MASTERING EMG WAVEFORM RECOGNITION SKILLS IN JUST 2 HOURS!

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Electromyography studies the electrical activity of muscles to assist in the diagnosis of neuromuscular diseases. A variety of different waveforms are generated in normal and diseased muscles. The needle examination is separated into three parts, during which the electrical activity is recorded and analyzed: 1) insertional activity, 2) spontaneous activity, and 3) activity of voluntary motor unit potentials. During each section of the examination, normal or abnormal signals may be recorded and represent the underlying function or dysfunction of the muscle fibers or nerve supplying the muscle examined. The source of all of these potentials is the electrical activity of single muscle fibers, which occur in isolation (e.g. endplate activity, fibrillation potentials), as groups of adjacent but unlinked potentials (e.g. insertional activity, complex repetitive discharges), or as groups of individual muscle fibers linked together as part of the same motor unit.

The task of the clinical electromyographer is recognition, quantitation, and interpretation of the waveforms. These skills depend on the electromyographer's skills of learning pattern recognition and rapid quantitation. Pattern recognition is a basic skill that allows for the identification of waveform, such as distinguishing a fibrillation potential from an endplate spike or voluntary motor unit potential. The skill of rapid quantitation is used to determine whether the parameters of a waveform, such as a motor unit potential, are normal or abnormal. Pattern recognition and rapid quantitation are equally important in mastering clinical electromyography, and can be learned simultaneously.

PATTERN RECOGNITION

Each potential recorded during EMG may be characterized by its: 1) firing pattern (regular, semi-rhythmic, irregular), 2) configuration (triphasic, biphasic, polyphasic, etc.), and 3) auditory sound. Pattern recognition allows for identification of the pattern of firing of each of the discharges and is most useful in the recognition of each type of waveform. Pattern recognition is learned by associating a sound with a name when hearing them together many times. The skill of pattern recognition allows our auditory systems to do much more than any computer or visual representation is able to do, in recognizing and categorizing the wide range of EMG signals that occur in normal and diseased muscle. Auditory, like visual pattern recognition is so intrinsic to our cortical function, that once learned, it occurs essentially instantaneously. Clinical EMG ultimately relies on our ability to recognize individual waveforms not only occurring alone, but also occurring in combination with other signals. Our ears and brains are well designed to separate out individual waveforms.

The skills of auditory pattern recognition form the basis of learning the major distinct patterns of firing of EMG discharges:

- **Semi-rhythmic** – recurring in orderly, but not precise intervals
- **Regular** – recurring at precisely defined intervals that may be identical, be changing slowly or rapidly, or be changing in linear or exponential manners
- **Irregular** – recurring in random intervals with no predictability
- **Burst** – groups of discharges firing at one interval in the burst, with the burst recurring at slower intervals.

RAPID QUANTITATION IN EMG

Quantitation refers to placing a numerical value on a measured parameter. Nerve conduction studies quantitate amplitudes, distal latencies, and conduction velocities of nerve and muscle responses to an applied electrical stimulus. During needle EMG, estimation of the different parameters of motor unit potentials is compared with normal values in determining whether a muscle is "normal" or "abnormal." In many cases, determination of whether a MUP is normal or abnormal is made by a general estimation (e.g. "these MUP sound normal" or "those MUP sound long"). In actuality, when the electromyographer is making these decisions, he or she is performing an aspect of rapid quantitation – possibly without even realizing!

In contrast to pattern recognition, quantitative assessment of voluntary motor unit potentials provides information that has specific clinical value in the assessment of neuromuscular diseases. It would be ideal to have formal, quantitative measures of each of the parameters of the motor unit that we assess during needle electromyography, just as we do for nerve conduction studies. The limitations of current EMG equipment, and the time required to accomplish such measurements preclude this for routine EMG. A number of methods have been published for formal quantitation of motor unit potentials, including manual and automated measurement of the motor unit potentials parameters described below (individual MUP measurement, turns-amplitude measurement and frequency analysis.) While these continue to be developed, none are sufficiently efficient for them to come into routine clinical EMG use, and formal quantitative EMG is rarely performed.

