New reusable elastomer electrodes for assessing body composition

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Abstract. The development of telemedicine requires finding solutions of reusable electrodes for use in patients’ homes. The objective of this study is to evaluate the relevance of reusable elastomer electrodes for measuring body composition. We measured a population of healthy Caucasian (n = 17). A measurement was made with a reference device, the Xitron®, associated with AgCl Gel electrodes (Gel) and another measurement with a multifrequency impedancemeter Z-Metrix® associated with reusable elastomer electrodes (Elast). We obtained a low variability with an average error of repeatability of 0.39% for Re and 0.32% for Rinf. There is a non significantly difference (P T-test > 0.1) about 200 ml between extracellular water Ve measured with Gel and Elast in supine and in standing position. For total body water Vt, we note a non significantly difference (P T-test > 0.1) about 100 ml and 2.2 l respectively in supine and standing position. The results give low dispersion, with R² superior to 0.90, with a 1.5 % maximal error between Gel and Elast on Ve in standing position. It looks possible, taking a few precautions, using elastomer electrodes for assessing body composition.

1. Introduction
The development of telemedicine requires finding solutions of reusable electrodes for use in patients’ homes and abandoning gradually, for these applications, the usual gel electrodes. Many authors have worked on this issue for the development of textile electrodes [1] or metal electrodes [2]. The problem comes particularly from the interface between electrodes with skin, more than the intrinsic properties of conductivity of the electrodes [3]. The objective of this study is to evaluate the relevance of conductive elastomer electrodes for assessing body composition.

2. Material and methods
The first step of the approach was to select materials with mechanical and electrical properties suitable for the production of flexible electrodes. Then, we optimized the geometry and the relative positioning of the electrodes used for injection and reception to be able to obtain relevant measurement for the operating frequencies. Particular attention has been paid to the contact resistance between the electrode and the skin. According to various studies, we chose a strip of commercial soft conductive
elastomer for the electrodes, which can be simply sizes according to the expected use. The electrode thus obtained has an excellent electrical conductivity, including for lower tensions. To implement measurement on the electrode, we only need to plug a 2 mm male rod in the conducting channel provided for this purpose. The problem was to fix the electrodes at different points of the human body for impedances measurement, intending that people can be lying down or moving as in the case of measurement on athletes. For that purpose, we designed a box with a location for the electrode and a path for the Velcro that will keep the box and the electrodes together (Figure 1). In the box are collected all connectors (injection and reception) to be linked to the impedancemeter. In the future, the embedded electronics for wireless transmissions will be implemented in the same box. Four different types of boxes were made thanks using rapid prototyping material. Moreover, these electrodes have the advantage of being inexpensive, easy to clean and flexible, that permits to adapt perfectly the measuring system to all skin types and morphologies.

A campaign of measurement has been conducted on a population of healthy Caucasian, n = 17, mean age 38.5 ± 19.0 years (from 11 to 62 years old) and average Body Mass Index 25.6 ± 3.9 kg.m⁻². Two devices are implemented: a reference device, the Xitron ® Hydra 4200 (Xitron Tech, San Diego) and its AgCl Gel electrodes (Gel) on the one hand and the multifrequency impedancemeter (Z-Metrix ®, Bioparhom, France) [4, 5] associated with the reusable elastomer electrodes (Elast) described before, on the other hand. Measurements were made in supine position, with the reference device – corresponding results are denoted with “x, n” subscript, and in standing and supine position with the Z-Metrix – corresponding results are denoted with “z” subscript. Before each measurement, the skin has been cleaned with water. Extracellular resistance Re and infinite Rinf, defined according to the Cole model [6] and corrected as Jaffrin et al. method [7], were calculated, as well as water volumes associated Ve [8] and Vt [9]. This was done for measurements realized for the whole body and for body segments (arm, trunk and leg).

3. Results and Discussion

First, we tested the impact of the rest time of the electrodes on the electrical characteristics without cleaning the skin with water or alcohol.

