Motor Unit Anatomy/Physiology. A motor unit is anatomically defined as being comprised of a single anterior horn cell (AHC) and all of the muscle fibers innervated by that parent anterior horn cell (Fig. 1). Anterior horn cell activation results in the ensuing depolarization of all its corresponding single muscle fibers.

The spatial and temporal summation of all the single muscle fibers’ electrical activity corresponding to that AHC depolarization is referred to as a motor unit action potential (MUAP/MUP; Fig. 2). In other words, the MUAP is essentially the electrical correlate to the anatomic motor unit. The above noted MUAP’s respective “spatial” and “temporal” qualifiers are related to the fact that: 1) all of the single muscle fibers belonging to one anterior horn cell are distributed in muscle tissue within a so called motor unit territory approximating a cylindrical volume of roughly 6 mm in diameter extending the length of the muscle, and 2) the voltage associated with all those single muscle fibers summate electrically based on their individual arrival times at the recording electrode.

Let’s unpack the above concepts for a more clear appreciation of MUAPs. As noted above, all of the single muscle fibers for a single motor unit are
contained within a volume of muscle tissue with an approximate cross sectional diameter of 6 mm (Fig. 2). Within this motor unit territory, single muscle fibers from multiple other anterior horn cells are interspersed and subsequently share the same volume with each other. There may be 10 or more motor units within this particular volume. This pattern repeats throughout the entire muscle. The dispersal pattern for the single muscle fibers from one anterior horn cell is randomly but not necessarily uniformly distributed throughout this 6 mm oval (Fig. 2). Specifically, individual single muscle fibers may or may not cluster together in a random manner such that small groups of muscle fibers may be within rather close proximity to each other, while other muscle fibers from the same parent AHC may be somewhat far from their related muscle fibers. The net result of this non-uniform “packing density” is that a single MUAP may have quite different appearing shapes directly dependent upon where in the 6 mm territory the needle recording electrode is located. This is the reason the same MUAP can appear quite differently and change its appearance as the needle electrode is moved through the physical expanse of the 6 mm motor unit territory (Fig. 2). Appreciation of this non-homogeneous motor unit/muscle fiber distribution is particularly important when performing quantitative MUAP analysis so as to avoid recording the same motor unit over and over again. Therefore, when attempting to analyze different motor units, it is mandatory to reposition the electrode at least a few centimeters within the muscle to ensure the same motor unit is not counted more than once.

The preceding description explains why the same motor unit may appear somewhat different with small needle movements and results from the spatial distribution of the single muscle fibers from one AHC. However, there is another factor not usually appreciated, specifically the temporal relationship of voltage summation from the depolarizations of all the individual single muscle fibers belonging to one AHC. Recall that a single axon splits into a terminal arborization comprised of multiple small caliber axons each with different diameters (hence different conduction velocities/arrival times) innervating its related single muscle fiber. Each terminal axon will form a neuromuscular junction with its corresponding single muscle fiber. Further, each muscle fiber has a somewhat different cross sectional area/diameter. This anatomic description takes on electrophysiologic relevance when one considers that each terminal axon has a slightly different diameter and hence different conduction velocity. Also, each terminal axon has a different length to its corresponding single muscle fiber. The time delay across each neuromuscular junction is somewhat different as well. Finally, the conduction velocity of each muscle fiber is slightly different and may vary between 2 to 5 M/s. When the above anatomic/electrophysiologic issues are considered, one can quickly appreciate that each muscle fiber of the motor unit will fire somewhat differently from their counterparts. Also, each will conduct along their
corresponding muscle fiber at a somewhat different velocity. Of course, all of this electrically activity is initiated at the end-plate zone or so-called motor point. Therefore, locating the needle electrode at different locations longitudinally along the muscle with respect to the end-plate will result in slightly different appearing waveforms for the same MUAP. Additionally, MUAP waveforms recorded at the end-plate compared to the muscle’s middle as well as the musculotendinous junction will result in grossly different appearing waveforms. This is because of the manner in which the electrical current is recorded by the electrode with respect to the summated action potentials current sources/sink as is explained by volume conductor theory. That is, the gross MUAP configuration will vary if the electrode is located at the end-plate zone (biphasic initially negative), in the muscle’s middle (triphasic initially positive), or at the musculotendinous junction (biphasic initially positive).

