Ann. Bull. RILP (1983) No. 17, 13-22

ELECTRICAL CHARACTERISTICS AND PREPARATION TECHNIQUE OF HOOKED-WIRE ELECTRODES FOR EMG RECORDING

Kiyoshi Honda, Hajime Miyata and Shigeru Kiritani

1. Introduction

Bipolar hooked-wire electrodes have been commonly used for recording EMG signals from articulatory and phonatory muscles. These electrodes consist of a pair of thin wires with insulation coating, and the electrode is prepared by cutting the wire using a cutter blade or a pair of scissors and attaching a pair of wires together to form a bipolar electrode. The wires are inserted into a hypodermic needle and each end of the wire is bent to make a hook. The electrode is inserted into a muscle with the needle, and its end remains in the muscle by means of the hook after retracting the needle. In speech research, this type of electrode is most commonly used for recording isolated EMG signals from small and/or deep muscles, since it is flexible and follows the dynamic movements of the articulatory organs with minimum interference.

While this type of electrode is easily assembled with simple devices, several problems due to the configuration of the electrode have been noted as summarized below

(1) Variation in electrical impedance due to the shape of electrode surface (the cut end of the wire).
(2) Unpredicted change in the inter-electrode distance when inserted into a muscle.
(3) Damage to insulation at the angle of the hook in the process of preparation and insertion.
(4) Insufficient magnitude of the signal detection area for recording the interference pattern of the EMG.

A few modifications have been made to minimize the problems (1)-(3). Niimi, et al. (1979) made electrodes by cutting the wire on a glass plate by a razor blade, bending the wire at the edge of a piece of paper, and fixing the two wires together with glue. Hiki, et al. (1979) used a pair of small medical scissors to cut the wire, and made a triple-wire electrode by glueing two straight electrode wires to a dummy hooked wire. Both types of electrodes use the cut surface of the wire for the electrode-tissue interface, and the impedance value of these electrodes is considerably high. For problem (4), a larger electrode area is required, since the size of the electrode determines the detecting field of the EMG signal. Although the optimal size of an electrode surface varies with the purpose of the EMG recording (e.g. recording of single motor units vs. interference patterns), electrode with an increased electrode surface area, such as Basmajian's type (1973), should be preferable for recording the interference pattern of EMG signals.

We have tested a few processes to increase the electrode area with a consistent reproducibility and to stabilize the electrode characteristics by an electrolytic treatment. This report presents some preliminary results from impedance measurements for a few types of electrodes prepared by different methods, and introduces the preparation technique for the new type of electrode.

2. Some Procedures Influencing an Electrode's Property

The impedance of a metal electrode (Ze) is generally determined by the capacitance due to the electric double layer formed by the electrode and the electrolyte, and by the electrical resistance of the electrode-tissue interface. Because of these RC components, the electrode impedance decreases with frequency. De Boer (1978) notes that the impedance function of a metal electrode is simply shown by

$$Ze = K / (iw)^m$$

$$|Ze| = K / w^m$$

where $w = 2\pi f$ (f is the signal frequency.), and $i = \sqrt{-1}$. K is a constant which correlates inversely with the area of the electrode surface, and m is known to vary from 0.5 to 1.0. This equation indicates that a linear relationship is observed between $\log|Ze|$ and $\log f$, and that the electrode impedance is smaller when the electrode surface is larger.

The electrode impedance may not affect the gain of the EMG signal as long as it is negligibly small compared to the input impedance of the preamplifier. However, this type of electrode tends to have an undesirably high impedance which can cause a loss of the gain. The influence of the electrode impedance on the gain (G) is shown by the following equation

$$G = 20 \log \frac{Zi}{Ze + Zi}$$

where Zi is the input impedance of a preamplifier. For instance, Zi of our current system is 150 kΩ and Ze of an electrode is about 100 kΩ. The calculated loss of the gain is about 4.5 dB, indicating that the electrode impedance is significantly high. A smaller impedance for the electrode could effectively reduce the gain loss and the effect of the electrode-to-electrode variation as well.

2.1 Effect of the electrolytic treatment

The impedance of a metal electrode can be reduced by electrolytic treatment. A DC current passed through a metal electrode placed in an electrolyte solution induces an electro-chemical reaction between the electrode and the solution, effectively reducing the impedance to its minimum level (Kanai, 1966). This impedance change is reversible when a very low voltage is applied, but, a high voltage load can cause an irreversible impedance reduction.

