the descriptive term, ‘objective-interactive’ needle EMG.

There are numerous computer-assisted algorithms available at present on commercial electromyographs.\(^{15,23,36}\) It is not possible to review all of them, nor is that the intention of this workshop. Instead, a more ‘back to basics’ approach will be made that is universal in understanding any of them, i.e., the ‘Buchthalian’ basic technique along with trigger/delay averaging.\(^{9,36}\) Both require operator interaction with the electromyograph as described above.

In conjunction with the above steps toward achieving our goal, three themes deserve mention at the outset. First, there is no substitute for signal quality. This is something the operator controls at every level (i.e., patient cooperation, instrumentation, analysis, and interpretation). Second, the EDX consultant must always bear in mind that the recorded MUAP is a result of the motor unit’s anatomy and physiology as modified by the recording device (particularly the physical characteristics of the needle electrode). Third, despite their impressive ability to ‘quantitate’, computers are ‘idiot savants’ and are only as good a servant as the EDX consultant is a master.

INSTRUMENTATION

Few topics are guaranteed to alienate readers faster than instrumentation. By this we mean how the electromyograph may influence acquisition of the signal. For detailed reviews on filters, averaging, sensitivity, and sampling rate, the participant should
see references 19, 26, 30, and 31. The effects of commonly manipulated instrumentation settings on the EMG signal are summarized in Table 1.

Table I Effects of Instrument Settings on EMG Signals

<table>
<thead>
<tr>
<th>Instrument Setting</th>
<th>Effect on EMG signals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing highpass frequency (low filter) from 3 Hz - 20 Hz.</td>
<td>Usually, the MUAP duration decreases. The baseline becomes stable. An artifact in the form of a negative phase may result at the end of the MUAP giving longer durations.</td>
</tr>
<tr>
<td>Setting highpass frequency (low filter) to 500 Hz.</td>
<td>MUAP amplitude and duration decrease significantly. EMG may appear ‘myopathic’.</td>
</tr>
<tr>
<td>Decreasing lowpass frequency (high filter) from 10 kHz to 1 kHz.</td>
<td>MUAP amplitude decreases and the rise time increases.</td>
</tr>
<tr>
<td>Increasing the numerical value of display sensitivity (i.e., from 100 µV/div to 500 µV/div).</td>
<td>Amplitude of large MUAPs can be measured. The duration of MUAPs by visual assessment may be reduced.</td>
</tr>
<tr>
<td>Increasing the duration of the sweep.</td>
<td>Late components can be detected, but the waveform details of the main spike may be obscured.</td>
</tr>
<tr>
<td>Averaging waveforms.</td>
<td>Gives a better baseline for duration measurements. In unstable complex MUAPs, the averaged waveform may lose turns and phases that are seen in individual discharges of the MUAP.</td>
</tr>
<tr>
<td>Decreasing the sampling rate below 10 kHz.</td>
<td>Waveform amplitude may appear variable even in a normal MUAP giving a false impression of instability. Amplitude will be underestimated.</td>
</tr>
<tr>
<td>Decreasing the number of bits of the analog-to-digital converter.</td>
<td>For large amplitude MUAPs, the least bit resolution may be inadequate for quantitative analysis.</td>
</tr>
</tbody>
</table>

**TERMINOLOGY**

To lay the groundwork for the discussion that follows, it may be useful to review definitions. The following are excerpted from the A-AMEE Glossary of Terms in Clinical Electromyography.27

Motor Unit (MU): “The anatomic unit of an anterior horn cell, its axon, the neuromuscular junctions, and all of the muscle fibers (MFs) innervated by the axon.”27

MU Territory: “The area in a muscle over which the MFs belonging to an individual MU are distributed.”27

Motor Unit Action Potential (MUAP): “The action potential reflecting the electric activity of a single anatomic MU. It is the compound action potential of those MFs within the recording range of an electrode.”27

See Figure 1 for concentric needle (CN) electrode recordings. The CN has an elliptical recording surface of 150 x 580 µ (=0.07mm²) ground to an angle of 15 degrees.18,24,25 The cannula acts as the reference electrode. The various features of the CN MUAP (e.g., amplitude, duration; see below) are dependent on the location of the MFs within a given MU territory relative to the position of the CN (see Figure 2). The so-called ‘facial’ CN has a smaller recording surface and thinner diameter cannula than the standard CN electrode. Therefore, reference values for standard and facial are not interchangeable.4 Monopolar needle (MN) electrodes differ from CN electrodes and will be considered separately below.21

