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Characteristics of Skin-Electrode Impedance for a Novel Screw Electrode

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Abstract

Our group has developed a novel dry electrode, the skin screw electrode, for EEG measurement. This electrode can be conveniently and rapidly installed on the human scalp requiring no electrolyte application and skin preparation. In this paper, we further evaluate the performance of this electrode by investigating its frequency-dependent electrical impedance at the skin-electrode interface. Comparing with the traditional disc electrode, we found that the two types of electrodes showed very different spectral properties. We also found that the impedance of the screw electrode decreases after coating with gold.

Keywords

dry electrode; electrical impedance; EEG

I. Introduction

Since an EEG system that allows fast installation of electrodes is highly desirable in both clinical practice and research studies, the development of dry electrodes has attracted increasing attention [1-9]. Compared to the traditional wet electrodes, the major advantage of dry electrodes is that they do not require the use of electrolyte. However, existing dry electrodes have a common disadvantage of high skin-electrode impedance (e.g., [8, 10]). It is believed that the electrical impedance at the skin-electrode interface affects the quality of EEG signal. In most cases, a specific amplifier characterized with extremely high input impedance is required for dry electrodes. Therefore, the design of a dry electrode with a low skin-contact impedance benefits EEG performance and is cost-effective.

Since the top layer of skin attributes the most to the skin-electrode impedance, our group has developed a novel dry electrode that can penetrate this layer with microteeth along the bottom rim (Fig. 1(a)). We call it skin screw electrode. When the electrode is pressed and twisted, these teeth can penetrate the top layer and hook on the scalp. Neither electrolyte nor skin preparation is required for its installation. Thus this electrode can be applied to or

removed from the scalp very quickly. The metal used to make our current electrode is stainless steel (Grade 316L), which has very good mechanical property. A protocol to manufacture the electrodes at low cost has been developed using photolithography technique [11]. Based on our preliminary experiment using a clinical EEG electrode impedance meter, it has been found that the impedance at the measurement frequency of 30Hz is still high for the raw screw electrode, usually tens of kilo-ohms. Therefore, we utilized a sputtering machine to coat gold on the electrode to reduce the skin-electrode impedance.

II. Impedance Measurement

The impedance spectroscopy is a useful measurement of the skin-electrode interface. In our study, the impedance spectroscopy was assessed at two scalp locations (no hair site F4, hair site C4). Three electrodes, including raw screw electrode, gold-coated screw electrode, and conventional disc electrode (Fig. 1) were placed at each location. A disc electrode on the forehead was used as the counter electrode. Standard skin preparation using the Nuprep abrasive gel and Ten20 conductive paste was utilized when installing the disc electrodes, but no skin preparation was conducted for the screw electrodes. The screw electrodes were installed approximately 2-3cm away from the disc electrode to avoid contacting the prepared skin.

The impedance between each test electrode and the counter electrode was measured using the potentiostatic EIS mode of the Gamry instrument. The impedance data were collected in the frequency range between 1 and 10,000 Hz at 5 mV RMS. To study the long-term effect of these electrodes, this impedance test was conducted four times: right after the installation, and then every hour for three hours. Between two tests, the subject was allowed to walk around, talk or read.

III. Experiment Result

Following the abovementioned protocol, two human subjects were tested under an approval of Institutional Review Board (IRB) at the University of Pittsburgh. The aim of this test is to investigate the property of electrical impedance of the screw electrode and compare it with the conventional disc electrode.

Our measurement data showed similar characteristics in the two subjects. Figure 2 shows typical frequency-dependent impedance measurements at sites F4 and C4 for one subject. The impedance of the raw screw electrode is high at very low frequencies, but drops quickly when the frequency increases. On the contrary, the impedance of the disc electrode is relatively constant, with a slow decrease in high frequency region. The coated screw electrode exhibits a similar impedance profile to the raw screw electrode, but with a much lower impedance. Typically its impedance is lower than $10K\Omega$ at 30Hz, as shown both in this experiment and our previous experiments [11].

The impedance changes of these electrodes within three hours after their installation are plotted in Fig. 3. Since no electrolyte was applied for any of the screw electrode, their

impedances were very stable during this period. On the other hand, the impedance of the disc electrode increased because of the drying of the electrolyte paste.

IV. Discussion

The electrical impedance of our newly-developed skin screw electrode has been evaluated. We found that this impedance was quite different from that of the disc electrode, but very similar to that the stainless steel needle electrodes, although the impedance of needle electrode was measured in saline at room temperature [12]. From this similarity, we thought that the high impedance of screw electrode at low frequencies may also come from the effect of the electrode polarization impedance (EPI) [12] because of the small tissue contact area. Since the EPI is also determined by other factors, e.g., type of material, surface roughness, geometry, and surface treatment, the screw electrodes with different teeth size and coating could reveal more insights into the observed electrical impedance property.

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Figure 1.
(a) Skin screw electrode and (b) the experimental setup.

Fig 2.
Frequency-dependent impedance measurements of three kinds of electrodes at no hair site F4(a, c) and hair cite C4(b, d).

Figure 3.

Impedance changes during three hours at site C4 for raw screw electrode (a), coated screw electrode (b), disc electrode (c).