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IMPEDANCE CARDIOGRAPHY FOR MONITORING CHANGES IN CARDIAC OUTPUT

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Abstract : Impedance Cardiography (ICG) is a non invasive method useful for continuous monitoring of cardiac output but, it still has not found wide usage for measuring cardiac output in clinics and research. Most studies focused on comparing the cardiac output measured at rest with reference methods. In the present study we evaluated the validity of ICG against Doppler Echocardiography (DE) in measuring cardiac output changes that occur during static exercise. Cardiac output of 30 healthy males between 18-26 yrs of age was measured during supine rest, during and 5 min after completion of 3 minute static exercise by ICG and DE. The increase in cardiac output during exercise measured with ICG and DE does not differ significantly (1.04±0.72 L/min and 1.05±1.24 L/min respectively) and has significantly high correlation (r=0.76, P<0.001). The bias and limits of agreement are (–0.01±0.83) in acceptable limits. The pooled means of cardiac output measured by ICG and DE do not differ significantly and bears a significant correlation (r=0.812, P<0.001). The bias (d±s) calculated is 0.15±0.64 L/min. ICG could provide valid information regarding the relative changes in cardiac output.

Key words : cardiac output echocardiography monitoring stroke volume

INTRODUCTION

Impedance Plethysmography (IP), a noninvasive technique, originally was described for measurement of blood flow (1). Application of this technique, has been extended for determining cardiac output by recording changes in impedance that occur as blood is pumped into the aorta (2). Cardiac output and stroke volume represents the functional expression of cardiovascular performance and can be used to monitor changes in a patient's hemodynamic status. Impedance Cardiography (ICG) have been found potentially useful in monitoring cardiac output of patient in inpatient settings

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as the changes in impedance and thus stroke volume can be recorded and displayed continuously on screen. In critical care settings, monitoring of hemodynamic parameters by pulmonary artery catheterization though useful but have received several criticism because of higher risk of infections and increase mortality owing to the invasive nature of the technique (3, 4). Recently, Silver et. al. (2004) have pointed out that owing to high cost involved in pulmonary artery catheterization this procedure may be replaced by noninvasive ICG (5). There are reports suggesting ICG is fairly comparable to the dye dilution, thermodilution techniques and also to Doppler Echocardiography (DE), for measurement of cardiac output at rest (6,7,8). Results from studies comparing the absolute values of cardiac output at rest may not be extrapolated to situations where gauging the fluctuations in cardiac output rather than absolute values were needed for example in exercise physiology research and in intensive care setups.

In the present study we evaluated the validity of ICG against DE,. as a reference method for comparison, in measuring the changes in cardiac output that occurs during static exercise. DE has shown a good correlation with invasive methods for measurement of cardiac output and is the most accepted non invasive method for determining cardiac output (9, 10). DE is particularly advantageous to be used in this exercise paradigm as it is capable of determining the cardiac output quickly and easily (8, 11).

In the present study, hand grip isometric exercise paradigm has been employed to register changes in cardiac output/stroke volume in healthy subjects. The change in cardiac output, which takes place during isotonic exercise, has been measured with ICG and DE.

MATERIAL AND METHODS

Subjects

30 healthy males, between 18-26 yrs of age, were recruited for this study. Brief history and clinical examination was done to rule out cardiovascular and respiratory diseases. Informed consent was obtained after explaining the nature of study to the subjects and ethical clearance was taken from the institutional ethics committee. Subjects were called 2 hrs after light break fast in morning.

Devices

Doppler echocardiography

The diameter of the left ventricular outflow tract was used to calculate the cross sectional area, assuming a circular profile. Measurements were made by cross sectional echocardiography in the parasternal long axis view (Hewlett-Packard Sonos 5500® Echocardiography System). Stroke volume and cardiac output were measured using protocols as described earlier (12).

