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Assessing Novel, User Friendly, Dry EEG Electrodes

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***Abstract*—We now know the brain is affected by several disorders, which bring physical and behavioral consequences. However, as much as the study of brain activity has evolved, we are still limited when it comes to understanding how our nervous system works and relates to all our daily activities. The goal of this study is to create a new EEG electrode that is more convenient both for patients and for doctors or researchers who are trying to understand what the electrical activities in those brains mean. A few groups have conducted research in this area, and many more are required, but in this study we attempt to understand the areas in which the previous ones did not succeeded in order to create an electrode that is ready for use and to be introduced to the market. Dry electrodes showed to be a good option, as these devices do not require conductive paste, nor any other skin preparation, before the procedure. However, the fabrication for such electrodes is more expensive and need some improvements in order to be accepted as a commercial option.**

Keywords*— *electrodes; action potential; biopotential; EEG; electroencephalophy; brain activity

I. INTRODUCTION

EEG (Electroencephalogram) is an equipment used to diagnose disorders related to brain activity, and it does so by tracking and recording the summation of the electric potential of several neurons that align to create a similar spatial orientation [1]. Although nowadays these devices are used combined with other brain imaging systems like fMRI (Functional Magnetic Resonance Imaging) and CT (Computed Tomography), EEG was the first biotechnology to detect brain (dys)function related to drowsiness, arousal, sleep, and attention [2]. Despite this current tendency to use EEG to just locate electrical activities in the brain, it could be used as a brain imaging tool itself [3].

The electrodes are the part of the EEG that are attached to the patient's scalp and serve as conductors, tracking the brain activity and sending it to the device that will read the signals [4]. The most common type of electrodes commercialized for EEG devices are Ag/AgCl, which have excellent electric potential reproducibility and signal to noise ratio. The main drawbacks is that these are considered "wet" electrodes, which require extra work and demand the presence of specialized technical staff [5].

Our goal, with this study, is to find the best option for a new electrode that does not require as much work in preparation and decreases the effects of skin irritation and inflammation, but making it possible to be commercialized, as usually "dry" electrodes are more expensive [6].

II. RESEARCH METHOD

Understanding previous work in neuro technology and the history of brain activity measurement is important in the pursuit of a more convenient electrode [7], as it gives rise to the significant aspects that are essential to the success of electrodes' capacity to deliver information regarding the electrical behavior of the central nervous system, and so need to be kept from the technologies that are currently being used [8] as well as the advances that can be done with the intention of maintaining EEG as one of the leading techniques in detecting brain disorders [5], [9], and [10].

This paper will consist of the study of five different electrodes for EEG recording, analyzing their assets and focusing on how they could be implemented in order to create a device that is more user friendly presents fewer negative effects.

The first electrode to be studied is the currently most commercialized, which consists of a silver/silver chloride material that requires electrolytic gelling. From that we will look into the idea of semi-dry electrodes, which require only a fraction of the gel used in traditional devices. Furthermore we will discuss the working progress in finding an ideal dry electrode, which pursue an electrode-skin interface, not requiring the gel used in so called "wet" electrodes; the advantages of this principle will be analyzed and improvements will be considered.

III. ASSESSING THE FABRICATION OF AN USER FRIENDLY EEG ELECTRODE

As technology advances in the pursuit of understanding the brain and how its mechanisms affect human beings physically and psychologically, more researchers attempt to find easier ways to measure these activities. The devices currently being used are bringing substantial information to the field, however, scientists have several conflicting ideas regarding the human brain that only novel researches will be able to clarify.

One known technique to study neuronal activity that has been used for almost one century is the electroencephalography (EEG), which mainly measures the action potential or spikes produced by aligned neurons with synchronous movement that will generate electrochemical activity in the brain. As said in Reference [11], functional brain studies based on EEG aim to estimate the location in the brain that are producing the signals recorded on the scalp. When measuring biopotentials through the scalp, a finite, small current flow is detected by the electrode. As this signal consists of an ionic current, the electrode works as a transducer that will transform it into an electronic current and send the information to a computer in order for it to be analyzed [12].

Widely used in the diagnose of certain brain diseases like epilepsy; a study conducted by Reference [9] explains the importance of electroencephalography in the initial diagnosis of the disorder and the need for a novel mobile EEG device that would bring valuable additional information of unclear seizures [13]. The use of EEG to understand brain activity can take medicine elsewhere. The combination of medicine and technology makes it possible for us to create a communication channel from the brain to an output device [14]. Such a system, called Brain-Computer Interface (BCI), uses the signals recorded from the scalp or from inside the brain in order to empower users with some deficiency to control other devices in a variety of applications. For that reason, more efficient and user friendly EEG electrodes become necessity.

