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STUDY OF CARDIAC OUTPUT BASED ON NON – INVASIVE IMPEDANCE PLETHYSMOGRAPHY IN HEALTHY VOLUNTEERS.

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Abbreviations: CI, Cardiac index; CO, Cardiac output; SD, Standard deviation; SV, Stroke volume.

ABSTRACT

Background-Impedance plethysmography is latest *non – invasive* technique to measure blood flow in any part of the body. As only heart rate & blood pressure is not sufficient to access a person's haemodynamic status, cardiac output measured by this simple technique will help further to access heart's functional status with avoidance of all complications associated with previous invasive techniques. **Objective** -To measure cardiac output noninvasively in healthy male volunteers of 2 age groups using impedance plethysmography & compare it with earlier study using different electrode placement technique. Also to compare cardiac parameters between these 2 age groups. **Methods-**Study has been done in 2 age groups (16–25 & 26–35 yrs), each of 26 healthy male subjects on Nivomon Series computerized software at Govt. Medical College, Bhavnagar. **Results-**Mean values of SV (Mean+SD) is 66.46+8.74 & 63.07+8.01; CO=5.08+0.9 & 4.8+0.68; CI=2.92+0.47 & 2.75+0.36 in respective age group. Compared with an earlier study (n=38), p>0.05. Also p>0.05 for comparison between 2 groups. **Conclusion-**No difference was there between 2 methods. There was no variation of parameters in this range of age group (16–35 yrs). So if it is further validated, than baseline normative data will be helpful in many future studies.

INTRODUCTION

Plethysmography is a technique of measuring volume of an organ; volume may be due to blood, water or air. It is of many types like Photo Plethysmography, Pneumo Plethysmography, Magnetic Plethysmography, Impedance Plethysmography, Body Plethysmography and Strain Gauge Plethysmography.

Impedance Plethysmography is one of the latest, simple & non – invasive techniques that measures volume of blood in chest, calf or any other region of the body by sensing electrical resistance changes in respective area. Impedance Arteriography measures blood flow in Arteries. Occlusive Impedance Plethysmography (OIP) measures blood flow in Veins. Impedance Cardiography (ICG) measures blood flow in major vessels of Cardiac region from which Stroke Volume is obtained.This study is carried out to measure Cardiac Parameters like Stroke volume (SV), Cardiac output (CO) and Cardiac Index (CI) using the principle of Impedance Plethysmography that is ICG.

In ICU or emergency set up, and at OPD for patient coming with cardiovascular complaints, only heart rate & blood pressure is not sufficient to access a person's haemodynamic status. Cardiac output (CO) is the functional expression of cardiovascular performance[1]. CO is measured with many techniques like Fick's method, dye-dilution and thermo-dilution, of which common is thermodilution. All these are invasive methods associated with complications like infection, hemorrhage, arrhythmia etc. Further continuous CO monitoring is not possible with these all cathetar related invasive methods.

The symbol used for impedance is 'Z'. Impedance in vague term, means Electrical Resistance. Resistance (R) means according to Ohm's law, voltage (V) to constant current (I) ratio.

$$R = V / I$$

In this technique, the ELECTRICAL IMPEDANCE of any part of the body is measured by constant current method & variations in the impedance are recorded as a function of time as a Graph. Since blood is a good conductor of electricity, the amount of blood in a given body segment is reflected inversely in the electrical impedance of the body segment. Pulsatile blood volume by heart that is systemic blood circulation causes proportional decrease in the electrical impedance. Variation in the electrical impedance thus gives adequate information about the blood circulation in any part of the body, either Heart or any other Blood Vessels[2].

