Transthoracic Impedance Compared to Magnetic Resonance Imaging in the Assessment of Cardiac Output

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Resumo

Background: Cardiac magnetic resonance imaging is considered the gold-standard method for the calculation of cardiac volumes. Transthoracic impedance cardiography assesses the cardiac output. No studies validating this measurement, in comparison to that obtained by magnetic resonance imaging, are available.

Objective:To evaluate the performance of transthoracic impedance cardiography in the calculation of the cardiac output, cardiac index and stroke volume using magnetic resonance imaging as the gold-standard.

Methods:31 patients with a mean age of 56.7 ± 18 years were assessed; of these, 18 (58%) were males. Patients whose indication for magnetic resonance imaging required pharmacologic stress test were excluded. Correlation between methods was assessed using the Pearson's coefficient, and dispersion of absolute differences in relation to the mean was demonstrated using the Bland-Altman's method. Agreement between methods was analyzed using the intraclass correlation coefficient.

Results: The mean cardiac output by transthoracic impedance cardiography and by magnetic resonance imaging was 5.16 ± 0.9 and 5.13 ± 0.9 L/min, respectively. Good agreement between methods was observed for cardiac output (r = 0.79; p = 0.0001), cardiac index (r = 0.74; p = 0.0001) and stroke volume (r = 0.88; p = 0.0001). The analysis by the Bland-Altman plot showed low dispersion of differences in relation to the mean, with a low amplitude of agreement intervals. Good agreement between the two methods was observed when analyzed by the intraclass correlation coefficient, with coefficients for cardiac output, cardiac index and stroke volume of 0.78, 0.73 and 0.88, respectively (p < 0.0001 for all comparisons).

Conclusion: Transthoracic impedance cardiography proved accurate in the calculation of the cardiac output in comparison to cardiac magnetic resonance imaging. (Arq Bras Cardiol 2012;99(6):1149-1155)

Keywords: Heart failure; electric impedance; cardiac ouput; magnetic resonance spectroscopy.

Introduction

Heart failure (HF) is a disorder associated with neurohormonal activation, which ultimately results in hemodynamic changes such as decreased cardiac output (CO), increased left ventricular filling pressures and increased systemic vascular resistance (SVR)[1,2]. In addition, most of the medications used for the treatment of both chronic and acute HF have effects on the cardiovascular hemodynamics. Specific hemodynamic measurements such as CO, SVR, and pulmonary capillary pressure are usually obtained only in critically ill patients due, to a great extent, to the risk, discomfort and costs of invasive procedures such as Swan-Ganz catheter monitoring. However, these measurements could be useful in the management of patients with HF, even those not critically ill.

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Transthoracic impedance cardiography (TIC) is a noninvasive method that allows the estimate of hemodynamic parameters[3-5]. It is a type of pletismography that uses the changes in the thoracic electric impedance to estimate changes in the blood volume within the aorta and changes in the thoracic fluid volume. Thus, hemodynamic parameters and the volemic status can be estimated. Although TIC has been evaluated in some clinical situations[6-9], some questions remain on its accuracy and usefulness[10]. Cardiac magnetic resonance imaging (CMRI) is considered the gold-standard for the calculation of cardiac volumes[11,12], and no previous study comparing the two methods has ever been conducted.

The objective of the present study is to determine the performance of TIC in the calculation of the CO using CMRI as the gold-standard.

Methods

From March to June 2007, 31 patients who had been referred by their physicians for ambulatory CMRI were included in this study. Their mean age was 56.7 ± 18 years

and 18 (58%) were males. Indications for CMRI were the following: 1) assessment of chronic ischemic heart disease (previous myocardial infarction, myocardial viability) in 11 patients; 2) assessment of arrhythmia (ventricular arrhythmia, frequent ventricular extrasystoles on Holter, palpitations, etc) in 11 patients; 3) assessment of the etiology of cardiomyopathies in six patients; and 4) assessment of acute/subacute myocarditis in three patients.

For internal logistic reasons, patients undergoing CMRI in a specific day of the week were included. Immediately before CMRI, they were assessed by TIC. Patients whose indication for CMRI included pharmacological stress test were excluded.

