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DESIGN OF AN EXPERIMENTAL SYSTEM FOR SCANNING ELECTROMYOGRAPHY METHOD TO INVESTIGATE ALTERATIONS OF MOTOR UNITS IN NEUROLOGICAL DISORDERS

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The aim of this study is to establish an experimental system for scanning electromyography (EMG) to visualize the electrical activity of the motor unit (MU) territory in investigating the alterations in MU size in Juvenile Myoclonic Epilepsy (JME). MU is the basic unit of the skeletal muscle. Conventional EMG has already been used in routine clinical examinations to diagnose neuromuscular diseases. It provides information in terms of the amplitude and the duration. It reflects only a limited part of the MU. Scanning EMG method gives temporal and spatial information about the MU providing a map for the entire motor unit. An experimental system consisting of an EMG instrument, an actuator, a data acquisition system and a notebook for scanning EMG was designed and set up. The measurements are achieved by two concentric needle electrodes (CNE). An M-File in MATLAB 7.2 is used to construct 3-D plots of the MU territory. Measurements have been performed with seven JME patients and two healthy volunteers. The genetic origin of the JME suggested the subclinical anterior horn cell involvement in JME. Some evidences were found on the preponderance of the normal 'large' MUs using several electrophysiological methods. Scanning EMG system is used to confirm the presence of these large MUs. 3-D maps of the MU territories are constructed using the data acquired from the subjects. It has been demonstrated that the experimental system can be used to examine the motor unit territory different groups of diseases for clinical studies. This study will be extended to ten JME and to ten healthy volunteers, and by including three spinal muscular atrophy cases (SMA).

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1. Introduction

Motor unit (MU) is the basic anatomical and functional unit of the skeletal muscle [1]. It consists of the anterior horn cell located in the spinal cord, the motor neuron, its neuromuscular junction and the muscle fibers innervated by this motor neuron [2]. The electrical signal generated by the fibers belonging to MU is called Motor Unit Action Potential (MUAP) and is monitored by Electromyography (EMG) and is the voltage varying with time [3][4][5].

Conventional EMG is commonly used in routine clinical studies for the diagnosis of the neuromuscular diseases by examining the alterations in the amplitude and in the duration of EMG signals which implies that it only depends upon the temporal characteristics [6]. However, since the spike portion of the MUAP is derived from 10 to 15 fibers corresponding only to 5-10% of all fibers within the MU territory conventional EMG does not give information about the entire MU territory [1][7]. An electrophysiological method measuring the temporal and spatial characteristics

of the entire MU is required to obtain information about the entire MU territory. Scanning EMG is the method used for this purpose [7][8][9].

In addition to the parameters used with conventional EMG such as amplitude and duration, new parameters are introduced with Scanning EMG. These are length of MU cross-section, fractions of MUs, silent periods, polyphasic and complex portions of MUAPs, maximum duration and the maximum amplitude. The length of MU cross-section is defined as the distance between the first and the last signals along the recording corridor. The fractions of MUs produce the spiky part of the MUAP. They are separated by low-voltage sections (< 50μV) and reflect the activity from groups of muscle fibers innervated by the same axon branch and have end-plates in a limited region. The silent periods are the sections in electrical activity with peak-to-peak amplitude less than 50 μV. The silent periods separate the fractions of MU activity along the path of the upward movement of the scanning (recording) electrode. They can be due to the proliferation of the fat or connective tissue in the muscle during the degenerative process. The polyphasic and complex portions of MUAP are detected by conventional EMG only by chance. In Scanning EMG they are revealed anywhere along the path of upward movement of the scanning electrode. The maximum duration is the real duration of MUAP. The maximum amplitude is the real maximum peak-to-peak amplitude of the MUAP [7][9].

The new parameters provide information not only for the evaluation of the electrical properties but also for obtaining new data on the normal anatomical distribution of the muscle fibers and the change of this in different pathologies of the muscle. Besides, they help to visualize the MU size.

