COMPUTER METHODS AND PROGRAMS IN BIOMEDICINE 129 (2016) 172–185

journal homepage: www.intl.elsevierhealth.com/journals/cmpb

The effect of recording site on extracted features of motor unit action potential

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 25 May 2015
Received in revised form
18 November 2015
Accepted 6 January 2016

Keywords:
Electromyography
Neuromuscular disease
Feature extraction
Motor unit action potential
Innervation zone and tendon
EMG simulator

ABSTRACT

Motor unit action potential (MUAP), which consists of individual muscle fiber action potentials (MFAPs), represents the electrical activity of the motor unit. The values of the MUAP features are changed by denervation and reinnervation in neurogenic involvement as well as muscle fiber loss with increased diameter variability in myopathic diseases. The present study is designed to investigate how increased muscle fiber diameter variability affects MUAP parameters in simulated motor units. In order to detect this variation, simulated MUAPs were calculated both at the innervation zone where the MFAPs are more synchronized, and near the tendon, where they show increased temporal dispersion. Reinnervation in neurogenic state increases MUAP amplitude for the recordings at both the innervation zone and near the tendon. However, MUAP duration and the number of peaks significantly increased in a case of myopathy for recordings near the tendon. Furthermore, of the new features, "*number of peaks* × *spike duration*" was found as the strongest indicator of MFAP dispersion in myopathy. MUAPs were also recorded from healthy participants in order to investigate the biological counterpart of the simulation data. MUAPs which were recorded near to tendon revealed significantly prolonged duration and decreased amplitude. Although the number of peaks was increased by moving the needle near to tendon, this was not significant.

1. Introduction

The motor unit is the final common pathway for all types of movement and consists of lower motor neuron, its axon and the innervated muscle fibers. Muscle fibers belonging to different motor units intermingle. Bioelectrical activity of the motor unit that is recorded from the muscle fibers during voluntary contraction is known as motor unit action potential (MUAP).

Motor unit action potential is the summation of action potentials coming from the muscle fibers belonging to the same motor unit in the uptake area of the needle electrode [1]. This summation depends on temporal and spatial properties such as innervation order of the muscle fibers, the distance of

* *Corresponding author*. Tel.: +90 212 867 25 00.
E-mail addresses: tugrulartug@arel.edu.tr, tugrulartug@gmail.com (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. Kocasoy Orhan), mbbaslo@istanbul.edu.tr (M.B. Baslo).
http://dx.doi.org/10.1016/j.cmpb.2016.01.003

the needle electrode to the muscle fibers and to the innervation zone [2].

During the examination of a muscle in conventional electromyography, the needle is inserted at a certain point over the muscle which is near to "motor point" [3]. The motor point coincides with the innervation zone for this muscle, that is, the muscle fibers get their motor innervation through motor end plates located in the middle part of a fusiform skeletal muscle. Muscle fiber action potential emerges at the motor end plate and propagates along the muscle fiber towards the tendons in both directions. When the needle is inserted near the motor point, the muscle fiber action potentials are acquired with a brief delay determined by the distance between the needle electrode and the innervation zone [4]. As a result, these action potentials reach the recording electrode with shorter delays in innervation zone when compared with tendon recordings and cause less muscle fiber action potential (MFAP) dispersion leading a shorter MUAP duration. Alternatively, inserting the needle electrode near the tendon rather than the motor point may change the MUAP parameters which are the main interest of the present simulation study.

Needle EMG detects the alterations of motor units in either neurogenic or myopathic disorders. In neurogenic diseases, muscle fibers that belong to the motor unit are denervated because of the loss of motor axon or motor neuron. Some of these denervated muscle fibers located in the area of overlapping intact motor unit territory can be reinnervated by the collateral sprouts of terminal axons. This collateral reinnervation process by sprouting is limited to the overlapping areas between the intact and denervated motor units [5]. Reinnervated muscle fibers have immature motor end plates causing irregular neuromuscular transmission. Furthermore, new MFAPs are added to the MUAP. Irregular neuromuscular transmission and the newly added MFAPs increase the MFAP dispersion and the number of phases causing a complex MUAP waveform which has prolonged duration. However, motor unit territory remains relatively the same. The reinnervation process increases the muscle fiber density at the overlapping areas and clustering occurs. Thus, more muscle fibers from the same motor unit are detected within the uptake area of the needle electrode yielding higher MUAP amplitudes [6].

