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# Quantitation in EMG

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**ABSTRACT:** The neuromuscular system may be affected by disorders of the central nervous system as well as other disorders affecting motoneurons, axons, neuromuscular transmission, the sarcolemmal membrane, the contractile elements and other components of the muscle fibers themselves. One or a combination of these possibilities can present in patients in the critical care unit. This paper reviews various qualitative and quantitative methods for assessing the various components of the peripheral contributions to the electrical and force output as well as the central motor drive to motoneurons. These methods all have their own strengths and weaknesses but many are complementary and together, can provide important diagnostic and prognostic information to guide management.

**RÉSUMÉ: Quantification à l'EMG.** Le système neuromusculaire peut être affecté par les maladies du système nerveux central ainsi que par d'autres maladies qui affectent les motoneurones, les axones, la transmission neuromusculaire, la membrane sarcolemmique, les éléments contractiles et les autres composantes des fibres musculaires elles-mêmes. Une ou plusieurs de ces pathologies peuvent survenir chez les patients hospitalisés à l'unité de soins intensifs. Nous revoyons différentes méthodes qualitatives et quantitatives pour évaluer les contributions périphériques aux mesures électriques et de force ainsi que l'influx moteur central vers les motoneurones. Ces méthodes ont toutes leurs forces et leurs faiblesses, mais plusieurs sont complémentaires les unes des autres et peuvent toutes fournir des informations diagnostiques et pronostiques importantes pour élaborer un traitement.

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The neuromuscular system may be affected in a variety of ways in critically ill patients.<sup>1-8</sup> Disorders of the central nervous system may, for example, affect the patient's ability to effectively recruit motoneurons, while other disorders may affect motoneurons, axons, neuromuscular transmission, the sarcolemmal membrane, the contractile elements and other components of the muscle fibers themselves. This wide range of potential problems may also be found in patients with severe neuromuscular diseases who need intensive care.<sup>9-11</sup> Because one or more of the various components of the neuromuscular system may be affected at one time or another in the course of a patient's illness, it may be difficult, if not impossible, to identify and weigh the relative importance of specific factors contributing to any given patient's weakness.

One way to examine the various factors affecting neuromuscular performance is to begin by asking how the neuromuscular system as a whole might be assessed, then to consider how each sub-component of the neuromuscular system might be examined and finally to consider how these approaches might be applied in the setting of critical illness related to neuromuscular disorders.

## ASSESSING THE FORCE OUTPUT OF MUSCLES

Clinical examination of the neuromuscular system is based largely on the assessment of strength. For this reason, and because the ability to generate and sustain force is an essential measure of the capacity of the neuromuscular system to function properly, currently available methods for assessing the force output of muscles will be examined. These methods may be use-

fully divided in the following manner: 1) assessment of maximum voluntary contractions, 2) assessment of the force generated in response to direct or indirect muscle stimulation, 3) assessment of the "central drive" to motoneurons by magneto-electrical cortical stimulation.

## The Assessment of Maximum Voluntary Contractions

Testing strength at the bedside is usually carried out by asking the subject to make a maximal, usually isometric, contraction against the resistance provided by the examiner. From the quality and strength of the contraction assessed subjectively by the examiner, inferences are made about the presence or absence of any weakness and, in the case of the latter, whether the effort made by the subject was sufficiently full to justify the conclusion that weakness is indeed present. The determination of what represents normal strength is clearly a subjective assessment and based on the examiner's experience of what might reasonably be expected of healthy subjects of similar age, sex and body build when they put out their "best effort". Strength is graded in some fashion, most commonly by applying the MRC scale.<sup>12</sup> This method has proven to be invaluable and reasonably reproducible in the hands of experienced examiners and an effective means of determining the overall pattern of weakness as well as the severity of the weakness. However, the method, despite its undoubted clinical utility in service, suffers from several pitfalls. Some of

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these include: 1) Subjects may fail to make a full effort because the task and effort required has not been fully explained to the subject by the examiner or, if explained, are not understood. Both of these are common in intensive care settings for a variety of reasons. 2) The subject may find it difficult to comply because of discomfort. 3) The assessment of strength depends on the experience of the examiner. 4) There is no truly satisfactory and universally accepted definitions for the grades. 5) The scales are not linear. For example, the difference for the MRC scale between grade 3 (anti-gravity strength) and 2 (less than antigravity) is less than between grade 4 (less than full strength) and 3. This non-linearity imposes several major problems including varying sensitivity to strength change and also makes it inappropriate for using the more powerful parametric statistics for analysis.<sup>13,14</sup>

The assessment of maximum voluntary contractions may be enhanced by the substitution of a force transducer for the subjective assessment of a clinical examiner. One such method, the Tufts Quantitative Neuromuscular Examination (TQNE) measures the force generated by a variety of upper and lower extremity muscles and has proven to be a valuable tool for serially assessing the strength of representative muscle groups in clinical trials in ALS.<sup>15-17</sup> However, the method cannot be readily applied to the intrinsic hand muscles or a variety of other smaller muscle groups. With some modification, quantification of the contractile force generated by isometric voluntary contractions also lends itself to an examination of fatigue by assessing the ability of subjects to sustain steady or repeated maximal or submaximal voluntary contractions.