**MUAP RECRUITMENT.** Recruitment of MUAPs may be defined as the temporal and spatial summation of individual motor units with respect to themselves and each other in response to a sequential increase in force production. Let's explore both the physiologic meaning and clinical implications of this assertion.

**Physiologic Meaning.** A needle recording electrode located in skeletal muscle at rest should detect no electrical activity with the exception of an electrode placed in, or in close proximity to, the end-plate region. In which case, it may be possible to record miniature end-plate potentials (monophasic negative spikes) or end-plate spikes (biphasic initially negative/triphasic initially positive/biphasic initially positive: end-plates are not always biphasic initially negative and may lead to confusion with positive sharp waves/fibrillation potentials). Either electrical silence or the above noted end-plate activity is to be expected for a recording made in normal muscle at rest. For the purposes of this discussion, let us assume that the needle recording electrode is purposefully positioned along a normal muscle somewhere between the end-plate zone (roughly middle of the muscle) and the musculotendinous junction. This purposeful needle location should result in the recording of typical triphasic MUAPs. The MUAP’s approaching source currents should generate a waveform with an initial positive deflection. When the MUAP’s negative sinks subsequently arrive at, and are coincident with, the recording electrode a large negative spike is recorded. Finally, as the MUAP propagates away from the recording electrode, the MUAP’s terminal depolarization (sometimes erroneously called repolarization) source currents are detected, thereby generating a terminal positive deflection resulting in the above noted triphasic (initial positive, subsequent negative, and terminal positive deflections) MUAP. As long as the needle electrode remains in the same physical location with no further insertion or lateral movement longitudinally along the muscle, the recorded MUAP will have an identical appearance each and every time it
discharges thereby yielding a stable MUAP.

**Temporal Recruitment.** Ultimately, the reason for producing a MUAP is to generate muscular force so as to move in most cases, a joint, so as to interact with our environment. In order to move a joint for example, it is necessary to activate not just a single motor unit (MUAP), but multiple MUAPs each producing an individually defined amount of force. The force produced by a single motor unit associated with its commensurate electrical discharge occurs in a rather prescriptive manner. A motor unit begins to fire somewhat irregularly at a rate approximating 5 Hz. As we desire more force production, that motor unit increases first its rate and regularity of discharge. It may start at about 5 Hz and serially increase its rate of discharge to 6 Hz, then 7 Hz, then 8 Hz, and so on.

**Figure 3.** The first recruited motor unit is shown with a firing rate of 10 Hz.

When a single motor unit sequentially increases its rate of discharge so as to summate its own amount of force production in time, we describe this process as **temporal recruitment** (Fig. 3). That is, the motor unit is summatating with itself from the perspective of an increasing rate of discharge thereby summatating its own force production. In other words, the motor unit discharges with shorter and shorter repetitive intervals “recruiting” itself within a temporal or “time” domain, hence the term: **temporal recruitment.** This process does not continue indefinitely for obvious reasons. Specifically, a single motor unit no matter how fast it fires is simply incapable of generating a sufficient amount of force to produce any meaningful environmental interaction. Therefore, another process is required to generate the amount of force demanded for a particular environmental interaction.

**Spatial Recruitment.** As noted above, a single motor unit cannot infinitely increase its temporal recruitment/firing rate. At some point, when the degree of force production demanded results in the first recruited motor units reaching about 10 Hz, a second motor unit begins to discharge at roughly 5 Hz (Fig. 4).

**Figure 4.** When the first recruited MUAP (A) just exceeds 10 Hz a second MUAP (B) is spatially recruited.

The act of bringing in a second motor unit is referred to as **spatial recruitment.** That is, a totally distinct motor unit from that initially activated is “recruited” from a different but nearby location in the muscle territory, i.e. the "spatial" as opposed
to “temporal” domain. The first and second motor units now summate their combined force (first motor unit temporally recruiting itself as well as the spatial recruitment of a second motor unit) to assist in the desired action.

As previously noted, it is highly unlikely that two motor units can produce enough force to interact with the environment, and so the above process repeats itself. The first described motor unit that started at 5 Hz and increased its temporal recruitment to 10 Hz which resulted in the spatial recruitment of a second motor unit, now increases its discharge rate yet again, i.e. increases its temporal recruitment from 10 Hz to about 15 Hz. At this point the second motor unit which also began discharging at 5 Hz then temporally recruits itself to increase its firing rate to around 10 Hz. At this point, a third motor unit begins to discharge somewhat irregularly at 5 Hz thereby constituting the spatial recruitment of a third motor unit (Fig. 5).

