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Comparison of Dry-Textile Electrodes for Electrical Bioimpedance Spectroscopy Measurements.

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Abstract. Textile Electrodes have been widely studied for biopotentials recordings, specially for monitoring the cardiac activity. Commercially available applications, such as Adistar T-shirt and Textronics Cardioshirt, have proved a good performance for heart rate monitoring and are available worldwide. Textile technology can also be used for Electrical Bioimpedance Spectroscopy measurements enabling home and personalized health monitoring applications however solid ground research about the measurement performance of the electrodes must be done prior to the development of any textile-enabled EBI application.

In this work a comparison of the measurement performance of two different types of dry-textile electrodes and manufacturers has been performed against standardized RedDot 3M Ag/AgCl electrolytic electrodes. 4-Electrode, whole body, Ankle-to-Wrist EBI measurements have been taken with the Impedimed spectrometer SFB7 from healthy subjects in the frequency range of 3kHz to 500kHz. Measurements have been taken with dry electrodes at different times to study the influence of the interaction skin-electrode interface on the EBI measurements. The analysis of the obtained complex EBI spectra shows that the measurements performed with textile electrodes produce constant and reliable EBI spectra. Certain deviation can be observed at higher frequencies and the measurements obtained with Textronics and Ag/AgCl electrodes present a better resemblance.

Textile technology, if successfully integrated it, may enable the performance of EBI measurements in new scenarios allowing the rising of novel wearable monitoring applications for home and personal care as well as car safety.

1. Introduction
Textile technology might play an essential role enabling home and personal healthcare systems and applications. Measurements of Electrical Bioimpedance (EBI) are being uses for cardiovascular monitoring[1], body composition assessment [2] and other monitoring applications that could benefit significantly from smart textile technology. The reliability of physiological measurements obtained
with textile-enabled measurements systems must be ensured prior obtaining any satisfactory optimal integration of textile technology in a health-related measurement system.

Recent developments in textile technology have made available textile electrodes [3] that can function as sensors in non-invasive physiological measurements[4]. In an EBI measurement the electrode has a determinant role in the system due to its double function in the system: as potential sensing elements and as electrical charge interface between the measurement system and the body. The absence of an electrolyte compound in the composition of textile electrodes may impede the charge transfer from the current injecting terminals into the body, thus affecting the measurement.

In this work the performance of two different kinds of dry-textile electrodes from two manufacturers are compared against the performance of typical Ag/AgCl electrolytic electrode, observing the possible influence of time in the obtained EBI complex spectra.

2. Material & Methods
In this study ankle-to-wrist EBI spectroscopy measurements have been done on three healthy subjects lying supine in a resting state at different times, using two types of textile electrodes and conventional electrolytic electrodes. The EBI spectra obtained with textile and electrolytic electrodes have been studied in order to assess their resemblance.

2.1. Electrodes
For this comparative, three different types of electrodes have been used: textile bracelets, wrist cuffs both shown in Figure 1 A) and B) respectively and sticky electrolytic Ag/AgCl pads.

2.1.1. Textile bracelet.- The bracelet has been custom made with a width of 2.5 cm and adjustable length. The material of the inner surface is the electrode sensor manufactured by Clothing+ with synthetic wrap knitted textile material with silver fibre as a conductive element. The outer material of the bracelet is knitted cotton with spandex and Velcro for fastening it around the wrist and ankle.

2.1.2. Wrist/Ankle Cuffs Electrode.- The cuffs are manufactured by Textronics Inc. and made of polyamide (nylon) 15%, conductive fibres 30%, Spandex 20% and polypropylene 35%. The conductive textile material is knitted in the inner surface of the cuff electrode.

2.1.3. Electrolytic electrode.- The electrode is a repositionable electrode of the RedDot series manufactured by 3M with conductive and adhesive hydro gel. The electrode patch is rectangular with an area of 10.1cm$^2$ a snap-button connector.

2.2. Measurements & Analysis
EBI measurements with textile electrodes have been taken at four different times in a time window of 12 minutes with the Impedimed SFB7 spectrometer in the frequency range 3-500 kHz. The obtained EBI measurements have been compared with a final measurement taken with electrolytic electrodes. The comparison, based in a relative error analysis, has been made studying the deviation observed from the complex spectral values obtained with the electrolytic electrodes.

![Figure 1. Textile electrodes. Textile bracelet in A) and Wrist cuffs in B).](image-url)
Figure 2. Spectra obtained from the EBI measurements with both textile electrodes at different times. The spectrum obtained with the electrolytic electrode is shown as a reference value.

