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Motor Unit Number Estimation of Human Abductor Hallucis from a CMAP Scan

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Abstract

Introduction: This study performed motor unit number estimation (MUNE) of the abductor hallucis (AH) muscle from 16 healthy control subjects based on the compound muscle action potential (CMAP) scan.

Methods: Muscle responses to electrical stimuli ranging from sub-threshold to supramaximal intensity were recorded and MUNE was determined from a model of the responses (MscanFit program).

Results: The average CMAP amplitude and MUNE of the AH for the right and left sides combined were 19.6 ± 0.75 mV and 127 ± 5 (mean $\pm$ standard error), respectively.

Discussion: Findings of the study provide useful information about the motor unit number of the AH.

Keywords

motor unit number estimation (MUNE); compound muscle action potential (CMAP); CMAP scan; abductor hallucis (AH); muscle

Introduction

Motor unit number estimation (MUNE) is an electrophysiological technique to estimate the number of motor units in a muscle. Most MUNE techniques including the original incremental method and subsequent approaches (e.g. multiple point stimulation, F wave, spike triggered averaging) sample from a small proportion of the unit population¹. A relatively new MUNE method that samples from a larger number of units is used to record a

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Ethical Publication Statement

We confirm that we have read the Journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines.

Disclosure of Conflicts of Interest

None of the authors has any conflict of interest to disclose.

detailed compound muscle action potential (CMAP) scan followed by model simulation of the responses². In addition, the recording and modeling are automated, thereby reducing subjectivity in the estimation process and minimizing recording time.

The abductor hallucis (AH) muscle abducts and flexes the great toe and contributes to the maintenance of upright posture³. It is often used in nerve conduction studies since the tibial nerve is readily accessible^{4,5}. However, studies of the estimated number of AH motor units are rather limited^{6,4,7,8}. In one study of 11 healthy controls, the number of AH motor units was estimated by counting the number of step increments in the CMAP over the entire stimulus intensity range⁷. They found that the AH contained only 43 motor units on average, much less than the estimated number in other muscles of similar size⁹. However, Tilki and colleagues using the incremental MUNE method in 30 healthy adults found that the AH contained 98 motor units on average⁶. The reason for this difference in the estimated number of motor units is uncertain.

In this study, we applied CMAP scan and model simulation² to estimate the number of motor units in the AH, as well as the reliability of the estimation, in healthy subjects.

Methods

Subjects

Sixteen healthy subjects (6 female) between 25 and 44 years of age (mean±std: 34±6 years) were recruited for the study. None had any known sensorimotor abnormalities, obvious atrophy of the foot muscles or neuropathy based on a medical history and examination, as well as measurement of tibial nerve conduction velocity, performed by a physician experienced in electrodiagnostic studies. The right leg was dominant in all subjects except two, based on which leg they preferred to kick a ball. They submitted written consent approved by the Committee for the Protection of Human Subjects at University of Texas Health Science Center at Houston and TIRR Memorial Hermann Hospital.

Experimental set-up

Subjects were supine on an ultrasound table (Biodex Medical System, NY) with hip and knee fully extended and the ankle in a neutral position. They remained relaxed and awake during all procedures. After abrading the skin with prep pads, the active recording electrode (Ag-AgCl, 11 mm in diameter) was positioned 1 cm below and proximal to the navicular tubercle, and secured with tape. The reference and ground electrodes were positioned on the metatarsophalangeal joint of the big toe and the medial malleolus, respectively. The tibial nerve was stimulated (200 µs pulse width) with a bar electrode posterior to the medial malleolus.

The CMAP scan was performed using the UltraPro S100 system (Natus Neurology, Inc., WI). The protocol included an automatic search of two stimulation thresholds followed by the definitive scan. The thresholds were defined as the intensity to evoke the lowest-threshold motor unit and the maximum CMAP. The stimulating site was selected to reduce the maximal intensity and subject discomfort. After the thresholds were established, the stimulating range for the CMAP scan was set from 1 mA beyond the CMAP maximum

current to 2 mA below the lowest threshold, thereby accounting for the inherent variability in axonal thresholds.

The CMAP scan was performed automatically by delivering repeated stimuli from the highest intensity (supramaximal stimulation) to the lowest intensity (subthreshold for the lowest-threshold motor unit). The intensity decreased linearly in 1000 steps at 2 Hz, and took about 10 min to complete. In addition, 7 subjects were re-tested bilaterally 1 to 30 days later to determine the reliability of the CMAP scan measurements. All CMAP scans were performed by the same experimenter. Test order was randomized.

Data analysis

The CMAP amplitude, measured from baseline to negative peak, and corresponding stimulus intensity from 1000 stimuli were imported to the MScanFit program for MUNE calculation. The software was created by Prof. H Bostock and can be installed in most computers².

The intraclass correlation coefficient (ICC), the standard error of measurement (SEM) and the smallest real difference (SRD) were calculated to assess the relative and absolute reliability of the MUNE and CMAP measurements^{10,11}. SEM% and SRD% represent the percentages of the means of all observations. It is suggested that ICC>0.75, SEM% or SRD% <10% indicates excellent reliability. The coefficient of variation (COV) was computed¹².