**ACQUISITION OF MOTOR UNIT ACTION POTENTIALS**

The aim of the needle electrode study is to assess a sufficiently large sample of MUAPs from a muscle. When mean values of MUAP features (e.g., amplitude, duration, etc.) are being quantitated, 20 MUAPs are considered sufficient. The following steps may be helpful in recording good quality signals and representing as many MUs as possible in a time-efficient manner:
A. A helpful strategy is to move the needle electrode slowly along ‘corridors’ while the patient minimally activates the muscle. A corridor is the path along which the recording tip of the electrode passes into the muscle, typically from superficial to deep. The best positions for activation will vary with each muscle, but may need to be modified if significant weakness is present.

When the electrode reaches the end of the corridor (limited by either the length of the electrode or the size of the muscle), the needle electrode is withdrawn to the subcutaneous border of the muscle and the tip redirected about 45 degrees lateral to each side of the first corridor, but perpendicular to the long axis of the MFs. This gives 2 additional corridors.

B. Insert the needle electrode perpendicular to the muscle with the bevel of the CN perpendicular to the direction of the MFs. A good strategy is to avoid the end-plate area (usually painful to the patient) as well as the very distal portions of the muscle at its tendinous insertions/origins.

C. MU territory will vary between muscles (e.g., approximately 10 mm in the biceps brachii) which should be used as an aid to know how far to move the electrode to exit the previous MU’s presumed territory. Recruitment threshold may also reveal whether the same MUAP is being recorded, but from a different position in the MU. Depending on where in the MU territory it is recorded, the MUAP may change considerably in shape. This is readily demonstrated on scanning EMG studies (see Figure 2).

D. Patient comfort and cooperation is critical in acquiring high quality signals. In planning an expedient study, decide on what muscles need first priority to best address the clinical question. If possible, try to defer typically uncomfortable muscles until last. Needle electrodes will dull with prolonged use as in lengthy studies. For this reason, there may be merit in some instances to studying sensitive muscles (e.g., abductor pollicis brevis) earlier when the electrode is sharpest.

In most cases, 3 corridors of sampling from one skin insertion are adequate. If another skin insertion is needed; it must be made lateral or medial to the first insertion along the long axis of the MFs. If one inserts proximal or distal to the first insertion site along the long axis of the MFs, there will be a high likelihood of sampling the same MUAPs.

\[\text{Figure 2} \quad \text{Scanning EMG study through a normal biceps brachii muscle. With a stable trigger, a CN electrode is slowly withdrawn through a MU's territory. A MUAP is recorded at each “step” or stop-point along the corridor. (Courtesy of Professor Erik V. Stålberg).}\]

\[\text{Figure 3} \quad \text{MUAP Features. Dots represent phases and arrows indicate turns. Shaded portion represents area. [Nandedkar SD. Introduction to quantitative analysis in needle electromyography. In Johnson EW, Pease WS (editors): Practical Electromyography, 3rd edition. Baltimore: Williams & Wilkins; 1997. (with permission)]}\]
The MUAP is described in terms of various features (e.g., amplitude, area, etc.). These features have different implications as to how many MFs may be contributing to them, e.g., amplitude versus duration. These are summarized in Table 2. This section applies only to the CN electrode (Figures 3 and 4). The differences in MN electrode features will be discussed later.

**Amplitude:** This is measured from the maximum negative to the maximum positive peak (see Figure 3). The smaller facial CN electrode records higher amplitudes than the standard CN electrode.

**Duration:** Duration is measured from the initial deviation of the signal from the baseline to the return to the baseline and is composed of the action potentials of those MFs lying within a 2.5 mm radius of the recording surface of the CN. Temporal dispersion of the single MF action potentials may be increased in pathological processes, such as myopathy, resulting in increased MUAP durations without a commensurate increase in the number of MFs in the MU under consideration. Thus a typical finding is one of long-duration, complex MUAPs in myopathy. This is to be separated from long-duration, complex MUAPs as seen in neurogenic processes which are due to an increased number of MFs within a MU (i.e., reinnervation). Therefore, in order to increase diagnostic sensitivity, polyphasic MUAPs are conventionally excluded from duration measurements.