CMRI was performed with the patient at rest using an MRI scanner with a main field of 1.5 tesla (Gyroscan NT Intera, Philips Medical System, Best, The Netherlands). For the assessment of the functional parameters of the left ventricle (LV) a gradient-echo pulse sequence with steady-state free precession – (SSFP) transverse magnetization was used with the following parameters: TR 3.1 ms; TE 1.55 ms; inclination angle: 55º; FOV 350-420 mm; matrix: 192 x 192; scan percentage 70%; RFOV: 75%; phases: 24; WFS: 0,21 pixels; NSA 1, views: 8-10; thickness: 8 mm; interval 2mm.

Eight to 10 views of the left ventricular short axis were sequentially acquired, covering the whole ventricular cavity from the apex to the mitral ring. Acquisition of each view took approximately eight seconds (from eight to 12 heart beats, depending on the heart rate), during which the patients were asked to hold their breath.

Four parameters were calculated using the Simpson's method: ejection fraction (EF); end-diastolic volume (EDV); end-systolic volume (ESV); and stroke volume (SV). These parameters were obtained from cine-MRI images as follows: manual contour, in a specific software commercially available (ViewForum, version 4.2, Philips Medical Systems, Best, The Netherlands), of the LV endocardial border in the diastolic (larger area) and systolic (smaller area) phases in the 8-10 views of the LV short axis. EDV was measured as the sum of the products of the area of each view in the diastolic phase multiplied by the view thickness. ESV was calculated similarly, but using the systolic phase of each view for the calculation. SV was calculated as: SV = EDV–ESV; and the EF as: EF = (SV/EDV) x 100. EDV, ESV and VS were then normalized for the body surface area, thus generating the parameters IEDV, IESV and ISV. Finally, the cardiac output was calculated as: CO = SV x HR.

TIC was performed in a Bio Z Dx Diagnostics device (Cardiodynamics, San Diego, CA, USA). Four pairs of electrodes positioned on the neck and thorax were used; they were connected to a portable device the size of an electrocardiograph. A low-frequency high-amplitude alternating current is generated by the four external sensors and the internal electrodes capture the instant voltage changes. According to Ohm's law, when a steady current is applied to the thorax, the voltage changes are directly proportional to the impedance changes. The total thoracic impedance, named baseline impedance, is the sum of the impedance of all thoracic components (adipose tissue, heart, lung, skeletal muscle, vascular tissue, bones and air). Variations in relation to the baseline impedance occur because of the changes in the pulmonary volume with breathing and changes in blood volume within large vessels during systole and diastole. The respiratory component is filtered and excluded from the device analysis, leaving only the variations resulting from blood changes within the aorta, thus permitting hemodynamic calculations. Several parameters such as CO, cardiac index (CI), SV, peripheral arterial resistance, contractility parameters and thoracic fluid content are provided by the device. In the present study, only CO, CI and SV were analyzed.

Data were expressed as means and standard deviation, because they were normally distributed. Comparison between means was made using Student's *t* test. Correlation between methods was assessed using the Pearson's coefficient, and dispersion of absolute differences in relation to the mean was demonstrated using the Bland-Altman method. Agreement between methods was made using the intraclass correlation coefficient (ICC). The significance level was set at 5% and the analysis was made using the SAS® System software, version 6.04.

Results

The baseline population characteristics are shown in Table 1. The mean ejection fraction, as calculated by CMRI, was 62 ± 17%. Of the 31 patients, nine showed global systolic dysfunction on CMRI, and 12 showed regional contractility abnormalities. Four patients showed LV concentric hypertrophy. CO in the population as a whole, as calculated by TIC and CMRI, was 5.16 ± 0.9 and 5.13 ± 0.9 (p = 0.76), respectively. There was a good correlation between the methods as regards CO, CI and SV, as shown in Figures 1 to 3. The Bland-Altman plot showed small dispersion of differences in relation to the mean, with low amplitude of agreement intervals (Figure 4). There was good agreement between the two methods when assessed by ICC, as shown in Table 2.

Discussion

In the present study, we showed that TIC had a good performance in the calculation of CO, CI and SV, using CMRI as the gold-standard. This is the only study carried out in a stable outpatient population with the objective of evaluating the accuracy of TIC in the measurement of CO.

