Developing Pressure Sensitive Adhesive Electrodes: Preliminary Results

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***Abstract*— A mixture of carbon black powder, polar organo salt and a pressure sensitive adhesive (PSA) has shown to be able to collect skin bio potentials. Such PSA electrodes do not dehydrate even after a prolonged period of storage, which leads to a theoretically infinite shelf life. The PSA electrodes need to be electrically activated through electrophoresis. ECG data were simultaneously collected with PSA and Ag-AgCl electrodes from 5 healthy subjects. ECG morphology was almost identical for both media. Hence, given that PSA electrodes have an infinite shelf-life, potentially with less cost associated with their fabrication, and have ECG signal dynamics nearly identical to those of Ag-AgCl, the new electrodes provide an attractive alternative for ECG measurements.**

I. Introduction

The electrocardiogram (ECG) provides a graphical representation of the electrical activity of the heart, and to properly monitor the cardiac health of a patient, it is crucial to obtain an ECG signal with a high signal-to-noise ratio (SNR). In a typical ECG setup, depending on the particular application, three to twelve signal receptive electrodes are attached to the patient's body. These electrodes are able to measure minute changes in potential that occur as a consequence of the propagation of electrical signal from atria to ventricles during each heartbeat cycle, thus rendering it possible to produce the characteristic ECG waveforms that can then be used for diagnostic purposes. The ECG can also be further quantified by computing the heart rate variability (HRV) indices, as these have been shown to provide a good estimate of the dynamics of the autonomic nervous system[1]. To ensure optimal signal strength of the electrode, it is imperative to minimize the impedance of the electrode-skin interface by lowering the impedance of the electrode. High impedance levels at the skin-electrode interface can result in significant loss in signal strength and low SNR, which will lead to poor quality ECG waveforms.

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The current industry gold standard for electrodes is the Silver/Silver Chloride (Ag-AgCl) wet (hydrogel) electrode, which has been proven to provide accurate ECG waveforms[2]. These electrodes consist of a layer of silver chloride, often in the form of a paste-like hydrogel surrounding a silver disc. While the hydrogel layer significantly improves the signal quality by effectively lowering the impedance that exists at the electrode-skin interface, it is also the principal reason behind the relatively short shelf life of these electrodes. The hydrogel layer that exists in the skin-electrode interface degrades with time as it dehydrates. This leads to a loss of signal quality [3] and an increased incidence of motion artifacts and noise in the ECG[4]. Moreover, the electrodes need to be carefully packaged to ensure prolonged retention of the hydrogel layer. Due to finite shelf life and electrode dehydration, these electrodes can only be used to record signals for a few days at maximum[5]. Also, Ag-AgCl electrodes are limited to short-term use because they are known to cause irritation to the skin especially after their removal. Moreover, Ag-AgCl electrodes are also relatively expensive since silver is an expensive commodity.

A new type of electrode that does not require a hydrogel layer needs to be developed to address the issue of dehydration with the current industry gold standard electrodes. Our proposal is designed by combining a pressure sensitive adhesive (PSA) with carbon black powder and polar organo salt. This mixture is potentially much more economical than Ag-AgCl. PSA electrodes were found to reduce their impedance by electrophoresis[6].

Some comparisons between PSA and Ag-AgCl electrodes were carried out. First, electrode-skin contact impedance was measured for each type of electrode. Subsequently, simultaneous ECG data acquisition was performed using the two electrode types on human subjects.

II. Materials and Methods

A. PSA electrodes

PSA electrodes were created by mixing the dopant and the PSA in a beaker. The carbon is then added to the mix. A magnetic mixer is used to stir. The mixture is spread onto a liner using a spreading tool, and then placed into the oven. The dried adhesive is covered with a 2nd liner and is cut into pieces. Then, the Carbon electrode film is cut into pieces and the liner is removed from the adhesive. The adhesive is placed onto the film, leaving some carbon film exposed, in order to make the electrical connection. Electrophoresis is then applied for enhancing surface conductivity.

