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Textile Electrodes in Electrical Bioimpedance Measurements – A Comparison with Conventional Ag/AgCl Electrodes

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Abstract— **Work has been intensified around the integration of textile and measurement technology for physiological measurements in the last years. As a result nowadays it is possible to find available commercial products for cardiovascular personal healthcare monitoring. Most of the efforts have been focused in the acquisition of EKG for cardiovascular monitoring where textile electrodes have shown satisfactory performance. Electrical Bioimpedance is another type of physiological measurement that can be used for personal healthcare monitoring where the integration and the performance of the textile electrodes has not been investigated that thoroughly.**

In this work, the influence of the textile electrodes on the measurements and on the estimation of the Cole (R_0, R_∞, f_C and α) and body composition (TBW, ICW, ECW and FFM) parameters has been especially addressed. Complex Spectroscopy 4-electrode wrist-to-ankle electrical bioimpedance measurements taken with conventional Ag/AgCl and textile-electrodes on customized bracelets have been compared and analyzed in the frequency range 3 to 500 kHz.

The obtained results suggest that the use of textile electrodes do not influence remarkably on the complex spectral measurements neither in the estimation of Cole nor body composition parameter. In any case any possible effect introduced by the use of textile is smaller than the effect of preparing the skin by the using abrasive conductive paste.

I. INTRODUCTION

PERSUING to reduce costs for society, there is an ongoing shift in paradigm within healthcare towards home healthcare and preventive Personal Healthcare. The emerging home and personal health monitoring applications require a combination of several technologies for the implementation of what is call E-health applications and services.

Textile technology has been identified as the key element to catalyze the proliferation of E-health monitoring application for Home and Personal health care. Thus several research initiatives have been dedicated worldwide to investigate the feasibility of integrating textile technology into physiological Measurements System.

Measurements of Electrical Bioimpedance (EBI) can be used to monitor the cardiovascular personal health care [1, 2] body composition assessment in nutrition [3, 4] and body fluid distribution of patients under peritoneal dialysis [5].

The electrode is one of the most influential elements in an EBI measurement system, because electrodes do not only function as potential sensing elements but also as electrical charge interface between the measurement system and the body. Dry Textile electrodes do not have an electrolyte to facilitate the charge transfer, electrons or ions, from the current injecting leads to the biological tissue and this may influence the EBI measurement.

In this work, the influence of textile electrodes in the acquisition measurements of EBI first and later in the estimation of body composition contents is studied.

II. MATERIAL & METHODS

In this study textile electrodes are compared with conventional Ag/AgCl electrodes with respect to their ability to perform in spectroscopy measurement of complex EBI. The obtained complex spectra have been compared and used for estimation of body composition parameters. The variability of obtained parameters has also been studied.

A. Electrodes & Electrolytic Paste

1) Textile bracelet for wrist and ankle

- Width: 2.5 cm & length: adjustable, velcro fastener.
- Inner surface, sensor: Synthetic wrap knitted textile material with silver fibre as a conductive element. Sensor Manufactured by Clothing+ and developed by Elina Välimäki.
- Application: body monitoring in medical and healthcare applications.

Fig. 1 Textile bracelet electrode prototype for wrist and ankle

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- Outer material, garment: knitted cotton with elastane.

2) *Red Dot 3M repositionable monitoring electrodes.*

- Area: 10.1cm^2 with a snap-button connector.
- Outer surface: flexible non-woven polypropylene covered with polyethylene film.
- Inner surface: hydro gel conductive adhesive type.
- Application: diagnostic ECG measurements.

3) *EVERY Paste*

- Conductive and abrasive paste manufactured by spes medica.

B. Measurements & Analysis

Using the 4-Electrode method wrist-to-ankle Electrical Bioimpedance Spectroscopy (EBIS) measurements have been taken in four healthy subjects: 3 male and 1 female. See Fig.2. The Impedimed SFB7 spectrometer has been used to measure between 3 to 1000 kHz for the four different types of measurement: Red Dot 3M and Textile, with and without paste in both cases. **N.B.** The textile electrodes were slightly wet for the measurements.

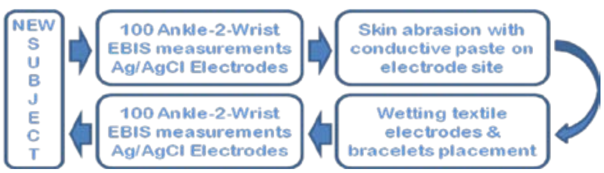

Fig. 2 Measurement protocol for the performed EBIS measurements with Ag/AgCl and textile electrodes.