We used CMRI as a reference method. Its usefulness in estimating the cardiac output has been confirmed by various techniques in both experimental and clinical studies, showing good performance[13-16].

The accuracy of cardiac output measurements using the new generation of TIC devices has already been analyzed using invasive methods in intensive care environments[3], postoperative period of coronary artery bypass grafting[5], and in hemodynamics laboratory in patients with pulmonary hypertension[4]. In all these studies, TIC showed good performance in the calculation of cardiac output, with moderate correlation with calculations made by the Fick or termodilution methods[3-5]. In our study, we

Table 1 – Baseline population characteristics

Variables	Values
Age (years)	56.7 ± 18
Male gender	18 (58%)
Weight (Kg)	73.8 ± 14.4
Height (m)	1.68 ± 0.1
Body mass index (Kg/m2)	26.2 ± 4.6
Body surface (m2)	1.83 ± 0.2
Heart rate (bpm)	66.4 ± 11
End-diastolic volume (mL)	140.6 ± 58.9
End-systolic volume (mL)	60.5 ± 55.9
Left ventricular mass (g)	114.7 ± 43.7
Ejection fraction (%)	62.1 ± 17
Cardiac output on CMRI (L/min)	5.16 ± 0.97
Cardiac index on CMRI (L/min/m2)	2.84 ± 0.47
Stroke volume on CMRI (mL)	80.2 ± 19.8
Cardiac output on bioimpedance (L/min)	5.13 ± 0.9
Cardiac index on bioimpedance (L/min/m2)	2.81 ± 0.43
Stroke volume on bioimpedance (mL)	79.3 ± 19.1

CMRI: cardiac magnetic resonance imaging.