**Area:** This is measured as the area under the rectified waveform within a defined duration.

**Phase:** A phase is the portion of the MUAP waveform between the departure from, and return to, the baseline. A simple method to measure phases is to count the number of crossings of the baseline and add one. Simple CN-EMG MUAPs have fewer than 5 phases. In most normal muscle, fewer than 12% of MUAPs may be polyphasic with slightly higher percentages allowed in proximal muscles.

**Turn:** A turn is essentially a positive or negative peak within the MUAP duration. Successive turns are separated by a threshold amplitude (25-100 V) to exclude peaks generated by noise. The use of the term in this context is not synonymous with the use of ‘turn’ as in interference pattern analysis. Increased turns

**Table 2 Anatomic Correlates of MUAP MUAP Features**

<table>
<thead>
<tr>
<th>MUAP Feature</th>
<th>Anatomic Correlate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude</td>
<td>Size and number of muscle fibers that are within 0.5 mm of the active recording surface. Size and distance of the nearest muscle fiber of the motor unit.</td>
</tr>
<tr>
<td>Area</td>
<td>Size and number of muscle fibers that are within 2 mm of the active recording surface.</td>
</tr>
<tr>
<td>Phases and Turns</td>
<td>Temporal dispersion of action potentials of muscle fibers that are within 1 mm of the active recording surface, i.e., action potential propagation velocity in terminal axon branches and muscle fibers, action potential propagation velocity in muscle fibers, and the width of the end-plate zone.</td>
</tr>
<tr>
<td>Duration</td>
<td>Number and size of muscle fibers that are within 2.5 mm of the active recording surface.</td>
</tr>
<tr>
<td>Waveform Stability</td>
<td>Efficacy of neuromuscular transmission at the motor end-plates of muscle fibers that are within 1 mm of the active recording surface.</td>
</tr>
</tbody>
</table>
(more than 5 turns) were found to be a sensitive but nonspecific feature in MUAPs from patients with neuromuscular diseases.\textsuperscript{23,24,35} In practical application, slight movement of the recording electrode may change a phase into a turn and vice versa.

**Complexity:** When turns and/or phases are increased or late components are present, the MUAP is considered ‘complex.’ An increase in phases, turns or late components (i.e., satellite components) may result from an increase in the number of MFs in a MU. This occurs in reinnervation. When there is an increase in variability in the diameter of MFs of a MU, or increase in the velocity recovery function of the MFs. These mechanisms are typical for myopathic process. Therefore, an increase in complexity per se is a sensitive, but nonspecific indicator of abnormality. A small percent of MUAPs in normal muscle may be complex, especially in proximal muscles.\textsuperscript{23,36}

**Rise Time:** For a MUAP, rise time represents the time interval between the maximum amplitude to the preceding maximum positive deflection or the onset of the main spike. Traditional teaching suggests that this be less than 0.5 ms. This was based upon earlier guidelines which were recently reconsidered to be too restrictive.\textsuperscript{2,31} One generally believes that the electrode recording tip is ‘closest’ to the MU when the amplitude is maximal, rather than solely relying on rise time.\textsuperscript{2} It must also be noted that rise time may, by necessity, be longer, as in neurogenic disease, when amplitude and area are increased, thereby resulting in enlargement of the main spike. Even in normal muscle, a rise time of greater than 0.5 ms may be acceptable for MUAPs.\textsuperscript{2,31}

**Stability:** This is a very useful, but often overlooked, feature. It is synonymous with variability, which is defined as the “change in the MUAP shape between consecutive discharges.”\textsuperscript{8,25,27} Unless the MUAP is complex or amplitude variations are marked, this may be difficult to perceive at standard instrumentation settings. An alternative and more revealing approach is to ‘focus’ the recording tip to only those MFs quite close to it (Figure 5), thereby increasing the ‘selectivity’ of the recording electrode.\textsuperscript{8,25,28} This can be done with either a CN or MN electrode.

