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The effect of contraction intensity on motor unit number estimates of the tibialis anterior

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Abstract

Objective: To examine the effect of contractile level on motor unit number estimates (MUNEs) and establish the contraction intensity that will yield the most representative MUNE for the tibialis anterior (TA) muscle.

Methods: Surface and intramuscular electromyographic (EMG) signals were collected during a range of submaximal (threshold, 10, 20, 30 and 40% MVC) isometric dorsiflexion contractions using decomposition-enhanced spike-triggered averaging (DE-STA). Six MUNEs were calculated, one for each of the five intensities, and an ensemble sixth MUNE that had equal MU contributions from all intensities.

Results: Mean surface-motor unit potential sizes increased significantly (26–69 μV) and MUNEs decreased accordingly (226-91) as contraction intensity increased from threshold to 40% MVC, respectively ($P < 0.05$). The ensemble MUNE was 153, and extrapolated to ~25% MVC.

Conclusions: There was a significant and progressive decline in the MUNE as contraction intensity increased, confirming the importance of monitoring torque during data collection. The ensemble MUNE suggests that collecting EMG signals at a contraction intensity of ~25% MVC provides the most representative sample of the actual number and sizes of MUs in the TA.

Significance: Establishing appropriate contraction intensities improves the utility of DE-STA as a useful method for tracking changes to the MU pool in disease states and healthy aging.

Keywords: Motor unit number estimation; Electromyography; Isometric strength; Decomposition-enhanced spike-triggered averaging

1. Introduction

Objective assessment of the number of motor units (MUs) in a skeletal muscle group is of considerable interest in determining the severity and following the natural history of diseases affecting the lower motor neuron, as well as the study of healthy aging. No method exists to count human MUs in vivo, so motor unit number estimation (MUNE) techniques are, at present, the best available indication of the numbers of MUs in a given muscle group. Over 30 years ago, McComas et al. (1971) developed the first MUNE technique, based on incremental stimulation of the peripheral nerve supplying a given muscle group. While this method was theoretically sound, it required considerable operator expertise and the phenomenon of alternation raised concerns regarding its validity and reproducibility. Accordingly, the clinical and investigative applications of the technique were limited. In recent years, research interest in MUNE has been renewed, in part, due to advances in computing capability in both research-based and clinically available EMG systems. These advances have allowed

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the development of EMG signal decomposition, in conjunction with spike-triggered averaging, as a means of collecting a sample of surface-detected motor unit action potentials (S-MUPs) to derive a MUNE.

Decomposition-enhanced spike-triggered averaging (DE-STA) has proven to be a valid and reliable method for estimating the number of MUs in a muscle group (Boe et al., 2004). However, it was recently demonstrated by our group (Boe et al., 2005) that MUNEs of intrinsic hand muscles were affected by the contraction intensity during the collection of the motor unit trains, i.e. the MUNEs were significantly lower at higher contraction intensities than lower intensities. Therefore, although DE-STA has demonstrated reliability with a single investigator (Boe et al., 2004; Conwit et al., 1997), it is possible that different investigators, or indeed a single investigator, may employ different contraction intensities in serial studies that would significantly affect the MUNE result for any one subject. Such a scenario would add to the variability of MUNEs in longitudinal studies unless experimental conditions, contraction intensity in particular, are strictly controlled. Thus, in order for DE-STA to be most effective, it would be ideal to develop standardized protocols that could be employed by all investigators. Moreover, because disparate results are possible in the same subject, it is an important consideration when designing such a protocol to establish which MUNE (i.e. contraction intensity) is most representative of the size distribution of S-MUPs that can be sampled with the method.

The size principle of MU recruitment states that smaller MUs will be activated preferentially at low level contraction intensities, and that larger MUs will be recruited progressively as the contraction intensity increases (Henneman and Mendell, 1981). Therefore, low intensity contractions will produce a small mean surface motor unit potential (S-MUP) size. Because MUNEs are obtained by dividing the maximum M-potential by the mean S-MUP, a small mean S-MUP size corresponds to a large MUNE at low intensities of contraction. In contrast, higher intensity contractions will yield a larger mean S-MUP size and hence a smaller MUNE. It is logical then that the MUNE that is most representative of the actual number of MUs would be obtained at a contraction intensity that incorporates small and large S-MUPs in proportions similar to the actual distribution of MU sizes in the muscle under investigation.

Thus the purposes of this study were (1) to confirm, in a different muscle (tibialis anterior; TA), the effect of contraction intensity on MUNEs observed in the intrinsic hand muscles, and (2) to determine the contraction intensity that will produce the MUNE that is most representative of the number and sizes of MUs in the TA of healthy, young men. The TA was chosen because relatively few MUNE studies have been done in lower limb muscles, and the TA is an important muscle in balance and gait. Moreover, the TA is part of an important functional muscle group that is often affected early and preferentially in many progressive disorders that affect the lower motor neuron (e.g. hereditary neuropathies). Therefore, normative data for this muscle is important for future expansion of DE-STA to include elderly and patient populations.

2. Methods

2.1. Subjects

Nine young men (26.8 ± 3.6 years, 178.4 ± 7.5 cm, 80.7 ± 8.9 kg), recruited from the university environment, volunteered for this study. All subjects were healthy with no evidence of neuromuscular disease and were considered recreationally active. The study was conducted in accordance with the guidelines for experimentation on human subjects established by the local university's ethics review board, and informed written consent was obtained from each of the nine subjects.

2.2. Experimental set-up

Subjects were seated in a custom-built isometric dynamometer (Marsh et al., 1981) with their right ankle positioned at 30° of plantar flexion, and an angle of 90° at both the hip and knee joints. A C-clamp pressing down on the distal aspect of the right thigh minimized hip flexion during the dorsiflexion contractions. Velcro straps across the toes and the dorsum of the foot secured the limb to the dynamometer footplate.

Surface electromyography (EMG) signals were recorded by self-adhering electrocardiogram electrodes (3 × 2 cm; Kendall-LTP, Chicopee, MA). The active electrode was positioned over the tibialis anterior (TA) to maximize the negative peak amplitude, and minimize the rise time of the M-potential (approximately 7 cm distal to the tibial tuberosity and 2 cm lateral to the anterior border of the tibia). The reference electrode was positioned over the distal tendon of the TA, and a ground electrode was placed on the patella. Intramuscular EMG signals were recorded by a disposable concentric needle electrode with a recording surface of 0.03 mm^2 (Model N53153, Teca Corp., Hawthorne NY) inserted into the belly of the TA.

2.3. Experimental procedures

The DE-STA method and associated algorithms have been described previously (Doherty and Stashuk, 2003; Stashuk, 1999; Stashuk et al., 2003). Intramuscular and surface EMG data were acquired using the DE-STA software on the Neuroscan Comperio system (Neurosoft Corp., El Paso, TX). Intramuscular signals were bandpass filtered from 10 Hz to 10 kHz, while surface signals were filtered from 5 Hz to 5 kHz. Data collection began with the determination of the maximum M-potential in response to supramaximal stimulation of the common peroneal nerve,