CONDUCTIVE 3D PRINTED MATERIAL USED FOR MEDICAL ELECTRODES

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ABSTRACT

Conductive polylactic acid (PLA) 3D printing material has been on the market, which consists of a mixture of resin and graphene. An investigation is performed in this paper to identify the effectiveness of medical electrodes that were 3D printed with the conductive PLA. A description of the construction of these electrodes are given, with the resistance properties that were measured and observed. The electrodes were tested in a hospital to be identified whether they will be appropriate for reusable electrodes in the medical field.

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1. INTRODUCTION

The United Kingdom (UK) National Health Services (NHS) purchase over 152 million adult electrocardiography (ECG) electrodes annually [1]. Currently, most disposable electrodes used for medical purposes have a wide range in price, yet averages to approximately US$ 1.00 per electrode. Some hospitals have been known to reuse disposable electrodes to reduce costs [2]. Electrodes are commonly used in the medical sector for electromyography (EMG) for identifying muscle contractions [3]; electroencephalography (EEG) for signal analysis from the brain and scalp [4], and ECG for investigating heart muscle contractions [5]. Transcutaneous electrical nerve stimulation (TENS) is when a signal is induced onto a person's muscles, often used to treat pain, or to identify a person's reaction time in reflexes. Reusable electrodes are considered ones that can be disinfected [2], with ideal conductivity or improved performance compared to current electrodes.

Reusable electrodes such as those made from stainless steel have been developed and tested [5]. Non-contact electrodes have also been investigated [6] for EMG [3] and EEG [4] applications. ECG electrodes in wearable material is also new research being explored [5]. The problem with the non-contact and wearable electrodes is that it has been shown that the movement of the skin, muscles, tendons and alike happens within the body, the electrode positions alter, creating noise, and inaccuracy in readings. Screen-printing electrodes and their characteristics were also identified as possible re-usable electrodes [7].

Properties of ungelled ECG electrodes have also been researched, where a person's sweat was considered as the electrolyte between the skin and electrode [8], which is similar to saline solution. Suction electrodes have been often used in some hospital applications [9].

It has been observed that there are many microorganisms and bacteria that can be spread with electrodes, especially those that have a wet surface [2]. It was found that a way to eliminate these microorganisms was to heat the electrodes to a temperature of 60 °C for a period of 1 hour [2].

Protoplast have released a 3D filament that is a conductive PLA. It is more brittle than the normal PLA, as it has carbon / graphene infused in the filament. The manufacturers state that the printed parts have a resistance of 15 Ω-cm^3 to 115 Ω-cm^3, depending on the orientation of the printed part [10].

The contributions of this paper are as follows:

1. Identify the resistance distribution of an electrode printed with conductive PLA.
2. Identify the effectiveness of the 3D printed electrode for medical applications.

This paper will describe the construction process of the electrodes, followed by the tests that were conducted to identify the resistance distribution of the electrode. The observations that were reported by the hospital and medical doctors that have tested the electrodes are given in the results section.

2. ELECTRODE CONSTRUCTION AND TESTS METHODOLOGY

The Anet A8 fused deposition modelling (FDM) 3D printer was used. A 3 mm glass was placed on the heating bed. The glass was sprayed with a layer of hairspray, to act as a gripping agent for the base layer that will be printed. The settings for printing were as the following:

- Layer height: 0,15 mm
- Shell wall thickness: 1 mm
- Shell top and bottom thickness: 0,8 mm
- Infill density: 100%
- No gradual infill steps
- Printing temperature: 230 °C

- Bed temperature: 80 °C
- Material flow: 100%
- Print speed: 60 mm/s
- Printing cooling disabled
- No build plate adhesion structure
- Print sequence: all at once.

The electrodes that were printed with the Protoplast conductive PLA, has a 4 mm hole in it, to allow for the leads with a banana plug to connect to it [11]. The 50 mm electrode and 35 mm electrode was positioned next to each other for each print, to allow for a comparison between the different size electrodes.

After the electrodes were printed, the electrode surfaces were cleaned with alcohol to remove the hairspray adhesive on it. The electrode surface was then sanded with a 220 grit sandpaper, and then with 1200 grit sandpaper, to remove the thin layer of printed material that could have mixed with the hairspray and act as an insulator. The 4 mm holes were also drilled, to make sure a smooth circular hole, to allow for better conductivity, was in place. The completed electrodes are shown in figure 1.

Figure 1: The 35 mm electrode (left) and 50 mm electrode (right) that was 3D printed with conductive PLA.

A stainless steel bolt was fastened to the electrodes with nuts as shown in figure 2, to allow ECG machines with the connections for the clip electrodes to be connected to the 3D printed electrodes. Stainless steel is often used for medical devices due to it not being able to corrode easily, and it can be disinfected.

Figure 2: The 3D printed electrodes with a stainless steel bolt to allow connection to the medical devices.