Impedance cardiography

The Impedance Plethysmograph (NICOMON, Larsen & Turbo India Ltd.) was connected to the subject via four pairs of button electrodes as described previously (13). The lower thoracic voltage sensing electrodes were placed at the level of the xiphisternum in the mid-axillary lines and the cervical sensing electrodes were positioned laterally at the base of the neck as close as possible to the clavicles. The "current" electrodes, delivering an alternating current of 4 mA at 48 kHz, were placed with one pair 5 cm above the cervical sensing electrodes and the other pair 5 cm below the thoracic sensing electrodes. The recorded waveforms of changes in impedance are analyzed as a function of time using Kubicek's equation and area under the curve represents maximum change in blood flow during systole i.e. stroke volume. The NICOMON automatically averages stroke volume over ten cardiac cycles and displays the cardiac output using corresponding R-R intervals which are simultaneously recorded by it.

Protocol

Baseline cardiac output was measured in supine position after 30 min of rest by Impedance Cardiography. Simultaneously trained cardiac physician recorded cardiac output by echocardiography. The subject was asked to perform the static exercise for 3 minutes using hand grip dynamometer with sub-maximal static effort at 30% of maximum voluntary contraction. The cardiac output was again determined during and 5 minutes after completion of exercise.

Statistical analysis

Paired 't'-test was used to compare the pairs of cardiac output measured by Impedance Cardiography and Doppler Echocardiography measured three times i.e. at rest, during exercise and 5 min after exercise. The changes in cardiac output measured as both increase during exercise and decrease after exercise, were calculated and were compared using correlation analysis. As the correlation analysis may be misleading for assessing validity, agreement was also calculated using Bland & Altman plots (14). All three pairs of data were pooled and correlation analysis was done between cardiac output measured by ICG and DE and limits of agreement, P value less than 0.05 was taken as significant.

RESULTS

A total of 30 subjects who were evaluated were healthy from clinical point of view and their baseline characteristics are presented in Table I.

Cardiac outputs, measured before exercise during rest, during exercise and 5 minute of rest after exercise by Impedance Cardiography and Doppler Echocardiography, are presented in Table II. The mean cardiac

TABLE I: Baseline characteristics of the subjects. Data are expressed as Mean±SD.

No. of subjects (n)	30
Sex (M:F)	18:12
Age (in yrs)	21.5±2.4
Height (in cms)	171.1±5.3
Weight (in kgs)	61.2±7.5
BMI (kg/cm^2)	20.97±2.7
Systolic blood pressure (in mmHg)	120.9±6.5
Diastolic blood pressure (in mmHg)	75.2±5.9

TABLE II: Cardiac output obtained during rest, during exercise and 5 minute after rest as measured by Impedance Cardiography and Doppler Echocardiography. N=30, Values represents Mean±SD of cardiac output in L/MIN).

Cardiac Output	*At Rest*	*During Exercise*	*After Exercise*
Impedance cardiography	4.87±0.83	6.01±0.98	5.07±0.87
Doppler echocardiography	4.98±0.88	6.17±1.01	5.26±0.95

output values measured with two techniques do not differ significantly (P>0.05) either during rest, during exercise or after 5 minutes rest.

The pooled mean of cardiac output measured by Impedance Cardiography and Doppler echocardiography are 5.32±1.01 L/min. and 5.47±1.07 L/min respectively, which again do not differ significantly (P>0.1).

Correlation analysis revealed a significant correlation (r=0.812, P<0.001) between the pooled cardiac outputs measured with Impedance Cardiography and Doppler echocardiography (Scatter plot Shown in Fig. 1).

To test the validity of Impedance Cardiography for measuring cardiac output, mean difference (d) and standard deviation (s) was determined and limits of agreement were calculated as d + 1.96 s and d – 1.96 s (Table III). And for graphical representation of limits of agreement Bland & Airman graphs are presented (Fig. 2) The bias (expressed as d ± s) for cardiac output measurement by Impedance Cardiography and Doppler Echocardiography was 0.15±0.64 L/min.