Constant current is passed through the body segment of interest with the help of 2 surface electrodes.Voltage signal devloped along the current path is sensed with the help of another pair of electrodes.The amplitude of the signal sensed is directly propotional to the elecrical impedance of the body segment. Amplification & detection of this signal gives instantaneous electrical impedance Z of the body segment. Difference between the

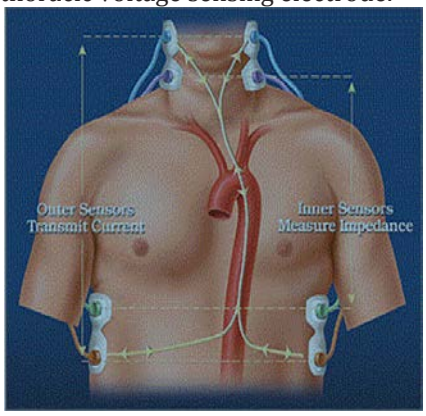
instantaneous electrical impedance & initial value of electrical impedance (Zo) gives variation in the impedance as a function of time, called the ΔZ (t) waveform. First time derivative of the impedance (dZ / dt) is obtained to give the rate of change of impedance[2]. With the help of this dZ / dt, used in Kubicek's equation, stroke volume can be measured[3, 4].

There are various types of electrodes and their method of placement across the chest wall. The Cardiac Output Monitor by Bhabha Atomic Research Center (BARC) uses the four band electrodes using vertical method (also called as Neck abdomen method) of electrode placement. This method requires special type of band electrodes made out of braided silver[1]. The four electrodes are placed above and other four below the chest wall, inner four are voltage sensing electrodes while outer four are stimulating or current injecting electrodes.

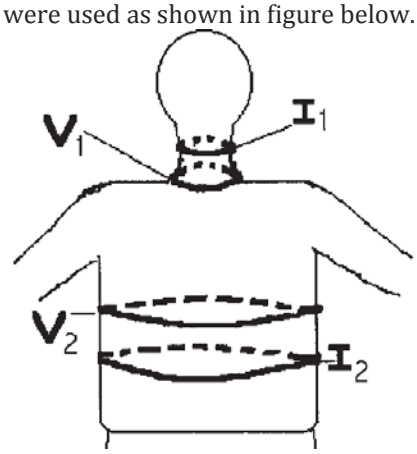
Purpose of this study was to compare with an earlier study done by Pradip B. Barde & co – workers in which they applied band electrodes vertically[1]. In our study, placement of electrodes are same as earlier vertically but in the form of standard stic-on type surface ECG electrodes for cardiac output determination using noninvasive impedance cardiography. Further, many studies in past had been done for comparison between invasive & noninvasive methods in cardiac patients[5-17]. Here in our study we are aiming for established normative baseline laboratory data which can be used in further physiological studies related to heart function in healthy normal subjects.

MATERIALS & METHODS

After obtaining ethical clearance from Institutional Review Board of Govt. Medical College, Bhavnagar; we carried out this study in two age groups: 16 – 25 yrs & 26 – 35 yrs. Each group was containing 26 healthy male volunteers. 5 subjects were excluded due to anticipatory tachycardia. Mean age was 20 yrs & 29 yrs respectively. Study was carried out in supine position after taking anthropometric data. It was done on Nivomon Series Product computerised software by L & T Company[18]. Among 8 surface electrodes used, four were current injecting electrodes (I1, I2, I1', I2') and other four were voltage-sensing electrodes (V1, V2, V1', V2'). The lower thoracic voltage-sensing electrode (V2, V2') were placed at the level of the xiphisternum on each side at anterior axillary line and cervical sensing electrodes (V1, V1') were positioned at the base of neck. The current injecting electrodes delivering constant current 4 mA were placed with two (I1, I1') at top of the neck 5 cm above the cervical sensing electrodes and the others (I2, I2 ') 5 cm below the thoracic voltage sensing electrode.

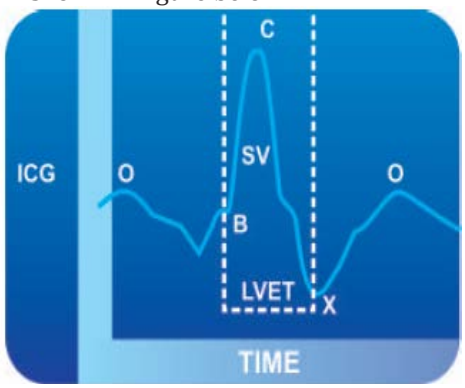


In earlier study by Dr. Pradip Barde & co – workers[1], instead of surface electrodes, band electrodes were used as shown in figure below.