However, the quantitation of MUP parameters in most clinical settings can efficiently be performed by "rapid quantitation". In fact, a skilled electromyographer can accomplish close to this ideal by applying the well-defined techniques of "rapid quantitation" EMG, by which the electromyographer learns to make estimates of each of the parameters (number of MUP firing, rate of firing, duration, percent polyphasic, turns and stability). This workshop will focus on learning the methods of rapid quantitation. Success at rapid quantitation EMG depends on taking the time to learn the methods, and then applying them consistently on each recording until the techniques are mastered. When that occurs, the time taken is no greater than that for routine, non-quantitative EMG. Rapid quantitation EMG requires three essential elements:

1. EMG equipment that permits both the display of the EMG signals free-running at a sweep speed of one second per sweep, and triggered at sweep speeds of 5 msec per division.
2. Low levels of activation of motor unit potentials that allow distinction of individual potentials.
3. Recording of potentials from multiple areas in a muscle.

Rapid quantitation EMG requires the following steps to be taken separately for voluntary EMG activity:

- One to three, individual MUP from a single area of muscle are recorded, holding the needle stable, and displayed as outlined above.
- The rate of firing is determined from the free-running sweep or from an automated measurement (triggering on a single MUP) for each of the potentials.
- The number of MUP is compared with the rate of firing of for any one of the potentials to determine recruitment
- The MUP parameters (duration, amplitude, phases, turns, stability) of each of the potentials with a rise time less than 0.5 msec are estimated from their sound and appearance on the triggered sweep.
- With no change in activation, the needle is moved to additional areas of muscle (0.5 mm), where the steps above are repeated.
- Recordings in different areas are repeated until a minimum of 20 - 30 potentials has been recorded. The findings at each location are averaged mentally for all locations tested in the muscle. .
- The averaged measurements of recruitment and motor unit potential parameters are written down for a muscle before proceeding to the next muscle.

When these steps have been mastered, the electromyographer will be able to make each of the measures with over 90% accuracy and do so in two minutes or less per muscle.
However, mastery requires taking the following learning steps:

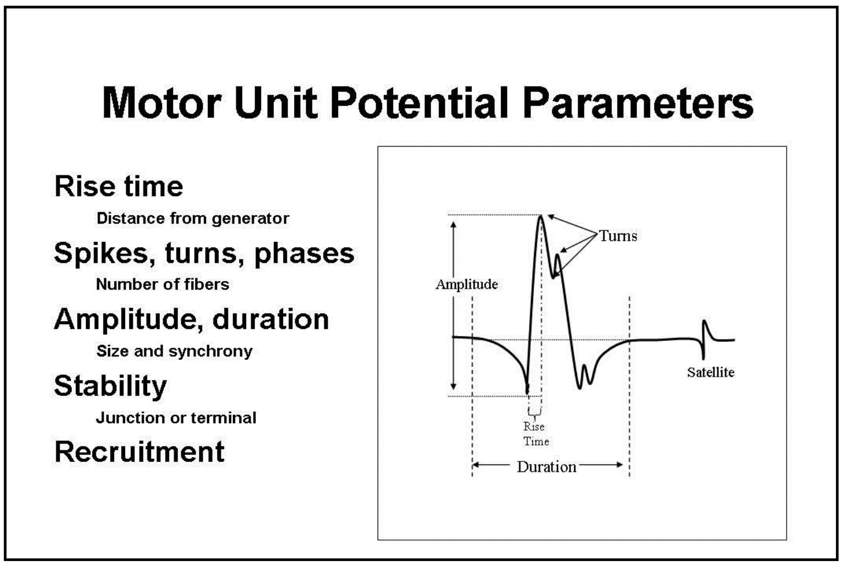
- The activation of motor unit potentials is maintained at a fixed level so that there are one to three potentials firing at each location in the muscle (fewer as learning begins; more as learning proceeds).
- The sound of the potentials at each location in the muscle is listened to for 3 - 5 seconds as the potentials are recorded.
- An estimate of the average firing rate, number of potentials firing, and of the other MUP parameters of each active potential is made by ear from the sound, and written down.
- The motor unit potentials that have been estimated are stored on the free running and triggered sweep.
- The actual firing rates, numbers of potentials and parameters of the potentials are made from the storage scope and compared with the estimates.
- Estimates are corrected and the measurements are repeated until the estimates are within 90% of the measured.

RAPID QUANTITATION OF MOTOR UNIT POTENTIAL PARAMETERS

Motor unit potentials (MUPs) are the electrical discharges of motor units under voluntary control and are identified by the semi-rhythmic pattern of firing which can be altered by patient effort. The following parameters of MUPs can be rapidly quantitated, and each parameter reflects the underlying changes of the motor units within the muscle being examined.