3. Results

3.1. Complex EBI Spectrum

Figure 1 contains the EBI spectra obtained with both textiles, dotted trace for the bracelet and continuous trace for the cuff, at two different times indicated by a circular marker. The EBI spectra obtained with electrolytic electrodes is included for comparison purposes with dashed trace. In the case of the resistance spectrum, depicted in Figure 2.a), the only spectrum that is remarkably different from the rest is the one obtained with the bracelet electrodes for t=0. The same EBI measurement taking 12 minutes later exhibit a better resemblance. In the case of the reactance spectrum, depicted in Figure 2.b), only the measurements obtained with the elastic cuff electrodes produce an EBI spectra that closely resembles the spectrum obtained with the electrolytic electrodes.

While Figure 1 contains the obtained spectra from the measurements on a single subject, Figure 2 presents the averaged relative error of complex impedance spectra. The error has been calculated considering the spectra obtained with the electrolytic electrode as reference.

It is clearly observed in Figure 2, that the deviation from the reference value obtained with the cuff electrodes is much smaller than the deviation obtained with the bracelet electrodes. The deviation obtained with the cuff electrodes exhibit also a smaller frequency dependency.

In Figure 3, it is also possible to observe certain time dependency. The relative error obtained with the bracelets exhibit a denoted time dependency that suggests that the error decreases with time. In the

Figure 3. Mean relative error of the resistance and reactance averaged among three subjects for both textile electrodes at different times.
case of the cuff electrodes such trend cannot be confirmed, since in most of the frequency range the deviations obtained are very similar.

The mean impedance relative error depicted in Figure 3 is obtained as the mean of the relative errors for the reactance and the resistance, averaged for the three subjects. Therefore, the differences between resistance and reactance for each of the subjects cannot be evaluated from Figure 3 alone. In order to study the error obtained in the resistance and the reactance as well as the time dependency for each of the subjects, the averaged sum of the relative errors have been calculated for both resistance and reactance spectra specifically at four different times for both textile electrodes. The obtained values are presented in Table 1.

In Table 1, the averaged sum values of the resistance and reactance relative errors are presented. From this table is possible to observe that in terms of the averaged sum of relative error the deviation obtained from the resistance spectrum is smaller than the produced in the reactance. The deviation obtained from de resistance measurements with both type of textile electrodes follow the same general trend seen in Figure 1, time reduces the obtained deviation. Therefore the averaged sum of the relative error for the measurements taken after minute 12 are smaller than the ones obtained at t=0. In the case of the reactance spectrum, the bracelet electrodes follow the general trend previously indicated while the deviation obtained with the cuff electrodes does not exhibit any specific trend.

When comparing the deviation obtained with both type of electrodes, it is easy to notice that for all cases with the exception of one, the deviation obtained with the cuff electrodes is smaller.

### 4. Discussion

The results obtained showed that the EBI measurements done with both textiles electrodes present reliable and repetitive measurements for the resistance spectrum. The error obtained with the bracelet electrodes for the reactance spectrum is very high while the reactance spectra obtained with the cuffs present exhibit a relatively low deviation.

Certain improvements can be observed on the performed spectroscopy measurements. In the case of the measurements taken with the bracelets an improvement can be observed especially in the reactance spectrum, where the initial error is significantly high. In the case of the measurements obtained with the electrode cuff such improvement cannot be notice, but this can be due to the fact that the error is much smaller. Such a smaller error can be due to the fact that the textile sensor used in the cuff exhibits a higher conductivity and the surface of the conductive sensor is also much larger than in the case of the bracelets. Such higher conductivity combined with a larger surface may improve significantly the electrode-skin interface.

### 5. Conclusion

The results obtained suggest a general good performance of textile electrodes when measuring resistance. The reactance spectrum obtained with the bracelets is not reliable enough while the reactance spectrum obtained with the cuff electrodes is more reliable. Moreover to be able to assess on
their reliability for EBI applications for body composition further analysis must be done, especially regarding the estimation of the Cole parameters like in [5]. With Home monitoring applications in mind, further improvements in the electrode ergonomics and textile design should be done aiming to increase their usability.

The cuff electrodes apparently exhibit a better performance and stability in time and frequency than the bracelet electrodes. As this study gives no clue to whether the difference is due to material or design of the electrode further studies may point out ways to improve the performance of textile electrodes for recording of Electrical Bioimpedance.

In any case the resistance spectra from the EBI measurements obtained with the textile and electrolytic electrodes exhibit a close resemblance. Recent work done on Cole parameters estimation from EBI measurements suggest that EBI applications using Cole model-based analysis can be implemented by only measuring the spectrum of the reactance [6]. Therefore if the latter it is confirmed the implementation Textile-enabled EBI application is not so far ahead.

References