

DRY ELECTRODES FOR ELECTROENCEPHALOGRAPHY: NOVEL TITANIUM BASED ELECTRODES

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Abstract: New areas of application for electroencephalography are in brain-computer interfaces, where disabled people might be able to interact with their environment based on measured brain signals. However, conventional electroencephalography is not suitable here. Thus, our aim is to develop novel dry electrodes for home use. We developed various novel EEG electrodes with titanium and polyurethane as base materials and nanometer sized coatings of titanium-nitride. We present results of the comparison of these electrodes with gold and silver/silver-chloride electrodes. In conclusion, our novel electrodes show equivalent signal quality compared to conventional electrodes and are suitable for home use.

Keywords: Electroencephalography, Biomedical Electrode, Electric Potential, EEG Cap.

1. INTRODUCTION

Electroencephalography (EEG) is a technique mainly used in the neurosciences for detecting potential changes at the surface of the head, caused by electric activity inside the brain. The state of the art is characterized by the placement of 21 to 256 wet (gelled) silver/silver-chloride (Ag/AgCl) electrodes on the scalp, typically with the help of an EEG cap. The preparation procedure is lengthy (up to one hour) and requires well trained staff (typically medical technical assistants), and wear time is limited by the stability of the electrolytes (gels) [1], [2]. New application areas of EEG are in the field of brain-computer interfaces (BCI) or ambient assisted living (AAL). BCIs might enable handicapped persons to interact with their environment based on

measured brain signals [3], [4]. For such applications, EEG systems are needed, which can be used by non-experts and where preparation times are in the order of seconds. Recently, first EEG systems based on dry electrodes for BCIs were developed, which, however, included only a very low number of channels [5], [6].

Our general aim is to develop a novel EEG system for home use with a high number of channels based on dry electrodes. In this conference abstract we present measurement results from the comparison of several types of newly developed electrodes.

2. METHODS

The basic design principle for dry contact electrodes follows the criteria of sufficient hair layer penetration, biocompatibility, electrochemical stability, long term applicability, as well as ease and speed of use. Based on these criteria three main types of electrodes were designed: (i) titanium pin electrodes, (ii) polyurethane pin electrodes, and (iii) gold pin electrodes. Figure 1 shows the three types of electrodes. The titanium pin electrodes and polyurethane pin electrodes were coated with titanium nitride, which provides high electrochemical and long term stability [7].

Table 1 details the parameters of the electrodes depicted in Figure 1. Note the different contact areas in row 3 of Table 1.

Electrode impedance characterization was performed with a Hewlett Packard 4192A LF impedance analyzer (Hewlett Packard Company, Palo Alto, USA) applying a standard four-point measurement setup in 0.9% NaCl solution. Open circuit potentials were measured in a 0.9%

NaCl solution with an Agilent 34401A multimeter (Agilent Technologies, Santa Clara, USA), where an Ag/AgCl electrode served as reference.

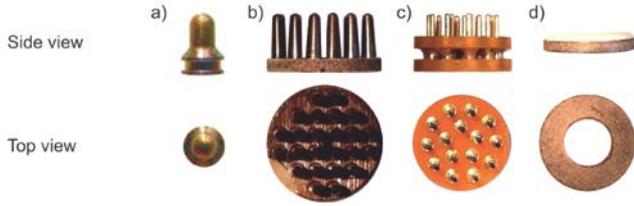


Figure 1: (a) Titanium pin electrode, (b) polyurethane pin electrode, (c) gold pin electrode, and (d) conventional Ag/AgCl ring electrode. The pin shape allows for hair layer penetration and causes a small indentation in the human scalp, which leads to an increased contact surface as well as reduced relative movements.