All data were screened for outliers and normality using SPSS (IBM, New York). Paired t-test was applied to compare the differences of CMAP, mean motor unit action potential (MUAP), and MUNE between dominant and non-dominant sides. All data are presented as mean±standard error unless specified.

Results

Calculation of MUNE

The mean stimulus currents for the lowest threshold and maximal CMAP responses were 10.23±0.87 mA and 30.48±1.02 mA. All subjects tolerated the procedures well and completed the CMAP scans. A stimulus-response curve recorded on two different days in 1 subject is shown in Fig. 1, and the corresponding MUNE were 109 and 108. In general, the CMAP amplitude decreased smoothly, similar to the sigmoid function, with a reduction in stimulation intensity over the steep portion of the plot.

CMAP scans were recorded from AH muscles bilaterally in 14 subjects and unilaterally in 2. The AH CMAP amplitude, MUAP, and MUNE were not different between sides (CMAP: non-dominant: 19±1.01 mV, dominant: 20.27±1.13 mV, p=0.13; MUAP: non-dominant: 157.16±9.87 µV, dominant: 165.89±14 µV, p=0.3; MUNE: non-dominant: 126±8, dominant: 127±7, p=0.78). Therefore, the data from both sides were pooled. The mean values for CMAP, MUAP and MUNE, across 30 muscles were 19.64±0.75 mV (range: 9.9–28.2 mV), 160±7.79 µV (95.9–290 µV), and 127±5 (79–189), respectively.

Reliability test

Mean values for CMAP and MUNE were not different between the two test days (CMAP: $p>0.51$; MUNE: $p>0.91$). The ICCs, SEM% and SRD% suggested good measurement reliability (Table 1)

Discussion

We found that the number of the AH motor units was slightly larger than the mean of 98 units reported by Tilki and co-workers⁶ who used incremental MUNE. Our estimate is consistent with the modestly lower estimate of approximately 100 motor units in individual hand muscles, which likely have a slightly smaller cross-sectional area than the AH⁹. In addition, AH MUNE (incremental technique) after spinal cord injury ranged between 80 and 130 in 4 people, whereas values ranged from 5 to about 40 units in 8 others due to motor unit loss⁴. Our study included a repeat test in 7 of the 16 participants. The average MUNE showed no significant difference between the test and retest. Calculation of the absolute and relative reliability parameters also confirmed high measurement reliability.

The MUNE values of the present study and those of Tilki⁶ are 2 to 3 times as large as a previous report of 43 motor units⁷. The subjects were of similar age in all 3 studies (Johns and Fuglevand: 25–43 years, Tilki: 40 ± 11 years, and ours: 34 ± 6 years), so age cannot account for the different motor unit counts. The difference may result from different data collection and MUNE techniques. In the study by Johns and Fuglevand⁷, a less conventional setup was used, involving small recording electrodes (4 mm in diameter) and a shorter inter-electrode distance (2 cm). This may affect CMAP amplitude and lead to smaller motor unit counts. Unfortunately, the CMAP maximum was not reported in their study. In addition, the relatively larger stimulus pulse width (1 ms) applied in the previous study⁷ may increase the chances of recruiting multiple motor units with overlapping thresholds and account for a lower MUNE. A CMAP scan (~30 stimuli) is also used in statistical MUNE for selecting appropriate stimulus intensity¹³. The method assumes a Poisson distribution of motor unit size^{1,14} and generates lower MUNE compared with other methods^{15,1}. The technique in this study uses more finely-graded stimuli to sample the entire motor neuron pool and implements a preliminary model to produce all individual units' size. This approach may reduce the sampling bias introduced by using a small portion of the unit population for MUNE, and could be an additional reason for our higher counts⁷. The advantages of the present approach include automation of data collection and analysis which minimizes experimenter bias, and excellent reliability¹⁶. However, CMAP scan requires intensive stimulation which may limit the test to participants with good tolerance. Further study is needed to determine whether similar results can be achieved using a smaller number of stimuli.

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Abbreviations:

MUNE	Motor unit number estimation
CMAP	compound muscle action potential
AH	abductor hallucis
ICC	intraclass correlation coefficient
SEM	standard error of measurement
SRD	smallest real difference
COV	coefficient of variation
MUAP	motor unit action potential

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Figure 1.

Examples of compound muscle action potential (CMAP) scan from the same subject on two different days. Stimulating ranges: 10.25 mA - 29.75 mA (day 1), 12 mA - 35.16 mA (day 2). Maximal CMAP amplitude: 18.1 mV (day 1), 18.78 mV (day 2). Mean motor unit size: 166.06 μ V (day 1), 173.39 μ V (day 2).

Table 1.

Reliability analysis

	CMAP	MUNE
Test_1	20.04 ± 0.79 (mV)	124 ± 6
Test_2	20.43 ± 1.06 (mV)	125 ± 8
ICC	0.89	0.93
SEM%	5.53%	5.19%
SRD%	4.98%	3.7%
COV	18.6±2.57%	13.39±4.02%

CMAP: compound muscle action potential; MUNE: motor unit number estimation

ICC: intraclass correlation coefficient; SEM: standard error of measurement; SRD: smallest real difference; COV: coefficient of variation