Juvenile Myoclonic Epilepsy (JME) is a benign seizure disorder characterized by myoclonic jerk appearing especially on awakening [10][11][12]. More recently, it has been shown that JME is linked to the HLA region on chromosome 6 [13][14]. In humans, a ‘‘locus regulating spinal development’’ and JME have been mapped to chromosome 6 [13][14]. Also, a subclinical anterior horn cell involvement has been previously demonstrated using conventional EMG and quantitative EMG techniques such as interference pattern (IP) analysis and turn/amplitude analysis [10][15]. Then, some evidence has been revealed for the preponderance of normal ‘large’ motor units by means of macro EMG technique and Motor Unit Number Estimate (MUNE) [16].

In this study, scanning EMG system was established to determine the length of MUs cross-section in order to confirm the preponderance of the normal ‘large’ motor units.

2. Material and Methods

In this study, an experimental scanning EMG system was designed and established. The drawing of this system is illustrated in Figure 1.

This study is approved by the local ethical committee of Istanbul University Capa Medical Faculty.

The essence of this method is based on recording the electrical activity through the territory step by step via a Concentric Needle Electrode (CNE). The concentric electrode with a length of 37 mm (Medelec ELITE Disposable, Madison, USA) is inserted into the biceps brachii muscle for this purpose and is used as scanning (recording) electrode. This electrode is connected to the EMG instrument (Medtronics, Keypoint version 7.0, Denmark) via a needle holder (or cable) (VIASYS Teca, Madison, USA). This needle holder is a shielded 106cm cable, terminating in a 5-pin 240° DIN plug. The filter setting is 5-Hz low-pass and 10-kHz high pass for this electrode.

Because a single fiber potential (SFAP) from a MU has been used previously as triggering signal, a single fiber EMG (SFEMG) electrode has been initially considered in the design of the system [1][7][8][9]. The filter setting for the channel of this electrode is 500 Hz for low-pass filter and 10 kHz for high-pass filter. However, the CNE electrodes are cheaper than the SFEMG electrodes and require a lower contraction level compared to the SFEMG electrodes. In addition, CNE electrodes are disposable and do not require sterilization after the use in each patient in contrast to SFEMG electrodes [17]. By adjusting the filter settings to 2 kHz and to 10 kHz respectively for low-pass filter and for high-pass filter for the channel of the triggering signal , a CNE electrode can be used as triggering electrode instead of a SFEMG electrode. Therefore, a

CNE is used in this study as triggering electrode [17]. This electrode is inserted into the same muscle in order to record and monitor the action potential of one muscle fiber during the slight voluntary contraction. This is used as triggering electrode to select the time-locked electrical activity among the recorded signals by the scanning electrode. It remains fixed during the scanning process. It is connected to the EMG Instrument (Medtronics, Keypoint version 7.0, Denmark) via a needle holder (cable) (VIASYS Teca, Madison, USA).It is a 112cm, PVC coated cable, terminating in a 5-pin 240° DIN connector.

The EMG instrument (Medtronics, Keypoint version 7.0, Denmark) is used to amplify EMG signals coming both from the scanning electrode and the triggering electrode. It has a gain factor of 1000. Therefore, the measured signals in mV are amplified to volts to be processed by the DAQ system. Filter settings for both signals are adjusted via this EMG instruments. The insertion process of both electrodes to the correct location inside the muscle and the