One major pitfall of using voluntary contraction as a means of assessing the force output of a muscle is that such contractions necessarily involve both the "central" and peripheral limbs of the neuromuscular system. Any loss of strength or increase in fatigue could, therefore, be a consequence of either a "central" failure to sufficiently drive the motoneuron pool or alternatively a failure somewhere in the peripheral arm of the neuromuscular system between the motoneuron and the muscle.

#### **Assessment of the Force Generated in Response to Direct or Indirect Muscle Stimulation**

There are several ways to assess the "central" component to the force generated by a maximum voluntary contraction. One method is to deliver a single supramaximal stimulus or a pair of stimuli to enhance the response to the peripheral nerve while the subject attempts a maximal voluntary contraction. The size of such an "interpolated twitch" is roughly proportional to the extent to which the subject fails to recruit all the motor units within the muscle.<sup>18-21</sup> The force generated by a maximum voluntary contraction may also be compared with the force generated in response to a supramaximal train of electrical stimuli delivered to the motor nerve in the case of indirect stimulation or muscle in the case of direct stimulation, with a frequency sufficient to evoke the maximum force. Generally such direct and indirect stimulation evokes a force very similar in peak force and rate of decline (fatigue) to the force profile of a maximal voluntary contraction, especially where subjects are trained and well motivated to make a maximal voluntary effort. However, such peripheral methods for assessing the maximum force output of a muscle are decidedly uncomfortable when applied to whole muscles or muscle groups.

#### **Assessment of the "Central Drive" to Motoneurons by Magneto-electrical Cortical Stimulation**

Magneto-electrical stimulation presynaptically stimulates pyramidal tract neurons in the motor cortex, especially the direct cortico-motoneuronal component of the motor cortical drive to spinal motoneurons. The latter is a subset of the central motor system which includes the forebrain, premotor cortex, supplementary motor cortex, sensori-motor cortex, basal ganglia, cerebellum and related brainstem structures. Maximal response of a muscle group requires a low level of background voluntary contraction, i.e., "facilitation" of those muscles. This helps the operator to achieve a degree of selectivity of activation of the particular target muscles being studied. To examine the integrity of the central vs. peripheral arms of the neuromuscular system, the maximum compound action potential and twitch evoked by supramaximal stimulation of the motor nerve may be compared with the corresponding parameters evoked by a maximal magneto-electrical stimulus delivered to the motor cortex.<sup>22,23</sup> Although the muscles activated by magneto-electrical stimulation are more extensive than peripheral nerve stimulation, these comparative ratios are still useful indicators for gauging the relative integrity of the central and peripheral components of the motor system.

#### **ASSESSING THE ELECTRICAL PROPERTIES OF THE MOTOR SYSTEM**

##### **Examination of the Recruitment Patterns and Firing Rates of Motoneurons During Voluntary Contractions**

The firing rates of motor units can provide useful indications to the probable underlying cause of weakness, whether "central", motoneuronal or in the muscle. There is clear evidence that 1) motoneurons are recruited in an orderly manner,<sup>24-30</sup> 2) force is governed by the number of motoneurons recruited and the firing rates of those motoneurons and 3) the motor system exhibits "muscular wisdom" whereby the firing rates of motoneurons are reduced during the course of a fatiguing contraction to maintain the force of the contraction as best as possible.<sup>31-33</sup>

