



Development of a New Algorithm for the Estimation of the Step Percentage in Compound Muscle Action Potential Scan

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Abstract—Compound Muscle Action Potential (CMAP) Scan used in the diagnosis and in the monitoring of Neuromuscular Diseases is based on recording the responses obtained from the gradual stimulation of a peripheral nerve. Clearly visible differences between CMAPs are referred as *step*. The maximum CMAP percentage of all detected steps are defined as *Step Percentage* and this is one of the parameters providing evidence for Motor Unit (MU) loss and for reinnervation. The aim of this study is to develop an algorithm which enables to estimate the step percentage more quantitatively. Motor neuron groups which were created through a simulator software were stimulated gradually. The step sizes were computed by utilizing the obtained responses as CMAPs in computing step sizes. Then, these step sizes were sorted in descending order. The step percentage was estimated by taking the cumulative sum of the values greater than two standard deviations (SD) of these sorted step sizes by running the aforementioned algorithm. It was seen that there are larger in fluctuations Step% values in motor neuron groups with lower number of axons, however, a more regular decreasing trend with smaller fluctuations was observed in higher number of axons. In the future studies, the inclusion of further motor neurons with greater axons numbers will be established. Moreover, the application of the algorithm for the patient data will be also considered.

Keywords — Compound Muscle Action Potential (CMAP) Scan; Step Percentage; Neuromuscular Diseases, Simulation

I. INTRODUCTION

Compound Muscle Action Potential (CMAP) Scan is an electrophysiologic method used in the diagnosis and in the monitoring of the Neuromuscular Diseases [Bostock]. It is based on recording the CMAPs as the responses of a gradually stimulated peripheral nerve which is graphically represented the stimulus-response (SR) curve [1][2]. This SR curve is in sigmoid form in healthy individuals as shown in Figure 1. On the other hand, some abrupt jumps may be present between some consecutive responses in SR-curve as in case of neuromuscular diseases such as amyotrophic lateral sclerosis (ALS)[3]. These jumps describe large visible MU potential differences between consecutive CMAPs and they are referred as *steps* and they exist in case of large MUs or whether MU number is severely reduced

[4]. The presence of the steps are illustrated in Figure 2. These steps may be considered not only to ensure information about the extent of collateral reinnervation but also to be an indicator of motor unit loss [5][6]. Both SR Curves represented in Figure 1 and Figure 2 were generated through the CMAP Scan Data through the EMG System (Nicolet, Viking, Natus, USA) in the Clinical Neurophysiology Laboratory of the Department of Neurology of İstanbul Faculty of Medicine. This study was approved by the Local Ethic Committee.

There are three parameters to express the steps quantitatively referred as step size, step number and the step percentage [4]. Among them, step percentage (step %) being the percentage of the maximum CMAP computed by summing all of the detected steps [7]. As the MU loss becomes severe and very few MUs are remained intact, Step % approaches 100% of the maximum CMAP [4][8].

The selection of the steps which will be taken into account in estimating step percentage depends on the experience of the operator. The lowest value of all step sizes is adjusted by the researcher [8].

The aim of this study is to develop an algorithm for the estimation of the step percentage by determining the lowest step size more quantitatively

II. MATERIALS AND METHODS

A. Building Data Sets

A simulator software ((Motor Nerve Conduction Studies (MNCS) Neurography Simulator version 2.4, Keypoint Club, Uppsala, Sweden) was utilized in building the data sets. Motor neurons consisting of 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 105, 110, 115, and 120 axons were formed by means of this software. Each motor neuron group were stimulated by currents of 0 to 99 mA from the distals of these neurons. Five different scenarios were constituted for each motor neuron group. The interface of this software is shown in Figure 3.