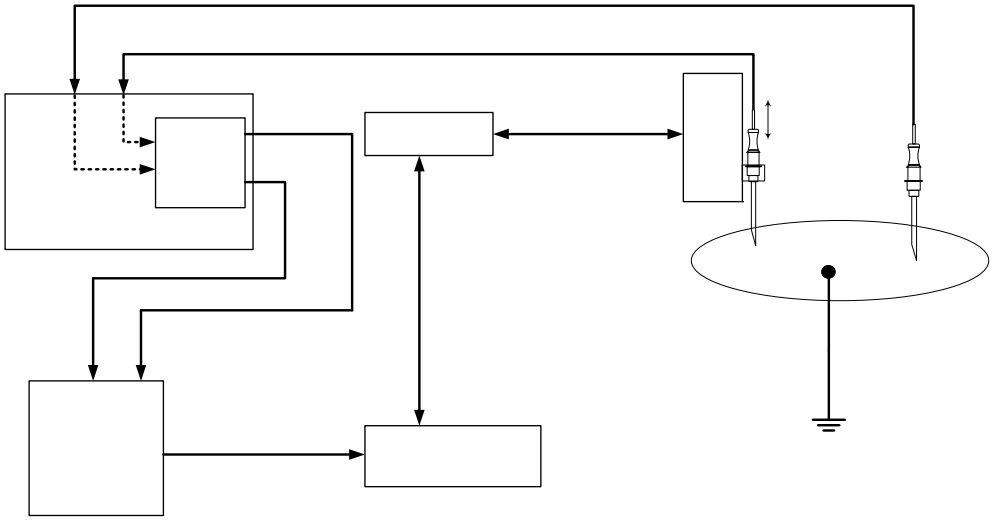

Fig. 1. The block diagram of the experimental scanning EMG system

electrical activity during scanning process are monitored on the display of the instrument. The analog signals coming from the electrodes are digitized by the EMG instrument.

In order to process and to record the signals coming from the electrodes by a computer, they is given as output from the EMG instrument. A D/A converter (Medtronics A/S, Analog Output Board, Denmark) board with four output channels is inserted into the EMG instrument. Two of these channels are used as outputs for either scanning signal or triggering signal. These signals are conveyed from the outputs of the D/A converter board to Data Acquisition (DAQ) System through two 50-Ω coaxial cables. These cables are connected to the

outputs of the D/A converter board via the phono sockets. In order to display and record the data measured from the patients, the analog signals coming from the EMG instrument is converted into the digital form. A data acquisition (DAQ) system (National Instruments, NI-USB-6009, Austin, TX, USA is used for this purpose. This DAQ system has 14-bit resolution for differential mode. It has a maximum (aggregate) analog input sample rate of 48 kS/s (kilo samples per second) where the sampling rate is 24 kS/s for either scanning signal channel or triggering signal channel.

The upward movement of the scanning electrode is achieved via a linear actuator (Zaber Technologies, T-LA60A, British Columbia, Canada).

This actuator has a motion range of 60 mm and a resolution of 0.1 μm. Since the step size of the upward movement of the scanning electrode was 50 μm and multiples thereof this resolution value satisfies the step size requirement of the study. In order to ensure that the total distance traversed by the CNE in the muscle is 2.5 to 3 cm, the step count is set to 250 to 300 steps and the step size is chosen as 100 μm at the console of the interface software.

The linear actuator is connected to the notebook via a RS-232 cable.

However, since the notebook has no RS-232 port, a RS-232-to-USB converted (S-Link, China) is used to adapt the connection of the linear actuator to the notebook. The scanning electrode is affixed to the lead screw of the actuator by means of a needle attachment specially designed and manufactured for this study.

This needle attachment is shown in Figure 2. The actuator is fixed to the arm of the subject via support attachment shown in Figure 3.The upward and downward movements of the actuator are controlled by a notebook (Packard Bell, Easy Note, Wijchen, Netherlands). This is established by means of the interface software created in Visual Basic 6.0 where parameters such as step size, step count, step period and the relative position of the electrode can be adjusted.

This software is also used to control the DAQ system during the recording process by adjusting parameters such as number of samples, frequency (or sampling rate), voltage range of the acquired signal. The DAQ system is connected to the notebook through an USB cable supplied with the DAQ system.

The data belonging to the scanning signal is stored in the notebook as a text file in the .csv format and then used to plot 3-D map of the electrophysiological cross-section of the MU territory.