##### **Motoneurons: Motor Unit Number Estimation**

The number and functional capacities of motoneurons (or motor units) are important additional measures of the neuromuscular system. Indirect indications of the number of motor units in a muscle may be gathered from the size of the maximum compound action potential evoked by a supramaximal stimulus delivered to the motor nerve or by judging from the number of motor units recruited at various intensities of voluntary contractions. However, more direct clues to the probable numbers of motor units may be obtained from several recently introduced and improved modifications<sup>34-41</sup> to the original method for estimating the number of motor units in a muscle (or muscle group) introduced in 1971 by McComas.<sup>42</sup> Some of these methods are based on electrical stimulation of the motor nerve and are most applicable to distal muscles, while others may be applied to proximal muscles. For all of these techniques, the estimate of the number of motor units within any particular muscle or muscle group is more difficult with healthy young subjects because the determination of the average motor unit action potential size is based on a relatively small sample of motor units relative to the total number of motor units in the muscle. The latter situation stands in

contrast to some pathological conditions where the actual number of motor units can be determined with relative ease in serial studies. The importance of a more direct estimate of the number of motor units rather than guessing the number of motor units from the size of the maximal compound muscle action potential is that muscle wasting disorders may appreciably reduce the size of the maximal compound muscle action potential with no appreciable losses of motor axons or motor units.

However, the total number of motor units is only part of the motor unit story. Equally important is a knowledge of the sizes and functional status of the surviving motor units.<sup>43-47</sup> For example, healthy elderly adults can generate contractile forces equivalent to younger adults with roughly one-half the number of motor units.<sup>48,49</sup> This contrasts with some ALS patients who may, in some instances, possess similar numbers of motor units to their age-matched controls but are unable to generate or sustain equivalent forces because a large fraction of the surviving motor unit pool may be "dysfunctional".<sup>50,51</sup> The functional status of surviving motor units may also be assessed from determining the sizes of the surface or intramuscularly "macro" detected motor unit action potentials.<sup>35,52,53</sup> More difficult is the task of assessing the contractile properties of single motor units, including their contractile speeds, twitch and tetanic tensions and fatigue characteristics.<sup>43,44,46,47</sup> The task of measuring the conduction velocities of single motor axons for distal intrinsic hand muscles is easier and provides a better profile of what is happening to transmission in motor nerve fibers than the maximum motor conduction velocity which only reflects conduction in the fastest motor nerve fibers.<sup>54-57</sup>

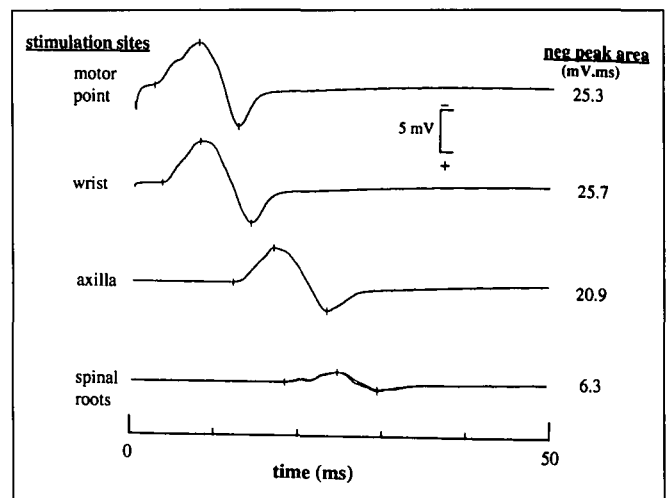
Assessing the innervation patterns of single motor units provides much valuable quantitative information about the presence or absence of reinnervation as well as the stability of axonal and neuromuscular transmission. Such information may be gleaned from a careful examination of the number of muscle fibers in each motor unit generating spikes within the detection zone of the electrode (fiber density).<sup>58-60</sup> The finding of increased jitter and perhaps blocking are indications of abnormal neuromuscular transmission, either at junctions undergoing degenerative changes or in immature, recently formed neuromuscular junctions.

### Peripheral Motor Conduction

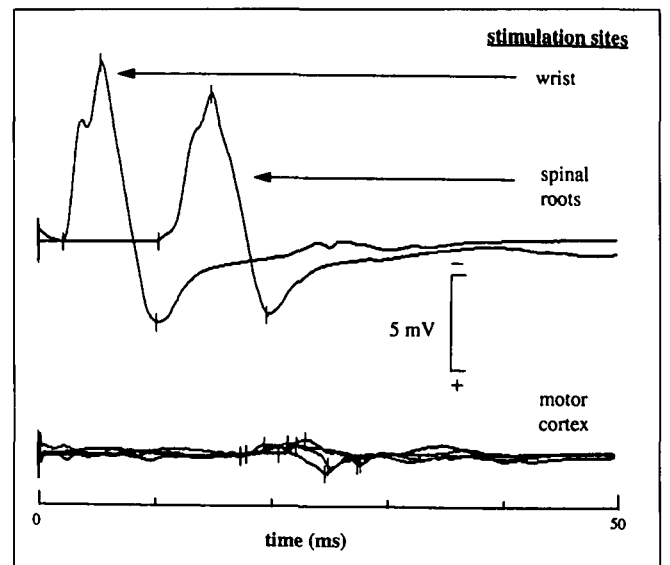
Methods exist for systematically examining conduction in motor nerve fibers between the spinal roots and close to the motor point.<sup>61-64</sup> Such methods make it possible to reliably identify conduction slowing, abnormal temporal dispersion and conduction block throughout almost the entire course of the peripheral nervous system, at least for the motor nerve supply to the intrinsic hand muscles and lateral calf and posterior calf muscles. An example of their utility is illustrated in Figure 1. With the addition of magneto-electrical cortical stimulation, conduction between the motor cortex and the spinal roots may also be identified as illustrated by Figure 2. Of particular relevance to the intensive care setting is the status of the respiratory muscles of those patients who are ventilator dependent. Bolton and co-workers have recently described several useful techniques to study the diaphragm.<sup>10,65</sup>