This process is believed to continue until the first recruited motor unit temporally recruits itself to about 30 Hz or possibly 40 Hz continuing to spatially recruit other motor units with those motor units also temporally recruiting themselves and spatially recruiting yet other motor units. The above process is occurring throughout the muscle to ensure a smooth increase in both muscle contraction and force production.

![Figure 5](image)

**Figure 5.** The recruitment of the previously first MUAP (A ~14 Hz) is shown along with the second recruited MUAP (B ~12 Hz) which recruited a third MUAP (C ~6 Hz). Note the superimposition of two MUAPs to create a fourth "pseudo-MUAP: D; bottom trace).”

Following this process electrically by observing the temporal and spatial recruitment of actual MUAPs on the electrophysiologic instrument is doable for the first few motor units after which time there are simply too many motor units activated to be discerned as individual MUAPs. This is because of the electrical superimposition of different motor units obscuring one’s ability to differentiate MUAPs as distinct entities (Fig. 5).

**Rule of Fives.** The above description of both temporal and spatial MUAP recruitment is sometimes referred to as the “Rule of Five(s)”. Note that each motor unit begins discharging at a rate of about 5 Hz. With a temporal increase of 5 Hz increments for each MUAP, an additional MUAP is spatially added. This concept has lead to the supposition that it is possible to predict the number of motor units that should be observed on an instrument’s screen at any one time depending upon the firing rate of the fastest and presumably the first discharging MUAP, i.e. a so called “recruitment ratio”. The recruitment
ratio is expressed as the fastest firing MUAP observed, divided by the total number of different (individual) MUAPs and should equate to 5 (fastest firing MUAP/total # MUAPs = 5). Of note, for the purposes of this discussion all “units” are ignored and only the numbers associated with MUAPs and firing rates are utilized. This equation can be rearranged to divide the firing rate of the fastest firing MUAP by 5 to predict the number of different MUAPs observed (fastest firing rate (Hz)/5 = total # MUAPs). For example, if the fastest firing MUAP observed is discharging at 20 Hz. Then dividing the fastest firing, and presumably the first recruited MUAP’s firing rate, by 5 (the recruitment ratio) results in a prediction of the total number of individual MUAPs that should be detected, i.e. 4 (20/5 = 4). In other words, if the fastest firing MUAP observed has a discharge rate of 20 Hz, then there should be a total of 4 different motor units each discharging with an approximate corresponding rate of 5 Hz (last recruited MUAP), 10 Hz (third recruited MUAP), 15 Hz (second recruited MUAP), and finally 20 Hz (first recruited MUAP). If, however, a single motor unit is observed with a firing rate of 20 Hz then the recruitment ratio is 20 (20/1 = 20) which is greater than the anticipated normal ratio of 5. A recruitment ratio of greater than 5 is believed to imply that a situation of “neurogenic” or “reduced recruitment” is operational and suggests a neurogenic loss of motor units (anterior horn cell loss or axonal loss/conduction block; Fig. 6).

Figure 6. A single motor units is noted to discharge at a rate in excess of 30 Hz. The recruitment ratio is 30 (30Hz/1MUAP = 30).

If there is a situation whereby the fastest firing motor unit is 10 Hz, but there are 5 distinct MUAPs observed, then a recruitment ratio of 2 is noted (10/5 = 2). In this case, a recruitment ratio less than 5 suggests there are too many motor units firing at intermediate rates implying that each motor unit is too weak compared to normal requiring a too early spatial recruitment (Fig. 7). This has been referred to as “early” or “myogenic recruitment”. The suggestion in this case is that there is a drop out of muscle fibers from each motor unit requiring the above noted type of compensatory temporal/spatial recruitment to produce the necessary force required.

