Journal of Biomedical Sciences
Research Article Peer-review, Open Access

Telescopic Needle Electrodes in Single-Fiber Electromyography, Reducing Painfulness and Labor Intensity, Increasing Accuracy of Tests

Alexander Kharibegashvili [1]

Abstract

Use of new telescopic monopolar and bipolar needle electrodes and new methods in the single-fiber electromyography offered by the author is described.

The offered needle electrode greatly facilitates single muscle fiber electromyography testing (parameters such as jitter and fiber density), reduces trauma, duration, labor intensity and painfulness of the examination.

Accuracy of examination results increases; the given electrode enables measuring transverse size of single fibers.

The author offers using new parameters in single-fiber electromyography for estimation of neuromuscular system functioning and for diagnostics of neuromuscular diseases - general density of fibers, degree of overlap, degree of territorial overlap, fiber power density.

Key words: Single fiber electromyography, jitter, fiber density, neuromuscular transmission, neuromuscular disease.

[1] Telavi State University Lecturer, Telavi Regional Hospital Neurologist

Studies on electric activity of single fiber has been given great attention recently. This is explained by the fact that single fibers (SF) electromyography (EMG) - SFEMG - allows receiving more accurate, detailed image of certain aspects of normal physiology as well as pathology of motor units (MU), including studying jitter and fiber density (FD) in MU.

It has been revealed that while recording action potential (AP) of two adjacent muscle fibers belonging to

a single MU, intervals in their discharge are inconstant and fluctuate around the average meaning defined for the given pair.

The variation in the latency (spread in the intervals) dependent on impermanence in synaptic latency periods is called “jitter”. Normally it is 10–70 mc and being the accurate quantitative characteristic of intimate processes of neuromuscular transmission in individual synapses, it increasingly attracts the attention of researchers and practical laboratories [1], as significant changes in it have been revealed during neuromuscular diseases, including sharp increase in variations latency during myasthenia. In order to obtain mean value of jitter per each person examined (patient) electric activity of 20 and above pairs is recorded, which requires at least 4–5 skin punctures [2].

Along with characterization of neuromuscular transmission, single-fiber electromyography (SFEMG) allows characterizing certain peculiarities of MU morphology. The parameter of fiber density (FD) in MU is used for this purpose. FD reflects the quantity of myofibrils innervated by terminal branches of a single axon [3, 4]. In normal conditions in certain muscle areas muscle fibers of several MUs overlap. Therefore muscle fibers belonging to various MUs are found near the microelectrodes (recording surface of the needle electrode) and when activating one MU, in most of the cases (in 65-70 % of injection of the needle) activity of one muscle fiber of the given MU can be recorded, while in 25% of needle injection activity of two muscle fibers can be recorded and only in exceptional (in single) cases – three and above muscle fibers in the form of relevant number of spikes.

During neurogenic pathological processes in association with the process of reinnervation of denervated muscle fibers by axon branch dendrites of another MU, the number of muscle fibers innervated by branches of one axon in the same space of the muscle tissue significantly increases and consequently more synchronically functioning fibers belonging to the single MU enlarged in the process of innervation are found close to the microelectrode. In such case 3-10 and above spikes can be recorded in a single discharge. FD is calculated as mean average of AP of SF recorded at 20 random positions of microelectrode in various areas of the given muscle, which can be achieved by no less than 4 skin punctures.

Methodology of SFEMG examination requires accuracy in positioning recording surface of the electrode close to the examined fiber, which is achieved by constant control of form, amplitude and configuration of SF AP on the monitor while accomplishing manipulations with the electrode within tens of a millimeter [1]. At the same time the electrode is very slowly and accurately moved forwards and backwards and rotated around the axis.

SFEMG is a useful development of clinical electrophysiology of neuromuscular system. However, though developed and described in details back in the 60s - beginning of the 70s of the last century and a detailed monograph capable of serving as a guideline for the given method published in 1977, [2, 5, 6, 7], till present it is not widespread in clinical diagnostics. In addition to setting relatively high standards to technical equipment, the key reason for the above is that the process of examination itself is complicated, labor intensity, and requires high levels of training of the electromyographer (necessity to manipulate with the electrode within tens of a millimeter) and cooperation from the patient’s end. Even according to the assessment of the authors of the method (6), an electrophysiologist skilled in the given methodology needs at 1 hour and more in order to select 20 pairs of fibers needed for jitter measurement. Testing additional AP parameter naturally prolongs the time of examination, which turns out to be very painful as well, as almost continuous manipulation with a needle inside the tense muscle is needed.

