DYNAMICS OF TISSUE IMPEDANCE BETWEEN ACTIVE ELECTROMYOGRAPHIC ELECTRODES DURING SKELETAL MUSCLE FATIGUE

I. F. Golovko

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Under isometric conditions (standing, active electromyographic skin bielectrodes over the right biceps brachii muscle, with the right elbow flexed to a right angle, a wide strap with a weight placed over the right wrist), after presentation of the weight to the subject a connection was found in 60% of cases between the impedance of the area of tissue between the active electromyographic electrodes (Z_{m-e}) and the physiological state of the test muscle during fatigue. The effect took the form of a temporary decrease in permeability of the skin cells in the tested area (mainly cells of the epidermis) and an associated and intensive cascade-like increase in the initial Z_{m-e} level followed by steady restoration of its initial level after removal of the weight.

Manifestations of the active and passive electrical properties of biological tissues have frequently been investigated. However, the link between the manifestations of these properties has not yet been adequately studied.

In the modern view, during neuromuscular activity (under normal external environmental conditions) the impedance of the investigated area of biological tissue between active skin (electromyographic, for example) electrodes fluctuates only very slightly in time relative to its initial value or decreases. The last effect is explained principally by the moistening and permeation of the stratum corneum of the epidermis electrolytically with the contact substance until electrochemical equilibrium is established between the epidermal cells and the paste [3, 9], by increased activity of the sweat glands [5, 10], and by the development of a psychogalvanic reflex [4, 8].

However, analysis of the material which has nowaccumulated suggests a closer link between the manifestations of the active and passive bioelectrical properties in the area between the active electromyographic (EMG) electrodes, at least during intensive muscular work.

This paper describes the results of investigations into the character of manifestation of passive bioelectrical properties (the impedance level Z_{m-e} of the area of tissue between the active skin EMG electrodes) under the influence of intensive muscular work. Every effort was made to reduce electrode and polarization artefacts due to the apparatus used (polarization "from without") to a minimum. Although the electrical conductivity of the cutaneous tissues has been investigated previously [1, 7], in the experiments now described a number of features meriting special description were discovered.

EXPERIMENTAL METHOD

The experiments were carried out under normal external environmental conditions on 11 apparently healthy men (15 experiments) aged from 18 to 35 years. The test object was the right biceps branchii muscle, above which (and along its fibers) were placed side by side two active-pressure skin EMG bielec-

All-Union Scientific-Research Institute of Surgical Apparatus and Instruments, Ministry of Health of the USSR, Moscow. Laboratory of Instruments for Statistical Analysis of Bioelectrical Processes, All-Union Scientific-Research Institute of the Medical Industry, Ministry of the Medical Industry of the USSR, Moscow. (Presented by Academician of the Academy of Medical Sciences of the USSR S. E. Severin.)
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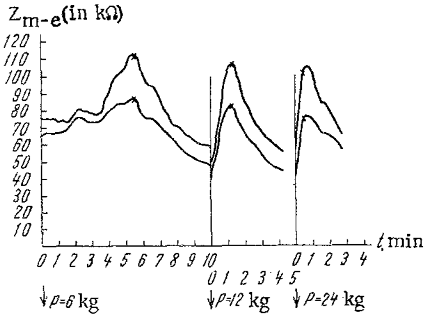

Fig. 1. Dynamics of interelectrode impedance as a function of load. 1) Manifestation of passive bioelectrical properties (Z_{m-e}) in area after preliminary local treatment of the skin until slight erythema developed (see text); 2) the same, in an area after preliminary local treatment of the skin until marked erythema developed. Cross marks time of removal of load — the character of recovery of the initial level of Z_{m-e} can clearly be seen. Intervals (rest) between applications of load 20-30 min. With a load (P) of 24 kg, the increase in Z_{m-e} in both cases is inertial in character.

trodes, made at the All-Union Scientific Research Institute of Surgical Apparatus and Instruments (VNIIKhAI), with silver–silver chloride cups 0.5 cm^2 in area and with a distance of 17 mm between their inner edges. The rubber bases of the bielectrodes were fixed to the test area by means of Kleol glue. Local treatment of the skin consisted of rubbing with gauze soaked in alcohol (until slight erythema of the skin appeared under the right EMG bielectrode and marked erythema of the skin under the left), followed by application of the electrode paste with the end of a glass rod at the site of application of the electrode cups, which also were first partly filled with paste. The difference between the degree of preliminary treatment of the skin under the electrodes enabled the results of measurement of the impedance level to be interpreted objectively. These measures guaranteed electrical contact and maintenance of a steady initial level of Z_{m-e} for at least 10 h, even during strong voluntary movements (changes not exceeding 5% were disregarded in all experiments). Exercises (holding the load) began 30-40 min after the end of application of the electrodes.