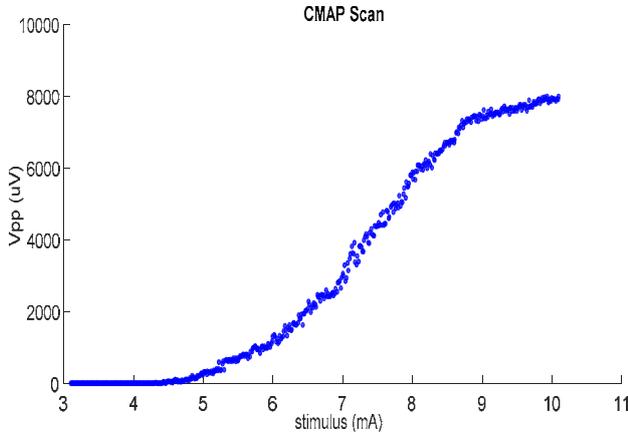


Figure 1. The Stimulus-Response curve of a healthy individual

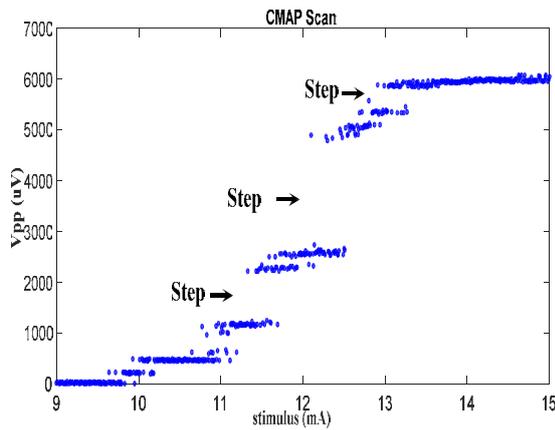


Figure 2. The Stimulus-Response curve of a patient with Anterior-Horn Disease (Steps are shown with arrows)

The CMAP traces which their waveforms can be monitored also in the simulator software were recorded in “.txt” format by means of “export” menu of this software to be processed by the MATLAB Code developed for the data analysis.

B. MATLAB Code for Data Analysis

A MATLAB® (Version R2015a) Code was built to analyze the CMAP data exported from the simulator software in “.txt” format. The peak-to-peak voltage values of CMAP traces and their consecutive differences were computed by this code which the flow chart is illustrated in Figure 4. The relative voltage differences with respect to CMAP were also computed. Their zero values were excluded. Afterwards, these relative values were sorted in descending order. Their standard deviation was computed in order to determine a threshold to select the steps. The step percentage was calculated by taking the cumulative sum of the relative step sizes over the threshold.

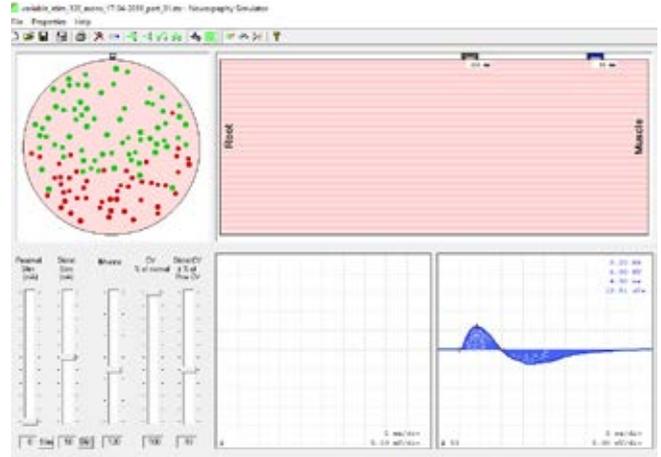


Figure 3. The generation of CMAP responses from the gradual stimulations in the Motor Nerve Conduction Studies (MNCS) Neurography Simulator version 2.4 simulator software

C. Computation of Step Percentage:

The CMAPs being the responses to stimuli are the peak-to-peak voltages V_{pp} of CMAP traces. In order to determine the steps, first, the voltage differences ΔV_{pp} should be calculated as follows;

$$\Delta V_{pp} = V_{pp}(i) - V_{pp}(i-1) \quad (1)$$

In equation (1), i is the indice of the corresponding stimulus.

The relative voltage difference is the percent difference relative to $CMAP_{max}$ which is the maximum CMAP and it is expressed as follows;

$$\Delta V_{pprel}(i) = \frac{|\Delta V_{pp}(i)|}{CMAP_{max}}, 100 = \frac{|\Delta V_{pp}(i)|}{\max(CMAP)}, 100 \quad (2)$$

To select the steps, a threshold value in terms of relative voltage differences should be determined as follows;

$$\Delta V_{\theta} = 2\sigma_{\Delta V_{pprel}} \quad (3)$$

Therefore, any relative voltage difference should fulfill the following criterion;

$$\Delta V_{pprel}(k) \geq \Delta V_{\theta} \quad (4)$$

where k is the index of the relative step size RSS . The relative step sizes that will be used in the computation of the step percentage can be expressed as the following matrix;

$$RSS(k) = [\Delta V_{\theta}, \dots, \Delta V_{pprel}(N)] \quad (5)$$

where N is the number of the sorted relative voltage differences having values greater than the threshold given in equation (3) and which satisfy the criterion indicated in Equation (4). RSS is considered of a vector of the sorted relative voltage differences satisfying Equation 4, in order to enable the computation of the Step Percentage via MATLAB Code in concordance with the algorithm being illustrated in Figure 4.