The Nivomon instrument estimated the stroke volume (SV) from the impedance signal recorded from the inner pair of electrodes using Kubicek's equation[3, 4] as,

- Stroke volume (SV) = k p (L / Zo)^2 [LVET (dZ / dt) max]
- where k is a constant which accounts for variation in body composition based on age, gender, relative fat content, chest circumference;
- L is the inter - electrode distance;
- p is the blood specific resistivity computed using hematocrit as [13.5 + (4.29 Hematocrit)].
- LVET – Left Ventricular Ejection Time is measured as shown in figure below.



Heart Rate was calculated as 60 / RR interval in sec, Cardiac Output (CO) as SV multiplied by heart rate. All calculation was done automatically by software & final average values of SV & CO were given. Also as we enter Height & Weight of the subject before each test, value of BSA & so that of Cardiac Index (CI) calculated by software.

The graph of SV recorded is as below in which dZ / dt derivative value is measured from the height of the graph, which is used in Kubicek's equation.

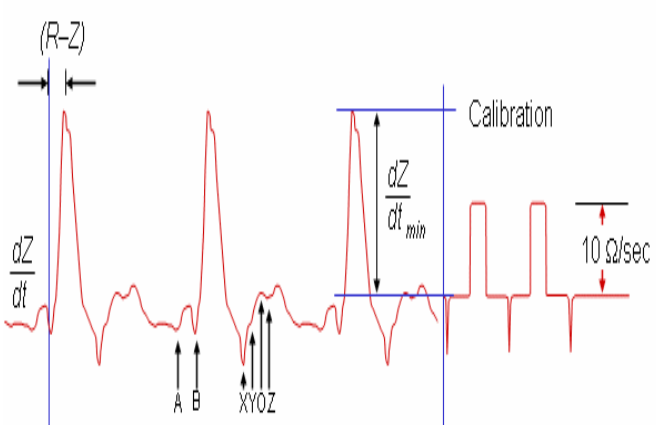


Table Timing of various notches in the first derivative impedance signal in impedance cardiography.

Event in the cardiac cycle	Notch
Atrial contraction	A
Closure of tricuspid valve	B
Closure of aortic valve	X
Closure of pulmonic valve	Y
Opening snap of mitral valve	O
Third heart sound	Z

Student t – test (unpaired) was used to compare these study parameters with earlier one & also to compare between 2 age groups in present study. Further Pearson correlation coefficient was calculated in each group to see relation between BSA & CO.

RESULTS

The first age group was of 16 – 25 yrs & second age group was of 26 – 35 yrs, each containing 26 healthy male volunteers. All values are in the form of Mean + SD.

The mean value of Cardiac Output (CO) in (L/ min) for 1st & 2nd group was 5.08 + 0.90 & 4.8 + 0.68 respectively. That of Cardiac Index (CI) in (L / min / m^2) was 2.92 + 0.47 & 2.75 + 0.36 respectively. That of Stroke Volume (SV) in (ml) was 66.46 + 8.74 & 63.07 + 8.01 respectively. Values of CO, CI & SV in earlier same study with band electrodes were 5.03 + 0.64, 3.00 + 0.63 & 69.03 + 10.42 respectively with n = 38[1]. All values are summarised in below table no. 1 (Mean + SD).

Table No. 1: Mean ± SD values

Earlier Study		**This Study**	
Age ; 22 – 34 yrs		**Age ; 16 – 25 yrs**	**Age ; 26 – 35 yrs**
n = 38		**n = 26**	**n = 26**
CO	5.03 + 0.64	5.08 + 0.90	4.8 + 0.68
CI	3.00 + 0.63	2.92 + 0.47	2.75 + 0.36
SV	69.03 + 10.42	66.46 + 8.74	63.07 + 8.01

Unpaired t – test was applied for statistical calculation.

P value for CO, CI & SV for comparison between earlier study & this study (Age group 16 – 25 yrs) were 0.80, 0.59 & 0.32 respectively. P value for same in Age group 26 – 35yrs were 0.18, 0.07 & 0.02 respectively.

Table No. 2: Comparison between 2 methods

Earlier study & 16 – 25 yrs		**Earlier study & 26 – 35 yrs**
CO	t = 0.256	t = 1.354
CO	**p = 0.80**	**p = 0.18**
CI	t = 0.542	t = 1.8
CI	**p = 0.59**	**p = 0.07**
SV	t = 1.01	t = 2.4
SV	**p = 0.32**	**p = 0.02**

P values for CO, CI & SV for comparison between 2 age groups in present study were 0.22, 0.16 & 0.16.

