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A Washable Silver-Printed Textile Electrode for ECG Monitoring †

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Abstract: Electrocardiography (ECG) is one of the most widely used diagnostic methods to examine heart situations. This paper focuses on the development of a textile-based electrode and studying its ECG detecting performance. We developed silver-printed textile electrodes via a flat-screen printing of silver ink on knitted polyester fabric. The silver-printed PET fabric stayed reasonably conductive after washing and stretching which makes it suitable for wearable applications. Moreover, the ECG measurement at static condition showed that the signal quality collected before and after washing was comparable with the Ag/AgCl standard electrodes.

Keywords: ECG; textile electrode; flat screen-printing; silver-coated PET

1. Introduction

Traditionally textile clothing is used for protecting the wearer from different weather conditions and is expected to have a good fit and comfort. But nowadays we demand a lot from our clothing to make our life easy, and this is becoming possible due to the rapid emergence of new types of materials and miniaturization of electronic components which led to the development of smart textile materials [1,2].

Textile-based electrocardiogram (ECG) sensors are one application area of wearable healthcare smart textiles. Silver/silver chloride (Ag/AgCl) gelled electrodes are the most commonly used types of electrodes for ECG monitoring because of their ability to capture a high-quality signal. But the gel employed in such electrodes can cause skin irritation and dries out during prolonged recordings, which causes deterioration of the signal quality [3,4]. This makes gelled electrodes unsuitable for wearable systems.

Textile electrodes are ideal for building wearable health monitoring devices due to their inherent flexibility and softness [5]. Conductive textiles can be used for this application by fixing them to an elastic band or tight garment, which creates a good contact of the electrode with the skin of the user. Recently, many textile-based ECG electrodes have been developed. Yokus & Jur [6] developed fabric electrodes by screen-printing of Ag/AgCl conductive inks on nonwoven fabrics encircled with adhesive sheet and they reported that the printed electrode yields comparable ECG signals to wet electrodes. However, still they didn't investigate comfortability, washability, and durability.

In this paper, a silver-printed textile electrode is created for ECG detection. The electrode is developed by screen printing of polyester knitted fabric with silver ink. Knitted fabric is preferred because of its flexibility and ability to fit to the body. ECG test results showed that the developed electrodes have a capacity to acquire ECG signals.

2. Experimental

2.1. Materials and Sample Preparation

Knitted polyester fabric having 140 g/m^2 and thickness 0.49 mm was used to fabricate electrodes. High-performance silver ink (Metalon HPS-FG32) having solid content of 75% and particle size 1.5 micron was provided by Novacentrix. Screen printing was used to develop conductive textile with electrode size of 6 cm2 (3x2 cm) to be used as ECG electrodes. Stainless steel screen mesh with mesh count 90 was used to develop the screen. The silver ink was stirred thoroughly before use to achieve a good dispersion. Three samples were printed and cured at 120 0C temperature for 30 min according to the manufacturer's recommendation. A metallic snap connector was attached to the textile electrode in order to connect to the wires of an ECG recording module.

2.2. Electrical Conductivity Measurement

The surface resistance of the silver printed electrodes was measured with the four-point method, using surface measuring instrument MR-1 (Schuetz Messtechnik). This method is more accurate compared to the two-point method [7]. In the four-point method, there are four contacts, the current I supplied via the two outer contacts, and the voltage V is measured through the two middle contacts. Ten readings were taken and recorded to compute the mean and standard deviation. The surface image of the fabric before and after printing was studied by scanning electron microscope (SEM- FEI Quanta 200 FFE) with an acceleration voltage of 20 kV.