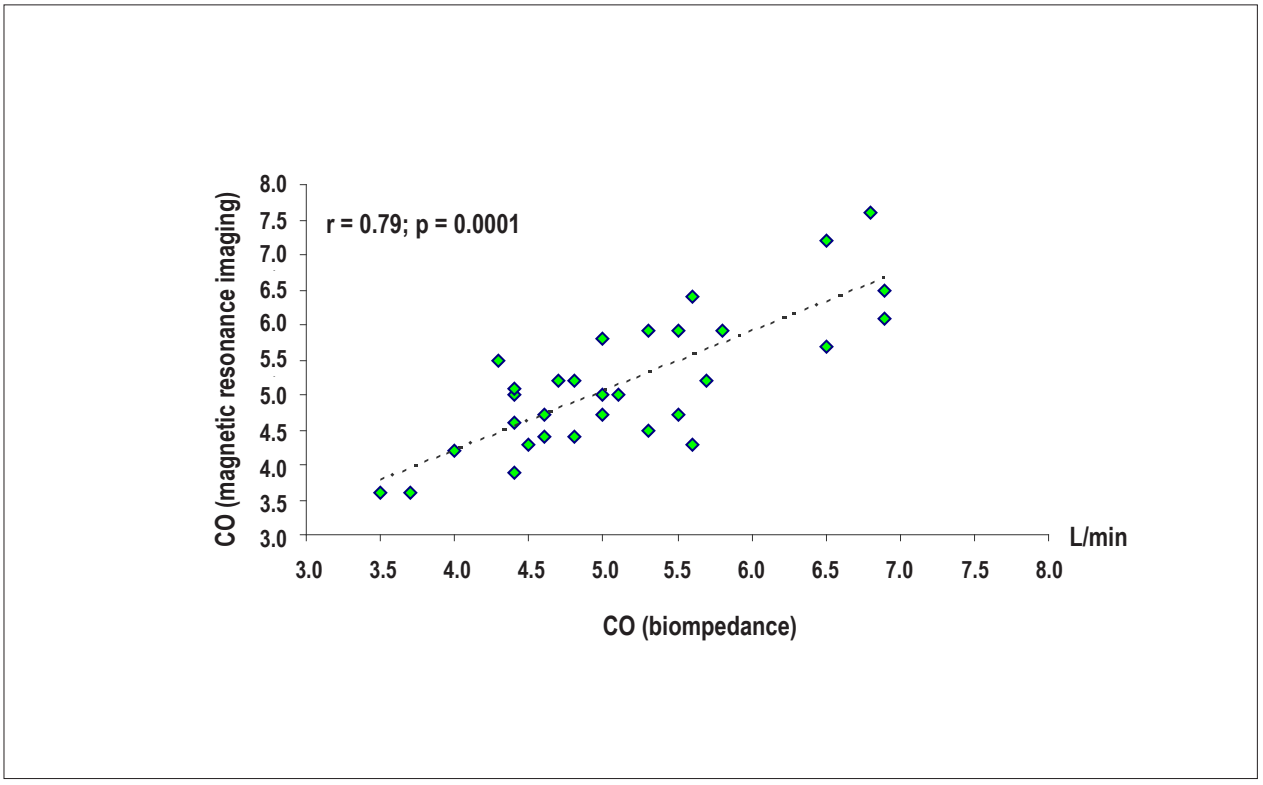

Figure 1 – *Correlation of cardiac output (CO) values as calculated by transthoracic bioimpedance and by cardiac magnetic resonance imaging*

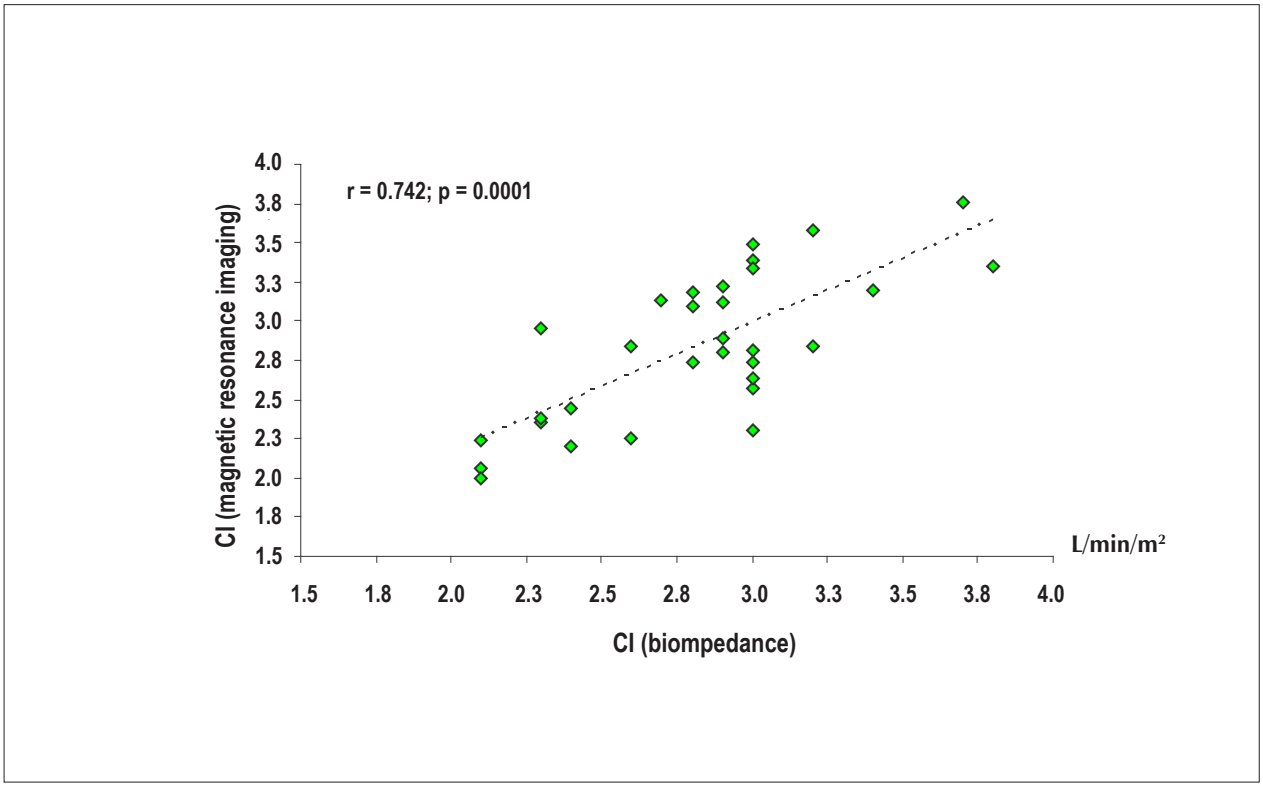

Figure 2 – *Correlation of cardiac index (CI) values as calculated by transthoracic bioimpedance and by cardiac magnetic resonance imaging*