- Recruitment
- Rise time
- Duration
- Phases / turns
- Stability

Motor unit potential parameters should be estimated at the same level of contraction where individual potentials can be readily distinguished with flat baseline between them. Duration and amplitude estimates should be made only where potentials are recorded with a rapid rise time (sharp, clicking sound). This is best done at a gain of 200 µv/cm and sweep speeds of both one second (50 msec/div.) for pattern and rate, and of 50 msec (10 ms/cm) for configuration.



The following are the parameters of motor unit potentials that can be rapidly quantitated:

Rise Time

The time from the initial positive peak to the initial negative peak is the fastest component of the motor unit potential and is referred to as its rise time. This is a function of the distance of the recording electrode from the fibers of the motor unit. This very fast component produces the sharp, “clicking” sound heard on the loud speaker. When the needle electrode is near a motor unit the rise time is 0.5 msec in duration or less. The accurate assessment of the characteristics of all of the motor unit potentials assumes that the needle electrode is in the immediate vicinity of the motor unit and therefore only motor unit potentials with a rise time of 0.5 ms or less should be considered in making these estimates.

Rise Time
• Time from maximal positive deflection to negative deflection. • Reflects the distance of the recording electrode to the muscle fiber. The closer to the fiber, the shorter (more rapid) rise time. • Rise time <u>should be less than 0.5 msec</u> (recording from fibers within 0.5 mm) when assessing MUPs

<u>Duration</u>

The duration of a single motor unit potential is the time from the initial (often slow unless at the end-plate zone) shift of the potential away from the baseline until its final return to the baseline (also often slow). This duration is much longer than the spike component of the potential. The durations of motor unit potentials in a muscle have a normal distribution that can be described by a mean and standard deviation. The normal values differ from muscle to muscle and also vary with age and temperature. Average duration increases by 35% from infancy to adulthood (biceps) and by 65% (abductor digiti minimi), probably due to dispersion of the endplates with enlargement of muscle. Mean duration increases by 10% per degree decrease in temperature and the percent of polyphasic potentials also increase with decreased temperature.

The mean values published by Buchthal (which exclude long polyphasic units) are the accepted normal:

1. Normal - A mean duration for the motor units in a muscle within two standard deviations of the mean values determined for the same muscle in normal individuals of the same age group (20 or more units measured) and no more than 10% of the units outside the normal range for that muscle.

2. Short Duration - The mean duration of motor unit potentials is less than a value two standard deviations below the mean of that muscle in normal individuals or more than 10% of the potentials are of shorter duration than the lower limit of the normal range for that muscle. This abnormality may be described as: (1) Increased proportion of short duration potentials; (2) Scattered, few occasional, moderate numbers of or many short duration potentials; or (3) Localized areas of short duration motor unit potentials. While short duration MUP may be described as "spiky" it is always best to specify the mean and range of durations, or give some estimate of the number or percentage of short duration motor unit potentials seen in the total population. It should be based on the study of at least 20 motor unit potentials in different areas of the muscle.

3. Long Duration - The mean duration of motor unit potentials is greater than a value two standard deviations above the normal mean, or more than 10% of motor unit potentials are longer duration that the upper limit of the normal range. The description of this change should use grades similar to that used for short duration potentials, and should include an estimate of the proportion of long duration potentials in the population. It should be based on the study of at least 20 motor unit potentials in different areas of the muscle.

Duration

• Time from leaving the baseline (initial positive deflection) until returns to baseline (end of final positive tail).
• What contributes to the duration of a MUP?
    • Duration of a single muscle fiber potential is <u>2-3 msec.</u>
    • Motor endplates of a motor unit are scattered over 20-30 mm along muscle fibers. This results in temporal dispersion of the action potentials of about <u>7 msec</u>.
    • Propagation of potentials along muscle fibers away from endplate region at about 4.7 meters / second may add another <u>3 msec</u> to total duration time
• Adds up to about <u>10 – 13 milliseconds</u> of total duration
• Varies among different muscles.
• Major portion of the total duration is determined by the initial and terminal components of MUP. These are generated by more distant fibers (greater than the 1 mm area that makes up the spike, but within 2.5 mm of recording electrode).

Amplitude

The amplitude of the motor unit potential is measured from the maximum negative peak to the maximum positive peak (peak-to-peak). The amplitude of a single motor unit potential remains constant throughout its period of firing. It is a function of the distance of the needle electrode from the motor unit potential as well as other features of the unit. It is therefore more variable for any single motor unit than is the duration. Because of these difficulties acceptable normal values for amplitudes of motor unit potentials are not available. Amplitude is the parameter that is least able to be quantitated rapidly, since there is minimal recognizable auditory change with different amplitude sizes. In other words, a high amplitude MUP will sound essentially the same, only louder, than a smaller amplitude MUP of the same duration.

