Studying the Performance of Conductive Polymer Films as Textile Electrodes for Electrical Bioimpedance Measurements

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Abstract. With the goal of finding novel biocompatible materials suitable to replace silver in the manufacturing of textile electrodes for medical applications of electrical bioimpedance spectroscopy, three different polymeric materials have been investigated. Films have been prepared from different polymeric materials and custom bracelets have been confectioned with them. Tetrapolar total right side electrical bioimpedance spectroscopy (EBIS) measurements have been performed with polymer and with standard gel electrodes. The performance of the polymer films was compared against the performance of the gel electrodes. The results indicated that only the polypropylene 1380 could produce EBIS measurements but remarkably tainted with high frequency artefacts. The influence of the electrode mismatch, stray capacitances and large electrode polarization impedance are unclear and they need to be clarified with further studies. If sensorized garments could be made with such biocompatible polymeric materials the burden of considering textrodes class III devices could be avoided.

1. Introduction

The advance on conductive textile materials and the progress on textile-enabled measurement instrumentation integrating textiles and electronics producing sensorized garments are fostering the development of electrical bioimpedance (EBI) technology for personalized healthcare monitoring [1].

Textile electrodes or textrodes are rising as an application of conductive fabrics but so far mainly silver-based fabrics are the raw material to make textile electrodes. Due to economical issues like the high and highly variable price of silver, environmental issues regarding the disposal of such silver-textile material and medical device certification issues like class III classification under rule 13 [2] other alternatives are being investigated.

Certain polymer compounds present conductive properties that might allow the material to function as electrode in some cases. Some of these polymer compounds allow to be manufactured as flexible films. Such films are very textile-friendly and can be integrated in textile manufacturing processes easily.
In this work the measurement performance of three different polymeric materials as bioimpedance electrodes has been evaluated. Wrist and ankle straps were custom made with 3 different polymer films: Two films made from polypropylene and one film was made from a thermoplastic elastomer. The textrode performance was compared with tetrapolar wrist-to-ankle measurements performed with commercially available gel-based electrodes used as reference.

2. Materials and Methods
The work presented in this paper has been executed during the realization of a final degree work. In such final degree work several measurements have been performed with different skin preparation conditions and with two different bioimpedance spectrometers. This paper focuses on a limited set of experiments to assess on the feasibility of using these film materials as bioimpedance electrodes.

2.1. Electrical Bioimpedance Spectroscopy Measurements
The EBI spectroscopy (EBIS) tetrapolar measurements were obtained with the spectrometer SFB7 manufactured by ImpediMed Ltd in the frequency range of 3.096 to 999 kHz. A set of 20 measurements was performed for each electrode type with the electrodes placed on the right wrist, and right ankle with the volunteer lying in a decubitus supinus position.

2.2. Gel Reference Electrode
Electrolyte gel-based Ag/AgCl, Red Dot repositionable electrodes manufactured by 3M were used to perform the wrist-to-ankle EBIS tetrapolar use as reference for the comparison.

2.3. Polymeric Raw Materials
For this work three different kinds of polymers containing carbon black and with different electrical characteristics were selected: polypropylene PP 1380 and PP 1386 as well as thermoplastic elastomer TPE 1503. The polymers were in the granulated state and with specific process of melting they were transformed into films. The polymer materials were supplied by Premix ThermoPlastics Oy, Finland.

The PP1380 was selected after a selection process that involved preliminary EBIS measurements with several textrode materials. The PP1386 and the TPU1503 were selected because of their mechanical properties, which could contribute to facilitate the textrode manufacturing process.

| Polymer Material | Volume resistivity | Surface Resistivity |
|------------------|--------------------|---------------------|
| PP1380           | <=5 Ωcm            | <=100 Ω             |
| PP1386           | <=1000 Ωcm         | <=10000 Ω           |
| TPU1503          | <=300Ωcm           | <=10000 Ω           |

2.4. Film-Textrode Bracelets
Straps were confectioned as bracelets with a customized length for the wrist and the ankle, a pair for each site. The bracelets have been confectioned with a triple layered structure using the polymer films on the inner side, woven fabric in the outer side and foam in between, as shown in Figure 1.