2.1 Electrode resistance mapping

The electrode resistance distribution was investigated. The Ohm meter's one probe was placed on the connection point of the electrode, while the other probe was placed on different points on the surface of the electrode and the resistance was measured. The resistance at each point on the electrode was performed five times, which was recorded and the average value for each point was calculated. The different average points of the electrode's resistances were plotted and mapped to identify the areas of similar resistance.

2.2 Hospital and medical application tests

TENS tests were conducted. The 35 mm 3D printed electrodes were attached to a patient as shown in figure 3. A saline solution was placed on the electrodes surface and they were taped to the forearm.

Figure 3: A collage of images showing the hand and the placement of electrodes on the forearm.

Three electrode ECG placements are used in theatre within the hospitals, to monitor a patient's heart rate. More electrodes are often used for other ECG monitoring, depending on the observations required. The 3-electrode ECG configuration was conducted in theatre, to observe the results with the minimal electrode configuration possible. A saline solution was placed on the electrodes as a conductive agent between the patient's skin and the electrode, and the electrodes were kept in position with medical tape. The position of the 3-electrode ECG configuration on the patient is shown in figure 4.

Electrode disinfection was performed with the COVID-19 protocol, with the use of 70% alcohol mixed with chlorhexidine. Another means of disinfection is to heat the electrodes to the recommendation of 60 °C for a period of 1 hour [2].

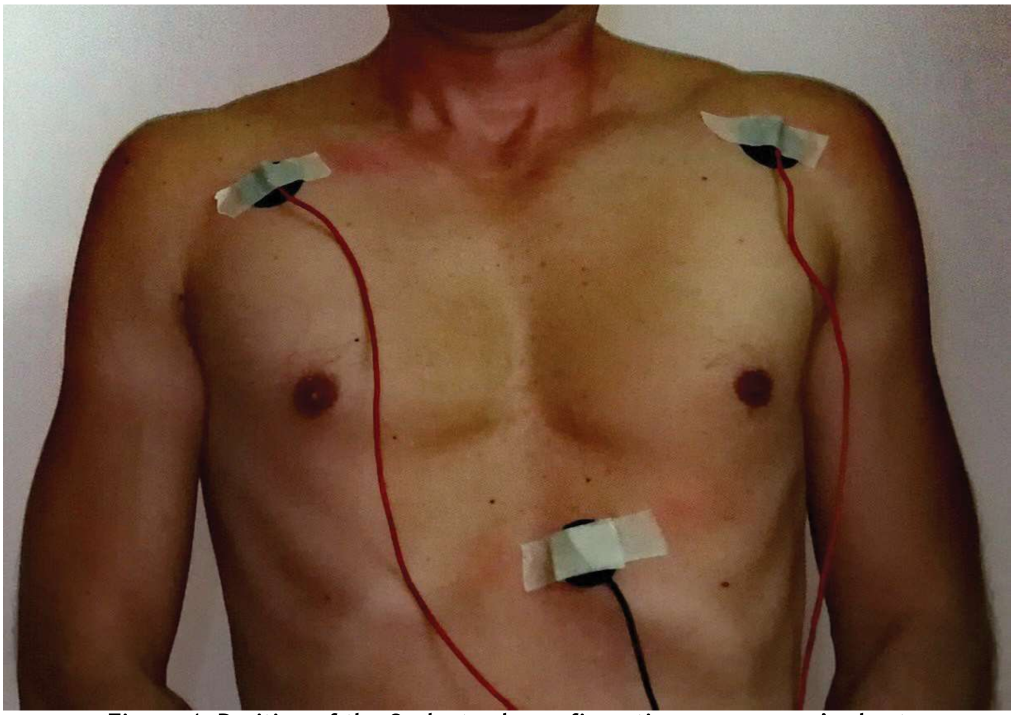

Figure 4: Position of the 3-electrode configuration on a person's chest

3. TESTS AND RESULTS

Two sets of tests were conducted and are presented in this paper. The resistance distribution map of the electrode was identified, and then the tests conducted of the electrode in the hospital.

3.1 Electrode resistance mapping results

The resistance of different points on the electrode was measured five times at each point to be able to map the average resistance density of the electrode, as shown in figure 5.

It was found that the 35 mm electrode had an average resistance of 738 Ω, while the 50 mm electrode had an average of 788 Ω. The 50 mm electrode has a larger average resistance. Round disposable Ag/AgCl wet gel foam electrodes have a diameter of 35.925 mm [12] and the average resistance measured from five different electrodes was a consistent 19 Ω with a deviation of 0.2 Ω.