Amplitude
• Positive peak to negative peak • Sum of the action potentials of muscle fibers closest to the recording electrode. Usually made up of less than 15 muscle fibers (typically 1-8). • Determined by the diameter of muscle fibers, number of muscle fibers, and temporal distribution of action potentials closest to the recording electrode. • May have several peaks due to asynchronous firing of potentials. • Larger amplitudes may reflect increased fiber density of muscle

Number of Phases or Turns

A phase of a MUP is defined as the number of baseline crossings plus one. Turns are defined as potential reversals without crossing the baseline. Both reflect the synchrony of firing of the muscle fibers in the motor unit. Motor unit potentials are typically triphasic with an initial positivity followed by a negative spike and then a slow positivity. They may be more complex, having four to six phases in normal muscle. Potentials with more than four phases are referred to as “polyphasic”, and are found in different normal muscles in varying proportions (5 to 15%).

1. Normal - A muscle contains no more than the accepted percentage of polyphasic units for that muscle in a patient of that age.

2. Increased Numbers of Polyphasic - A greater-than-normal proportion of polyphasic potentials for that muscle. Usually graded by percentage.

3. Highly Polyphasic - The occurrence of potentials having greater than six separate phases. The number of these as a proportion of the total number of motor unit potentials should be estimated.

Caution - Estimates of the numbers of polyphasic motor unit potentials should be made with minimal to moderate contractions since with strong contractions the superimposition of different motor units may give the appearance of polyphasic units, particularly in the presence of tremor.

Phases / Turns
• Phases = changes in direction of the potential which cross the baseline (equals baseline crossings plus one) • Turns = changes in direction of the potential greater than 50 microvolts that do not cross the baseline • Both are indicators of **synchrony** of firing of potentials. With decreased synchrony (loss of muscle fibers in myopathy, collateral sprouting in neuropathy), there is increase in number of spikes (either turns or phases) • **Normal potentials have 3 or 4 phases**. Less than 15% of motor unit potentials should have more than 4 phases (polyphasic).

Recruitment

The number of motor units in a muscle may be considered in two ways. The first is the total number of motor units that could be fired if the anterior horn cell pool received adequate input. The second is the actual number of motor units that are activated when a patient attempts a voluntary contraction. The first of these is more pertinent in assessing the presence or absence of disease involving the lower motor neuron and is called recruitment. The second is quite variable and changes with the patient's cooperation, the strength of the muscle, pain, and the presence or absence of disease of the upper motor neuron.

The recruitment of motor unit potentials as reported in the EMG report should estimate the total number of motor units available for activation and not the actual number which the patient fires. The total number available can be best assessed by the pattern of recruitment of motor unit potentials with increasing voluntary effort. In a normal muscle as the effort exerted increases each motor unit potential already firing will increase its frequency. As it does so additional motor unit potentials will begin to fire (be recruited). This pattern of recruitment can be characterized objectively by the *recruitment frequency* - the frequency of firing of any single motor unit potential when the next motor unit potential is recruited. It can also be described by the number of units firing at specific frequencies.

In the presence of a lower motor neuron disease with loss of the anterior horn cell or peripheral motor axon, the recruitment frequency will increase (i.e. motor unit potentials will fire more rapidly before additional motor units are recruited). Conversely the rate of firing of motor unit potentials already firing will be unduly fast for the number of motor unit potentials that have been activated. By using the pattern of recruitment it is possible to assess the normality of the number of motor units in the muscle with mild, moderate, or maximal effort on the part of the patient.

Although there have been few studies that have identified the normal recruitment frequencies for each muscle, for most muscles a general guideline to assess recruitment is the *"Rule of 5"* .*This guideline suggests that the ratio of the firing rate of a MUP compared to the number of individual, near MUPs firing **less than 5**.* For example, when the firing frequency of an initial MUP reaches 10 Hz, a second MUP should begin to fire (10 Hz / 2 potentials). When the frequency reaches 15 Hz, 3 MUPs should be firing (15 / 3 = 5). With loss of motor units as in neurogenic lesions (see below), MUPs fire faster with a reduction in number of units firing (e.g. initial motor unit fires at 20 Hz before 2nd MUP begins firing – 20 Hz / 2 = 10). This indicated reduced recruitment.