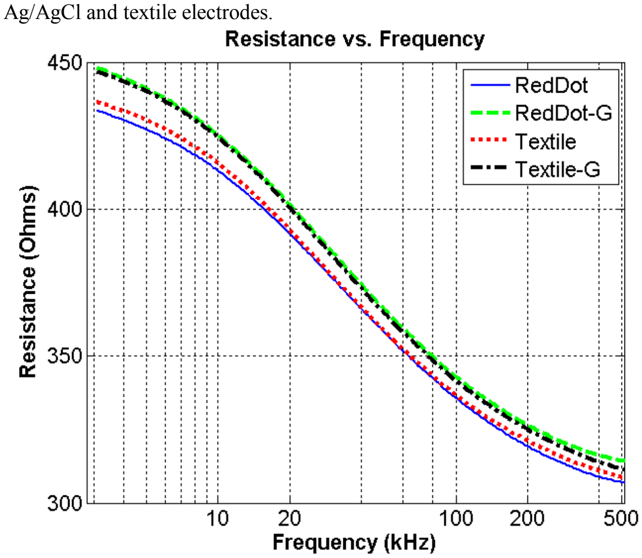

Fig. 3. Resistance spectrum for wrist-to-ankle measurements of subject 2 with the Red Dot 3M and textile electrodes with and without gel.

1) Spectral Analysis

100 measurements have been taken for each type of measurement and both the reactance and the resistance spectra in the frequency range of 3 to – 500 kHz have been statistically analyzed and plotted with Matlab. The analysis was limited to 500 kHz following the recommendation of Scharffeter in [6]. From the measurements the Cole parameters, R_0, R_∞, α and f_C have been also estimated using BioImp software.

2) Body Composition & Cole Analysis

The obtained EBIS measurements have been process with the BioImp software to estimate the body composition parameters, TBW, ICW, ECW, and FFM, of each of the healthy subjects.

III. Results

A. Impedance Spectrum

Figures 3 and 4 show that the spectra of the measurements with Ag/AgCl and with the textile bracelets do not exhibit any marked differences. In Fig. 3 it is possible to appreciate the coincidence on the resistance spectra between the Ag/AgCl and the textile electrode measurements. Fig. 4 shows that the coincidence is high but not as high as in the resistance spectra, especially at low and high frequencies where the spectra of the reactance differ the most.

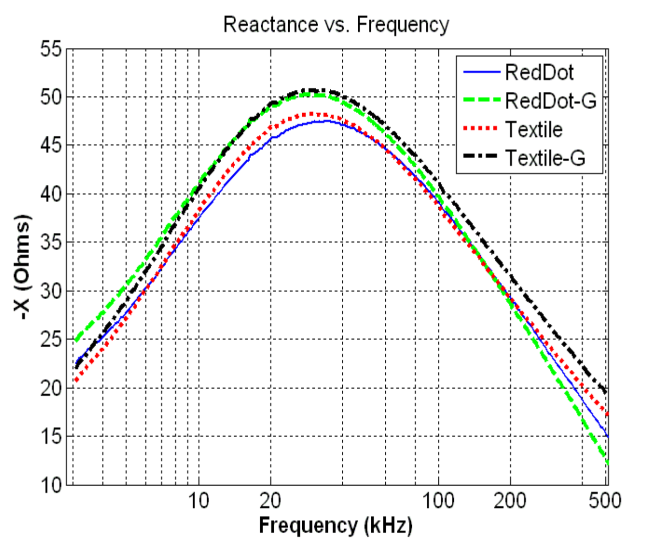

Fig. 4. Reactance spectrum for wrist-to-ankle measurements of subject 2 with the Red Dot 3M and textile electrodes with and without gel.

TABLE I

Mean Value of the Estimated Cole Parameters from EBI Measurements with Textile & Electrolytic Electrodes with & without Gel

	R_0 (Ω)				R_∞ (Ω)				f_C (kHz)				α			
S	3M	Tex	3M_G	Tex_G	3M	Tex	3M_G	Tex_G	3M	Tex	3M_G	Tex_G	3M	Tex	3M_G	Tex_G
1	*424.0*	*445.3*	*447.9*	*439.4*	*265.9*	*282.5*	*276.6*	*276.7*	*31.1*	*29.8*	*29.6*	*31.1*	*0.728*	*0.711*	*0.714*	*0.713*
2	*461.4*	*439.5*	*478.4*	*464.6*	*301.0*	*288.4*	*310.9*	*301.7*	*35.7*	*37.1*	*32.7*	*36.9*	*0.709*	*0.717*	*0.702*	*0.706*
3	*581.9*	*567.3*	*595.3*	*581.4*	*425.3*	*410.2*	*420.6*	*417.4*	*41.7*	*42.0*	*40.9*	*40.5*	*0.714*	*0.721*	*0.701*	*0.721*
4	*449.4*	*451.6*	*465.5*	*463.7*	*295.9*	*298.1*	*305.0*	*299.0*	*32.9*	*33.0*	*29.5*	*33.4*	*0.705*	*0.713*	*0.713*	*0.702*