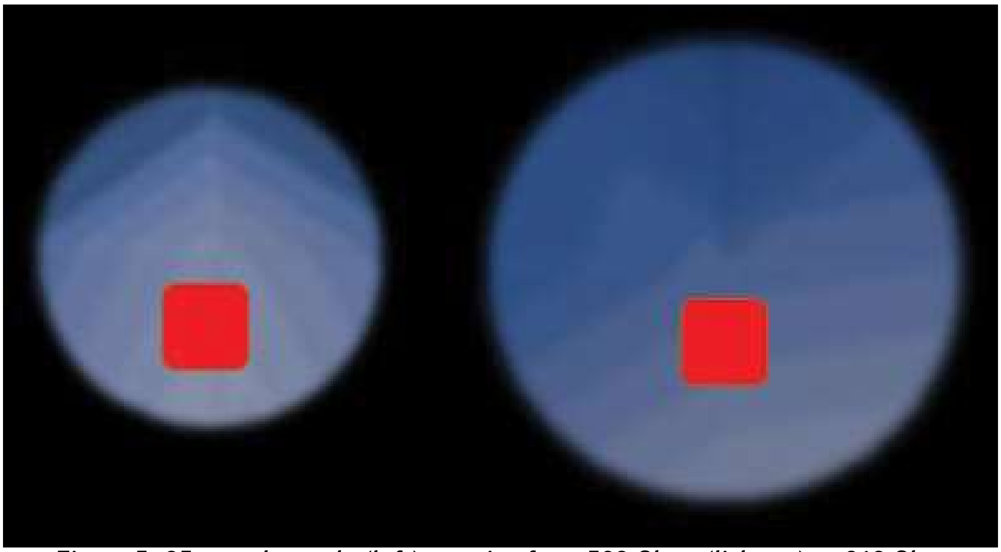

Figure 5: 35 mm electrode (left), ranging from 592 Ohms (lightest) to 862 Ohm (darkest). 50 mm electrode (right), ranging from 522 Ω (lightest) to 992 Ω (darkest). Red point indicates electrode lead connectivity point from which measurements were made.

3.2 Hospital and Medical Application Tests

Larger electrode would be able to obtain more signal [3], yet the larger electrode has a larger resistance, and therefore the 35 mm size electrodes were considered for the medical tests. The 35 mm size electrode uses 0,21 m of conductive PLA filament, resulting in a cost of US$0,083. This value excludes the production time (consisting of 12 minutes) and other costs related to manufacturing.

It was found that with foam electrodes, the TENS device required to produce 40 mA to 50 mA of current, to initiate muscle twitching, while the 3D printed electrodes required 35 mA current.

The electrodes were also cleaned with 70% alcohol mixed with chlorhexidine, as required for disinfection in hospitals and surgery, and there were no effect to the electrodes.

The ECG machine was able to monitor the patient's heart rate, and it was reported that the observations on the ECG monitor, was appropriate, as shown in figure 6.

Figure 6: The ECG monitoring that was observed with the 3D printed electrodes.

A video compilation of the manufacturing of the electrodes, and the hospital tests conducted, can be found at: https://www.youtube.com/watch?v=fbY9rLUqZdY .

It was also tested with a magnet to identify if there was any magnetic properties with these electrodes. It was found that the magnet did not attract to the electrodes, therefore making it possible to be left on a patient's body should an MRI be needed to be performed on the person.

The electrodes were placed in an oven at a temperature of 70 °C for a time period of 1 hour. This temperature was 10 °C higher than the recommendation of 60 °C [2]. It was found that as long as the electrode's flat side were placed on a flat surface, no deformation of the electrodes were found. The electrodes were tested after the heating process, and there was no change observed in the conductivity. Therefore it would be acceptable to have all microorganisms killed by placing the electrodes in a temperature of 60 °C for a period of 1 hour.

4. CONCLUSION

The conductive PLA filament was used to construct the electrodes, which uses just over US$ 0,08 worth of material. The print time per electrode is 12 minutes. The constructions process, and printer settings have been explained to produce the electrodes.

The two contributions of this paper were achieved. Resistance distribution of an electrode printed with conductive PLA was identified with the resistance distribution map, and a comparison of the average electrode resistance is compared to that of the disposable electrode resistance.

The 3D printed electrode were tested in hospital for medical applications, including TENS and ECG applications. The electrodes were possible to be disinfected with the chemical agents used in hospitals, especially with the COVID-19 pandemic, and the electrodes were possible to be reused. Disinfection of microorganisms is also possible by leaving the electrodes in 60 °C temperatures for a time period of 1 hour. The electrodes were also found to not have any magnetic properties, therefore being possible to use them in a MRI machine. With these properties, it allows for such electrodes to be reusable and to be used in the medical sector.

Future work to identify ways to make the electrodes to stick to the skin, in a way that will prevent the transmission of microorganisms. Further work is also required to evaluate the conductive PLA resistance properties, and how the material can be used for other sensors or purposes. An investigation of the different disinfection methods could also be conducted to identify the bacterial contamination between the FDM layers.

5. ACKNOWLEDGEMENT

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