Figure 7. There are two large (A&B) but different MUAPs each firing at about 5 Hz with at least 2 and possibly 3 (C,D,E)other MUAPs for a recruitment ratio of about 1 (5/5 = 1).
Problems With the Rule of Five. The above description of the so called “Rule of Five” is nice and neat for testing purposes with respect to writing examination questions and has some basic clinical utility. The interaction between the peripheral force production sensors and the central nervous systems modulatory input controlling force production is far more complicated than can be fully explained by a simple rule of five. The entire above explanation is founded on a number of assumptions. First, it is assumed that the patient in question is highly cooperative and capable of producing such fine gradations of force that individual motor units can be sequentially activated. This may not be true in the vast majority of our patients. Second, it is assumed that the needle electrode just happens to be located next to the first MUAP activated in the entire muscle. Third, it is assumed that motor units are not simultaneously activated throughout the muscle, which clearly cannot be true. Fourth, it is assumed that the drop out of a single axon is sufficient to be manifest with an alteration of spatial and temporal recruitment which in turn can be detected by the electromyographer. Fifth, I am unaware of a single study that has actually showed that this so called rule of five is objectively reproducible and correlated with a specific drop out of a known quantity of anterior horn cells/axons. No doubt there are other unfounded assumptions, but you get the point. There is simply no experimental or clinical data other than anecdotal suppositions to confirm that this entire concept is sufficiently useful upon which to base an actual diagnosis at least with respect to such tight tolerances as 5 Hz increments. This does not mean, however, that attempting to do any type of MUAP recruitment analysis is worthless or has no clinical utility. It clearly does, but within particular confines with several caveats operational (see below).

CLINICAL UTILITY OF MUAP RECRUITMENT ANALYSIS

General Assumptions. First and foremost it is critically important to appreciate that recruitment analysis can be very helpful in carefully selected scenarios, but is not diagnostic of any one disorder, and certainly is not particularly sensitive in situations of mild-to-moderate axonal loss. Recruitment analysis can be best defined as a rather crude analysis method manifesting abnormalities only when significant disease is present. It is simply not capable of defining subtle disease. The analysis of motor unit recruitment is simply one of many “tools” available for the electromyographer and like all tools is not applicable for any and all jobs, but only for those instances for which the tool was designed, or is highly relevant. Attempting to use a hammer to drive a screw is simply unwise for many reasons. Similarly, attempting to employ recruitment analysis for minor to moderate axonal loss is just not helpful. Why? Quite frankly because quite a few axons have to be lost prior to recruitment abnormalities becoming manifest on the needle EMG. Exactly, how many must be lost: no body knows. Don’t believe me? Try the following two exercises in your own practice.
1) Next time you have a patient with clearly defined denervation (positive sharp waves and fibrillation potentials) in a myotomal distribution indicative of a cervical or lumbosacral radiculopathy with a 4 to 5 grade of strength, measure the recruitment ratio as defined above. You will find that the recruitment analysis of intervals and ratios are completely normal. 2) In a patient with a peripheral neuropathy as documented by nerve conductions irrespective of the sensory or motor responses’ amplitudes, the recruitment intervals and ratios will be normal as long as the patient has a grade 4 or better strength in the muscle no matter how much denervation you detect. Far too many electromyographers assume that recruitment “must” be abnormal if denervation is present because axonal loss has occurred. This just isn’t true. You usually don’t start to see recruitment abnormalities until there is at most a grade 3 muscle strength or less no matter how much denervation is present. No one has defined scientifically exactly how many axons/conduction block/muscle fibers, or AHCs must be lost prior to clinical recruitment analysis demonstrating an abnormality.

Recruitment Analysis: Qualitative Method

Qualitative recruitment analysis requires considerable practitioner experience with the ability to recognize individual MUAPs flitting across the instrument’s screen, and to appreciate individual waveform characteristics. We begin with the muscle under investigation completely at rest. We will assume you have already looked for spontaneous activity and further we will not be discussing individual MUAP parameters (size, shape, duration, rise time) but only consider the recruitment of individually recruited MUAPs. Further, we set the instrument’s sweep speed so that it yields 100 ms across the entire screen. The patient is requested to gently activate the muscle in question. It is highly likely though not impossible, that more than one MUAP will usually be simultaneously recruited as opposed to just one MUAP. Recall that the above description of the “rule of 5” is nice for textbook discussions but is less clear cut in actual clinical practice unless “significant” disease is present. We usually observe more than one MUAP initiating at about 5 Hz most likely because of the above described overlap of multiple motor unit territories. The needle recording electrode is likely positioned so as to record the volume conducted electrical activity from the physical territory of several overlapping AHCs. Let’s get back to our patient. If you have the skill to appreciate that the two MUAPs you observe are different in configuration (two individual MUAPs), and both MUAPs appear once and only once on the instrument’s screen (single trace not a raster mode), or at the extremes of the screen, you are done. This is normal recruitment. Why? Recall that the total amount of time on the screen is 100 ms. A motor unit appearing only once every 100 ms is firing at 10 Hz. You have two MUAPs firing at 10 Hz. If you like to use the rule of 5, then $10/2 = 5$; normal recruitment. If you have just one MUAP firing, then you need to request the patient to deliver
more force since you haven’t “recruited” a second motor unit. If the second motor unit appears in and you now have two MUAPs on the screen, then you have reproduced the above noted scenario. As noted above, you can certainly find significant numbers of fibrillation potentials and positive sharp waves in these muscles with normal recruitment as long as the patient has a grade 4 strength or better. Also, some patients with a grade 3 strength may also have normal recruitment.