Table 1: Electrode parameters

	Ti/TiN	PU/TiN	Gold pin	Ag/AgCl
Pin diameter	1.5 mm	1.5 mm	0.5 mm	n.a.
Pin number	1	24	15	n.a.
approx. contact	3.5 mm ²	85 mm ²	6 mm ²	42.5 mm ²
approx. weight	0.05 g	0.73 g	2.21 g	0.61 g

For EEG measurements, the patient ground electrodes were placed at the AFz position. The sampling rate was 512 samples/s. For all EEG tests the room temperature was 22 °C and the relative air humidity was 35%. In a healthy volunteer, we recorded three types of EEG activity: resting state, alpha activity, and visual evoked potentials (VEP). All measurements were performed with a set of Ag/AgCl electrodes placed adjacent to the pin electrodes. For the Ag/AgCl electrodes reference measurement, two sets of Ag/AgCl electrodes were placed adjacent to each other (last column in Table 2). Between the two sets, the root mean square deviation (RMSD) of 30 s of data (1024 samples/s) and the correlation coefficients were computed, indicating magnitude and mapping differences. All signals were recorded using ASA software (ANT BV, Enschede, The Netherlands) and analysis was performed using MATLAB (The Mathworks Inc., Natick, USA). Data recorded using two sets of conventional Ag/AgCl ring-shaped electrodes (ANT B.V., Enschede, The Netherlands) served as reference.

3. RESULTS

Figure 2 shows the electrochemical impedance spectra of all four types of electrodes. The Ag/AgCl electrodes exhibited the lowest absolute values of the impedances, followed by the gold pin electrodes, the titanium pin electrodes, and the polyurethane electrodes. For the gold pin

and the titanium pin electrodes, significant capacitive behaviour was observed (high impedances at low frequencies, lower impedances at higher frequencies).

For the phase responses, all electrodes showed a decreasing phase shift with increasing frequency, where the Ag/AgCl electrodes had the lowest total phase shift at low frequencies, followed by the polyurethane pin electrodes, the gold pin and the titanium pin electrodes. However, due to measurement equipment restrictions, the polyurethane pin electrodes were not measured over the entire frequency range, which makes the values not comparable for the very low frequencies.

The mean open circuit potential (Figure 3) for the Ag/AgCl electrodes was 221.8 mV and the most stable in terms of mean STD (2.1 mV). For the gold pin electrodes a mean value of 610.8 mV and a mean STD of 439.4 mV, for the titanium pin electrodes a mean of 360.3 mV and a mean STD of 63.3 mV, and for the polyurethane pin electrodes a mean of 422.2 mV and a mean STD of 56.7 mV were measured.

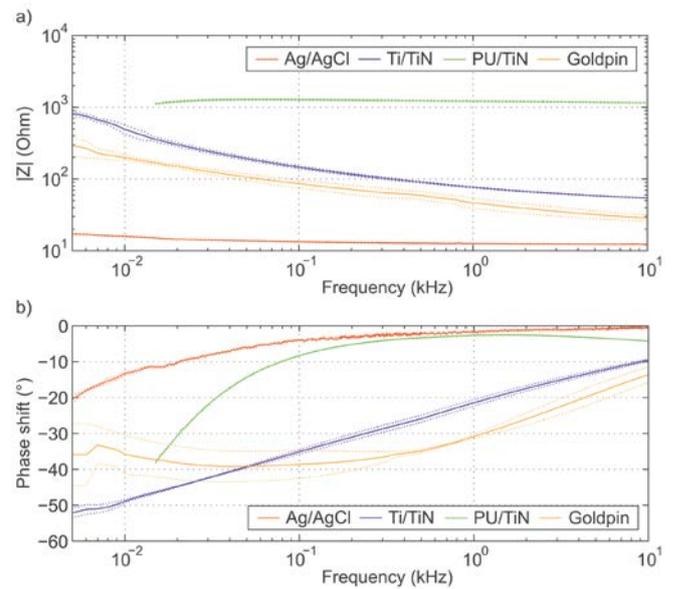


Figure 2: Impedance spectra of the four types of electrodes: (a) absolute value and (b) phase of the impedance. Solid and dotted lines represent mean and STD of 10 measurements respectively.