Aim: — increasing accuracy of the examination, simplifying manipulation with the needle electrode during SF EMG, reduction of duration and labor intencity, as well as trauma and painfulness of the examination.

Material and methods: Consideration of existing needle electrodes and methods used in electromyography, their positive and negative aspects, creation of new types of needle electrodes and

methods.

The goal is achieved by changing the construction of existing needle electrodes and EMG methods.

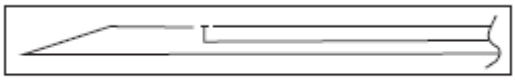


Fig.1

The SFEMG method requires special refined technology and methods. Activities of SFs included in MU are recorded by special mono or multi electrodes [1, 5]. Recording surface of the electrode is withdrawn not to the end of the needle, but the lateral part. The recording area makes approximately 500 mc, diameter – 25 mc. In case of multielectrode examination additional needle electrode is used as a reference inserted subcutaneously, while in case of a monopolar electrode – the body of the cannula of the needle electrode. The monopolar concentric needle is represented by a hollow needle (Fig. 1) through which passes a platinum or stainless-steel lead separated from it with an insulation, connected with the recording surface located on the lateral side of the needle (subelectrode).



Fig.2

Multielectrode is a needle electrode (Fig. 2), on which several, most frequently 14 individual wires with contact areas (subelectrodes) located at equal distances are positioned longitudinally, connected by wires isolated from each other, located within the needle electrode [5].

The drawbacks of the multielectrode are: big diameter, since 14 individual wires (rods) are located inside the multielectrode, unlike mono-electrode with only one insulated conductor in it, which increases painfulness and traumatic nature of examination. In addition, multiple channels of the multielectrode, consequently, require a bigger number of channels in electromyography device or complex system of commutation.

Scanning EMG method elaborated by Erik Stalberg et al [8,9] is based on scanning, i.e. a step-by-step, slow, gradual movement (insetion) of standard concentric needle electrode inside the muscle within the distribution zone of muscle fibers of the tested motor unit, collection of data on changes in action potential of the certain motor unit (MU). Painfulness and traumaticity of this method, derived from the necessity of slow and gradual insertion of the electrode in the muscle is very high.

We have developed a project of monopolar and bipolar telescopic needle electrodes [10], which was recognized as an invention by the National Intellectual Property Center of Georgia, and methods of its use.

The present invention and methods of its use make it possible to increase the accuracy of the study, enables measuring transverse size of single fibers, reduce manipulations with the needle electrode during of the SFEMG test, labor intensity and painfulness, as well as the invasiveness and duration of the study.

DESCRIPTION OF MECHANISM OF THE PROPOSED NEEDLE ELECTRODE

Proposed telescopic needle electrode (Fig. 3) represents a hollow needle (canula) 1, on the lateral side of which there is a longitudinal groove (opening) 2, inside the hollow needle there is a movable dielectric rod with axial movement 3, on the lateral surface of which two microelectrodes (recording surface) are created 4, (for routine SFEMG tests there may be one wire inside the rod and one subelectrode on the lateral side of this dielectric rod) connected with two wires 5 separated from each other by insulation, located inside the dielectric rod 3.

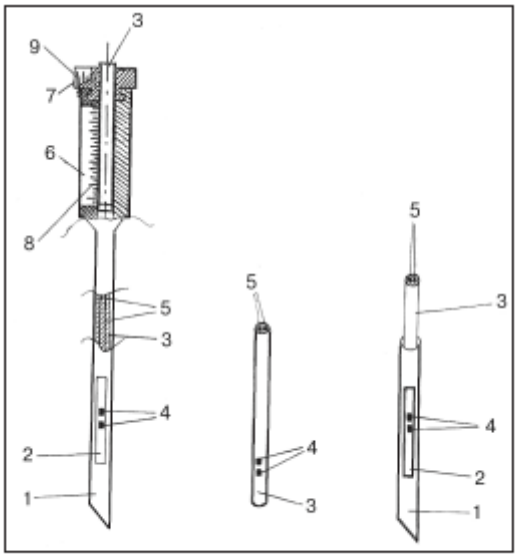


Fig.3

Microelectrodes 4 emerge in the groove 2 of the hollow needle 1. The hollow needle 1 and the dielectric rod 3 are connected to the movement mechanism 6, on which a micro screw is installed 7, enabling movements of the dielectric rod 3 along the axis of the hollow needle 1. On the body of the movement mechanism 6 and the micro screw 7 scales 8 and 9 are applied, measuring the movement of the dielectric rod 3 along the hollow needle 1.

