Biomedical Signal Processing and Control 41 (2018) 109–128

Contents lists available at ScienceDirect

Biomedical Signal Processing and Control

journal homepage: www.elsevier.com/locate/bspc

New features for scanned bioelectrical activity of motor unit in health and disease

N. Tuğrul Artuğ[a,*], Imran Goker[b], Bülent Bolat[c], Onur Osman[a], Elif Kocasoy Orhan[d], M. Baris Baslo[d]

[a] Electrical and Electronics Engineering, Istanbul Arel University, Tepekent, Buyukcekmece, Istanbul, Turkey
[b] Biomedical Engineering, Istanbul Arel University, Tepekent, Buyukcekmece, Istanbul, Turkey
[c] Electronics and Communication Engineering, Yildiz Technical University, Esenler, Istanbul, Turkey
[d] Istanbul Medical Faculty, Istanbul University, Fatih, Capa, Istanbul, Turkey

ARTICLE INFO

Article history:
Received 8 March 2017
Received in revised form 12 October 2017
Accepted 19 November 2017

Keywords:
Electromyography
Scanning EMG
Neuromuscular disease
Feature extraction
Motor unit action potential
EMG simulator

ABSTRACT

The present study aims to find new features that support the differential diagnosis of neuromuscular diseases. Scanning EMG is an experimental method developed for understanding the motor unit organization and for observing temporal and spatial characteristics of motor unit's electrical activity. A motor unit consists of a motor neuron and muscle fibers that are innervated by its motor neuron.

Both simulation and biological data on neuromuscular diseases are considered in this study. Biological data were acquired from 3 patients with neurogenic involvement (2 with poliomyelitis sequela and 1 with spinal muscular atrophy), 2 patients with myopathy (1 with inflammatory myopathy and 1 with muscular dystrophy) and 4 healthy participants. Seven features are extracted by specifications of neuromuscular diseases and characteristics of EMG signals. These features are maximum amplitude, spike duration, the number of peaks, maximum amplitude x spike duration, number of peaks x spike duration, the ratio of the power outside the activity corridor to the power inside the activity corridor and the number of peaks outside of the activity corridor.

The autocorrelation function of the sum of scanning EMG signals is effective in determining the activity corridor of these signals and the spike duration can be determined more easily by using the activity corridor. Wavelet transform based noise reduction and the windowing method are proposed for calculating the features correctly. By this method, spike duration and the number of peaks should be able to be calculated more precisely. It is confirmed that if the signals are filtered by a high pass filter with a cut off frequency of 2 KHz, the calculation of the number of peaks should be easier.

While maximum amplitude and maximum amplitude times spike duration are found to be significant for diagnosing neurogenic diseases, other features are found to be significant for all groups by ANOVA test. It is determined that which features are more effective for differential diagnosis and the dataset that contains normal people and patients is classified using multi-layer perceptron (MLP), radial basis function network (RBF), support vector machines (SVM) and k nearest neighbor algorithm (k-NN). The best accuracy is obtained as 85% with MLP network.

1. Introduction

Neuromuscular diseases affecting the muscular and nervous systems are diagnosed by means of needle EMG. The most basic functional unit to be considered in the diagnosis of these diseases is the Motor Unit (MU). Muscle fibers innervated by a single motor neuron and the motor neuron itself constitute the MU [1]. The neuromuscular disorders affecting the nerves innervating the muscles are known as neurogenic diseases and those affecting the muscles are referred to as myopathic diseases [2]. In a neurogenic patient, the motor neuron innervating the MU loses its function. This MU is reinnervated by the adjacent motor neuron to make it functional again [3]. Since muscle fibers are degenerated in myopathic diseases, not only does the number of fibers decrease but also the variation between the diameters of the surviving fibers increases.

* Corresponding author.
E-mail addresses: tugrulartug@arel.edu.tr (N.T. Artuğ), imrangoker@arel.edu.tr (I. Goker), bbolat@yildiz.edu.tr (B. Bolat), onurosman@arel.edu.tr (O. Osman), elifkorhan@yahoo.com (E.K. Orhan), mbbaslo@istanbul.edu.tr (M.B. Baslo).

https://doi.org/10.1016/j.bspc.2017.11.011
1746-8094/

The bioelectrical activity of the MU is represented by the Motor Unit Potential (MUP). During voluntary contraction, muscle fibers individually generate action potentials. These are referred to as Single Fiber Action Potentials (SFAPs). The summation of the electrical activities generated by all of the muscle fibers belonging to the MU during contraction or when an exogenous stimulus is applied is known as Motor Unit Action Potentials (MUAP) [4–10]. In a healthy individual, the amplitudes of MUAPs vary between 200 μV and 3 mV and their phase durations range from 3 to 15 ms. The maximum number of phases in normal individual is 4 [6,11,12].