### Neuromuscular Transmission

Neuromuscular transmission may be assessed in several ways including: (a) Looking for variations in shape and size of



**Figure 1:** This 56-year-old man presented with respiratory symptoms suggestive of a viral infection 1 week prior to developing acute and rapidly progressive weakness affecting all four limbs and the respiratory muscles. Although he had marked weakness of the intrinsic hand muscles, this study of the hypothenar motor fibers carried out 4 days after the onset of weakness revealed that conduction between the hypothenar muscles and axilla was normal except for the fact that the sizes of the maximal compound muscle action potentials were at the lower limit of normal. In this case, conduction was slowed and block was present only between the spinal roots (stimulated by means of a Devices D180 high voltage electrical stimulator) and the axillary stimulation site.



**Figure 2:** This 74-year-old lady slipped and struck her forehead against the curb during the fall. She subsequently developed tetraparesis, greater in the arms than the legs. Conduction in the hypothenar motor fibers between the motor point and spinal roots was normal (upper traces). However, the latency difference between the "M" potential evoked by magneto-electrical cortical stimulation in the hypothenar muscles (lower superimposed traces), and the latter in response to supramaximal stimulation of the spinal roots, was prolonged. As well, the hypothenar response to cortical stimulation was reduced in size. Although less severe, the same pattern of conduction abnormalities was also present in her lower limb motor conduction studies. These electrophysiological results supported the clinical diagnosis of central cord syndrome. MRI of the cervical spine showed extensive osteophyte formation but no fracture or dislocation was present.

voluntarily recruited or electrical stimulus evoked motor unit action potentials as detected with either surface or intramuscular electrodes.<sup>66</sup> In the case of the latter, abnormal jitter and sometimes blocking may be readily seen even with concentric needle recordings and may be taken as indications of instabilities in neuromuscular transmission. (b) Looking for abnormal decrements in the compound muscle action potential or motor unit action potentials in the case of single motor units, in response to repetitive stimulation. (c) Measuring the jitter and incidence of blocking in single muscle fibers using a single fiber EMG electrode and either voluntarily recruited or carefully graded electrical stimulation of presynaptic motor axons to recruit the muscle fibers (stimulation single fiber EMG).<sup>58-60</sup>

### Muscle

Muscle may be examined with several tools. First, using needle electrodes, the sizes of motor unit action potentials may be assessed as a means of identifying patterns indicative of either a reinnervation or a myopathic process using voluntarily or peripheral nerve stimulus recruited motor units.<sup>67-70</sup> The same tool may be used to detect "denervation activity", myotonic and neuromyotonic activity and hypoexcitability of muscle fibers, the last of which may be associated with hypokalemic paralysis or ischemic-infarction of muscle.

Second, CT and MRI may be profitably employed to assess muscle atrophy, especially as this affects the iliopsoas and other muscles whose bulk may be difficult, if not impossible, to assess clinically.<sup>71,72</sup>

Lastly, muscle biopsies may be used to identify fiber type grouping as an indication of reinnervation, muscle atrophy, fiber type preponderance as well as more specific muscle pathological changes which may prove invaluable in assessing the primary or, in some instances, secondary neuromuscular disorders affecting a given patient.<sup>73,74</sup>

### SUMMARY

Many of the preceding tools for assessing the neuromuscular system are simply not applicable in the setting of an intensive care unit because they are too cumbersome, technically difficult or impractical. However, some of the methods could usefully be applied in special circumstances to shed more light on the pathogenesis of some of the complex neuromuscular disorders in the intensive care unit. Using a combination of these available methods maximizes the chances of establishing the nature, severity and sites of the neuromuscular deficits. This forms an important first step when trying to determine the most appropriate interventions.

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