Variability of Body Surface Impedance Measurements in Cardiac Transplant Patients and Normal Subjects

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Abstract

The aim was to establish the variability of body surface impedance measurements in cardiac transplant patients and healthy subjects. In 11 healthy subjects, impedance measurements were taken: i) daily over 5 days; ii) before and after a meal; iii) in 5 different body positions. In the transplant group of 3 patients, 2 consecutive impedance recordings were taken daily after transplantation. All recordings were of 1 minute duration at excitation frequencies of 1, 3, 10, 30 and 100 kHz. There were large differences in the impedance of different subjects in both the healthy and patient groups which ranged from 15 ohm to 98 ohm at 1 kHz. The maximum difference in daily repeated measurements in the transplant group was a mean of 9 ohm. The maximum difference in recordings taken on the same day was less than 1 ohm. In the control group the largest mean change in impedance due to change in posture was from supine to lying on left side for which the impedance increased by 4 ohm. Eating a meal reduced the impedance by a mean of 2 ohm in the supine position.

1. Introduction

Impedance measurements may have clinical utility in the detection of organ rejection in cardiac transplant patients. Biopsy is the gold standard for rejection assessment and because of the invasive nature of this technique, many noninvasive measurements for detection of rejection have been proposed, including electrocardiography, impedance cardiography and echocardiography [1-3]. Invasive intramyocardial impedance measurements, have been shown to be highly sensitive to rejection in dogs [4]. This involved the injection of constant amplitude alternating current into the myocardium, via electrodes placed within the right and left ventricular walls, and monitoring daily the level of impedance. Changes in the electrical characteristics of cells during organ rejection were detected as increases in impedance by up to 30% [4]. The ability to perform such measurements from the body surface could provide a simple noninvasive tool for detection of organ rejection. With this in mind we set out to establish, in a control group of healthy subjects, the variability of body surface impedance measurements with regard to body posture, consumption of food and drink, and the effects of repeated electrode placement, and to compare these with impedance measurements from cardiac transplant recipients.

2. Method

2.1. Instrumentation

The impedance measurement system comprised the impedance unit and control/data acquisition computer. The impedance unit was based on the four electrode impedance measurement principle. It delivered an alternating current of 10 µA via two excitation electrodes, and monitored the resulting voltage via two sensing electrodes. Excitation frequency and duration of recording were controlled by the computer. In this study frequencies of 1, 3, 10, 30 and 100 kHz were used with a recording period of 60 s at each frequency. The impedance unit provided an output signal proportional to the component of the patient voltage in phase with the excitation current, and this was logged to the computer at a sample rate of 100 Hz.

2.2. Subjects and data collection

Impedance was recorded in 11 healthy volunteers. Figure 1 shows an example of the positions of the excitation and sensing electrodes on the body surface. Repeated impedance measurements were recorded for five consecutive days at approximately the same time each day. Each day the electrodes were re-applied with reference to anatomical features on the body surface. In a further exercise, to establish the effect of variability in electrode placement, electrodes were re-applied with reference to markers on the body surface allowing more accurate repeat electrode placement, in a subgroup of 5 subjects.

We investigated the effects of consuming food and drink, and posture on body surface impedance

measurements. Recordings were taken before and after the volunteers had consumed food and drink, and in five body postures i) supine (flat), ii) lying on left side (left), iii) lying on right side (right), iv) semi-supine (s-s), and v) sitting upright (up). Electrodes were not removed between any of these changes.
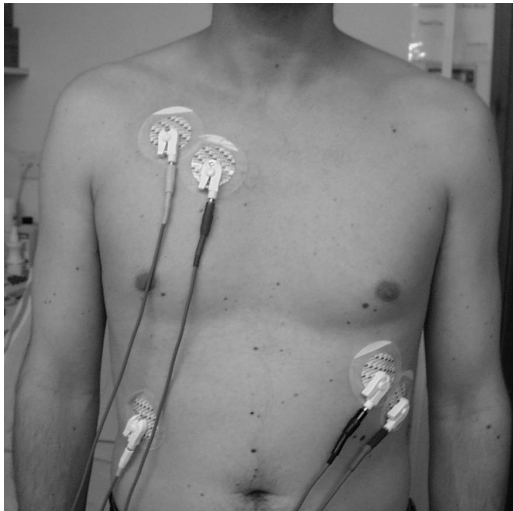

Figure 1. Positions on the body surface of excitation electrodes (outer pair) and sensing electrodes (inner pair).