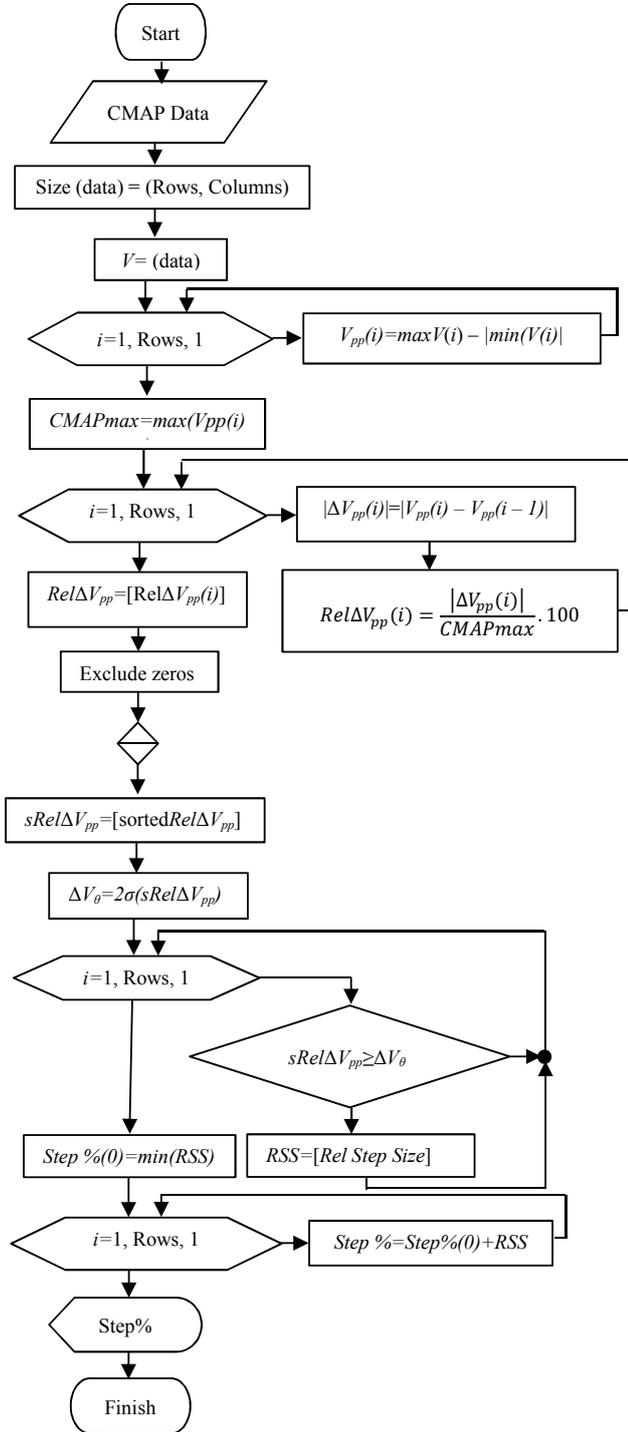


Figure 4. The Flow-Chart of the Data Analysis Code

The step percentage (*Step %*) is the cumulative sum of the relative step sizes and it can be given as follows;

$$Step \% = \sum_{k=1}^N RSS(k) \quad (6)$$

III. RESULTS

The step percentage values computed from the CMAP Scan data generated in the simulator software are summarized in terms of number of axons in Table 1. Moreover, the trend of change in step percentage in terms of number of axons is illustrated in the chart in Figure 5.

It is observed that the step percentages vary between 48.27% and 93.38% in axon numbers less than 50. However, these values vary between 52.19% and 80.13% for axon numbers greater than 50.

IV. DISCUSSION AND CONCLUSION

When the values in Table 1 are considered, a decreasing tendency is observed in step percentage values as the number of axons increases. This trend is also seen in Figure 5.