A representative PSA electrode is shown on the right panel of Fig. 1 and the left panel shows a standard Ag-AgCl ECG electrode.

B. *Electrode-skin contact impedance measurements*

Over-skin impedance measurements were carried out for a pair of PSA and Ag-AgCl electrodes. The skin of the test subject was cleaned before each measurement by wiping with a 2%-alcohol impregnated cotton pad, which was allowed to evaporate before applying the electrodes. PSA and Ag-AgCl electrodes were mounted on the right forearm, one pair at a time, one on the palm side of the wrist, and the second 5 cm apart from the first but situated towards the elbow. These electrodes were connected to the Hioki IM3570 impedance analyzer. The signal voltage amplitude was set to 1 V and the frequency range from 4 to 100 KHz, as used in[4].

C. *Collection of electrode comparison data*

A simultaneous set of 3 PSA and wet Ag-AgCl electrodes was used to collect ECG signals from 5 healthy subjects (26 ± 3 years old). An electrode was placed just below the sternum as ground. A second electrode was placed above the central bone on the sternum, and the third electrode was placed just under the left pectoral near where a V6 electrode would be placed. These placements allowed us to measure the lead II ECG configuration.

Subjects were seated for 7 minutes. ECG signals were collected using Rozinn® Holter monitors which sampled data at 180 Hz. The ECG signals were band-pass filtered (0.05-40 Hz) offline to reduce noise and low-frequency motion artifacts, like respiration movements.

III. RESULTS

A. *Electrode-skin contact Impedance*

Fig. 2 shows the comparison of electrode-skin contact impedance between Ag-AgCl and PSA electrodes as a function of varying frequencies. As shown, PSA electrodes exhibit lower electrode-skin contact impedance than Ag-AgCl electrodes for the frequency band of 4 to 100 KHz. Ag-AgCl electrodes' impedance is more than twice that the PSA electrodes' for most of the range, and about 1.5 times in the lowest frequencies. Note that the measured Ag/AgCl impedance shown in Fig. 2 is in agreement with previously reported studies[4].

D. *ECG signals comparison*

The morphologies of the ECG waveforms between the two different media were very similar for all subjects. Fig. 3 includes a short example to show how the PSA electrodes gather all the relevant morphologies of ECG signal.

IV. DISCUSSION

Prototype PSA electrodes were developed and their characteristics were compared to the standard Ag-AgCl electrodes. It was found that our dry electrodes are comparable to the industry gold standard Ag-AgCl electrodes in terms of impedance and ECG morphological characteristics. These electrodes need to be activated prior to use in order to reduce their impedance; once the electrodes are activated, they are permanent.

PSA electrodes address two of Ag-AgCl electrode's issues: dehydration and high cost. The PSA electrodes are theoretically more economical than Ag-AgCl electrodes since carbon is cheaper than silver. Further, the PSA electrodes have an infinite shelf life whereas the Ag-AgCl electrodes dry out and the standard practice is to discard them after 1 month of storage.

Electrode-skin impedance measurements showed lower values for PSA electrodes when compared to wet Ag-AgCl electrodes. Moreover, the impedance of PSA electrodes is even lower than those reported for carbon nanotube-polydimethylsiloxane (CNT-PDMS) flexible electrodes [5].

All ECG morphological waveforms are well captured with Carbon-Polar organo salt-PSA electrodes. Further analysis, like heart rate variability indices for instances, could be derived from the PSA electrodes in the same manner than from Ag-AgCl.