A preliminary experiment was performed to examine the effect of the electrolytic treatment. A 6V DC was passed through a pair of electrodes for 10 sec, and the subsequent change in the electrode impedance measured at 1 kHz was recorded for 30 min. This procedure was repeated 4 times, and the final trial used the treatment for 60 sec. Figure 1 shows the data for this procedure. The impedance increased rapidly for 10 min after the treatment, and subsequent gradual changes were observed. Repetitive treatments produced a substantial reduction in the impedance.

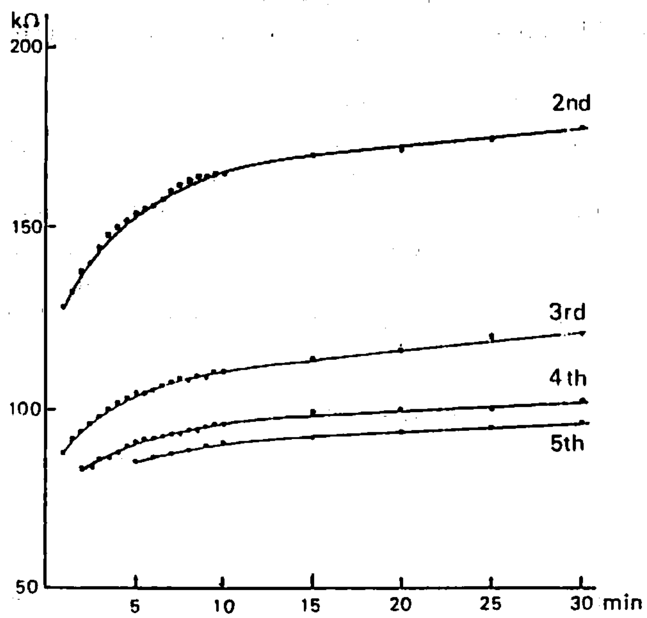

Fig. 1 *Effect of the electrolytic treatment on impedance reduction.*

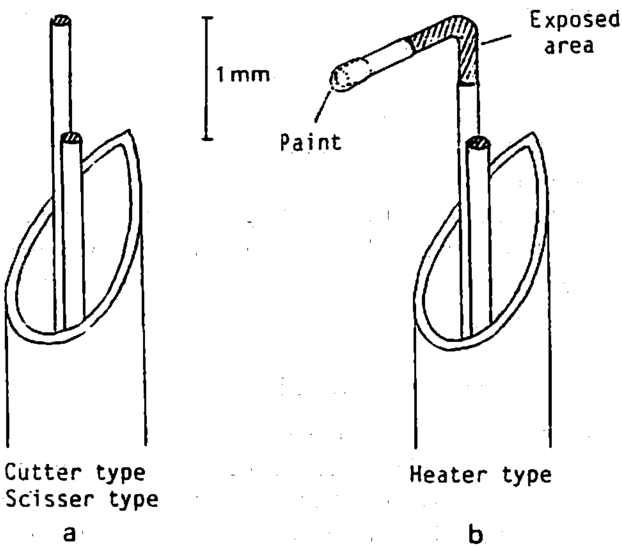

Fig. 2 *Configurations of the tested electrodes.*

An electrolytic treatment for 40 sec in total reduced the impedance value to a nearly minimal level. This result reveals that a stabilized low value of the electrode impedance is obtained by applying the electrolytic treatment for a sufficient duration.

2.2 Initial drift of the electrode potential

A metal electrode in an electrolyte solution derives an electro-chemical equilibrium, in which a stable potential difference is formed between the electrode and the electrolyte. Before this equilibrium is reached, the electrode potential shows the initial drift, and irregular pulse noises are often recorded. The initial drift for a Pt-Ir electrode has been measured to last about 1 hr (Matsuo, et al. 1970). Therefore, it is preferable for the electrode to be kept in a saline solution prior to insertion.

3. Impedance Measurement of Types of Electrodes

We have devised a method for increasing the electrode surface by removing the wire insulation with a nichrome heater. In order to examine the electrical property of the electrode made by this method, the impedance value and its variation were measured and compared with other types of electrode which were prepared using a cutter blade and a pair of scissors. The impedance measurement for each electrode was conducted before and after the electrolytic treatment to evaluate the effect of this treatment.