An M-File module is created in MATLAB 7.2 in order to construct the 3-D plot of the MU territory for each measurement session established for each patient. The data stored into the notebook are used for this purpose. In order to eliminate non-time locked activity in each trace of the recorded activity, median filtering is applied to the recording data [9].

Scanning EMG recordings are performed on the biceps brachii muscle of the selected JME patients and volunteers. The subjects are lying in supine position and then a surface electrode connected to the EMG instrument as the ground electrode of the EMG instrument is attached to the wrist of the subject. A conductive paste is used between the ground electrode and the skin of the patient. First, the needle attachment is affixed to the lead screw of the linear actuator.

The number of sample in one step is adjusted to 4700 samples and the sampling frequency is adjusted to 23.5 kHz in the console of the interface software.

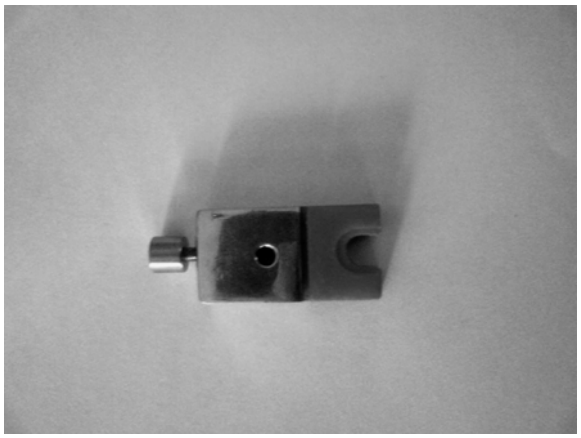

Fig. 2. The Needle Attachment

The period of one step where the actuator waits before pulling the scanning electrode for the next step is automatically calculated and set to 200 milliseconds. The CNE used as scanning electrode is inserted into this needle attachment and is connected to the EMG instrument via the needle holder. The triggering electrode is inserted into the muscle until a single fiber action potential (SFAP) of a muscle fiber belonging to any MU is detected. Then, this electrode is left fixed. Afterwards, the linear actuator is fixed to the arm of the subjects by means of the support attachment in the fashion that the scanning electrode will be inserted into muscle as close as possible to the triggering electrode in order to pick up the MUAPs from the same MU as that of the SFAP picked up by the triggering EMG. This distance is approximately 5 mm. Both triggering and the scanning signals are monitored in two channels on the display of the EMG instrument in

real time to achieve the correct location of both electrodes. Once the electrical activity synchronous with that of triggering electrode is found, the scanning electrode is pushed away inside the MU until a position is reached where no further spike components of the activity of the scanning signal are detected. This is the lower boundary of the MU territory. Positioning procedure of both electrodes usually takes almost 1 minute. Then, the scanning electrode is pulled step by step by the linear actuator during a slight voluntary contraction until no further spike component is seen on the display of the EMG instrument in the channel of the scanning signal.

Fig. 3. The Support Attachment and the needle attachment connected to the linear actuator

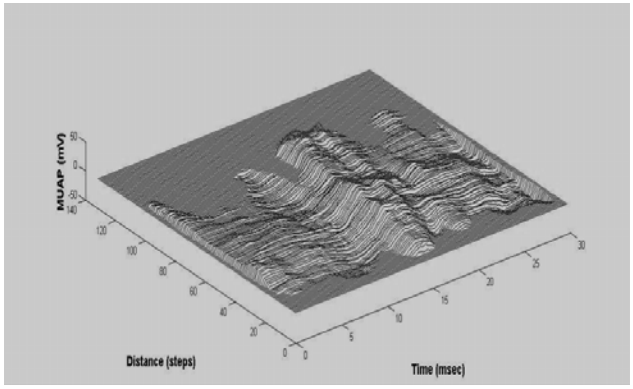

Fig. 4. 3-D plot of MU of a subject from the normal control group

This step represents the upper boundary of the MU territory. Then, the scanning electrode is pulled out completely to repeat the insertion procedure described as above in order to measure the electric activity of another MU.