1. Normal - The pattern of recruitment is normal for that muscle, with adequate numbers of motor unit potentials being recruited for the frequency of firing present. If maximal effort can be obtained, a full interference pattern is seen.

2. Reduced Recruitment - A higher recruitment frequency or a smaller number of motor unit potentials recruited for any given rate of firing than is expected from that muscle. This should not be used to describe patients who fire relatively few motor unit potentials because of pain, strong muscles, upper motor neuron lesions, or poor cooperation, since they fire few potentials the potentials are firing slowly with a normal pattern of recruitment.

3. Poor Activation - A normal recruitment pattern and normal recruitment frequency, but with relatively few motor potentials firing. These potentials fire slowly, but recruitment of additional potentials is normal. This occurs in upper motor neuron disorders, poor cooperation, pain, an excessively strong muscle, or two joint muscles, such as the gastrocnemius. It is not evidence of lower motor neuron disease.

4. Increased Number in Proportion to Force - The occurrence of large numbers of motor unit potentials with normal recruitment frequency and normal patterns of recruitment, but with minimal effort. This must be graded in proportion to the force exerted, since the patterns of firing are entirely normal. It is the only estimate described which requires a consideration of the force exerted by the muscle. It is evidence of disease involving the muscle directly.

Recruitment	
• The orderly addition of MUP firing as the rate of individual MUP firing increases. • Normal muscle – increasing voluntary effort causes an increase in the rate of firing of individual motor unit potentials and the initiation of the discharge of additional motor unit potentials. • Individual motor unit begins firing at 4 – 5 Hz and second unit is recruited when first unit is firing at 11 – 15 Hz	
Reduced recruitment	• With loss of motor units (conduction block or axonal loss) fewer motor units are present to generate the force required to contract muscle. As a result, the remaining units fire faster to sustain contraction. The rate of firing is out of proportion (increased) to the number firing. • Occurs in any disease process that destroys or blocks conduction in the axons, or destroys a sufficient proportion of the muscle so that whole motor units are lost. • May be the only finding in a neuropraxic lesion, in which the sole abnormality is localized axonal conduction block. • May be the initial finding in cases of acute axonal loss, when fibrillation potentials have not yet developed.
Rapid Recruitment	• With loss of muscle fibers from the motor unit (myopathy), need to recruit more units and fire them faster to generate the same force. • More motor units are activated than expected for the force exerted. Smaller units fire first because their cell bodies are smaller and excited with less upper motor neuron excitatory input than larger neurons • Full interference pattern with minimal effort • Difficult to isolate units. May appear that patient has "difficulty cooperating or relaxing".
Poor activation	• Slow rate of firing, but consistent with degree of effort • Seen in upper motor neuron lesions, pain, poor effort

Stability

Each time a normal MUP fires, the morphology of the waveform remains identical. This is due to maintenance of the integrity of neuromuscular transmission at each nerve terminal innervated all of the muscle fibers within that motor unit. When neuromuscular transmission fails, such as in diseases of the neuromuscular junction or in immature collateral nerve sprouts in neurogenic disorders, MUPs become "unstable" and their morphology varies with each firing. Varying MUP can readily be recognized by the "bongo drum" sound during the needle examination. Formal quantitation of the degree of MUP variation requires single fiber EMG (assessing jitter and blocking), although the degree of variation can be estimated by rapid quantitation.

Stability

• Refers to function of neuromuscular junction
• If amount of Ach released with each nerve action potential is sufficient to reach threshold, EPP is achieved, and muscle action potentials occur with each impulse.
• If decreased amount of Ach (due to pre- or post-synaptic abnormalities) reaches endplate, EPP won't always reach threshold.
• Therefore, serial discharges of the same motor unit potential will intermittently consist of fewer fibers firing than others, and the synchrony of firing between single muscle fibers will vary. This translates into *varying motor unit potentials* on concentric needle EMG.
• MUP variation occurs in:
  • Defects in neuromuscular junction (myasthenia gravis, LEMS, congenital myasthenia)
  • Early (ongoing) reinnervation – immature nerve terminals

RAPID QUANTITATION OF SPONTANEOUS WAVEFORMS

Fibrillation Potentials

Fibrillation potentials are the muscle action potentials of single muscle fibers firing spontaneously in the absence of innervation of that muscle fiber. Fibrillation potentials occur in disorders of either muscle or nerve dysfunction, such as polyneuropathies, mononeuropathies, radiculopathies, motor neuron disease, or myopathies. Fibrillation potentials fire with a regular rate, although a linear slowing of firing rate may occur. Typical fibrillation potential configurations include biphasic and monophasic spike potentials, or triphasic, initially positive spike potentials firing slowly and regularly (sound like the "ticking of a clock").