The changes in cardiac output (Mean±SD) during and after exercise measured with Impedance Cardiography and Doppler echocardiography was 1.04±0.72 L/min and 1.05±1.24 L/min respectively which did not differ significantly (P>0.05). The detected

TABLE III: Limits of agreement between cardiac output measured measured with Impedance Cardiography and Doppler Echocardiography. d=bias, s=standard deviation.

Cardiac output measured with ICG and DE	d	s	d+1.96s	d–1.96s
Pooled data before exercise, during exercise and rest after exercise	0.15	0.64	1.41	–1.10
Change in cardiac output during exercise and before exercise	–0.01	0.83	1.61	–1.64

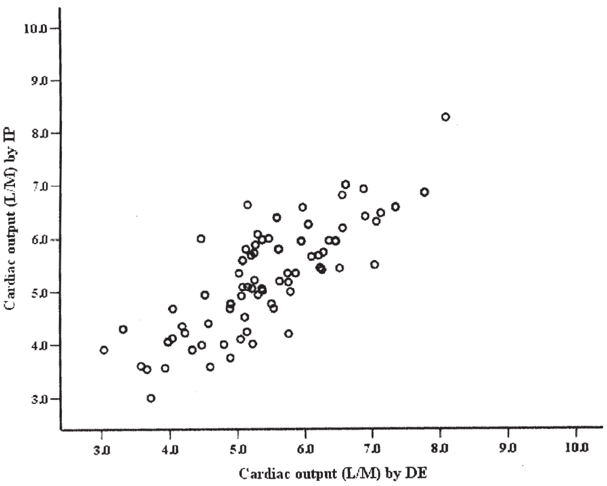

Fig. 1: Correlation between cardiac out measured by Doppler Echocardiography (DE) and Impedance Plethysmography (IP).

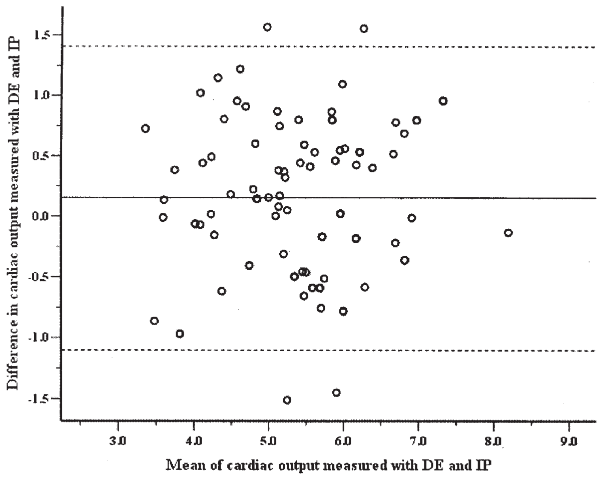

Fig. 3: Bland & Altman plot showing limits of agreement [solid reference line represents mean difference (d) and dotted reference lines represent d±1.96s].

change in cardiac output with two techniques have significantly high correlation (r=0.76, P<0.001). The bias and limits of agreement have been presented in Table III and graphical representation in Fig. 3.

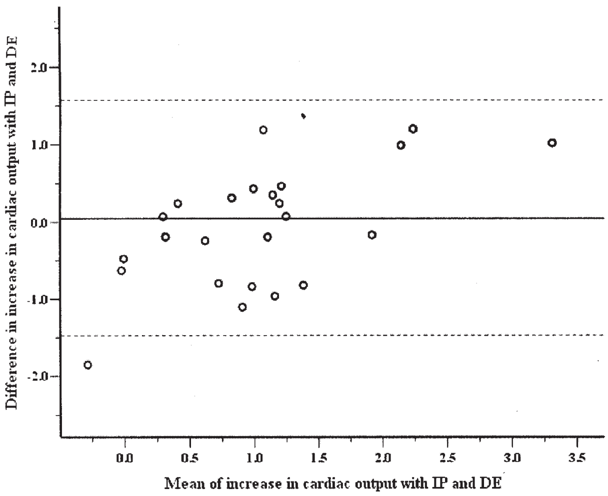

Fig. 3: Bland & Altman plot showing limits of agreement [solid reference line represents mean difference (d) and dotted reference lines represent d±1.96s].