N.B. the index _G indicates the use of abrasive conductive gel for that type of measurements

On the other hand, Figures 3 and 4 show that the use of conductive paste introduces more noticeable differences. Fig. 3 shows that resistance increases at all frequencies while Fig. 4 shows an increase in reactance up to frequencies around 150kHz with the use of conductive paste in the case of electrolytic electrodes and from 4 kHz and above of textile electrodes. Notice that above 200 kHz the reactance measured by the Red Dot 3 decreases remarkably.

B. Cole Parameters

Table I contains the mean values for the Cole parameters estimated from each type of measurements and for all the subjects, while Fig. 4 contains the minimum, maximum and mean values for the Cole parameters estimated for subject 4.

1) R_0 and R_∞ estimation

The values in Table I indicates that the mean of the observed differences, with the exception of R_0 estimation for subject 1, are below 5% and occur in both directions.

2) α estimation

According to Table I, the maximum observed difference in mean of the estimated values is smaller than 2.4%.

3) f_C estimation

In this case, according to Table I, the mean of the deviations do not reach the 4.4%. In the case of using abrasive electrolytic paste, the use of textile electrodes creates an overestimation of f_C.

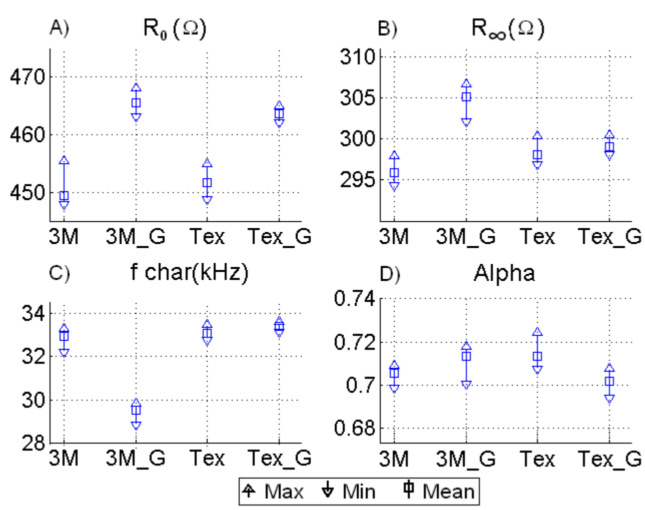

Fig. 5. Cole Parameters estimated from wrist-to-ankle measurements of subject 4 with the Red Dot 3M and textile electrodes with and without gel.

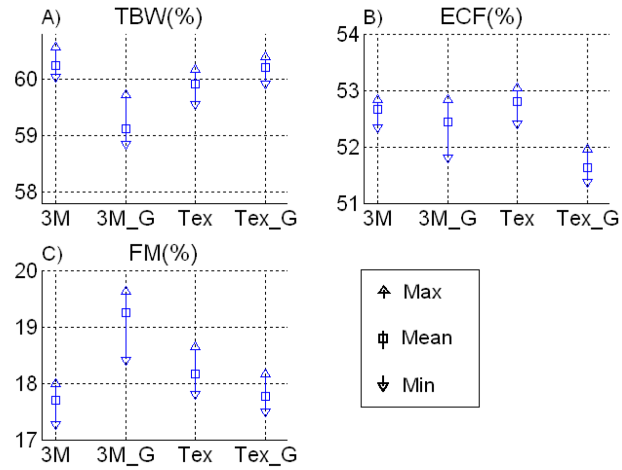

Fig. 6. BCA Parameters estimated from wrist-to-ankle measurements of subject 4 with the Red Dot 3M and textile electrodes with and without gel.

4) Influence of application of abrasive conductive paste

Looking at Table I it is possible to see that the differences observed between the estimation done with textile electrodes and with conventional Ag/AgCl is smaller in the case of using abrasive conductive paste than without it for the estimation of R_0 and R_∞.

C. Body Composition Analysis

Table II contains the mean values for the Cole parameters estimated from each type of measurements and for all the subjects while Fig. 6 contains the minimum, maximum and mean values for the Body Composition parameters estimated for subject 4.

1) Total Body Water

According to Table II, the use of textile electrodes do not introduce a remarkable difference. In Fig. 6.A) it is possible to observe that the range of the estimations of TBW presents noticeable overlaps. The only remarkable difference occurs for subject 1 where the difference reaches 4%.