Figure1. Complete Confectioned Strap with the layered structure, the buckle and the press-stud.
The straps are 2.5 cm width with an adjustable length using buckle system to fasten the bracelets around the limbs. A metallic press-stud is used to connect with the alligator clip attached to the measuring leads of the SFB7 spectrometer. The buckle and the press-stud are also shown in Figure 1.

2.5. EBIS comparison Measurements
After the textrode-bracelets were placed, wrist-to-ankle EBIS tetrapolar measurements were performed at two different times T5 and T10, after 5 minutes and 10 minutes correspondently. Both EBIS measurements were compared with the obtained with gel electrodes.

3. Experimental Results
For the textrode-bracelet made of PP 1386 and TPE 1503 no EBI spectrum was produced, the obtained impedance measurements obtained presented an oscillating resistance spectrum with negative values consistent with equipment saturation.

For the polymeric film PP 1380, the reactance spectrum obtained after 5 minutes and 10 minutes is shown in Figure 2b). In addition of the obvious difference in magnitude observed across the whole spectral spectrum, there is also a difference observed in the frequency behavior. Such difference can be observed easily in the reactance spectrum plotted in Figure 2a). In such plot, it is possible to see the different value for the characteristic frequency between the PP1380 measurements and the gel electrodes.

Both in the reactance spectrum plotted in Figure 2b) and the susceptance spectrum plotted in Figure 3, it is possible to observe an increase on the magnitude for both the T5 and the T10 measurement. Looking at the susceptance spectrum the increase at high frequencies suggests a second dispersion almost overlapping with the one at medium frequencies for T5. The observed capacitive behavior decreases for the T10 measurements. From both plots it is also possible to observe that the characteristic frequency for the reactance and the susceptance decreases with the attenuation of the deviation observed at high frequencies, i.e. the value for the characteristic frequencies for T10 measurements are lower than for T5 measurements.

Figure 2. Impedance spectrum obtained with the reference gel electrodes and the PP1380 textrode-bracelets. Resistance spectrum in a), and reactance spectrum in b).

Figure 3. Susceptance impedance spectrum obtained with the reference gel electrodes and the PP1380 textrode-bracelets.
4. Discussion
The results presented here correspond with a single test but the results agree with several other test measurement performed with a complete different spectrometer and reported in the report of the final degree thesis.

The obtained results showed that only the textrode bracelets made with PP 1380 films produced EBI spectral measurements. Apparently when measurements were taken with any of the other two polymer electrode materials, the SFB7 spectrometer saturated suggesting that the skin-electrode polarization impedance, $Z_{ep}$, of the electrodes were larger than the load dynamic range of the meter. That the PP1380 exhibit a smaller $Z_{ep}$ than the PP1386 and TPU1503 could be expected since the surface and volume resistivities of the PP1380 is significantly lower than the other two polymeric materials.

When using the PP 1380 films as textile electrode the obtained impedance spectra presents a certain deviation of the reactance and the susceptance at high frequencies, that is consistent with the presence of parasitic capacitances, large values of electrode polarization impedance or the combination of both. This deviation was observed already during the material selection process and it is consistent with the results presented in [3-5], which deal with poor skin-electrode interfaces causing large $Z_{ep}$ and the presence of parasitic capacitances.

The difference observed in the value of the resistance at all frequencies is consistent with the use of electrodes around the limb and it is consistent with EBIS measurements obtained with textile electrode straps previously reported in [6].

5. Conclusions

Despite that the effects observed on the performed EBIS measurement have been observed in more than one test and in more than a single subject during the material selection process aforementioned (unpublished) and also EBIS measurement have shown similar deviations in works studying the use textile electrodes [3,6], and measurement artifacts caused by stray capacitances [5] and large $Z_{ep}$ values [4], the fact that the experimental results only show measurements from a single subject and that very important issues like electrode-skin polarization impedance have not been reported remains.

Therefore the only conclusions that can be drawn from these preliminary results is that PP 1380 films have the potential to be used for the confection of sensorized garments to perform EBIS measurements and that more detailed and deep studies must be performed to confirm the suggested potential. Such studies should be aimed to fully characterize the textrode measurement performance, and its main measurement characteristics and dependencies, prioritizing the study of the skin-electrode interface.

Considering textile electrodes containing silver as class III medical devices under rule 13 bring up significant challenge for medical device manufacturer that might hinder the rising of textile-based EBI applications, thus alternative materials to silver for manufacturing textile electrodes must be found.

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