To assess stability, changes in instrumentation are necessary. The operator activates the trigger/delay, increases the low-frequency filter to 500 Hz (this ought to be familiar to those who have tried single fiber EMG), increases the sweep speed to at least 1 or 0.5 ms/div, and if possible, superimposes the consecutively acquired traces. If ‘instability’ is present, it will be seen as increased variation between consecutive interpotential intervals (i.e., increased jitter), or in some cases, actual ‘blocking’ (i.e., loss of one or more of the presumed single MF action potentials observed). Large degrees of instability may be seen at slower sweep speeds (Figure 6).\textsuperscript{8,25} Stålberg and colleagues have also introduced the concept of vertical instability of the MUAP, or ‘jiggle’, which will not be considered here.\textsuperscript{24}

Instability is rare in normals, but common in neuromuscular diseases, particularly neurogenic ones.\textsuperscript{8,25} In the latter, denervation is typically a fairly short-term process (i.e., days) whereas reinnervation may take weeks to months. In chronic neurogenic processes we infer that the instability most likely represents ongoing reinnervation changes. The MUAPs in myopathic disorders are generally stable.\textsuperscript{1,5,7,8,24,25} Instability is also the electrophysiologic hallmark of disorders of neuromuscular transmission. If one observes marked instability in a weak patient with otherwise normal appearing MUAPs, then a disease such as myasthenia gravis should be considered. An important caveat is to be certain that the low-frequency filter is set back to 2 Hz. This can be a common oversight rendering the subsequent MUAPs ‘myopathic’ in appearance.\textsuperscript{8,25}

**Area/Amplitude Ratio:** This feature quantifies the thickness of the MUAP waveform.\textsuperscript{20} The ‘thin’ waveforms seen in myopathic processes have a commensurately reduced numerical value of this feature.

**Effect of Electrode Position on MUAP Features:** Except for the MUAP duration and the area/amplitude ratio, all MUAP feature values may change significantly with a slight change in the position of the recording electrode within the MU territory.\textsuperscript{20}
As a result, one may observe several different MUAP waveforms for the same MU with minimal displacements of the needle electrode (Figures 2, 15).

MONOPOLAR NEEDLE (MN) ELECTRODE

Over the years there has been ongoing debate as to the superiority of needle recording electrodes in EMG, mainly CN versus MN electrodes. For routine or quantitative EMG, either is acceptable, as long as the electrode is of good quality and the operator appreciates the differences in their physical characteristics and how this affects the MUAPs they record. The reference values for a muscle using CN cannot be applied to MN electrode recordings, although MUAP durations tend to be similar.

The features that tend to show the most difference are MUAP amplitude and phases, both being higher when using the MN electrode. This is due to the differences in the physical characteristics of the MN electrode, which in turn alter the pattern by which the MFs within a MU’s territory are recorded (Figure 4). The MN electrode’s conical tip has a larger recording surface than the standard CN. Therefore, the MN electrode records from more MFs immediately adjacent to the tip whose action potentials contribute to the amplitude feature. Also, because these MFs are often not discharging completely in synchrony, there tends to be some phase interaction and therefore polyphasia in the MUAP recorded from the MN. This is a general statement and is of variable importance depending on the muscle being studied, the distribution of the endplates within the muscle, and etceteras.

In contrast to the schematic representation in Figure 4 of the recording territories of each electrode being similar in size, the actual overall recording area of the MN is larger than the CN. In the author’s experience, however, MUAP durations for these electrodes are similar. This is probably explained by the minimal contributions to the MUAP by the more distant MFs and the greater inherent ‘noise’ associated with the MN electrode. Duration may also be affected (i.e., reduced) by recording MUAPs at higher low-frequency settings, e.g., 10-20 Hz versus 2-3 Hz.

QUANTITATIVE EMG TECHNIQUES

Evolution of Techniques

Given the number of techniques for quantitating MUAPs, it may be useful to briefly review, in chronological order of development, the 3 main categories: manual, trigger/delay, and decomposition.

In the manual method, MUAPs are identified from strip chart recordings of the EMG signal or by direct observation of the signal on the screen (see Figures 9 and 10). In the trigger-delay method, successive discharges of a single MUAP are averaged to extract the waveform (see Figure 11). Decomposition is a computer-based method that mimics the manual method and may be more successful at high activation levels at which the manual method may not be able to resolve individual MUAP waveforms.

One can make the same observation of these styles as Dale Berra did of his father, Yogi: “Our similarities are different.” Although the techniques differ, MUAP duration remains a very robust measurement and really shows no differences between techniques in normal controls. This is not surprising since MUAP duration shows minimal change when manipulating the CN electrode.

MUAP amplitude values are largest in the trigger/delay technique. This might be anticipated since the CN electrode is intentionally manipulated to maximize amplitude. Amplitude values are lowest in the manual technique where CN electrode position is not manipulated. Values for MUAP amplitude using the decomposition technique fall between the trigger/delay and manual techniques.