The patient group comprised three patients who had received donor hearts. Impedance recordings were taken daily for 6 days commencing within 1 week following the transplant. Consecutive recordings were taken each day so that within day repeatability could be assessed. Recordings were taken at approximately the same time each day. Electrodes were positioned each day with reference to anatomical locations as in figure 1.

3. Results

3.1. Characteristics of the impedance

Figure 2 shows an example of an impedance recording from a healthy subject. As would be expected the impedance falls as the frequency of the excitation current increases. Short term variation in the impedance is mainly due to respiration and is most apparent at the lowest excitation frequencies.

There were large ranges of measured impedance values over all the subjects. Table 1 shows the mean impedance at each frequency for each subject and patient.
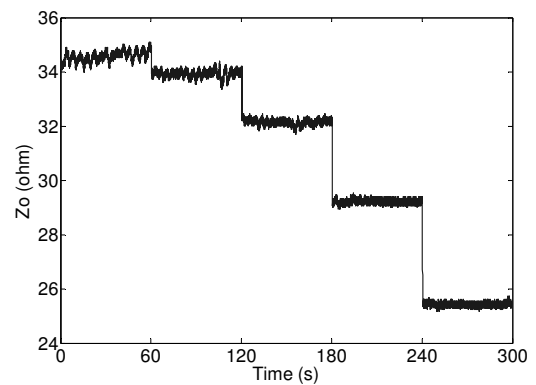

Figure 2. 300 s impedance recording from a normal subject. Each 60 s interval corresponds to excitation frequencies of 1, 3, 10, 30 and 100 kHz.

Table 1. Mean impedance (ohm) of subjects and patients at each excitation frequency.

Subject /patient	Frequency (kHz)				
	1	3	10	30	100
s1	65.6	62.8	59.6	55.0	49.8
s2	52.4	51.2	49.0	45.0	39.0
s3	85.4	82.6	79.2	74.4	67.6
s4	55.4	55.0	52.2	46.8	40.0
s5	52.2	50.8	47.8	42.4	37.6
s6	55.2	53.2	51.0	47.2	41.6
s7	78.6	75.0	71.8	68.2	62.4
s8	52.0	50.0	47.8	44.2	39.2
s9	58.6	56.4	53.6	49.2	43.8
s10	97.9	93.3	89.8	88.2	82.2
s11	88.0	85.2	81.6	77.2	71.2
p1	22.3	21.9	21.1	19.9	18.7
p2	17.9	17.8	17.2	16.1	14.6
p3	29.4	28.9	28.0	26.3	24.2
Mean	57.9	56.0	53.6	50.0	45.1

3.2. Repeatability

The repeatability of the daily impedance measurements in the healthy group showed a mean maximum difference of 10 ohm when electrode positions were not marked but placed according to anatomical features. Figure 3 shows the daily measurements for this group.
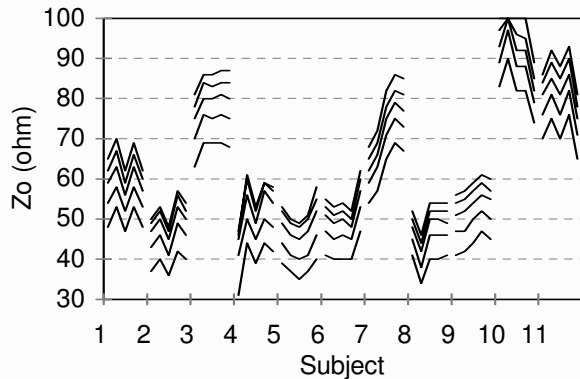

Figure 3. Daily impedance measurements for the control group. Each trace starts at day 1 and ends at day 5. Top trace for each subject is for an excitation frequency of 1 kHz with subsequent traces corresponding to 3, 10, 30 and 100 kHz.