5 to 10 distinct measurements are performed for each subject.

The data acquired during the scanning process are stored in the notebook in .csv format. In order to plot the 3-D map of the MU territory these data are processed by an M-File created in MATLAB 7.2. Only the MUAPs that are time locked with the triggering signal detected by the triggering electrode are selected by this software to plot the map of the MU territory.

3. Results and discussion

Since JME and a locus regulating the spinal development is mapped to chromosome 6, it is suggested previously that an anterior horn cell disorder may accompany JME [10][13][14]. Because such a disorder will affect the functional and anatomical structure of a motor neuron and that of MU, these alterations are expected to be found by investigating the electrical activity of the MU. Also, a subclinical anterior horn cell involvement has been revealed in a recent study by means of conventional EMG and quantitative electrophysiological techniques such as IP analysis

and turn/amplitude analysis [10]. Because an increase in MU size is expected due to the reinnervation of this MU by the collateral sprouts from the adjacent motor neurons in case of anterior horn cell involvement, a sensitive method reflecting the electrical activity of the

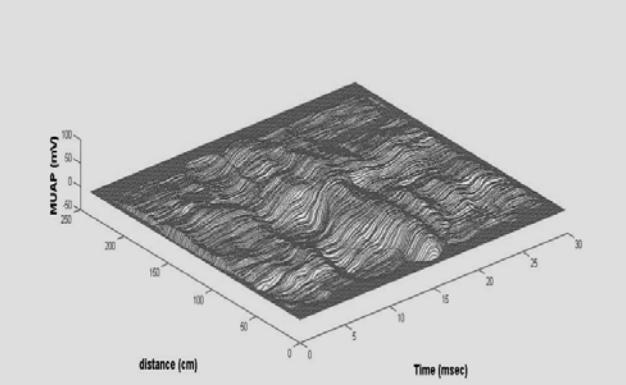

Fig. 5. 3-D plot of MU of a subject from the JME group

entire MU such as a Macro EMG was used in a previous study [15]. Since, it gives quantitative aspects of the size and it would have differentiated between reinnervation and other reasons for the enlargement by means of its inbuilt single-fiber EMG (SFEMG) recording [3][4][15][18]. It is possible to assess also the fiber density (FD) of a motor unit beside the macro MUAP [15]. Previously, the fiber density of the MU was found almost normal in JME cases although the macro MUAPs were increased. This suggests that this evidence is the due to the large motor units with normal organization of individual muscle fibers rather than reinnervation [15]. Also, a decrease in the number of motor axons to the muscle under the investigation implies the preponderance of the large MUs and therefore a motor unit number estimate (MUNE) analysis was performed previously in JME patients which concluded that MUNEs of JME patients were nearly half of those of the normal subjects [16]. However, this technique does not give an insight for the MU size.

Therefore, another technique that reflects the spatial and temporal characteristics of the MU is required to evaluate the MU size to support the preponderance of the large MUs. Scanning EMG is such a method that enables to measure the length of MU cross-section [1][7][8][9]. The experimental system described in this article is established to serve for such a purpose. 3-D maps are constructed for each MU using the acquired data via this system. Some examples of the 3-D plots of the MU territory for both normal individuals and JME patients are illustrated in Figure 4 and Figure 5 respectively. The y-axis represents the time in milliseconds, the z-axis represents the voltage in mV and the x-axis represents the distancein steps where the scanning electrode traverses during the data acquisition

4. Conclusion

The experimental scanning EMG system depicted here is still used in an ongoing study to assess the length of MU size in JME patients and to compare their findings with those of the control group consisting of normal subjects, neurogenic and myopathic patients. The measurements have been done on seven JME patients and on two normal individuals until now. The number of the subjects in JME group will be extended to 10 individuals and that of the subjects in normal control group to 10 individuals. In addition, 5 neurogenic subjects and 5 myopathic subjects will be included to the study in order to draw a conclusion for the clinical part of this study

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