In neurogenic diseases, typical MUP alteration is emerged through re-innervation. New components are added to MUP so the amplitude increases and the phase duration becomes longer. The number of muscle fibers also increases due to the collateral re-innervation and clustering among muscle fibers takes place in some locations. The amplitude of the MUP may be ten folds in neurogenic cases compared to the mean values of that of normal individuals. Due to the imperfections in conduction in newly formed neuromuscular junctions via re-innervation, unstable MUPs are observed [3,13]. In myopathic diseases MUPs are polyphasic and the duration of them are shorter. The amplitude is generally lower but it is occasionally possible to observe amplitudes close to a normal person. High amplitude MUPs can be rarely observed but their duration is shorter [3]. In a study conducted by Kugelberg in 1949, he proved that the number of peaks decreased in myopathic disease compared to neurogenic disease in the progressing stages of the disease [14]. Kugelberg et al. conducted a study on the experimentally reinnervated mouse muscles. They showed the distribution of reinnervated muscle fibers in the MU. Furthermore, this study helped to describe the alterations in the MUAP in neurogenic diseases. It was observed that the number of fibers increased and the collateral sprouting occurred only in the MU territory and that this did not affect another territory [15]. One of the most important factors that affects the measured parameters of MUP is the position of the needle electrode within the MU territory. As the location of the needle electrode changesso do the MUP features [16]. In conventional needle EMG all bioelectrical activity of the MU under investigation cannot be recorded. The EMG method which can reveal the distribution of the electrical activity within the MU territory is Scanning EMG [17,18].

Scanning EMG is an experimental technique developed not only to figure out the electrical activity of the MU better but also to be able to study its temporal and spatial features. It has been used both individually and by combining with other techniques in many different studies [3,11,19].

In addition to the parameters revealed conventional needle EMG, some parameters such as fractions of MU, silent areas can be also demonstrated. Silent areas are the regions where no electrical activity can be recorded. They can especially be encountered in myopathic motor units [17,20].

Due to the branching of the motor neuron axon, groupings of muscle fibers can occur within the MU territory. These are referredto as fractions of motor units. These fractions can be separated either by silent areas or time delays according to the location of the trigger electrode. These separations are not uniformly distributed in the territory. The reason for the silent areas is the variation between muscle fiber conduction velocities (MFCV) [21].

Scanning EMG was performed in 1980 by Stålberg and Antoni in order to study the organization of MU. An electrophysiological cross-section of an MU was acquired for this purpose [17].

Hilton-Brown and Stålberg used scanning EMG with single fiber EMG (SFEMG) on myopathic patients.The aim of this study was to reveal that alterations in EMG originate not only from muscle fiber loss but also from the neurogenic components' regenerative process. They studied the changes in the fiber density and in jitter parameters by means of SFEMG. They demonstrated that regional fiber clustering results in silent areas in the MU territory [22].

In another study conducted by Hilton-Brown and Stålberg scanning EMG was used with macro EMG to investigate the activity distribution within the MU territory on patients that had muscular dystrophy. They studied the total size of the MU and the fiber density. They found that there were smaller motor units on myopathic disorders when concentric needle EMG was used [23].

Stålberg and, Eriksson studied the topography of human masseter single motor units by virtue of scanning EMG in 1987. They revealed that the mean length of the MU cross-section was less than that was found in large muscles found in extremities. This confirmed that motor units in masseter contain fewer muscle fibers compared those in limb muscles. On the other hand, large MU territories were found in three muscles in some motor units. They reported that small MU territories may be related to the fine adjustment of jaw movements however, large territories may play a role in force development in biting and balancing the gravity [24].

In another study conducted by Stålberg and Diószeghy, recordings were made from the anterior tibialis and biceps brachii muscles of healthy people, neurogenic and myopathic patients. As a result of the comparison of these three groups, they verified that the arrangement of muscle fibers in terms of types of diseases in addition to that of healthy individuals by virtue of scanning EMG [20].

Gootzen, Vingerhoets and Stegeman used the scanning EMG method to study the motor units of quadriceps muscles on a group of healthy individuals, a group of neurogenic patients and a group of myogenic patients. They concluded that the size of the MU territory of myopathic patients was found smaller and that of neurogenic patients was found larger [25].

Navallas and Stålberg investigated the electrophysiological origin of temporal jumps between MU fractions within the MU territory by studying motor end-plate topography by means of scanning EMGin 2009. They calculated complexity and latency as a measure of temporal dispersion in SFAPs reflecting the relationship with the temporal jumps and the differences in the MEP positions, lengths of axonal branches and conduction velocities. They concluded that MU fractions observed by Scanning EMG can be used to investigate the MEP topography and the branching patterns of the axons innervating the MU [21].

Göker et al. designed an experimental system for scanning EMG in order to visualize the electrical activity of the MU [26]. They used a concentric EMG electrode as a trigger electrode besides the scanning electrode in this system [27]. One year later, they published a study in which they used the scanning EMG to investigate the electrophysiological cross-sections of the MU territories of juvenile myoclonic patients, neurogenic patients and healthy individuals. They studied the lengths of MU territories' cross-sections and the maximum amplitudes for each MU territories. They presented evidence on the presence of the larger motor units in juvenile myoclonic epilepsy patients and they reported that these larger motor units were structural rather than being due to the progress of the disease [28].

In another study of Göker et al., juvenile myoclonic epilepsy obtained via the scanning EMG method was classified by using machine learning algorithms. Methods such as feed-forward neural networks, support vector machines, decision-trees were used and a higher classification success ratio was obtained [29].

Artuğ et al. presented an Activity Corridor Computation Method that is beneficial for easier calculation of the spike duration and that of the number of the peaks for the signals of Scanning EMG. The method was tried with 34 real records and activity corridor was computed correctly in all of these records [30].

van Dijk et al. studied the MU activity of the masseter muscle by using an adapted scanning EMG technique which