3.1 Electrodes tested for impedance measurement

Figure 2 gives the schematic configuration of the tested electrodes, which were made by three different methods with respect to the preparation of the electrode surface. In all these types, the wires were fixed in a needle shaft using a cianoacrylic resin. Figure 2(a) indicates the electrode assembly for the type which uses the cross-sectional area as the electrode surface. The wire was cut by pressing a cutter blade at a constant angle (cutter type), or by using a pair of precision scissors (scissor type). The inter-electrode distance was kept at 1 mm. Figure 2(b) shows the type which is treated by a heater (heater type). This type has a hook at the end of one of the wires, and the insulation coating is thermally removed for 1 mm at the angle of the hook. It is prepared by hanging the electrode assembly on a nichrome string heater connected to a power supply (for details, see 5.1). The cut end of the hook is insulated by paint.

3.2 Method for measuring the electrode impedance

Each electrode was placed in a glass container filled with a saline solution. Before the measurement, the electrode was kept in the solution for 1 hr to minimize the effect of the initial drift of the electrode potential. Ten electrodes for each type were measured before the electrolytic treatment and 10 min after the electrolytic treatment. Figure 3 shows a block diagram of the impedance measurement system. The measuring signal of a constant current AC (0.1 μA) was loaded across both electrode wires, and the voltage difference across the electrode was read. All the measurements were taken at the 5 different frequencies of 100 Hz, 300 Hz, 1 kHz, 3 kHz and 10 kHz.