A. Goal and Factors Model

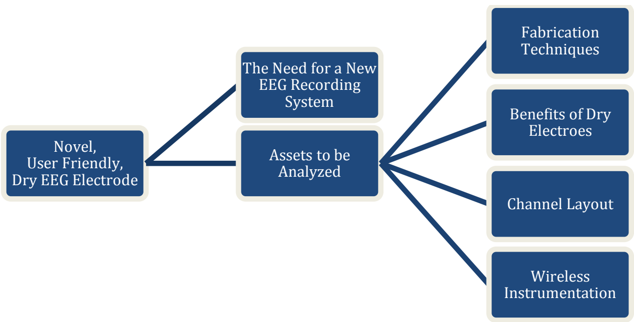

Figure 1. Assessing information on EEG Electrodes in order to create a user friendly version.

1) The Need for a New EEG Recording System

The idea for conventional is based on conductive/electrolytic gel, which provides a stable low skin-electrode impedance [15]. However, this model has many limitations that are now being studied in an attempt to be replaced by a novel electrode. Amongst the numerous drawbacks of, currently used, wet electrodes is the fact that they require a long process of preparation that includes some sort of conductive paste or gelling. This process demands the presence of professionals, which also makes for it to only be usable in specialized facilities; moreover, the negative effects of the long term use of these products on the patients' scalp are to be considered in the creation of an innovative device. According to Reference [16], a possible solution for increased ease of use and stable long-term EEG recordings may be the use of dry electrodes. Reference [17] also takes into consideration the limitations of wet electrodes, which are sometimes referred to as the golden standard, when looking at the promising features that have been suggested in past years innovative solutions, which include dry electrodes.
Some of the solutions that may lie upon the development of dry electrodes are the ease of application, which will make it possible for out-of-the-clinic use, and the reduction of time consumed in the process. As mentioned by Reference [18], the application of dry electrodes involves no skin preparation, nor needs electrolytic gel. The elimination of the conductive gel, consistent with what studies have said, would reduce most of the disadvantages of the standard Ag/AgCl electrode system [19]. In order to get to understand the full (dis)advantages of the current technology and the advances of the devices, this study will present an evolution from dry electrodes, passing through quase-dry electrodes and getting to the three different prototypes of dry electrodes.

2) Assets to be Analyzed

After examining properties of five different electrodes, ranging from wet to dry models, the main discrepancies were analyzed. When aiming to commercialize a product, the cost for the research and mass manufacturing should be relevant, and that is one factor in which wet electrodes have their advantages as they have been in the market for so long and have their production well understood. However, there are other models that show promising features while maintaining low cost and bringing up newer, and more effective, assembly. For instance, one of the main electrodes to be considered in this study is produced in 3D printers, which may be the future of this field for its simplicity. The material to be used is also an important factor for keeping it affordable, and one of the materials with greatest properties for this use is the carbon nanotubes (CNT), which have been reducing their cost lately and so promise a bright solution for the future. Furthermore, the lack of a conductive gel might represent a reduction on the cost of applications, however, the electrode itself would have to be reusable to keep the budget low. On that same face, reducing the time a professional would take to do the preparation would also be financially beneficial. With all that been said, dry electrodes do sound like they could be the ideal solution for a novel EEG recording system.

a) Fabrication Techniques

The main technology used to build electrodes currently is lithography, as Reference [4] discusses and Reference [20] optimizes with their novel technology. However, a quicker way to fabricate dry electrodes is explored by References [18] and [21], which believe in the 3D printing application in this field. Studies conducted by References [22] and [23] go further to suggest the application of novel materials in the fabrication of electrodes with better electrochemical performance as well as ecofriendly properties.

b) Benefits of Dry Electrodes

It is important, as Reference [19] has said, that we eliminate the use of conductive gel in order to reduce the main disadvantages of currently used electrodes. Nonetheless, it is essential to consider what References [5] and [24] showed in their studies, regarding high-quality monitoring and its need for low contact impedance between dry electrodes and the skin. One of the main issues present on wet electrodes to be addressed with the implementation of the innovative technology of dry electrodes is the time-consuming application of wet electrodes, as explored by Reference [7], which sees a substantial time reduction in this novel technology, while still providing interpretable signals. Another factor is the possibility of using dry electrodes in spaces other than the hospital, which make is easier to monitor patients in their day to day activities [12].

c) Channel Layout

As References [25] and [2] explored, multi-channel EEG electrodes are used in order to acquire information. Usually a cap of 32 or 64 channels of Ag/AgCl electrode is used in clinical exams, according to Reference [26], although in the research field as many as 126 channels can be used in order to get more information on the signals. The problem with an increased number of channels being applied to the scalp, like in the case of Brain-Computer Interface (BCI) application suggested by References [14] and [27], is the fact that the gel or paste used in the preparation for wet electrodes have conductive properties and may cause interference in the signals.