The percent of complex MUAPs is lowest in the manual technique where the needle is least manipulated and highest in the
Selection of MUAP Quantitation Technique

There are a number of computer-assisted techniques available to quantitate MUAPs. Discussion of the details of the advanced, computer-assisted programs such as those utilizing decomposition are beyond the scope of this handout. Commercially available electromyographs typically offer a MUAP analysis program using one or more of the above techniques. There is no 'best' technique. The technique that will be most suitable will depend on the operator, the equipment available, and the purpose of the study. If choosing a technique is an option, then it is recommended that any available literature or studies utilizing the technique be reviewed prior to use.

Outlier Approach

Even the most efficient recording techniques and algorithms consume time and it can be argued that 'quantitative EMG' is only needed in equivocal cases or for research. How can these seemingly opposite views be reconciled since every EDX consultant needs to have the ability to discriminate 'normal' from 'abnormal'?

One method is the outlier approach, which is similar to that utilized in single fiber EMG. Instead of collecting a cohort of MUAPs from a muscle and calculating their mean values to determine normalcy, one can identify individual MUAPs with features lying clearly outside of the range of reference values. If a

Figure 8  Trigger/delay technique of measurement using 3 high quality superimposed sweeps which can easily be averaged with little loss of amplitude or turns (i.e., serration less preferred term). Observations: A triphasic, serrated MUAP having an amplitude of 450 μV and 9.2 ms duration. Conclusion: This is a normal MUAP.
muscle obviously and rapidly shows consistent abnormality (i.e., similar changes in MUAP features) in more than 3 to 4 MUAPs, then the study of that muscle is concluded and the examiner proceeds to the next muscle. Only if the pattern of abnormality is inconsistent (e.g., both reduced and increased MUAP duration) would further evaluation be necessary. The outlier approach is somewhat similar to routine ‘subjective’ needle EMG in that individual MUAPs are being assessed. The ‘outlier’ approach in ‘objective-interactive’ EMG simply disciplines the operator to observe the MUAPs critically in terms of their features, for a consistent pattern of abnormality that lies outside reference values for individual MUAPs. Therefore in lieu of the subjective descriptor ‘large MUAP’, one ascertains that the MUAP is captured on the screen, measured, and quickly identified as being in or outside of reference limits for amplitude or duration with additional comment on area, complexity, and stability. The EDX consultant must constantly run MUAPs through this ‘checklist’ of MUAP features in assessing each MUAP. Although seemingly arduous and time consuming, with practice it can be performed quite rapidly.\(^3\,^2\,^3\)

**Description of MUAPs**

In reporting findings, the EDX consultant must remember that there is a difference between electrophysiologic descriptions of MUAPs versus making diagnostic implications.\(^1\) The concept of ‘myopathic’ versus ‘neurogenic’ MUAPs is just that, only a general gestalt that borders on jargon. It is preferable to describe the MUAPs in terms of their features. Using the objective-interactive approach describe above, one can offer a number of observations on the signals recorded, and in turn, make some correlations to neuromuscular pathology. This is shown by example, as much as possible, in the Figure legends (e.g., Figures 5-10 and 12-14).

Based on all of the electrophysiologic data, the EDX consultant may then offer some interpretation, but not with the intention of misleading the referring clinician away from other possible diagnoses. For instance, a general summary such as “rapidly recruited, stable MUAPs of normal to reduced amplitude, reduced duration, occasionally complex with thin appearing main spikes” followed by an interpretation of ‘myopathic process’ informs the referring clinician that there is cogent electrophysiologic evidence to support the presence of a myopathy.

**Reference Values**

This term is preferred to that of ‘normal’ values. Based on the above, it should be obvious that reference values can be, in part, derived from the literature\(^3\,^2\,^3\,^\) and indeed each EMG laboratory should utilize published values as a means of validating their own results. However, it cannot be emphasized enough, that in doing so, the technique used in one’s lab must be absolutely symmetric to that used in the literature so as to permit comparison to other reference values. Therefore the EDX consultant must ensure that there is no variation in needle electrode or instrumentation (i.e., no variation in filter or sensitivity settings in the amplifier). It must also be stressed that most reference values published are mean values\(^9\) and that the concept of ranges of individual values is a more recent consideration in MUAP measurement.\(^3\)