DESCRIPTION OF USE OF THE PROPOSED NEEDLE ELECTRODE DURING

SFEMG

The examination with the given needle is conducted in the following manner:

The dielectric rod 3 (Fig. 3) is inserted to the end into the hollow needle (canula) 1, following which the proposed needle electrode (the needle 1 with the dielectric rod 3) is inserted in the muscle. After that, with the help of the micro screw 7 of the movement mechanism 6 dielectric rod 3 is slowly and gradually inserted (is led) upwards while the needle 1 remains motionless in the muscle. Subelectrodes 4 and the distance between them are so small that they can fit within the transverse dimension of a single muscle fiber. While subelectrodes remain within the single muscle fiber, synchronous action potentials (synchronous electric activity) will be recorded from them. When the upper subelectrode 4 crosses the boundary of the given muscle fiber and is placed within the upper adjacent muscle fiber, the action potentials recorded from the subelectrodes 4 will become asynchronous. Moreover, asynchrony will be within the limits of jitter (will correspond with jitter asynchrony) if adjacent muscle fibers belong to the same motor unit or asynchrony of the action potentials of the muscle fibers will be much greater and correspond with asynchrony of muscle fibers belonging to different motor units. As soon as electric activity recorded by the sub electrodes 4 becomes asynchronous, location depth l_1 of the upper electrode 4 is identified by the scale 8 and 9 on the movement mechanism 6, which will correspond to the depth of the boundaries between adjacent muscle fibers. And when the lower subelectrode 4 also crosses the boundary between the muscle fibers and both subelectrodes 4 are within the upper muscle fiber, electric activity recorded from the subelectrodes 4 will become synchronous again. We continue withdrawal of the dielectric rod 3 and when the upper subelectrode 4 crosses the boundary of the upper muscle fiber we define the location depth l_2 of the upper boundary of the upper muscle fiber and calculate the dimensions of the muscle fiber $l_2 – l_1$. When continuing the withdrawal of the dielectric rod 3 towards (relative to) the needle 1, which will remain motionless in the examined muscle, location depth of desynchronization points of action potentials of muscle fibers as the boundaries between the muscle fibers are identified: l_1, l_2, l_3, l_4, etc., after which transverse dimensions of muscle fibers throughout the total depth of needle electrode insertion are measured: $l_1 - l_2$, $l_2 - l_3$, $l_3 - l_4$, etc.

Simultaneous to determining transverse size of single muscle fibers jitter is also measured and it is identified whether adjacent muscle fibers belong to the same or different MU, muscle fiber density is also measured.

RESULTS

The proposed needle electrode allows measuring single muscle fibers as a result of increasing accuracy of examination. And since transverse dimensions of muscle fibers are measured during pathologies (such as primary muscle diseases and neurogenic muscle diseases) as well as during certain normal conditions (such as training and detraining), measuring this parameter may give additional information on normal physiology and pathology of MUs [11,12].

In addition we offer new parameters (which become measurable due to the offered telescopic needle electrode) for defining functional state of MU and muscles: total density of fibers, degree of overlap of MUs (DO) and degree of territorial overlap (DTO), muscle fiber power density (FPD).

When determining total density of fibers, the quantity of all muscle fibers belonging to different MUs, located at a certain section – 1000 mcm (1 mm) - are calculated. For this purpose, dielectric rod is moved to the given section - 1000 mcm and all muscle fibers recorded during the process are counted. The given parameter reflects degree of atrophy or hypertrophy of muscles. Degree of overlap of MUs demonstrates how often muscle fibers of other MUs can be found in the given MU. For this purpose, while moving dielectric rod 3 of the proposed needle electrode the number of synchronous adjacent muscle fibers of a single MU is counted until first asynchronous muscle fiber of another MU is found, after which again the number of synchronous adjacent muscle fibers belonging to the same MU are counted until another asynchronous muscle fiber of another MU. 20 calculations are made this way, after which mean value - degree of overlap of MUs is defined. By dividing 20 by the obtained mean value of number of synchronous adjacent muscle fibers DO is received: 20/ number of synchronous adjacent muscle fibers.

The proposed DO parameter can be informative for research (physiology of neuromuscular system) as well as clinical (diagnostics) purposes. The greater the degree of overlap, the more neurons are involved in controlling the given muscle, the more difficult to control it and the more refined movements are accomplished by the given muscle. When growing older, or in case of primary muscle diseases and neurogenic muscle diseases people become incapable of refined movements.