By means of a 5-channel system (developed by VNIIKhAI), incorporating a recorder of the active and monitor of the passive bioelectrical properties, the investigations could be carried out with single channel electrode units. Each channel, with an input resistance of the arms of 2 + 2 MΩ in the working frequency band contained principal (10-2000 Hz, level 0.8) and accessory (65-2000 Hz, level 0.8) circuits. Two such channels were used, and with the accessory circuits the EMG was recorded in two bipolar leads, while the corresponding levels of Z_{m-e} were evaluated by the principal circuits functioning in parallel. The Z_{m-e} level was established by recording the amplitude of the decrease in voltage supplied by the external physical generator of the monitoring stimulus (a sinusoidal frequency of 20 Hz) on the interelectrode area tested, which is proportional to it; the strength of the current passed through the tissue was preassigned at an extremly small level and was constant during the experiment (of the order of 10-50 nA).

The four electrographic recordings were made by means of an N-700 loop oscillograph.

Each subject held a load of different weight under isometric conditions with intervals of 20-30 min (standing, with the right elbow flexed to 90°, a wide strap with the weight held over the right wrist, weight of the load 6, 12, and 24 kg). The EMG was recorded and Z_{m-e} measured continuously throughout the period that the subject held the weight and for 3 min after its removal.

EXPERIMENTAL RESULTS

During static contraction of the test muscle until the subject could continue no longer, a characteristic response to the change in the physiological state of the muscle (during its fatigue) appeared in 60% of cases a short time (measured in minutes and depending on the magnitude of the load) after application of the load. A marked and cascade-like increase in the initial level of Z_{m-e} was observed. Measurements of the Z_{m-e} level during one experiment are illustrated in Fig. 1. (The absolute values of Z_{m-e} in this figure are shown as the corresponding impedance, a conventional equivalent in the nature of active resistance; high values of the Z_{m-e} level are due to the increase in its value which accompanies a decrease in strength of the measuring stimulus [2, 3] and also to topographical differences in impedance [5, 6].)

Analysis of the results shows that this phenomenon has the following features.

The intensity of increase in the initial level of Z_{m-e} is directly dependent on the intensity of the muscular contraction (on the load applied), which also determines the level of bioelectrical activity in the area tested.

The cascade-like increase in the initial level of Z_{m-e} can begin as early as the 5th minute. In some experiments this increase was stepwise in character. The increase in value of the Z_{m-e} level could also continue for some time after removal of the load (the time of removal of the load is marked by a cross in Fig. 1).

In experiments in which the initial level of Z_{m-e} was increased, it fell more or less steadily (recovery) after removal of the load until it reached its initial value (after 3-6 min) or sometimes fell below it. This directly indicates the biological nature of this phenomenon. In some experiments, when no increase in the initial level of Z_{m-e} was observed, and it sometimes actually fell under the load, a further and more rapid decrease in the level of Z_{m-e} (by 20-30%) also was recorded after removal of the load.

Investigations using a measuring stimulus with a frequency within the range 20-1000 Hz not only confirmed the capacitance character of Z_{m-e}, but also gave quantitatively analogous results. The value of the increase in Z_{m-e} was shown to be dependent on the intensity of the preliminary local treatment of the skin. After excessive treatment of the skin ($Z_{m-e} \leq 1$-3 kΩ), no changes in Z_{m-e} were recorded during application of the load. These facts show that the phenomenon described is due to components of the epidermis of the skin. Control tests on other groups of muscles (gastrocnemius, quadriceps femoris, rectus et obliquus abdominis, latissimus dorsi, flexor and extensor of the forearm, deltoid, and trapezius muscles) also yielded qualitatively similar results, so that the phenomenon observed is evidently universal in character.

These investigations thus revealed well-marked changes in the level of the passive bioelectrical properties in areas of recording of the interference EMG during changes in the physiological state of the fatigued muscle under natural conditions. The changes in the initial level of Z_{m-e} thus revealed show the need for further study of this phenomenon in order to shed light on its biological significance and its informative value.

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