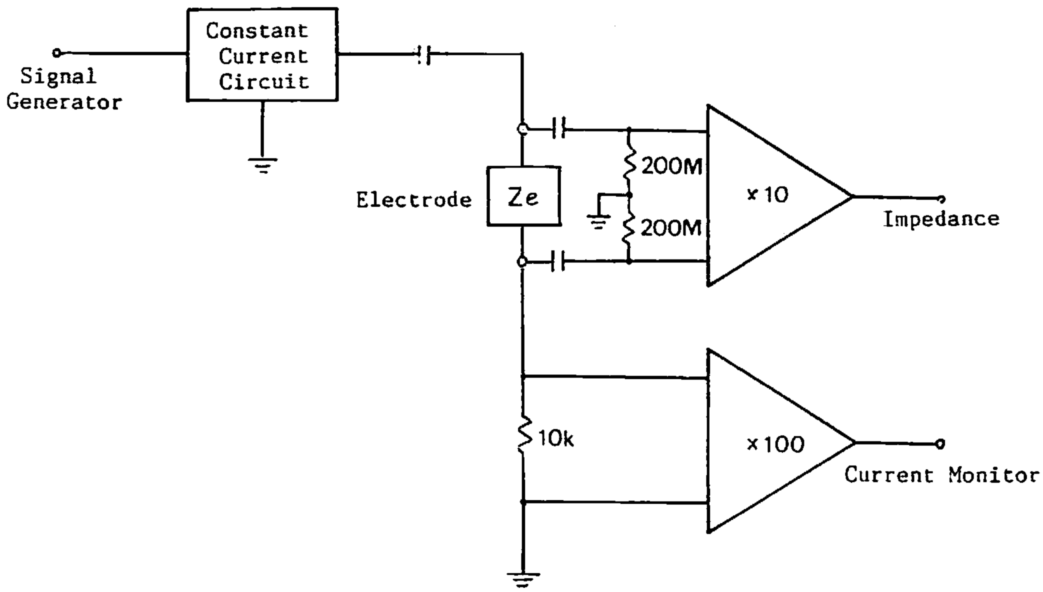

Fig. 3 *The block diagram of the circuit for impedance measurement.*

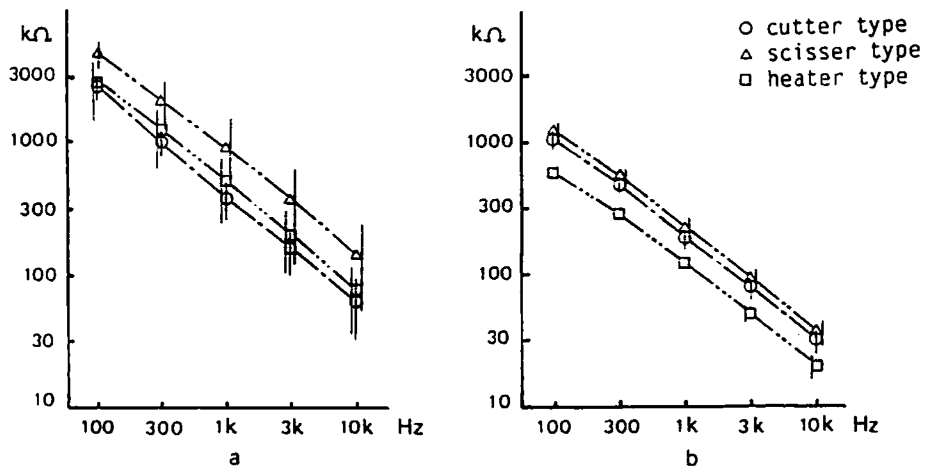

Fig. 4 *Impedance value and its variation.*

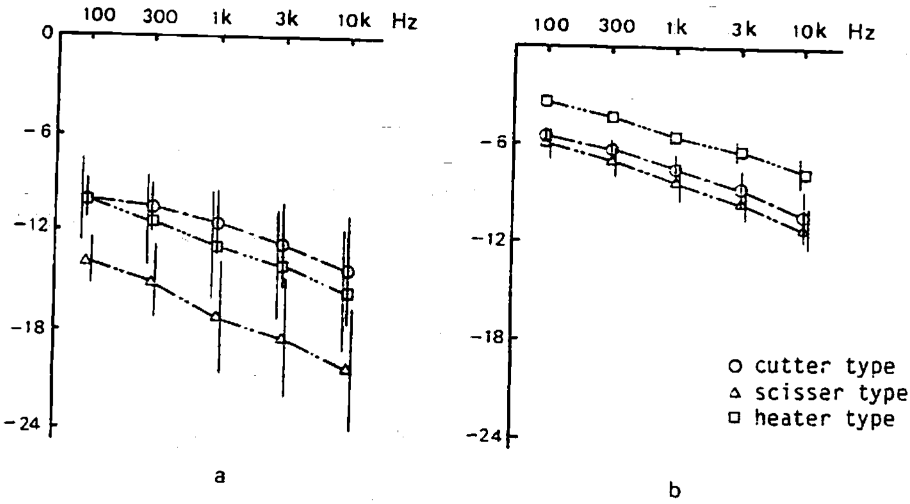

Fig. 5 *Influence of the impedance variation on the gain.*

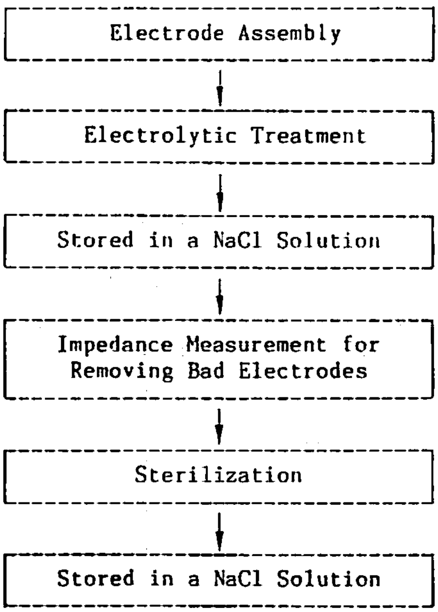

Fig. 6 *Steps for the electrode preparation.*

3.3 Results

3.3.1 Impedance values and their variation

Figure 4 shows the results of the impedance measurement plotted as a function of frequency. The calculated means and standard deviations of the measured impedance before and after the electrolytic treatment are shown in Figure 4(a) and 4(b), respectively. Thus, the electrode impedance decreases monotonously with the frequency, suggesting that the electrode impedance is capacitive. The effect of the impedance reduction by the electrolytic treatment is obvious. The impedance is reduced to 1/2 to 1/4 of the initial value, and its variation is also remarkably reduced. Figure 4(b) indicates that widening of the electrode surface can effectively lower the electrode impedance. Electrodes of the heater type have the lowest means, as expected. The standard deviations for this type are also the lowest. The removal of the insulation coating was performed only for one side of the pair of electrodes. Therefore, a smaller impedance is further expected when the both sides were treated similarly. For the other types, slightly lower means are obtained for the cutter type. However, the steepness of the distribution is larger for the scissor type than for the cutter type, indicating that the scissor type may be suitable for selecting electrodes with a nearly equal impedance.

3.3.1 Effect of the impedance variation on the gain

Using the result of the impedance measurement, the effect of the impedance variation on the gain for our recording system was calculated. The current system uses HP8811A (by Hewlett-Packerd, input impedance: 10 MΩ at DC; input capacitance: 820 pF) for the EMG anplifier, with 3.3 m RF cables (RG-58A/V, capacitance: 100 pF/m) connecting the electrode and the amplifier. With these values as a reference, the system gain was calculated. Figures 5(a) and (b) show the means and standard deviations of the gain obtained for the electrodes before and after the electrolytic treatment, respectively. The data indicate that the electrolytic treatment increase the gain about 4 dB to 9 dB and reduces its variation. In addition, Fig. 5(a) indicates that before the electritic treatment the effect of the impedance variation may result in a gain of up to 12 dB.