DISCUSSION

After introduction of Impedance Cardiography for cardiac output in 1985 by Muji et. al., (2) the validity of this technique has been in question despite a large no. of published reports comparing it with Thermodilution and Doppler Echocardiographic methods (10, 15, 16). Most of the studies focused on comparing the absolute values of cardiac output at rest therefore their results may not be extrapolated to situations where gauging the fluctuations in cardiac output is important as in intensive care setups.

For cardiac output measurement, as Pick method is time consuming and invasive, DE is particularly advantageous in this exercise paradigm as it is quicker and easier (8, 11). In the present study we evaluated the validity of ICG using Doppler Echocardiography as a reference method for measuring the changes in cardiac output that occurs during static exercise.

The cardiac output by Impedance Cardiography did not differ from that by Doppler Echocardiography measured at rest, during static exercise and after static exercise. The pooled Cardiac outputs at rest, during and after static exercise also did not differ significantly measured by Impedance Cardiography and Doppler echocardiography. The correlation coefficient for the pooled data was also quite high signifying the fact that Impedance Cardiography is as good as Doppler echocardiography for measuring cardiac output over a wide range (2.8 L – 8.3 L). The high correlation levels are in accordance with the previous studies over a limited range of cardiac output measurement (10, 17, 18) Moreover, the limits of agreement calculated for pooled data is within acceptable limits and are in accordance with previous studies (17-20). Thus high correlation and acceptable limits of agreement signify the reliability of Impedance Cardiography in measuring cardiac output over wide range.

The reliability of Impedance Cardiography for gauging the changes in cardiac output has also been evaluated in this study and again the changes measured with Impedance Cardiography correlates well with the results with Doppler Echocardiography. The limits of agreement are favorable in this case too. Previous reports have established excellent preciseness and reproducibility of Impedance Cardiography (15, 21) therefore; the Impedance Cardiography can be expected to become the standard modality for monitoring cardiac output in intensive care setups as well as exercise physiology research and similar applications.

Recently two multicentre studies PREDICT study (Prospective Evaluation and identification of Decompensation by Impedance Cardiography Test) and BIG study (Bioimpedance cardiography) have been published and show encouraging results for application of ICG in the management of heart failure patients (22, 23). In addition, the data from the critically ill patients with altered states of cardiac output needs to be explored to establish the use of Impedance Cardiography in critical care settings.

Doppler Echocardiography itself may not be used for monitoring purposes as it is operator dependent technique which needs expertise. On other hand ICG does not need expertise and is a cost effective method which may be used for continuous monitoring purpose.

In this investigation, the study population was limited to healthy young subjects and as the Impedance Cardiography depends on the pressure area relationship, age related changes in the arterial system e.g. arteriosclerosis, may influence the results Although the aortic compliance did not depend on the degree of sclerosis for pressure in the physiological range (24) the influence of increased arterial wall stiffness with aging would be prominent with increased blood flow and pressure during exercise. Furthermore, the influence of an enhanced sympathetic activity during intense exercise on the propagation of a pressure pulse might be increased in aging therefore, further investigation in various age groups are required. In addition, more data regarding its application in patients with different clinical conditions with altered states of cardiac output needs to be explored.

In conclusion summary, we tested the validity of non invasive cardiovascular parameters measured by Impedance Cardiography during sub maximal static exercise in healthy young males. The good agreement between Impedance Cardiography and Doppler Echocardiography both for absolute values and for gauging changes in cardiac output suggest that Impedance Cardiography could provide valid information regarding the relative changes in cardiac output during sub maximal static exercise in healthy young humans. This conclusion can be extrapolated to critical care setup where beat to measurement of cardiac output may provide crucial information regarding the hemodynamic status of the patient. More data from patients may be helpful in judging the clinical utility of the impedance Cardiography for continuous monitoring of cardiac output non-invasively.

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