To investigate the wash stability, the textile electrodes were washed with 4g/l non-ionic detergent and 1g/l sodium carbonate at 40 0C for 30 min according to ISO norm 105-C06-A1S, 2010 standard method. The effect of stretching on the conductivity of the textile electrodes was also studied by stretching the textile electrodes on a light-duty drill vise modified for this purpose as shown in (Figure S1(a)). The samples were stretched from 5 to 40% of their original length with 5% intervals and the surface resistance was recorded at different stretching percentages of the sample using a two-point probe method using Fluke 87 multimeter. The increase in surface resistance was calculated as follows:

$$R \text{ increase} = \frac{Ri - R0}{R0} * 100 \tag{1}$$

Where Ri is the surface resistance at different stretching levels and $R0$ the original surface resistance when not stretched.

2.2. ECG Measurement

ECG performance of the electrodes was tested by placing three electrodes on the skin of a healthy volunteer; one on the right wrist, one on the left wrist, and the third one i.e., the reference electrode on the back of the left forearm (Figure S1 (b)). The electrodes are wrapped on the wrist using an elastic strap to assure the electrodes remain in the correct position. Once all electrodes were placed in the right spot, the electrodes were connected to a portable ECG device (PC-80B easy ECG monitor purchased from Shanghai Lishen Scientific Equipment, China). For comparison of the performance of the developed electrodes with standard Ag/AgCl electrode, asynchronous ECG recording method i.e., two electrodes fixed at the same place and signal recorded at a different time was implemented. We collected data from both the textile and standard electrodes in the following conditions: sitting down on a chair, with two arms on the table for 3 min, and walking on a smooth surface for 3 min. Collected ECG signals are uploaded to a computer for analysis using the software ECG viewer manager provided by the manufacturer of the device. This software allows to determine the amplitude of P, QRS, and T waveforms, as well as beats per minute (bpm).

3. Results

Conductivity is one factor that affects the ECG detection performance of textile electrodes. The silver printed polyester electrodes have a surface resistance of 1.78 Ω/Sq ± 0.2, which showed that they have acceptable conductivity to be used as ECG electrodes. After washing, the sheet resistance of the electrodes increased to 3.77 Ω/Sq (2.12 times the original value). This increase in resistance is due to the washing away of silver particles as they are loosely attached to the fabric surface. Kazani et al. have also reported the silver-printed textiles show a considerable increase in resistance after ten washing [7]. The SEM image (Figure S2 (a)) shows that the silver flakes coated on the fabric and gaps between adjacent loops filled with the silver particles which makes the fabric conductive. The stretch test results (Figure S2 (b)) on the other hand show that resistance increases linearly with stretching up to 40%. The increase in surface resistance at 5% stretch was around 6% which increased to only 18.28% at 40% stretch. This reveals that even at 40% stretching the conductivity of the electrodes is not affected in a way that would make signal acquisition problematic.

A typical ECG signal contains three main picks as shown in Figure 1a. An ECG waveform is acceptable if the major picks are clearly visible, with no missing R-peaks or falsely detected R-peaks in the QRS complex [8]. Figure 1b shows the ECG signal collected using standard Ag/AgCl electrodes and Figure 1c shows signals acquired using printed textile electrodes in static position. The major picks were visible in both waveforms. Visual examinations of test results demonstrated that ECG signals collected using the printed textile electrode are consistent with signals collected using the standard electrodes. In the signal collected using textile electrodes, the P, QRS, and T waves are recognizable with signal amplitude of 0.09, 1.20, and 0.30 mV, respectively, and their R-peaks the waves are approximately the same. The P, QRS, and T waves of the signals collected using Ag/AgCl electrodes are 0.10, 1.21, and 0.30 mV, respectively. The heartbeat result was 72 bpm and 76 bpm for the polyester electrode and the standard electrodes during asynchronous measurement, respectively, which is sufficiently similar to allow comparison. As shown in Figure 1d, the ECG signals collected by the textile electrodes after washing still contain clearly visible P, QRS, and T waves with amplitudes 0.08, 1.13, and 0.27 mV, respectively, and the heartbeat was 77bpm, which are comparable to signals acquired before washing.