Table NO. 3: Comparison between 2 age groups

Present study between 2 age groups	
CO	t = 1.24
CO	**p = 0.22**
CI	t = 1.43
CI	**p = 0.16**
SV	t = 1.42
SV	**p = 0.16**

Pearson correlation coefficients for relation between BSA & CO were 0.40 & 0.21 in present study in respective age group.

Table NO. 4: Correlation coefficient 'r'

BSA & CO	**Age group 16 – 25 yrs**	**Age Group 26 – 35 yrs**
Correlation Coefficiant 'r'	0.40	0.21

DISCUSSION

The history of impedance plethysmography extends back to 1932 when Atzler & Lehmann observed changes in the Capacitance between 2 parallel plates kept across the human chest. These changes were observed to be Synchronous with the activity of the Heart[2]. The technique that exists today was first introduced by Jan Nayboer & co – workers in 1940[19]. For the *chest*, the technique was developed by NASA to measure the split second impedance changes within the chest, as the heart beats, to calculate both Cardiac output and lung water content. This technique has progressed clinically, often now called BioZ (Biologic Impedance), and allows low cost, non-invasive estimations of Cardiac output and total peripheral resistance. In the year 1978, the first Impedance Plethysmograph System was developed at Electronics Division, BARC (Bhabha Atomic Research Centre). It was then taken to Department of Surgery, Seth G.S. Medical College & K.E.M. Hospital and Department of Medicine, Grant Medical College & J.J. Hospital, Mumbai. It was used for the assessment of central and peripheral blood flow in the human body[20].

In present study, we compared the surface electrode placement for CO measurement with the earlier study in which band electrodes were used. Table no. 2 indicates that p value was found to be always greater than 0.05 except in SV comparison between earlier study & present study (Age group 26 – 35 yrs) with p = 0.02. It states that there is not much significant difference. There is not much variation between earlier & present study. Only 1 significant value of p was mostly due to small sample size. Further in table no. 3, all p value > 0.05 indicating that there is not significant variation for cardiac parameters between these 2 age groups in present study. Table no. 4 is showing positive Correlation Coefficiant in both age groups for BSA & CO. Although not so strong, but positive value indicates that increased BSA is associated with increased CO & that is physiological. Apart from BSA, there are many other factors affecting CO.

So if this study is carried out for all age groups & in both sex with large sample size, we will able to get normative baseline laboratory data for particular region. These data will be helpful in any future physiological, pharmacological or clinical studies. We can study the effect of physiological factors like age, sex, BSA, posture, exercise, diurnal variation on CO. We can study the effect of drugs like beta blockers, arteriodilator (After load reducer) or venodilator (Pre load reducer) on CO. We can study the effect of all chronic heart diseases on CO. In ICU set up, for patients of MI, LVF or CCF, & for post cardiac surgery patients[6, 8, 9, 21-24], CONTINUOUS CO monitoring with this non – invasive technique will be a great milestone. We would able to avoid complications like infection, hemorrhage or arrhythmia associated with invasive catheter related CO measurement techniques like dye – dilution, fick's principle or thermodilution. Further it requires minimal clothes removal. So it is comfortable on the patient side also. As it is simple & easy non – invasive technique with portability of instrument, a trained staff can also take required data instead of a qualified doctor. So it is helpful with the problem of man – power also, particularly in our country. Here we conclude that Impedance Cardiogrphy with surface stic on type of electrodes is equally efficacious to earlier band electrodes for measuring cardiac parameters.

As this technique mainly detects changes of blood flow in aorta, in conditions like coarctation of aorta, its validity is still questioned. Also increased thoracic fluid volume may interfere with impedance signal & give false results[25]. Echocardiography is also non – invasive, but again it requires a qualified radiologist or cardiologist, & continuous CO monitoring is not possible with this[26, 27].

CONCLUSION

Impedance cardiography is effective & advantageous in many ways. If it is further validated, then it can be widely used either for research purposes or in clinical set up.

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