On the other hand, what if you ask the patient to gently contract their muscle and you observe one MUAP with gentle contraction. Upon requesting an increase in strength you observe that MUAP increase its firing rate to where it appears 3 times on the screen with no other MUAP (Fig. 6). This is clearly an abnormal finding and suggests the MUAP is discharging three times in 100 ms for a firing rate of 33 Hz. If you like to use the rule of 5, then we should see a total of roughly 6 individual MUAPs instead of just 1 (33/5 = 6). More typically, in patients with significant weakness you may see two motor units each appearing twice on the screen (twice in 100 ms or 20 Hz) again suggesting an abnormality of recruitment whereby this scenario should be generating 4 and not 2 MUAPs (20/5 = 4). These examples are all consistent with significant axonal loss or conduction block with so called “reduced” or “neurogenic” recruitment. That is, too few MUAPs firing with too fast a discharge rate for the amount of force requested. The physiologic implication is that there is a reduction in the total number of motor units and those that are missing cannot begin firing at their typical force production discharge rate. As a result, the earlier recruited MUAPs must temporally recruit themselves until such time that their increased rate demands those later induced MUAPs then begin to discharge.

It is certainly possible to also observe a patient who produces 4 or more MUAPs with just minimal contraction and each MUAP appearing once in the 100 ms time frame. The MUAP discharge rate may be 10 Hz or even 5 Hz. In either case, using the rule of 5 would suggest that you should have no more than 2 MUAPs (10/5 = 2) and likely just 1 yet we detect 4 individual MUAPs. In this situation we have a recruitment ratio of 2.5 (10/4 = 2.5) which is less than 5. In this circumstance we have too many MUAPs firing at low to moderate rates for the amount of force requested. This constitutes the so called “early” or “myogenic” recruitment (Fig. 7). The physiologic implication is that each motor unit has too few normally functioning muscle fibers and can’t generate the amount of force requested so the CNS induces an early spatial recruitment as well as some temporal recruitment. This recruitment pattern is usually seen in myopathies. However, it is also important to keep in mind that some individuals with no nerve or muscle pathology can also generate a number of MUAPs firing at low rates that have similar appearing recruitment ratios. As noted above, this may occur when there is overlap of motor unit territories and the recording electrode is recording from multiple first recruited motor units. Clearly, MUAP
Recruitment is not a particularly sensitive tool and any type of MUAP analysis should not be limited solely to recruitment analysis, but also consider MUAP parameters and any spontaneous activity if present.

**Recruitment Analysis: Quantitative Method.** It is also possible to perform a somewhat more qualitative MUAP recruitment analysis as part of the routine needle EMG assessment. This is possible because most commonly available instruments now have the capability of storing some epoch of raw needle EMG data for a more in-depth analysis. Specifically, the patient is requested to perform a minimal contraction with a slight increase in force production so as to sequentially activate the first few recruited MUAPs. The data can then be replayed in a raster mode (multiple traces displayed on the screen) so that it is easier for the practitioner to observe several 100 ms epochs on the screen and actually measure the time interval between MUAPs. The operator can scroll the screen to the first recruited MUAP and then step forward in time to when the second MUAP first appears. Time markers are then placed on some easily identified location on the first recruited MUAP’s two successive appearances on the screen (e.g. peak negative spike) when the second recruited MUAP first appears. According to the rule of 5, the recruitment frequency of the first recruited MUAP should approximate 10 Hz (100 ms inter-potential interval: e.g. spike to spike interval of the first recruited MUAP) when the second MUAP initiates its activation.

If the patient is requested to produce a contraction and only two MUAPs are recruited for example, with the first MUAP appearing 3 times on the screen then its inter-potential interval is about 33 ms or roughly 33 Hz. Using the rule of 5 suggests that 6 MUAPs (33/5 ≈ 6) should be present and not 2. In this case we have too few MUAPs firing too fast suggesting a “neurogenic” recruitment pattern indicative of axonal loss or anterior horn cell loss/conduction block.