In myopathic diseases, the number of muscle fibers within the motor unit territory is decreased and the remaining ones demonstrate increased variability in diameter. Myopathic MUAPs are usually short in duration and low in amplitude. However, if the recording needle encounters a muscle fiber with an increased diameter, MUAP amplitude increases yet their duration remains short [6]. Motor unit diameter decreases and electrically silent areas appear within the territory due to the muscle fiber loss [7]. Especially in chronic stages, some myopathic motor units reveal long duration, complex MUAPs with dispersed phases which may cause confusion while differentiating myopathy from neurogenic involvement [8–12]. Advanced EMG techniques such as "Macro EMG" should be used in order to make correct diagnosis [13].

The features that are valuable for diagnosing neurogenic or myopathic motor unit changes such as MUAP amplitude and duration have been defined relying on conventional EMG recording in which the needle electrode is inserted near the innervation zone [1]. However, conventional needle EMG lacks of showing the features that occurred due to the changes at the MFAP propagation which mostly depend on the fiber diameter. The propagation velocity of a muscle fiber's potential was calculated by the formula [14]:

$$\text{Propagation velocity}\ \ (\text{m/s}) = 3.7 + 0.05(\text{diameter}\ \ (\mu\text{m}) - 55)$$

In an intact motor unit, muscle fiber diameter variation is insignificant; however, there is a considerable variation among them especially in cases of myopathy [14]. As the increased variation in diameters results in variation among MFAP propagation velocity, the muscles of patients with myopathic disease are expected to have measurable differences between the MUAPs recorded from the two recording sites; the motor point and near the tendon.

Previous studies reported attempts to record and analyze MUAPs in various locations outside the innervation zone.

In 1988, Nandedkar et al. simulated motor units and calculated MUAPs by using a concentric needle electrode. They examined how MUAP features are determined by the displacement of the needle in the vicinity of the innervation zone [14].

In another study, Nandedkar et al. investigated MUAP features where the needle was placed proximally or distally to the muscle fibers in a certain motor unit territory. The MUAPs were recorded from the biceps muscles of normal subjects, as well as patients with neuropathy and myopathy [15].

Nandedkar and Sanders made a simulation study about myopathic motor unit action potentials in 1989. They created a normal motor unit and then altered its features to create four different scenarios for simulating myopathic conditions. The MUAPs were calculated from three different distances from the innervation zone at the same motor unit. They found that both muscle fiber loss and increased fiber diameter variability are required to simulate complex MUAPs [16].

Falck et al. studied the influence of the recording site within the biceps muscle on MUAPs in a group consisting of healthy subjects. They made recordings from 4 different sites in the muscle; middle superficial, middle deep, distal superficial and distal deep. They found a significant difference of MUAP features between the superficial middle and deep distal parts. Their study revealed that if the recording was done at the end-plate region, MUAP dispersion and duration would be less compared to those recorded from a distance more than 20 mm away from the endplate due to temporal dispersion of MFAPs [17].

Stålberg and Karlsson made a simulation study using a normal muscle model in 2001. They revealed the effect of distance from end-plate in addition to many other features. They started calculating MUAPs on top of the innervation zone and moved the needle to the tendon in 6 consecutive steps with 10-mm displacements. They showed that MUAP amplitude decreased whereas the duration and the number of phases increased by moving the electrode towards the tendon [18].

Brownell and Bromberg studied the effect of intramuscular needle position on MUAP metrics in 2007. They used two different models to simulate a normal motor unit. They found a significant decrease in amplitude and area by displacing the needle electrode near the tendon. The number of turns and phases significantly increased. Nevertheless the duration