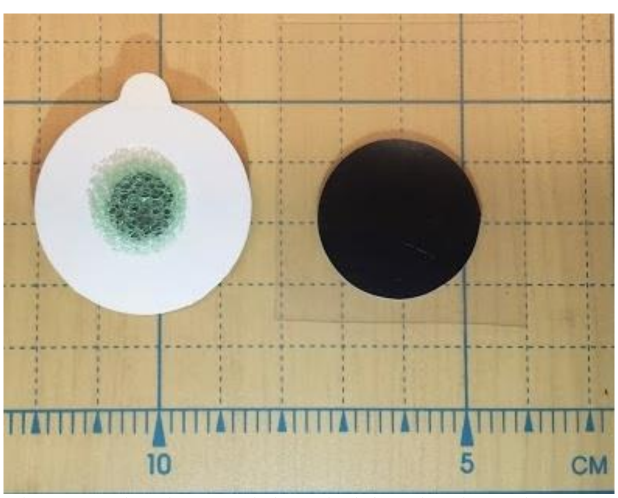

Figure 1. Hydrogel Ag-AgCl electrode (left) and Carbon-Polar organo salt-PSA electrode (right).

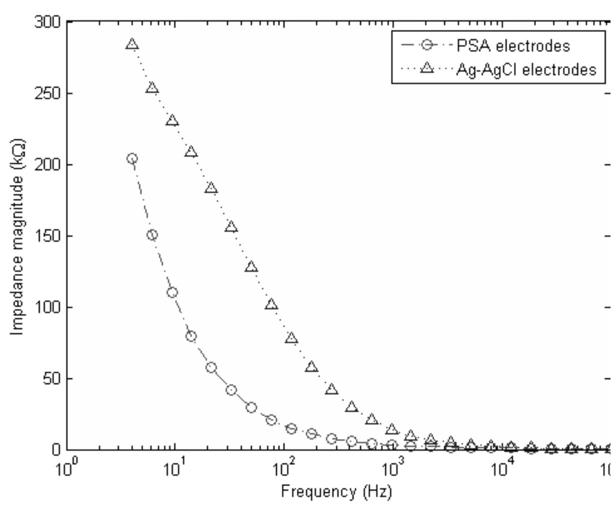

Figure 2. Impedance comparison.

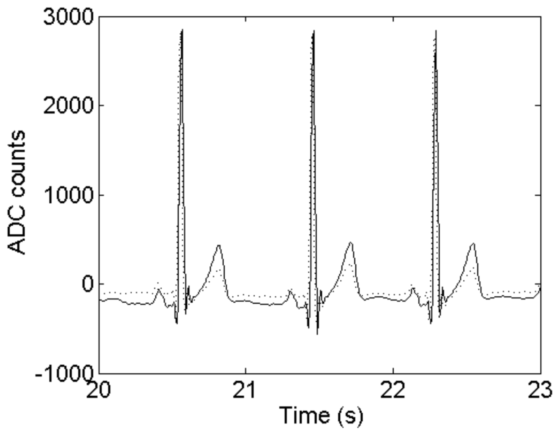

Figure 3. ECG segments acquired by using Ag/AgCl (solid line) and PSA electrodes (dotted line).

Based on 30 minutes of exposure to PSA electrodes, none of the 5 subjects showed any negative reactions to electrode-skin contact. Certainly, further experiments will need to be performed to determine the long-term biocompatibility of the PSA electrodes. Moreover, PSA electrodes will need to be tested in the future for their sensitivity to moisture as it is well known that perspiration can lead to degradation of the quality of ECG signals.

PSA electrodes are susceptible of optimization. For instance, the ideal concentration of carbon black powder in the mixture needs to be examined. The electrophoresis scheme could also produce better results (lower post-activation impedance) if optimized.

In summary, we demonstrated that dry ECG electrodes can be fabricated from a mixture of carbon powder, polar organo salt, and pressure sensitive adhesive. All ECG morphological waveforms were found to be nearly identical to Ag-AgCl electrodes. Moreover, the main advantage is their infinite shelf life which lowers both supply chain handling costs and scrap costs when compared to Ag-AgCl electrodes since the latter have a shelf life of only a month. Hence, PSA electrodes have the potential to be a viable and cost-effective alternative to standard Ag-AgCl electrodes.

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