Quantitation of fibrillation potentials is rarely necessary. In most cases, grading of the density of fibrillations (e.g from 1+ to 4+) is sufficient to estimate the degree of denervation of the muscle.

Fasciculation Potentials

A spontaneously occurring, single discharge having the general configuration of a motor unit potential is a fasciculation. Fasciculation potentials fire in an irregular pattern, and may occur only occasionally or continuously.. The size, shape, configuration, and duration of the discharge will not enter into the consideration of whether it is called a fasciculation. However, the waveform and its pattern of occurrence should be described. If such single, spontaneously occurring discharges are complex in appearance or have an unusual pattern of recurrence, these should be specifically described.

Fasciculation potentials may be rapidly quantitated by counting the number occurring per minute

Complex Repetitive Discharges

Polyphasic, usually complex, recurring at 10 - 150 per second, of uniform frequency, shape, and amplitude. The pattern of firing is regular, although they start and stop abruptly and may show a sudden change in their character during the discharge. They often sound like a "motor boat". Complex repetitive discharges may be seen in chronic or longstanding neuropathic or myopathic disorders, and are due to ephaptic activation of groups of several adjacent muscle fibers following reinnervation.

Quantitation of complex repetitive discharges is rarely necessary. However, rapid quantitation can be used to identify the firing rate of degree of polyphasia within a CRD.

Myotonic Potentials

Monophasic, biphasic, or triphasic individual muscle fiber potentials occurring at 20 - 80 per second with gradually increasing and/or decreasing amplitudes and rates. The firing pattern is regular, although gradually changes exponentially, and the discharges are usually induced by needle movement or other mechanical stimulus. Myotonic discharges sound like a "dive-bomber". They are seen in myopathies characterized by abnormalities and the sodium or chloride channel on muscle membranes, such as myotonic dystrophy, myotonia congenita, hyperkalemic periodic paralysis, and some inflammatory myopathies.

Quantitation of myotonic discharges is rarely necessary. However, rapid quantitation can be used to identify the firing rate of a discharge.

Neuromyotonia

Monophasic or biphasic potentials occurring at a very high frequency (over 100 per second), of gradually decreasing amplitude. May be spontaneous, induced by needle movement, of voluntary action. They often sound like an "Indy 500 racecar". Quantitation of neuromyotonic discharges is rarely necessary. However, rapid quantitation can be used to identify the firing rate of a discharge.

Myokymic Discharges

Regular recurrence of bursts of potentials at relatively constant intervals of 0.5 - 10 seconds. The potentials within the burst may have any of the characteristics of motor unit potentials, but fire at rapid rates of 30 - 80 per second. The number of potentials in a burst may vary from 2 - 50. These are involuntary discharges. They often sound like "marching soldiers". Quantitation of myokymic discharges is rarely necessary. However, rapid quantitation can be used to identify the firing rate within a burst and between bursts of a discharge.

EVOLUTION OF NEEDLE EMG FINDINGS IN ACUTE NEUROGENIC DISORDERS

Motor unit configuration is altered in disease states. In neurogenic disorders, loss of motor units results in reduced recruitment, and collateral sprouting of remaining axons produces long duration, high amplitude, and polyphasic motor unit potentials. In myopathic processes, loss of muscle fibers within motor units leads to reduction in amplitude and duration of MUP. Abnormal motor unit variation is also seen in some neurogenic and myopathic processes, in addition to neuromuscular junction disorders. By using rapid quantitation to assess the multiple parameters of MUP, determination of the chronicity of a neurogenic process can be made.

Time Interval	**Spontaneous**	**Recruitment**	**Stability**	**Duration**	**Turns/Phases**
Day 1-10	Normal	Reduced	Stable	Normal	Normal
Day 10 - 15	Increased	Reduced	Stable	Normal	Normal
Day 15 - 25	Fibrillation	Reduced	Stable	(Increased)	Turns
Day 25 - 60	Fibrillation	Reduced	Unstable	Increased	Polyphasic
Day 60 - 180	(Fibrillation)	Reduced	(Unstable)	Increased	Polyphasic
After Day 180	Normal	Reduced	Stable	Increased	(Polyphasic)