Similarly, if a patient is asked to produce a mild muscle contraction and 5 MUAPs appear while the data is being recorded to the instrument’s memory, it can again be analyzed at that, or a later time. The recorded time interval is again rastered for easy viewing on the instrument’s screen after being recalled from memory. The practitioner attempts to document visually which MUAP appears to be firing most rapidly of the 5 total MUAPs. Time markers are placed on these two MUAPs at the same location (e.g. peak negative spike for each one) and the ensuing time interval between these two markers noted. If the time is 70 ms then the recruitment rate is 14 Hz and the ensuing recruitment ratio suggests about 3 MUAPs should be present (14/5 = 2.8) and not the 5 documented. Instead we have 5 total MUAPs firing somewhat rapidly suggesting “early” recruitment or a possible myopathy. Of course, as noted above, MUAP parameters such as duration, amplitude, etc. as well as spontaneous activity must also be considered as some individuals without pathology may also produce this pattern.
PRACTICAL IMPLEMENTATION OF RECRUITMENT ANALYSIS

The Clinical Setting. Given all of the above information, exactly how can MUAP recruitment analysis be practically performed in the clinical setting. This portion of the discussion presents one manner of performing MUAP recruitment analysis; no doubt there are many others.

Initially the needle electrode is inserted into the muscle under investigation. As noted, if the muscle is completely relaxed, only electrical silence should be observed unless an end-plate region has been inadvertently entered. The needle is then gently inserted in multiple directions to provoke some degree of insertional activity (increased, decreased, or normal) and attempting to induce some type of abnormal membrane instability (positive sharp waves/fibrillation potentials), as well as to observe any other types of abnormal spontaneous/involuntary activity (complex repetitive discharges, myotonia, myokymia, etc.). Subsequently, the patient is asked to produce just a minimal contraction so that only a single or at least 3 or fewer MUAPs are observed. It is important to activate only a few motor units to ensure that there is a sufficient amount of a quiet electrical baseline so as to better identify individual MUAPs without superimposition from others. Also, be aware that even two MUAPs can superimpose with each other in time to result in the appearance of at least 3 and possibly more MUAPs when in fact there are only 2 (see above). This becomes important when trying to figure out how many total MUAPs are present with respect to the calculation of recruitment ratios. That is why rastering several seconds of MUAP recruitment is important to see if 2 distinct MUAPs approach each other in time and then superimpose to create a false third MUAP which obviously should not be counted in the total number of MUAPs observed (Fig. 5). If the total screen time is kept at 100 ms, it should be rather straightforward to qualitatively discern if the MUAP recruitment is normal. If 3 MUAPs are present and none of them repeat at an interval significantly less than the width of a single screen (100 ms), this situation most likely represent a normal MUAP recruitment pattern. On the other hand, if 4-5 or more MUAPs appear at minimal contraction with each one appearing about twice on the screen with an interval of roughly 100 ms or somewhat less (70-80 ms), and this is consistently observed despite multiple attempts at relaxation and minimal contraction, a myopathy should be considered. Additionally, if the patient produces a minimal contraction and a single MUAP is observed that increases to three times on a 100 ms screen prior to another MUAP appearing then clearly this first recruited MUAP is discharging at roughly 30 Hz which strongly suggests a “neurogenic” recruitment pattern implying axonal/motor unit loss, or conduction block.

The above examples are capable of being performed rather quickly by an experienced electromyographer and should not take more than a few seconds. If there is any doubt or
perhaps a borderline situation is suggested through qualitative analysis, then the recruitment can easily be stored into the instruments memory for the more quantitative analysis noted above. However, keep in mind, all of the above are a very crude type of analysis and provide only a limited amount of diagnostic information. Although it is certainly possible for recruitment abnormalities to be the only electrophysiologic finding, this type of occurrence is the exception and not the rule. Most individuals with discernable recruitment abnormalities also have other documentable abnormal findings on either needle EMG or nerve conduction studies. As noted above, patients with early peripheral neuropathies or those with radiculopathies typically have perfectly normal MUAP recruitment on both qualitative and quantitative recruitment analysis.