2) Body Fluid Distribution

The mean values in Table II for estimation ECF and ICF exhibit differences below 2%, that is similar to the dynamic range of the estimation for a single type of measurement in a single subject, see Fig. 6.B.

3) Fat Mass

In this case the mean values show larger relative differences, up to 14% in subject 1.

TABLE II
BODY COMPOSITION PARAMETERS ESTIMATED FROM EBI MEASUREMENTS WITH TEXTILE & ELECTROLYTIC ELECTRODES WITH & WITHOUT GEL

	TBW (%)				ECF (%)				FM (%)			
Subject	3M	Tx	3M_g	Tx_g	3M	Tx	3M_g	Tx_g	3M	Tx	3M_g	Tx_g
1	*57.0*	*54.5*	*55.7*	*55.4*	*50.3*	*50.8*	*49.6*	*50.5*	*22.2*	*25.5*	*23.9*	*24.3*
2	*52.7*	*54.2*	*51.7*	*52.7*	*52.2*	*52.5*	*52.0*	*52.0*	*28.0*	*26.0*	*29.4*	*28.0*
3	*46.1*	*47.5*	*47.1*	*47.0*	*59.9*	*59.3*	*57.9*	*58.9*	*37.0*	*35.2*	*35.7*	*35.8*
4	*60.2*	*59.9*	*59.1*	*60.2*	*52.7*	*52.8*	*52.4*	*51.6*	*17.7*	*18.2*	*19.2*	*17.8*

N.B. The ECF and ICF and complementary parameters, related by ECF (%) = 1- ICF (%)

4) Influence of application of abrasive conductive paste

From Table II, In general no remarkable influence can be observed in the use of textile electrodes with or without conductive paste. But the differences observed in TBW (%) when using textile electrodes are slightly smaller with conductive paste.

IV. Discussion

A. Influence of the use of the Textile Electrodes

Since the textile electrodes do not have any electrolytic properties like an Ag/AgCl electrode, it would be expected that an increase in the Electrode Polarization impedance, *Zep*, would caused more noticeable changes in the measurements, but such remarkable difference has not been observed. This can be due to the fact the textile electrodes were wet prior the measurement. Wetting the textile electrodes is necessary in order to obtain any measurement and it improves the electrical interface between the electrode and the body. Thus by wetting the surface of the electrode the *Zep* of the textile electrode might not be much larger than the *Zep* of the Conventional Ag/AgCl Electrode.

To apply electrolytic gel onto the textile electrode should decrease the Zep as much as using water providing a reliable measurement. The use of electrolytic gel on textile electrodes for EBI measurements has been studied already in [7] reporting good obtained measurement performance.

Motion artifacts are a source of error in any wearable systems and even when the use of knitted structures as pointed in [8] decrease textile structure-related motion artifact, additional tests should be performed to study the influence of activity-related motion artifacts.

B. Influence of the use of the abrasive conductive paste

Preparing the skin using abrasive conductive paste would improve the interface resistance by removing dead cells from the skin, increasing the number of free charges available for the charge transfer process and increasing the humidity of the most superficial skin layer. Reducing the *Zep* reduces the total impedance of the electrical path that the injecting current should use through the body making the measurement more insensitive to influence of any parasitic capacitance that might be present with the load.

Decreasing the impedance of the current signal pathway would minimize the effect of small increments of *Zep* that could be introduced by using textile electrodes. There is not much information available about the influence of the *Zep* on EBI measurements but we see a direct relationship between *Zep* and the effects of parasitic capacitances that deserves to be investigated further.

The observed slight reduction in the differences estimation R0 and TBW(%) when using textile electrodes is due to the fact the body Composition Analysis method use by the BioImp estimates TBW(%) from R0 and R∞ [9].

V. Conclusion

The reported results suggest that the use of these textile electrodes instead of conventional 3M Red Dot does not significantly influence the EBI measurement. The spectral measurements obtained with textile electrodes and with conventional Ag/AgCl agree well and therefore the Cole and the body composition parameter that are estimated from EBI spectra do present any remarkable difference either.

On the other hand the use of abrasive conductive paste does introduce changes in the spectrum that are more noticeable than the changes introduce by the textile electrodes. Therefore any influence that the use of textile might introduce is not as strong as the influence of the use of abrasive conductive past.

This work initially suggests that textile electrodes can be use for EBI measurements for body composition assessment by Bioimpedance Spectroscopy analysis. Nevertheless, the role and influence of *Zep* on the EBI measurement should be investigated further to extend the work done by Medrano in [10], especially targeting the effects of conductive gels and the relationship of *Zep* with eventual parasitic capacitances.

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