In the subgroup of 5 subjects for which the electrode positions were marked, the mean maximum difference across the five measurements was reduced to 5 ohm.

For the patient group the maximum difference in repeated measurements was a mean of 9 ohm. The maximum difference in consecutive recordings taken on the same day was less than 1 ohm. These differences were consistent across all frequencies. Biopsy results showed that none of the patients experienced rejection at the time of the study.

3.3. Posture

Impedance changes due to changes in body posture from the supine position are illustrated in figure 4. On average all postures gave a greater impedance than the supine position, the greatest being a 4 ohm increase when lying on the right side.

3.4. Food consumption

The effect of eating a meal was to reduce the impedance by a mean of approximately 2 ohm. Figure 5 shows this effect for different body postures.
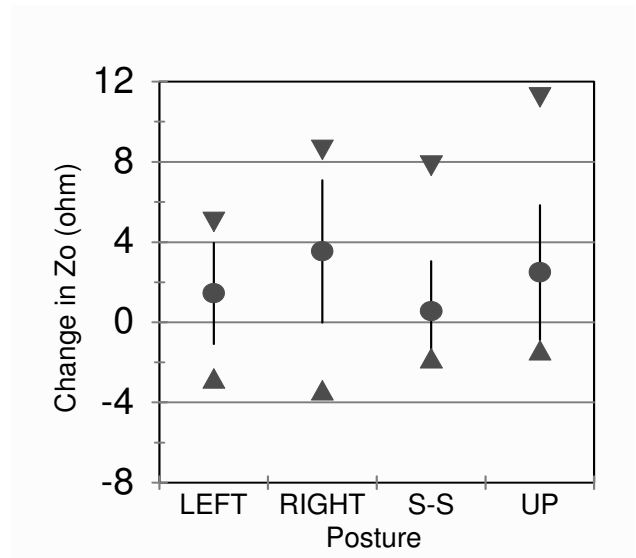

Figure 4. Change in impedance due to changes in posture relative to supine position. Data shown are the mean ± standard deviation and range across all subjects and excitation frequencies.
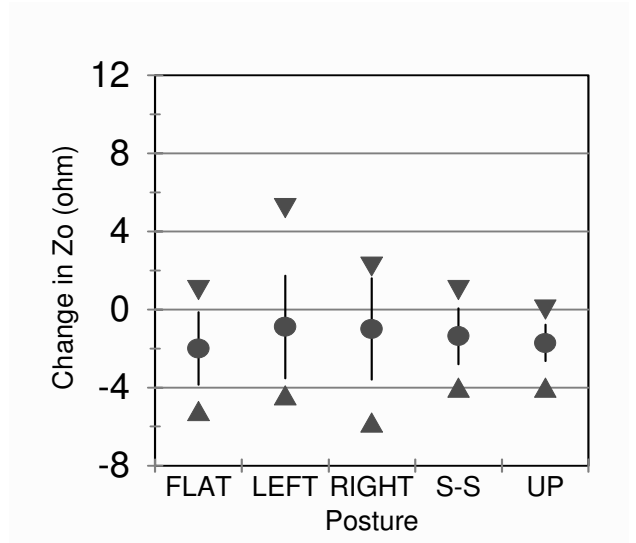

Figure 5. Change in impedance due to food consumption. Data shown are the mean ± standard deviation and range across all subjects and excitation frequencies.

4. Discussion

The body impedance may change due to many phenomena, and this has spurred its use in many clinically related applications. For example, body composition and impedance plethysmography for assessment of fluid content

and muscle mass [5,6]. It is not surprising then that the impedance measurements showed a wide variation across subjects in our study.

This work has shown the importance of accurate positioning of electrodes to ensure repeatable impedance measurements. The use of anatomical markers for repositioning of electrodes has proved inadequate in this study. Electrode positioning was problematic in the patient group because access was often limited due to dressings and connection of other monitoring equipment.

Although the mean impedance changes due to changes in posture and food consumption were small, some of the changes for individual subjects were large and of the order of the changes that are reported to occur in intracardiac impedance measurements during rejection. Further work should investigate the positioning of electrodes to improve more selective targeting of impedance measurement of the heart, and to assess the changes recorded in patients with rejection.

Acknowledgements

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