A Wearable Bioimpedance Device for Respiratory Monitoring

H. De Cannière1, C. JP Smeets1,2, P. Vandervoort1,2, S. Lee3, G. Squillace4, M. Vandecasteele3, L. Grieten1,2,3

1Mobile Health Unit, Faculty of Medicine and Life Sciences, Hasselt University, Belgium
2Department of Cardiology, Ziekenhuis Oost-Limburg, Belgium
3Body Area Networks, Holst Centre/imec the Netherlands, The Netherlands

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1. BACKGROUND
Bioimpedance (BioZ) is a promising technique that shows great potential for several healthcare applications. Moreover, wearable devices which are able to perform BioZ measurements will keep up with the trending topic of remote monitoring.

The electrical principle behind BioZ approaches Ohm’s law. When a sinusoidal electrical current passes, a sinusoidal voltage drop is generated. The electrical resistance gives the connection between the current and the corresponding voltage. A current that passes through biological tissue is impeded by biological tissue resistance, which causes a phase shift between the sinusoidal current and the sinusoidal voltage. Therefore, the tissue impedance that is calculated depends on both the magnitude of the signal and the phase shift that is generated. Depending on the frequencies that are used, different parameters can be measured within the body. High frequency signals are able to pass through the cell membrane and as a consequence both the intracellular and extracellular impedance is measured. Low frequency signals on the other hand only measure the impedance of the extracellular compartment. These properties can be used to measure different parameters (1).

Depending on the desired output, two different BioZ measuring techniques can be distinguished, i.e. single-frequency measurements and multi-frequency measurements. Multi-frequency measurements, also known as bioimpedance spectroscopy (BIS), sends currents of multiple frequencies through the body and can be used to determine static parameters (e.g. body composition, fluid status, etc.). Single-frequency signals on the contrary, can be used to measure more dynamic parameters, such as respiration (2). Single-frequency BioZ devices that measure respiration can have an added value in patients suffering from pulmonary problems such as chronic obstructive pulmonary disease, sleep apnea or asthma. For these patients, continuous monitoring is desirable. Therefore, a wearable and compact size device with low-power consumption would be the perfect tool for continuous monitoring of respirational parameters in these patients.

2. OBJECTIVES
The main objective of this study was to investigate whether a wearable low-power single frequency device from Holst Centre (Eindhoven, The Netherlands) was able to measure several respirational parameters (i.e. respiratory rate, respiratory volume and respiratory patterns) in a correct way compared to a gold standard spirometer system. Different electrode configurations were tested to determine the ideal electrode configuration needed for optimal BioZ detection.

3. METHODS
A pilot study was set up to validate respirational parameters measured by a wearable BioZ-device and to determine the ideal electrode configuration for these measurements. A wearable, compact-sized and low-power multi-parametric BioZ monitoring device from Holst Centre (Eindhoven, The
Netherlands) was used. During the measurements BioZ, ECG and accelerometer data were collected. BioZ was recorded with a fixed single-frequency of 20 kHz, with a sampling rate of 1024 Hz. Tetrapolar electrode configurations were used in order to suppress the skin-electrode contact impedance. Four different electrode configurations were tested (Figure 1). All BioZ measurements were validated by gold standard spirometer measurements, using a MasterScreen CPX Metabolic Cart from JAEGER® (Würzburg, Germany) in parallel. The sample frequency of the spirometer was equal to 100 Hz.

Healthy subjects (n=4) were asked to perform three different protocols for each electrode configuration (forty-eight measurements in total). The distances between the electrodes, which altered for each configuration, were kept constant for each subject. The first protocol focused on different respiration patterns, i.e. free breathing, thoracic breathing, abdominal breathing and apnea. During the second protocol different respiration rates were tested, i.e. 10, 15 and 30 breaths per minute. The final protocol focused on different respirational volumes (high volume, normal volume and small volume). The BioZ measurements and spirometer measurements were all performed simultaneously.

4. RESULTS AND DISCUSSION

Four healthy subjects performed three different protocols for each electrode configuration. The correlation and conformity between BioZ data and spirometer data were checked to validate the ability of the BioZ device to correctly measure respirational parameters.

4.1 Respiration Patterns

The respiration pattern protocol was divided into four different parts, i.e. a free breathing, thoracic breathing, abdominal breathing and apnea part. Each part was separated from one another by a period of holding breath for ten seconds. Figure 2 shows that the results obtained from the BioZ-device and the spirometer are similar. A nearly identical graph was obtained for both the BioZ-device data and spirometer data. Different breathing patterns, including apnea events, can be distinguished using the BioZ-device.
4.2 Respiration Rate

For the respiration rate protocol, the subjects were asked to breath at three different rates during the breathing protocol (Figure 3). The top part of the figure shows the actual respiratory pattern measured by the BioZ-device, which emphasizes the different rates. Each part was separated from one another by a 10 second holding breath period.