Muscle fiber overlap within MUs will be more precisely reflected by degree of territorial overlap (DTO), for which the number of muscle fibers of different MUs within the transverse section of the given MU is calculated and divided by transverse dimension (known in neurology and neurophysiology under the term ‘’motor unit territory’’) of the given MU in mm: number of muscle fibers of other MUs/MU territory.

When counting the number of fibers of other MUs on the territory of the given MU the dielectric rod 3 is moved and synchronous or asynchronous nature of muscle fiber potentials from the subelectrodes 4 is defined. Potentials of the given MU may be recorded from the body of the proposed electrode or from additionally inserted monopolar needle electrode. The greater the DTO volume the bigger the overlap. DTO more precisely reflects overlapping of the muscle fibers of MUs as compared to the DO, however it is more labor consuming to define the DTO. Measuring DTO will be much more facilitated if the data is processed by computer, and the micro screw is connected to an electric micro motor (engine) and is computer-controlled.

We also propose the concept - Muscle fiber power density = Amplitude of an individual muscle fiber/size of the transverse diameter of a given fiber - mV/μm (Amplitude of an individual muscle fiber divided by the transverse diameter of a given fiber). Allows to evaluate the effectiveness of muscle fibers.

The proposed needle electrode significantly facilitates testing electric activity of single muscle fibers during EMG – measuring jitter and FD, it also shortens the testing time as examination with the given needle electrode does not require high training levels of the electromyographist since even a beginner electromyographer can easily move the dielectric rod for not only tens, but also hundreds and thousands

parts of millimeters with the help of the movement mechanism 6 and the micro screw 7.

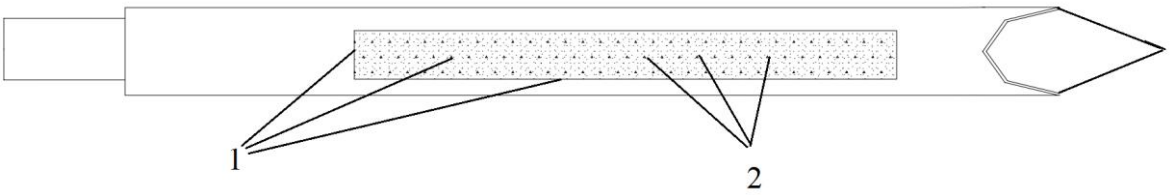
The proposed needle electrode also drastically reduces pain and trauma during the examination. As stated above EMG examination with currently existing needle electrodes requires manipulations with electrodes, plus frequent movements of the electrode backwards and forwards are needed which largely increases the traumatic nature and painfulness of the examination. During EMG testing of muscles with the proposed bipolar needle electrode only the dielectric rod 3 located within the hollow needle is moved as the needle itself 1 remains motionless inside the muscle, thus pain and trauma during the test is essentially reduced. Besides, since only two conductors are placed inside the offered bipolar needle electrode unlike the multielectrode in which 14 leads are located, the former is thinner as compared to the multielectrode, which also contributes to reduction of pain and trauma during the test.

In simplified monopolar design, the proposed telescopic electrode can be used in the same way as the existing concentric needle electrode for SPEMG. The labor intensity and painfulness of the study will also be significantly reduced.

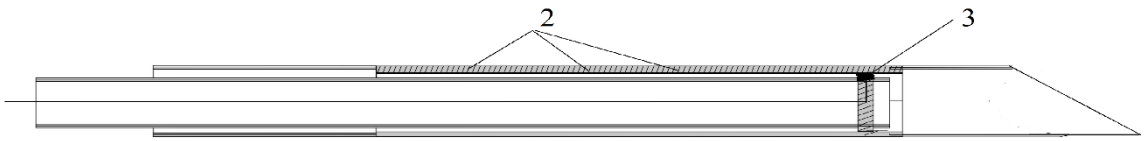
DISCUSSION

With the development and cheapening of the technology, a dielectric plate, curved with the same radius as the cannula wall - as an extension of the cannula wall - can be fixed in the longitudinal cutout – groove - of the cannula wall (Fig. 4).

In the dielectric plate there will be fixed vertically placed and insulated from each other thin wires - metal threads, one end of which will end on the outer side of the cannula wall and touch the muscles, and the other - on the inner side of the cannula wall and touch the contact surface of the dielectric rod protrusion.



a) above view of needle electrode, dielectric plate with insulated metal wires, 1 – dielectric plate, 2 – insulated metal wires



b) sectional side view, 2 - insulated wires in dielectric plate 3 - dielectric rod protrusion with contact surface

Fig. 4 Needle electrode with plate in the canal – longitudinal cutout

A protrusion is created on the dielectric rod with a platform on which a contact surface is applied, which in turn is connected to a conductor located inside the dielectric rod. The contact surface is in movable contact with the inner wall of the dielectric plate with wires vertically located in it.