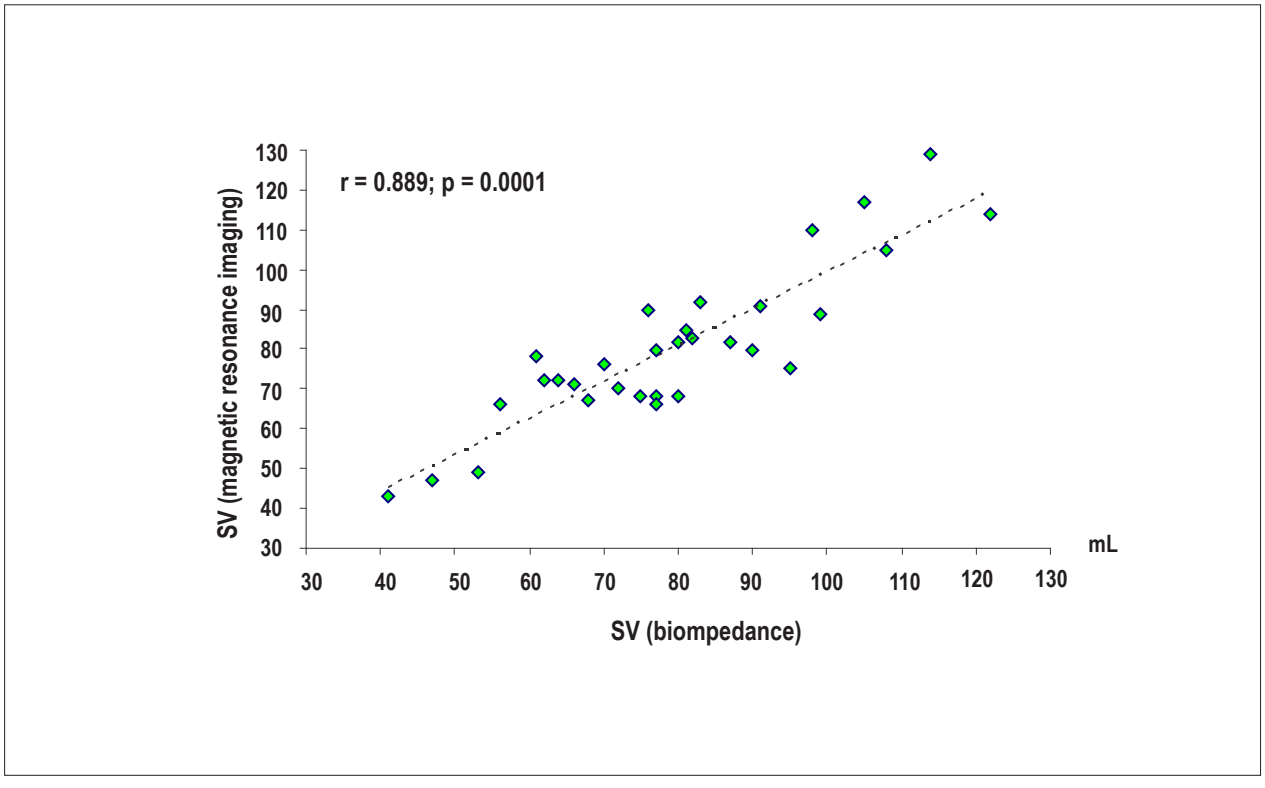

Figure 3 – *Correlation of stroke volume (SV) values as calculated by transthoracic bioimpedance and by cardiac magnetic resonance imaging*