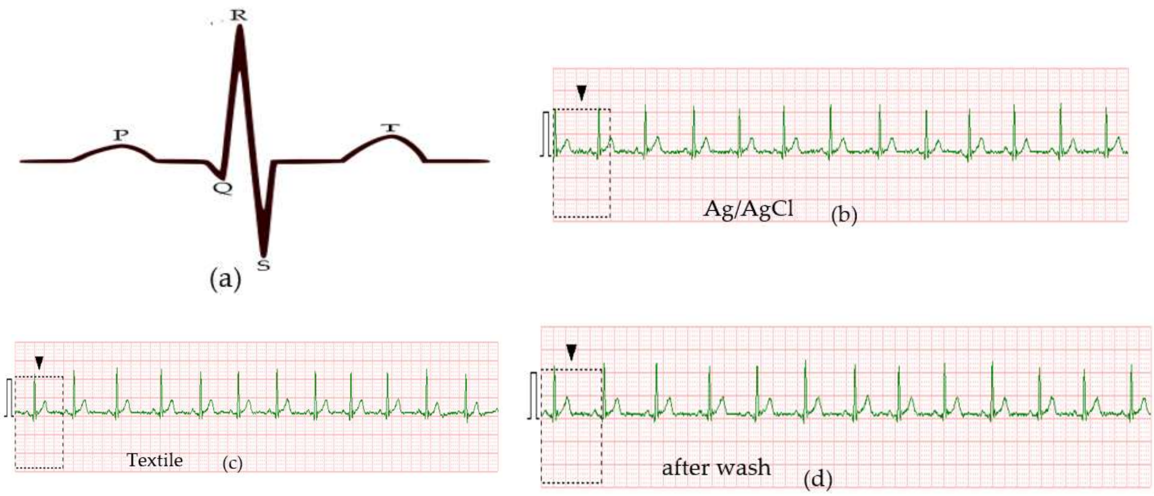

Figure 1. (a) components of ECG signal, (b) signal collected using Ag/AgCl electrode, (c) signal collected using textile electrode, and (d) signal collected using textile electrode after washing. All signals are collected in static conditions.

For better ECG signal detection, there should be stable contact between the electrode and the body. During movement, the skin-textile contact slides partly and hence the electrodes can’t capture the electric current as well which leads to deterioration of signal quality. A solution could be to fit the band more tightly to the body, but this would negatively affect the comfort of the user. Signals collected while walking using textile electrodes (Figure S3 (a)) gave lower signal quality compared to signals collected using Ag/AgCl electrodes (Figure S3 (b)), which could be due to an unstable contact of the electrodes with the skin when moving. P, QRS, and T peaks were not clear enough in the signals from the textile electrode, but it is sufficient to determine bpm. Work is in progress to improve the signal quality of the textile electrode in motion.

4. Conclusion

A textile ECG electrode was developed by screen printing of silver ink on knitted polyester fabric. The surface resistance of the printed electrodes was 1.78 Ω/Sq. After washing, the sheet resistance of the electrodes increased by 2.12 times but increased only slightly while stretching up to 40%. The ECG signals acquired using textile electrodes were comparable with signals from standard Ag/AgCl electrodes. The P, QRS, and T waves were recognizable with signal amplitude of 0.09, 1.20, and 0.30 mV for signals collected using textile electrodes, while 0.10, 1.21, and 0.30 mV were obtained respectively for signals collected from Ag/AgCl electrodes during asynchronous measurement. Even though the sheet resistance of the electrode increases after washing, they were able to capture signals with acceptable quality.

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Institutional Review Board Statement: The study was conducted following the Declaration of Helsinki, and the protocol was approved by the Institutional Review Board of EiTEX, Bahir-Dar university under the reference number EiTEX-PGPDO/37/2020.

Informed Consent Statement: All subjects gave their informed consent for inclusion before they participated in the study.

Conflicts of Interest: The authors declare no conflict of interest.

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