**Recruitment/Interference Pattern**

While the size and configuration of the MUAP may give clues to abnormality, the rate of firing of a particular MUAP and overall number of MUAPs firing at a given level of effort may also contribute information. Interference pattern (IP) is defined as “the electrical activity recorded from a muscle with a needle electrode at maximal voluntary effort.”\(^2\,^7\) Recruitment is defined as the “orderly activation of the same and new MUs with increasing strength of voluntary contraction.”\(^2\,^7\) Attempts to analyze IP have been ongoing for many years pari passu with MUAP analysis.\(^2\,^4\,^2\,^5\)

Recruitment pattern and firing rate can easily be measured on free run mode, especially when rastered sweeps are reviewed (see Figures 9 and 10). If a MUAP appears to ‘shift left’ on successive traces, then the interdischarge interval (1/ firing rate in Hertz) is less than the sweep duration on the screen and may be quickly inferred to be firing at more than 10 Hz. A ‘shift right’ indicates the opposite, i.e., discharging at less than 10 Hz.

Recruitment of a new MUAP can be easily recognized on a rastered display (i.e., the display of consecutive sweeps as in

![Figure 9](image.png)
The various features may be abnormal in isolation or in combination. The variation in size and configuration of MUAPs is best appreciated when groups of MUAPs from normal and neuromuscular diseases are compared (see Figure 15). This emphasizes why several MUAPs from a single muscle may need to be recorded in mild or questionable situations as alterations in MU architecture in neuromuscular disease are not homogeneous (see Figure 11).

**Figures 7, 9, 13** of the EMG signal. The firing rate immediately before the recruitment of a new MUAP is the recruitment frequency (Figure 9). Recruitment frequency is typically increased in neurogenic processes and is subjectively recognized as fast-firing single MUs on the screen.

**Neuromuscular Diseases**

The above discussion has been aimed toward MUAPs in normal controls. A comprehensive discussion of findings in neuromuscular disorders is beyond the scope of this handout. Here, as described above, how to define the various MUAP features is stressed, and in a basic way, how to recognize when these may be ‘outside’ a given set of reference values (i.e., outliers).

**Table 3 Patterns of MUAP Abnormalities in Discriminating between Neurogenic and Myopathic Disorders**

<table>
<thead>
<tr>
<th>MUAP Feature</th>
<th>Myopathic Process</th>
<th>Neurogenic Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude</td>
<td>Usually normal or reduced</td>
<td>Increased and may be 5 to 10 times normal</td>
</tr>
<tr>
<td></td>
<td>Occasionally mild increase</td>
<td></td>
</tr>
<tr>
<td>Area</td>
<td>Normal or reduced</td>
<td>Increased</td>
</tr>
<tr>
<td>Duration</td>
<td>Reduced for simple MUAPs</td>
<td>Increased</td>
</tr>
<tr>
<td></td>
<td>Reduced or increased for complex MUAPs</td>
<td></td>
</tr>
<tr>
<td>Area/Amplitude Ratio</td>
<td>Reduced</td>
<td>Normal or increased</td>
</tr>
<tr>
<td>Phases and Turns</td>
<td>Increased</td>
<td>Increased</td>
</tr>
<tr>
<td>Stability</td>
<td>Usually stable</td>
<td>Unstable during disease activity and progression</td>
</tr>
</tbody>
</table>
Typical patterns of MUAP abnormality in neuromuscular disorders are summarized in Table 3 (see also Figures 12, 13, 14). The relationships of individual MUAP features in pathology are summarized in Table 4. This is useful to interpret the MUAP findings when the patterns observed in a particular patient do not appear to conform to expected abnormalities such as those described in Table 3. This is more likely to occur in severely weakened or mild (i.e., subclinical) cases. Finding consistency in pattern of abnormality in the MUAPs of a muscle, and in turn other affected muscles, greatly strengthens the EDX consultant’s ability to reach an EDX impression of the underlying disease process, based on all electrophysiologic data. This handout, focuses only on MUAPs. Obviously nerve conduction data, the presence of rogue, sub-MUAP signals (e.g., complex repetitive or myotonic discharges), and fibrillation or fasciculation potentials may greatly influence the overall interpretation of the study.