4. Preparation Technique of the New Electrode

This section discusses the hooked-wire electrodes which are used in our laboratory and our actural preparation techniques. Using the results of the above study as an reference, a protocol for preparing the electrodes has been developed as summarized in Fig. 6. The assembling technique is described in detail below.

4.1 Removing of the insulation coating

The material for the electrode is a .002" platinum-tungsten alloy wire with polyester coating (P-91 Isonel, made by Consolidated Refining Metal, Inc., Mamaroneck, N.Y., U.S.A.). The metal surface is easily exposed by removing the coating of the wire by heat or flame. In order to obtain a consistent length of exposure along the wire, we used a nichrome string heater. The set-up for the procedure is shown in Fig. 7.

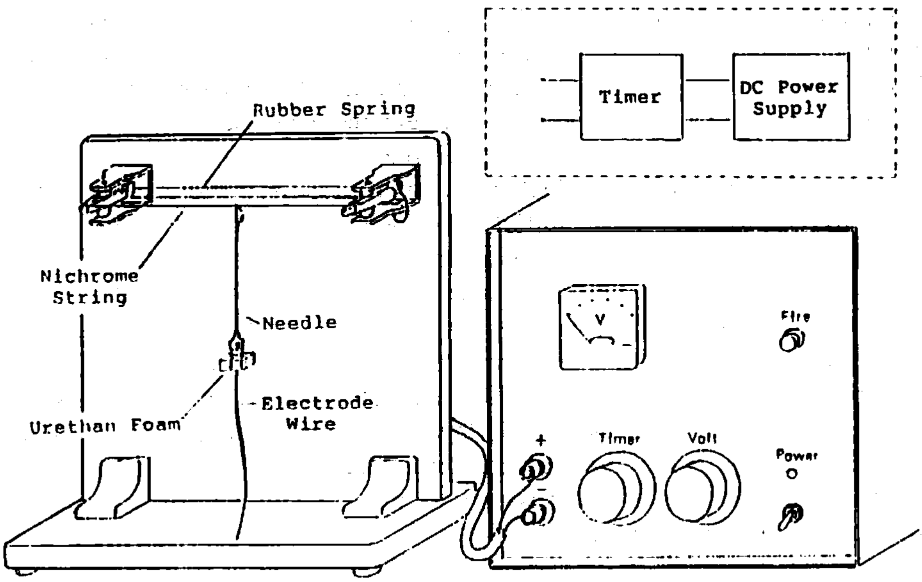

Fig. 7 *Method for removing insulation coating.*

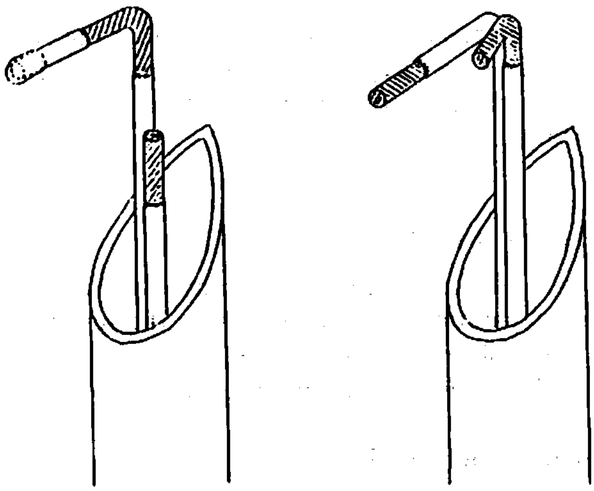

Fig. 8 *Two type of new electrodes.*

A pair of electrode wires are first inserted into a stainless steel hypodermic needle, and the end of both wires is bent to make a hook. The wire is clipped to a piece of urethane foam at the other side of the needle, and this assembly is hung on the heater. The wire heater consists of a string of nichrome wire and a pair of spring holders. The nichrome string (15 cm in length and 0.1 mm in diameter) is positioned horizontally, and both ends are connected to the spring-assisted arms to avoid a laxation of the nichrome string on heating. The power unit supplies a regulated DC current to the heater. The current system uses a 35V DC, 0.5 sec pulse, which was determined experimentally in order to obtain 1 mm of exposed length with a minimal area of half-burned borders.