If we connect the micro screw of the proposed electrode to a electric micro motor (engine) and a computer, the electromyographist only has to insert the needle electrode into the muscle, the rest - the movement of the dielectric rod with the microelectrode and the analysis of the electromyogram will be performed automatically by the computer.

CONCLUSION

Needle electromyography, like other areas of medicine, is developing rapidly [13-16] and one of its latest achievements is single fiber electromyography. However, the pain, complexity, labor intensity and duration of the study are much more greater than the same disadvantages of routine electromyography. It seems that the devices and methods we have presented can become one of the ways to reduce the severity of these shortcomings and will open the way for wider use of this progressive method - single fiber electromyography.

REFERENCES:

1. Зенков Л.Р., Ронкин М.А. Функциональная диагностика нервных болезней: Руководство для врачей. — 2-е изд., перераб. и доп. — М.: Медицина, 1991. — С. 553-561.
2. Stalberg E., Trontely J.V. Single Fibre Electromyography. — Old Waking : Miravelle Pres, 1977. — 215 p.
3. Stalberg E., Thiele B. Motor unit fibre density in the extensor digitorum communis muscle. Single fibre electromyographic study in normal subjects at different ages // J. Neurol. Neurosurg. Psichiat. — 1975. — Vol. 38, № 9. — P. 874-880.
4. Stikler D.E., Sanders D.B. Single-Fiber EMG // eMedicine Specialties «Neurology». Electromyography and Nerve Conduction Studies, Contributor Information and Disclosures. emedicine.medscape.com/article/1141438-overview, Updated: Jan 15, 2009.
5. EMG ELEKTRODES, mA NWAL, Disa, Printed in Denmark, December 1976, p. 4.
6. Stalberg E., Ekstedt J. Single fiber EMG and microphysiology of the motor unit in normal and deseased human muscle // New developments in Electromyography and Clinical Neurophysiology / Ed. J.E. Desmedt. — Basel: Karger, 1973. — P. 113-129.
7. Ekstedt J., Stalberg E. Single fibre electromyography for the study of the microphysyology of the human muscle // New developments in electromyography and clinical electrophysiology / Ed. J.E. Desmedt. — Basel: Karger, 1973. — Vol. 1. — P. 89-112.
8. Stalberg E. Macro EMG, a new recording technique // J. Neurol. Neurosurg Psychiatry. — 1980. — 43. — P. 475-82
9. Stalberg E., Antoni L. Electrophysiological cross section of the motor unit // J. Neurol. Neurosurg Psychiatry. — 1980. — 43. — P. 469-74
10. Харибегашвили А.С. Патентная грамота на изобретение № 152 «Игольчатый электрод». — Республика Грузия, приоритет 16.06.93.
11. Ярош А.А. Нервные болезни. — Киев: Вища школа, 1985.
12. Gunnar Grimby, Erik Stalberg. Muscle Function, Muscle Structure, and Electrophysiology in a Dynamic Perspective in Late Polio. Reprinted from Post-polio syndrome / Ed. by Halstead & Grimby. — Philadelphia: Hanley & Belfus, Inc., 1995. — Chapter 2. — P. 15-24
13. Sanders DB, Kouyoumdjian JA, Stålberg EV Single fiber electromyography and measuring jitter with concentric needle electrodes, MUSCLE &NERVE, Volume 66, Issue 2, August 2022Pages 118-130
14. Sanders B., Cui L., Ertas M., Farrugia M. E., Gilchrist J., Kouyoumdjian J. A., Padua L., Pitt M., Stalberg E. Guidelines for single fiber EMG, Clinical Neurophysiology, Volume 130, Isuue 8, August 2019, Pages 1417-1439
15. Guan Y, Ding Q, Liu M, Niu J, Cui L. Single-fiber EMG with concentric electrodes in lambert-eaton myasthenia. Muscle Nerve. 2017 Aug;56(2):253-257. doi: 10.1002/mus.25500. Epub 2017 Apr 12.PMID: 27935068

16. Chiou-Tan F., Gilchrist J. M., Repetitive Nerve Stimulation and Single Fiber EMG in the Evaluation of Patients with Suspected Myasthenia Gravis or Lambert-Eaton Myasthenic Syndrome: Review of Recent Literature Muscle & Nerve 24(3) June 2015 DOI: 10.1002/mus.24745