When Normal Recruitment Can Indicate No Pathology

This seemingly obvious statement is actually deceptively simple and may be quite helpful at times. Suppose you are called upon to assess a patient electrophysiologically who complains of sudden onset weakness and claims to be “paralyzed” from the waist down. You perform multiple nerve conduction studies and find no evidence of any abnormality to suggest either a motor or sensory neuropathy (normal: distal motor/sensory latencies; velocities; amplitudes; proximal-distal waveform configuration etc.). This may be expected if one is performing the assessment within a few days of weakness onset. A needle EMG reveals normal insertional activity and no evidence of any abnormal spontaneous activity. Again, this finding can be anticipated early on in a true disease process. At this point, it is certainly still possible for a patient to have some type of disorder producing either profound conduction block throughout or axonal loss that may require additional time to manifest. However, if this is the case, then every attempt must be made to encourage the patient to make a concerted effort to produce some type of muscle contraction (multiple muscles must be examined). If such profound paralysis is present, one should anticipate some type of recruitment abnormality. All you need is just one and preferably two MUAPs. If one can get 2 MUAPs to recruit, then it should be rather obvious if either profound axonal loss or conduction block are present. The first motor unit should increase it rate to beyond 15-20 Hz when the second MUAP is present if true pathology of the peripheral nervous system is present within this context of “complete” paralysis. Typically these patients are grimacing as if putting forth enough effort to lift a car: face turning red, teeth clenched, eyes squinting, etc. Yet, the MUAPs demonstrate a normal recruitment pattern indicating that there is no lower motor neuron cause for this amount of profound paralysis. Even in the time frame of acute conduction block or axonal loss not yet yielding membrane instability, recruitment abnormalities should manifest immediately as this is a compensatory interplay between the peripheral and
central nervous systems. In the above scenario, the patient is likely either manifesting some aspects of “hysterical paralysis” or malingering. Please note, that some clear provisos were imposed for the above situation to be operational: normal insertional activity, no membrane instability, normal nerve conduction studies, etc. Therefore, a completely normal MUAP recruitment pattern in association with complete or profound paralysis should at the very least raise the possibility of a disorder other than that involving the lower motor neuron.

PITFALLS

The most common pitfall with respect to MUAP recruitment analysis is believing that there is a great deal of sensitivity in this type of evaluation. In fact, considerable numbers of motor units must be lost prior to observing abnormalities like so called neurogenic or reduced recruitment. It is simply not know how many anterior horn cells must be lost prior to documenting a pattern of neurogenic recruitment.

For example, it is not uncommon in patients with radiculopathies or mild brachial plexopathies with clear evidence of positive sharp waves and fibrillation potentials to demonstrate completely normal MUAP recruitment (Figs. 8 & 9). Again, the issue is that we simply cannot assume that the presence of denervation suggesting axonal loss will necessarily result in abnormal MUAP recruitment. Similarly, neurogenic recruitment is not always accompanied by spontaneous activity suggestive of denervation. Specifically, a slowly progressive lesion destroying axons may permit reinnervation early in the disease process while still producing a neurogenic recruitment pattern.

![Figure 8](image1.png)

**Figure 8.** A patient with a mild traumatic brachial plexopathy with evidence of positive sharp waves and fibrillation potentials.

![Figure 9](image2.png)

**Figure 9.** The same patient as noted in Figure 8 demonstrates a normal MUAP recruitment pattern despite the presence of numerous positive sharp waves and fibrillation potentials. Note the MUAP in every trace in the middle of screen firing at 10 Hz with the presence of two additional MUAPs in the presence of positive sharp waves.

Another potential pitfall with recruitment analysis is mistaking the overlapping of already recruited MUAPs as newly recruited MUAPs (Figs 10 & 11). After the first two MUAPs are recruited, it is quite common for the already recruited motor units to overlap in time with other motor units. This overlapping of MUAPs can create the false impression that newly recruited MUAPs have appeared. Failure to recognize this occurrence can lead to an erroneous conclusion of early or so called
“myogenic” recruitment. It is recommended that whenever recruitment analysis is performed that the instrument’s screen display at least 4 traces. The displaying of multiple traces permits the practitioner the opportunity to watch motor units progress in time and readily show any MUAP overlapping.

SUMMARY
It is important to keep in mind that MUAP recruitment analysis is only one of many tools that can be used to assess patients for possible neuromuscular diseases. Further, recruitment analysis may appear quantitative and powerful but it is not particularly sensitive to early or mild disease. Recruitment analysis may be helpful in some circumstances but should be evaluated within the context of both the clinical and other electrophysiologic findings.

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