**CONCLUSION**

The advent of computers has greatly facilitated quantitation of the EMG signal. It is important, however, to remember that quantitative analysis as a technique is relatively old, beginning with the work of Buchthal and colleagues in the late 1940’s. It is a tribute to the meticulous quality of their efforts that their reference mean values for MUAP durations are still widely utilized. This in turn should reinforce to the EDX consultant the importance of consistency in technique. Each study must be approached with a high degree of organization and method. One may then extract much more meaningful information from each needle EMG study with the above ‘objective-interactive’ approach, without really expending more effort. To quote Yogi Berra, “You can see a lot just by observing.”

The author acknowledges Sanjeev D. Nandedkar for reviewing this manuscript.
REFERENCES


Figure 15  CN electrode recorded MUAPs in myopathic process (A), normal (B), and neurogenic process (C). Observations: (1) There are a wide range of MUAP waveforms within each group. (2) Note how some MUAPs from each ‘abnormal’ category could easily be interchanged with those in the ‘normal’ group, emphasizing the need for adequate sampling in mild disorders (Courtesy of Professor Erik V. Stålberg).

Table 4 Pathologic Correlations of MUAP features

<table>
<thead>
<tr>
<th>MUAP Abnormality</th>
<th>Pathologic Correlate</th>
<th>Myopathic Process</th>
<th>Neurogenic Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>↑ Amplitude</td>
<td>Hypertrophy of muscle fibers</td>
<td>Reinnervation</td>
<td>Question selective loss of smaller motor units</td>
</tr>
<tr>
<td>↓ Amplitude</td>
<td>Atrophy of muscle fibers</td>
<td>Atrophy of muscle fibers</td>
<td></td>
</tr>
<tr>
<td>↑ Duration</td>
<td>Increased variability of fiber diameter</td>
<td>Reinnervation</td>
<td>Question selective loss of smaller motor units</td>
</tr>
<tr>
<td>↓ Duration</td>
<td>Loss of muscle fibers</td>
<td>Question fractionation of reinnervated motor units</td>
<td></td>
</tr>
<tr>
<td>↑ Polyphasia</td>
<td>Increased variability of fiber diameter</td>
<td>Increased width of end-plate zone. Slow conduction in atrophic muscle fibers Slow conduction in newly formed terminal axon branches</td>
<td></td>
</tr>
<tr>
<td>↑ Instability</td>
<td>Question reinnervation</td>
<td>Increased velocity recovery function in muscle fibers</td>
<td>Reinnervation</td>
</tr>
</tbody>
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34. Stålberg EV, Sonoo M. Assessment of variability in the shape of the motor unit action potential, the “jiggle” at consecutive discharges. Muscle Nerve 1994;17:1135-1144.

Answers to Exercise (Figure 7)

(A) There are 2 MUAPs, both seen on the first trace. The larger, first MUAP, is discharging about 8 Hz: it is shifting right on subsequent discharges and therefore firing at less than 10 Hz. The second, smaller MUAP, is discharging slightly faster at 9-10 Hz throughout the traces.

(B) Three distinct waveforms are seen. The initial, smallest one, is discharging at about 12 Hz and 3 similar waveforms are noted on traces 1, 2, and 4. Three discharges of the second MUAP are also seen (traces 2, 3, and 4) shifting right with an estimated discharge frequency of 9 Hz. The third MUAP (second MUAP on trace 2) is seen only twice: therefore, since it is seen less than 3 times in these sweeps, we will not count it.

(C) This is tricky! The first, really discernible MUAP is the 280 μV amplitude waveform on trace 1 at the third division marker. It may have recurred again at the end of trace 1 but it is cut off. It recurs near the eighth division marker on trace 2, but on trace 3 at the fifth division marker it appears different: the smaller 80 μV component to the right of the main spike is missing. Is this a different MUAP or is this smaller component blocking? Note the time interval between these components changes between its first and second discharge, suggesting instability and therefore favoring the latter possibility. Use of trigger/ delay with the low pass filter set up to 500 Hz could resolve this, or by carefully measuring more discharges manually. Therefore, this would not be called a single unique MUAP until more information is available.

The second 200 μV amplitude, complex MUAP (trace 1, just before the seventh division marker) appears consistent and shifting left, therefore discharging at a frequency of greater than 10 Hz. The smaller MUAPs along the baseline are difficult to assess and it is important to make certain they are not satellites or linked components to larger waveforms. Remember that MUAPs of less than 50 μV amplitude would not be included in analysis.
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