TABLE I. THE CHANGE IN STEP PERCENTAGE IN TERMS OF NUMBER OF AXONS

Number of Simulated Axons (n_{axon})	Step % (Mean \pm S.D.)
5	93.38 \pm 11.09
10	81.45 \pm 17.53
15	92.53 \pm 13.14
20	76.24 \pm 26.18
25	59.28 \pm 24.76
30	79.38 \pm 16.09
35	65.98 \pm 17.77
40	88.97 \pm 15.14
45	48.27 \pm 14.27
50	79.52 \pm 20.25
55	80.13 \pm 9.63
60	69.49 \pm 30.92
65	74.92 \pm 5.16
70	74.17 \pm 24.05
75	73.98 \pm 14.33
80	62.42 \pm 30.11
85	66.22 \pm 18.96
90	65.95 \pm 14.54
95	57.16 \pm 18.79
100	66.43 \pm 18.97
105	52.19 \pm 15.58
110	59.93 \pm 10.04
115	54.16 \pm 11.55
120	57.89 \pm 22.98

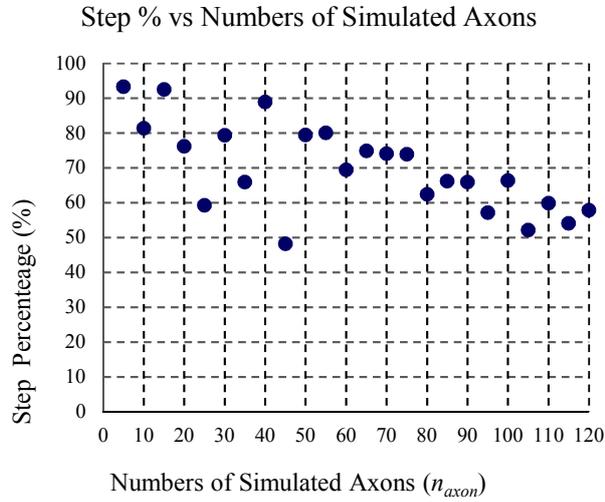


Figure 5. The change in step percentage in terms of number of axons

On the other hand, there are large fluctuations in axon numbers less than 50. The tendency to decrease in step percentage in axon numbers greater than 50 exhibits smaller fluctuations relatively to those less than 50.

Although it is expected that the step percentage will approach to 100% as MU loss takes place (i.e. number of intact axons decreases), the step percentages of simulated motor neuron groups with lower axon numbers fluctuated between higher step percentage values such as 93.38% and lower values such as 48.27%. This situation may be attributed to the irregular MU arrangement as in case of motor neuropathies characterized with MU loss. On the other hand, relatively more stable trend in the decrease of step percentage as the number of axons increases may be related with relatively more regular arrangement of healthy MUs.

Further studies may be conducted not only by including motor neuron groups with axon numbers higher than 120 to investigate the decreasing trend of step percentage but also by applying the algorithm in question for the patient data.

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REFERENCES

- [1] Sleutjes, B.T.H.M. et al. "CMAP scan discontinuities: Automated detection and relation to motor unit loss", *Clinical Neurophysiology*, Vol. 125, 2014, p388–395.
- [2] Henderson, R. D. et al. "The Stimulus–Response Curve and Motor Unit Variability in Normal Subjects And Subjects with Amyotrophic Lateral Sclerosis", *Muscle and Nerve*, Vol.34, 2006, p 34–43.
- [3] Maathuis, E. M. et al. "Reproducibility of the CMAP scan", *Journal of Electromyography and Kinesiology*, Vol.21, 2011, p 433–437.
- [4] Visser, G. H. et al Blok, J.H., "The CMAP scan. Motor unit number estimation (MUNE) and Quantitative EMG", *Suppl Clin Neurophysiol*, Vol.60, 2009, p 65–77.
- [5] van der Heyden, J. C., et al. "Decreased excitability of the distal motor nerve of young patients with type 1 diabetes mellitus", *Pediatric Diabetes*, Vol. 14, 2013, p 519–525.
- [6] Maathuis, E. M. et al. "The CMAP scan as a tool to monitor disease progression in ALS and PMA", *Amyotrophic Lateral Sclerosis and Frontotemporal Degeneration*, Vol. 14, 2013, p 217-223.
- [7] Maathuis E. M, et al. "Optimal stimulation settings for CMAP scan registration", *Journal of Brachial Plexus and Peripheral Nerve Injury*, Vol. 7, 2012, p 1-7.
- [8] Blok, J. H. et al. "The Electrophysiological Muscle Scan", *Muscle and Nerve*, Vol. 36, 2007, p 436-446.