4.2 Assembly of the wire electrode

Two types of electrodes (Type-I, Type-II) have been used as shown in Fig. 8. Type-I, the original type, is a single-hook electrode, which was designed to maintain a constant inter-electrode distance and to prevent short circuiting between two wires. Type-II is a double-hook electrode which was modified to simplify the assembly process.

The Type-I electrode consists of a hooked and a straight wire. For the hooked wire, the hook is trimmed to an appropriate length (2.0–3.0 mm), and the cut end is insulated with paint. The straight wire is made by stretching the hook and cutting the insulated portion. These two wires are placed on a sheet of section paper and carefully glued together with cyanoacrylic glue. The wires are fixed to make the inter-electrode distance about 1 mm from edge to edge of insulation.

The Type-II electrode has two hooked wires with different hook lengths. The short-hook wire is prepared by cutting the insulated part of the hook. The other wire is straightened and cut at the hook, leaving an exposed part. Then the wire is re-bent to make a new hook about 2.5 mm to 3.0 mm long. These two are hung on a loop of thin metal wire and stretched together for gluing. The wires are fixed together in the same way. The inter-electrode distance is similarly about 1 mm.

4.3 Notes on the two types of electrode

With respect to the consistency of the electrode configuration, Type-I seems to be reliable, since the inter-electrode distance is not likely to change in the muscle as long as the wires are glued together near the exposed portion. While the assembly of this electrode needs some skill, the Type-II electrode is easy to make because of the two hooks. However, the insulation at the angle of the long side hook is liable to be damaged by mechanical scratching.

One possible problem regarding the thermal removal of the insulation is a deterioration in the strength of the wire due to heating, which has not been tested. The breakage of the wire at the deinsulated angle has been experienced during preparation of the electrodes. A further investigation should be needed regarding this problem.

5. Summary

Hooked-wire electrodes have been used for recording EMG signals from the arti-

culatory organs. This type of electrode has certain problems due to the small electrode surface and its variability from electrode to electrode. For the desired recording of the interference pattern of EMG signals, we tested several methods to increase the electrode surface and stabilize the electrical property. An electrolytic treatment passing a DC current through a pair of electrodes in a saline solution had a consistent effect of reducing the electrode impedance and its electrode-to-electrode variation. By removing the insulation coating to increase the electrode surface, lower impedance values and variation were obtained. This procedure seems to be useful for recording EMG signals from a larger number of neuromotor units, since the effective field for the signal detection increases with the area of the electrode surface. It was reconfirmed that the electrode's properties became stable by soaking the electrode in a saline solution. These results have been applied to establish a preparation technique of the new electrode that is currently used in our laboratory.

6. Acknowledgement

This study was performed in cooperation with Prof. Kiyoshi Hashimoto, the University of Electro-Communications. The experimental results presented in this report are based on the graduation thesis by Hajime Miyata, the University of Electro-Communications, Tokyo. The original version of this paper is already published (Miyata, et al., 1979).

References

Basmajian, J.V. (1973): Electrodes and Electrode Connectors. New Developments in Electromyography and Clinical Neulophysiology, S. Karger, 1, 502-509.

De Boer, R.W. and A. Von Oosterom (1978): Electrical properties of platinum electrodes. impedance measurements and time-domain analysis. Med. & Biol. Eng. & Compt., 16, 1-10.

De Luca, C.J. and W.J. Forrest (1972); An electrode for recording single motor unit activity during strong muscle contractions. IEEE Trans. Bio-Med. Eng., Vol. 19, No. 5, 367-372.

Hiki, S. and S. Imaizumi (1979): A system for observing and processing electromyogram by pulse density detection. Ansactions of Committee on Speech Research. Acoust. Sc. Japan, S78-76.

Niimi, S., S. Kiritani, H. Hirose, N. Takahashi, K. Yana and K. Shirai (1979): Some basic studies on recording and processing techniques in EMG data assessment. Annual Bulletin of RILP, 13, 27-41.

Kanai, H. (1966); Polarization impedance of metal electrodes. Japanese Journal of Medical Electronics and Biological Engineering, Vol 4. No. 1, 34–44.

Matsuo, M. and T. Tagashira (1970); Electrical properties of biomedical metal electrodes. Japanese Journal of Medical Electronics and Biological Engineering, Vol. 8, No. 2, 150-159.