Figure 1 pictures of reusable electrodes made in conductive elastomer

Figure 2 impact of the rest time of the electrodes on the electrical data
Figure 3 impact of the body artifacts on the electrical data
Figure 2 shows an example of a monitoring during 5 min of resistance R and reactance X at 50 kHz. Gel have a low variability (1.2% and 2.0% of R on X) while Elast varies about 1.0% on R and 10.4% on X, from 64.9 to 50.4 ohm, then reaching a constant. Presumably the elastomer increases heating and moisture at the interface which reduces the reactance to the same value as that of Gel. These reusable electrodes are more reliable if you wait for about 5 minutes before doing a measurement.

Moreover, we wanted to test the impact of the body movement artifacts on the electrical characteristics. Figure 3 shows an example of a monitoring of a walk during 30 seconds after waiting 5 minutes of rest of the electrodes. Walking is an average simulation of various types of body movement artifacts (movement of arm, trunk and legs). The results were similar between Gel (an average variability of 5 ohms on X and 50 ohms on R) and Elast (2 ohms on X and 50 ohms on R). Presumably the decrease of the resistance comes from the movement of fluids in the lifting arm.

Whether Gel or Elast, the noted arm’s movements generate significant variations on resistance. Beyond the interface, in telemedicine measurements, it is necessary to detect a time of rest to perform reliable measurements of bioimpedance. After the electrical qualification of Elast, we are interested in the results on body composition.

We obtain a low variability with an average error of repeatability of 0.39% for Re and 0.32% for Rinf. We obtain similar results for Re, Rinf, Ve and Vt. There is no significantly difference between Gel and Elast. The results of the paired Student T-Test for Rinf (for example), measured for the right part of the body, are reported in Table 1.

| Segment  | Rinf  | Student T-Test |
|----------|-------|----------------|
| Total Body | Rinf/Rinfz supine | 0.877 Ns |
|          | Rinf/Rinfz standing | 0.924 Ns |
| Leg      | Rinf/Rinfz supine | 0.852 Ns |
|          | Rinf/Rinfz standing | 0.814 Ns |
| Trunc    | Rinf/Rinfz supine | 0.484 Ns |
|          | Rinf/Rinfz standing | 0.585 Ns |
| Arm      | Rinf/Rinfz supine | 0.886 Ns |
|          | Rinf/Rinfz standing | 0.905 Ns |

Table 1 Results of Paired Student T-test between Rinf obtained with Gel and Rinfz obtained with Elast

We can observe that there is no significantly difference (P T-Test >0.1) between the extracellular resistance and the infinite resistance measured with gel electrodes and those obtained with elastomer electrodes, in supine and standing position, for total body of corporal segment.

|                  | Veb     | Vtn     | Vez     | Vtz     | Student T-Test |
|------------------|---------|---------|---------|---------|----------------|
| Gel Supine       | 16.4 ± 2.9 | 40.2 ± 8.3 | 16.6 ± 3.0 | 40.1 ± 8.3 | Ref. |
| Gel Standing     |         |         |         |         | 0.603 Ns |
| Elast Supine     | 16.6 ± 3.2 | 40.1 ± 8.3 | 16.6 ± 3.2 | 37.8 ± 5.9 | Ref. |
| Elast Standing   |         |         |         |         | 0.635 Ns |

Table 2 Results of mean, Sd and Paired Student T-test for Ve and Vt with Gel and with reusable elastomer electrodes

Analysing data in table 2, it appears that there is no significantly difference (P T-test >0.1) about 200 mL between extracellular water Ve measured with Gel and with Elast electrodes in supine and in standing position. For total body water Vt, we note a non significantly difference (P T-test > 0.1) about 100 mL and 2.2 L respectively in supine and standing position. We can suppose that the accumulation of fluids in standing position in legs increase the difference between the two devices Xitron (used as reference in supine position only) and Z-Metrix (used in supine and standing position). We can suppose that it’s not related with the type of electrodes.
Figures 4 and 5 plots what we describe in the tables. The results give low R² dispersion, superior to 0.90, with a 1.5% maximal error between Gel and Elastomer on Ve in standing position.

4. Conclusion

Its looks possible, taking a few precautions (time of rest of the electrodes, detection of the movement of the body), using reusable elastomer conductive electrodes for assessing body composition. It is necessary finalizing a more ergonomic box and completely flexible. In addition, the interface must also be validated on subjects with skin with specific characteristics (elderly, athletes, children ...).

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