As currently most researches require the EEG to use a large amount of channels in order to acquire precise data, it would be convenient that these electrodes did not demand a long time for preparation nor the use of a conductive gel or paste that might obstruct the readings [2], [6], [14], [25], and [27]. On the other side, the implementation of novel dry electrodes could also enter new fields, since the quick and easy application of these devices are advantages for areas like motor rehabilitation [28].

d) Wireless Instrumentation

An additional factor that must be taken into consideration when seeking a user friendly device, is its mobility. In order to create an EEG electrode that enables patients to measure their own neuronal activity outside the health facilities, either to aim comfort and for the measurement to occur during daily activities or to reach remote locations where health care would not get to otherwise, it is ideal that the device to be created is small and lightweight. Reference [13] goes further to suggest a device that transmits the signals through wireless technology. Following that idea, Reference [29] created a wearable electrode that integrates textiles to the sensors industry.

For that to be possible, the technology will require a mounted amplifier, as mentioned by Reference [30] due to the reduced size of the device.

IV. EXPLANATION AND DISCUSSION

When analyzing the assets of wet electrodes and the inconvenience caused by their implementation, it becomes clear that dry electrodes have a great potential in this field. However, in order to commercialize a new device, there are other factors to be taken into consideration.

That is why, in this study, more than one specific point was investigated, and that is what will be seen in EEG electrodes comparison.

After discussing the main assets of wet electrodes, the model for a quasi-dry electrode seems appealing as the amount of gel used in this system is just a fraction of the traditional model. The moistener is released by the probe itself, which contains a container with the exact amount of electrolyte gel needed for each electrode [5]. These properties empower patients to do the measurement by themselves, as little training is needed and maybe the need for a specialized health care professional could be bypassed. Also, the interference between channels is greatly increased due to the absence of the unnecessary gel that is used in traditional wet electrode methods.

However, there is a tendency to create an even more beneficial type of electrode that overcomes the problems of impedance and allows for long-term measurements, and the solution seems to rely on dry electrodes.

According to Reference [18], 3D printing of an acrylic-based resin can bring some low cost electrodes with good properties. The main issue with these electrodes is that they are not fixed to the skin on the scalp, which requires for a new design in the way the preparation occurs.

Considering there is still a drawback in the preparation factor for the previous electrode, there is need to work on a device that attaches to the scalp without the need of a cap, and this is the working principle of micro-spiked electrodes. As suggested by Reference [15], the design of these electrodes would have needle like structures that should be long enough to penetrate through dead skin into the outermost layer of the skin, called dermis, but with wider shoulders that would avoid over penetration since it could cause pain sensations as it contacts the nerve. The negative aspect of such needles is that, although of minimum invasive properties, they could break into the skin and remain in the epidermis, increasing the risk of skin irritation and/or infection.

Furthermore, there is a similar idea of an electrode that attaches to the skin though spikes, but rather in a much smaller scale, that could address all previous concerns. Electrodes with carbon nanotubes (CTN) arrays have been studied because of their great conductivity properties and also for the fact they are almost noninvasive due to the size of their spikes [12]. However, although infection risks are greatly decreased when compared to micro-needle approaches, they are not completely evaded.

V. Contritution and New Insight

Due to the inconvenience of "wet" electrodes, EEG is becoming less used as a clinical device to measure brain activity, as other technologies require less work for the fact they do not demand much adaptation to individual patients. That is why a novel electrode would help in the goal of acquiring neuro electrical information though electroencephalogram, as it still is an important method when diagnosing and understanding central nervous system (dys)function.

VI. Conclusion

We are in a moment of neuroscience history where it is important to have easy and quick access to information of the current state of the patient in order to understand the pathology and its implications in order to prevent critical consequences. That being said, the creation of a novel EEG electrode is an important advance towards an uncomplicated approach to measure brain activity.

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