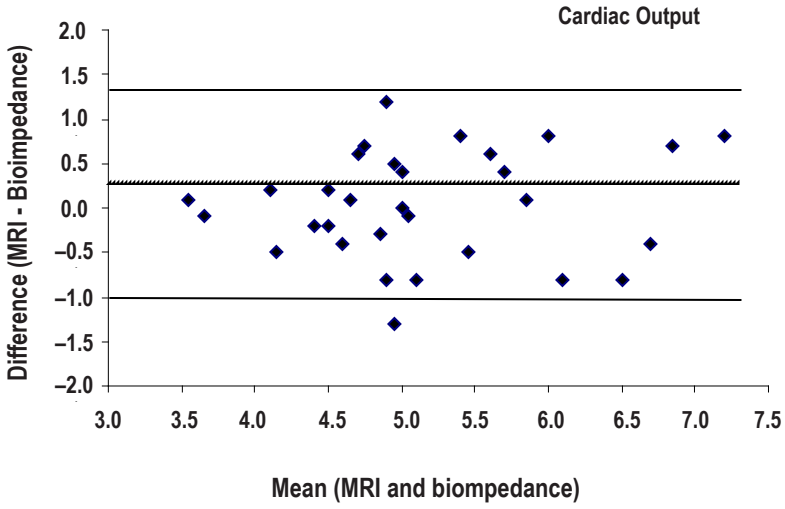

Figure 4 – *Bland-Altman plot for cardiac output, showing dispersion of absolute differences in relation to the mean*

Table 2 – Agreement between methods as regards the hemodynamic parameters, as assessed by the intraclass coefficient

Variable	Intraclass coefficient	p value
Cardiac output (L/min)	0.785	< 0.0001
Cardiac index (L/min/m^2)	0.729	< 0.0001
Stroke volume (mL)	0.884	< 0.0001

confirmed these findings in less severely ill outpatients in whom invasive measurement of hemodynamic parameters would not the ethical, so we used CMRI, a noninvasive but accurate method.

The clinical application of TIC has been assessed in patients with acute dyspnea in the emergency department[6,7]. TIC made physicians change patients' diagnosis in 13% of the cases, and medications in 39% of the patients[6]. In another study, it was useful to differentiate cardiac form noncardiac dyspnea[7]. However, these studies are limited by the lack of a control group and by non-randomization, which makes it difficult to evaluate the ability of the method in changing outcomes.

In an outpatient study – the PREDICT study – in recently hospitalized patients with HF, serial TIC was able to identify patients at a high risk for hospitalization and death. Three TIC parameters were useful in this analysis: velocity index, thoracic flow content index, and left ventricular ejection time. However, there is no study available demonstrating that serial TIC measurements could change clinical outcomes.

In the only randomized blind study in patients with severe HF, no clinical benefit of the method could be demonstrated[10]. The BIG study[10] includes a subgroup of the ESCAPE study[17] in which patients with severe HF were hospitalized for medication adjustments guided by invasive hemodynamic parameters. This approach did not prove superior to the conventional adjustment based on clinical assessment[17]. In the subgroup undergoing TIC assessment, a modest correlation of CO as measured by TIC was observed in relation to invasive parameters (r ranging between 0.4 and 0.6 in serial measurements). The thoracic fluid content as calculated by TIC was not a reliable measurement to estimate the pulmonary capillary wedge pressure. In addition, unlike in the PREDICT study, TIC did not prove useful to establish the prognosis.

In the context of arterial hypertension, a randomized study demonstrated that TIC was beneficial in the control of blood pressure[9]. The rate of patients with controlled blood pressure (< 140 x 90 mmHg) by the end of the study in the groups TIC and control was 77% and 57%, respectively. For blood pressure < 130 x 85 mmHg, these values were 55% versus 27%.

Based on these studies, we can conclude that, although TIC may measure cardiac output and peripheral resistance with moderate accuracy, there are no data indicating that the method results in changes in clinical outcomes, with a possible exception in patients with uncontrolled arterial hypertension. However, the method may be useful in research, such as in studies on the mechanisms of diseases and on hemodynamic responses to determined drugs or interventions.

In conclusion, the assessment of CO by TIC proved accurate in stable outpatients, using CMRI as the gold-standard.

Potential Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Sources of Funding

There were no external funding sources for this study.

Study Association

This study is not associated with any post-graduation program.

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