The actual respiratory rates were calculated through a home-made algorithm as seen in the bottom part of the figure. Both the respiratory rate from the BioZ-device and the respiratory rate from the spirometer are shown. The correlation between these respiratory rates was calculated for each subject (across the different configurations) and for each configuration (across the different subjects). However, some outliers were excluded from the analysis due to loss in signal quality.

The second column of Table 1 shows the correlations between the respiratory rates from the BioZ device and the spirometer. Similar breathing rates were obtained for both devices. The respiratory rates measured by the BioZ-device match the rates measured by the spirometer independently of the configuration that was used. Although all BioZ configurations show excellent correlations with the gold standard spirometer, configuration 4 is the most suitable one to measure respiratory rates using the

**Figure 2:** Wearable BioZ-device vs spirometer data obtained from the breathing patterns protocol. Four different parts are distinguished, i.e. free breathing, thoracic breathing, abdominal breathing and apnea. Each part lasts approximately one minute and is separated from one another by periods of apnea for ten seconds.

**Figure 3:** Respiratory rates obtained from the respiratory rate protocol. Three different respiratory rates are distinguished. The upper part of the graph shows the breathing pattern. The lower part of the graph shows the calculated respiratory rates. Bpm: breaths per minute.
BioZ device, as the highest correlation with the gold standard spirometer was obtained. Correlation analysis was performed using the Statistical Package for Social Sciences release 20.0 (IBM® SPSS® Inc., Chicago, Illinois, USA).

Table 1: Pearson correlation for each subject and each configuration between BioZ-device data and spirometer data for respiratory rates and respiratory volumes.

<table>
<thead>
<tr>
<th></th>
<th>Respiratory rates</th>
<th>Respiratory volumes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Pearson</td>
<td>Total Pearson</td>
</tr>
<tr>
<td>Subject 1</td>
<td>0.998*</td>
<td>0.909*</td>
</tr>
<tr>
<td>Subject 2</td>
<td>0.975*</td>
<td>0.214**</td>
</tr>
<tr>
<td>Subject 3</td>
<td>0.962*</td>
<td>0.840*</td>
</tr>
<tr>
<td>Subject 4</td>
<td>0.989*</td>
<td>0.669*</td>
</tr>
<tr>
<td>Configuration 1</td>
<td>0.982*</td>
<td>0.956*</td>
</tr>
<tr>
<td>Configuration 2</td>
<td>0.987*</td>
<td>0.881*</td>
</tr>
<tr>
<td>Configuration 3</td>
<td>0.984*</td>
<td>0.907*</td>
</tr>
<tr>
<td>Configuration 4</td>
<td>0.992*</td>
<td>0.878*</td>
</tr>
</tbody>
</table>

*p < 0.001; ** p < 0.05

4.3 Respiration Volume

The volume protocol was performed to check whether a correlation exists between the amplitudes of the BioZ and the spirometer data (difference in volume and BioZ). The correlation was again calculated for each subject across the different configurations and for each configuration across the different subjects (Table 1). Some values were excluded from the study due to too low signal amplitudes that were measured during the low volume part of the protocol. Interfering signals (cardiac output) prevented easy detection of the low volume signals. A significantly high correlation was obtained for subject 1 and 3 across the different configurations. A significant low correlation was obtained for subject 2, while a significant correlation was obtained for subject 4. However, these differences can be explained by the complexity of the study set up, since the subjects need to focus on both respiration rate and volume simultaneously, which is very challenging. For each configuration, significantly high correlations were obtained. This clearly demonstrates the ability of our wearable BioZ-device to measure breathing volumes in a correct manner. When dividing the subjects according to gender, an even higher correlation is seen for almost all configurations since it plays a significant role in BioZ measurements due to the different body composition.

5. CONCLUSION

Based on the above results, one can state that there is a clear correlation between the ability of a BioZ device to detect different respirational parameters compared to a traditional gold standard spirometer device. The similar breathing patterns and corresponding respiratory rates and volumes demonstrate these correlations. Configuration 4 is the most favourable as it has the ability to measure respiratory rates and volumes with the highest correlation compared to the gold standard spirometer. It can thus be concluded that the wearable compact size BioZ-device can be used to correctly measure multiple respirational parameters without the need for an obtrusive spirometer. It shows a promising technique for future applications in remote monitoring settings, as patients suffering from chronic diseases will benefit from constant follow-up using wearable technologies.

REFERENCES