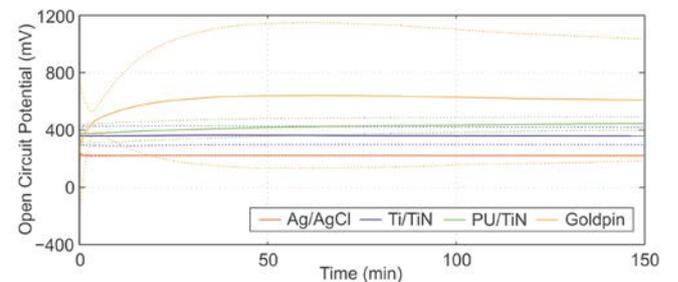


Figure 3: Open circuit potentials of the four types of electrodes recorded over 150 minutes after immersion into 0.9% NaCl solution. Solid and dotted lines represent mean and STD of 5 measurements, respectively.

The results of the EEG measurements are presented in Table 2. The RMSD between the different electrodes for the various signal types showed similar values for all tested electrodes, except for the gold pin electrodes at the VEP measurement.

As expected the correlation is highest for the VEP, followed by the alpha activity. The lowest correlation is found for the resting state EEG.

Table 2: Mean RMSD and Correlation of the EEG data

EEG test	Ti/TiN	PU/TiN	Gold pin	Ag/AgCl	
RMSD (μ V)	Resting EEG	6.9 ± 3.4	5.3 ± 0.6	6.1 ± 2.0	4.6 ± 2.1
	Alpha Activity	4.2 ± 1.8	4.4 ± 0.2	3.6 ± 0.6	3.9 ± 2.0
	VEP	0.6 ± 0.7	0.7 ± 0.3	1.9 ± 0.5	0.7 ± 0.4
Correlation (%)	Resting EEG	24 ± 19	59 ± 22	25 ± 13	58 ± 17
	Alpha Activity	76 ± 9	73 ± 9	72 ± 10	85 ± 2
	VEP	92 ± 10	95 ± 4	74 ± 22	94 ± 2

4. DISCUSSION

Our main result consists in the fact that with the dry electrodes standard EEG recordings were possible. The signal traces and spectra (not shown) were highly similar compared to the ones of the simultaneously recorded Ag/AgCl electrodes. The multichannel arrangements of dry electrodes will allow for brain source reconstruction procedures in current [8] and new areas of application [3], [4].

The differences in the RMSD in Table 2 were found to be similar for the different electrode types. This indicates that the main contribution to the RMSD stems from the spatial distance between the two sets of electrodes. Exceptions are the VEP measurements with the gold pin electrodes. Both the RMSD and the correlations show deviating values. This can be explained by the difficulty in placing these electrodes at the back of the head, where a stronger curvature makes it more difficult to get in good contact with the skin (compare also the length of the pins in Figure 1). At the same time, this region shows the most prominent mapping features in VEP.

The correlation values are also small for the resting state EEG (row four in Table 2). This can be explained by the fact that resting state EEG is highly variable and the spatial distances between the test and reference electrodes was too high to provide an adequate spatial sampling [9].

There are a number of differences for the dry electrode types. The price is lowest for the gold pin electrodes and highest for the titanium pin electrodes. More crucial for multichannel EEG applications, where up to 256 electrodes are applied, is the weight of the electrodes. Here, the gold

pin electrodes exhibit the highest weight, followed by the titanium pin electrodes (when taking 24 pins per electrode into account). The polyurethane electrodes are light weight with about 100 g for 256 electrodes. Furthermore, the mechanical flexibility of the substrate contributes to increased patient comfort while also maintaining contact reliability. This renders the polyurethane electrodes very suitable for the application in measurements with longer duration in time, like in BCI applications.

5. REFERENCES

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