International Journal of Aquatic Science
ISSN: 2008-8019
Vol 12, Issue 03, 2021

Determination of Cardiac Output based on Minimally Invasive Impedance Plethysmography in Various Healthy Subjects

S.Karthikeyani[1], C.Ganesh Babu[2], M.Ramkumar[3], R.Sarath Kumar[4], G.S.Priyanka[5], A.Manjunathan[6]

[1]*Department of Electronics and Communication Engineeeing, PG Scholar, Sri Krishna College of Engineering and Technology, Coimbatore*

[2]*Bannari Amman Institute of Technology, Sathyamangalam*

[3]*Department of Electronics and Communication Engineeeing, Sri Krishna College of Engineering and Technology, Coimbatore*

[4]*Department of Electronics and Communication Engineeeing, Sri Krishna College of Engineering and Technology, Coimbatore*

[5]*Department of Instrumentation and Control Engineeeing, PSG College of Technology, Coimbatore*

[6]*Department of Electronics and Communication Engineeeing, K.Ramakrishnan College of Technology, Trichy.*

Email: [1]karthikeyanis100390@gmail.com, [2]bits_babu@yahoo.co.in, [3]mramkumar0906@gmail.com, [4]sarathkumar@skcet.ac.in, [5]priyu3025@gmail.com, [6]manjunathankrct@gmail.com

Abstract: Impedance plethysmography is considered as one of the comprehensive and the latest minimally invasive technique for measuring the blood flow in any section of the human body. In various studies it has been revealed that only the parameter of blood pressure and heart rate is not enough for accessing the human's state under hemodynamic condition. Therefore, the measurement of cardiac output is being made by the proposed simple strategy referred as impedance plethysmography that will help in accessing the functional status of cardiac muscle in avoiding the critical complications which is being resulted from the ancient invasive measurement of blood flow. The main objective of this proposed study is to determine the measurement of cardiac output in the non-invasive manner of various healthy male subjects in 2 various age clusters using IPG and enumerate the comparison with the previous study utilizing the variant electrode placement strategies.Additionally, the comparison over the cardiac parameters between the mentioned 2 age clusters has been enumerated. Preceding over the study has been made in 2 clusters of age person with which one between (15-24) and the other between (25-34) years of age each of 9 healthy male subjects. The average value of Stroke Volume (SV) Mean value ± Standard Deviationis observed as 52.3±7.8 & 56.6±8.4, the resulted cardiac output is being observed to be as 5.07±0.8 & 4.9±0.67 and the resulted Cardiac Index (CI) is observed to be as 2.84±0.44 & 2.74±0.35 for the first and second chosen respective class of age groups. The IPG results are also being extracted with which the peak amplitude is measured

ranging between the mean value of 2.10±0.54 & 2.50±0.45 volts respectively for the respective cluster of age groups. It is being observed that in both the cases p value is less than 0.004 and the correlation coefficient is approximately ranged around 0.35 between IPG and SV data. With the available selected data which is being acquired and processed it is inferred that the correlation of Cardiac output through the stroke volume is estimated by the IPG waveform with adequate correlated value experimented with different male subjects under healthy condition.

Keywords: Cardiac Output, Cardiac Index, Impedance Plethysmography, Impedance Cardiography, Stroke Volume.

1. INTRODUCTION:

The theoretical meaning behind the term plethysmography is the process of estimating the calculation of any organ's volume. The volume might be either due to the measurement of water or blood or air. There are various kinds of plethysmography [1]. They are magnetic plethysmography, photo plethysmography, pneumo plethysmography, body plethysmography, impedance plethysmography and so on.

In the proposed study, it is dealt with the impedance plethysmography.It is one of the simple, non-invasive and recent novel techniques that is used to measure the blood volume surrounding the chest, throat, limbs or any other section of body parts by making the sense of variation of electrical impedance in the respective connected area. Impedance arteriography determines the blood flow measurement in arteries. Occlusive impedance plethysmography determines the blood flow measurement in veins. Impedance Cardiography determines the measurement of blood flow in the most important blood vessels of cardiac space with which the estimation of stroke volume is made [2].This study is preceded for measuring the parameters of cardiac muscles such as Stroke volume, Cardiac Index and Cardiac Output by utilizing the principle of Impedance Plethysmography (IPG).

In the hospital's ICU (Intensive Care Unit) clinical setting and under the emergency state to treat the patients those who are admitted due to cardio vascular illness, it is of the thought that only the blood pressure and the heart beat rate are sufficient to acquire the patient's condition to reveal the hemodynamic state. But it is not so. Cardiac output (CO) is the parameter which has been later on considered as an essential and needy parameter for which its measurement has to be undergone to reveal the performance over the functioning of cardiac muscle.The measurement of cardiac output is made with several techniques such as thermal dilution method, dye dilution method and the technique by Fick. Out of which one of the most common methods that have been used is thermal dilution method [3]. The above-mentioned methods that are used to measure the cardiac output is under invasive technique of measurement (undergoes with the tearing of skin surface externally). It leads to several complications and disorders such as normal to arrhythmia state, hemorrhage, severe infection etc. Moreover, the possibilities of continually monitoring the cardiac output are impossible with all these mentioned invasive techniques with the aid of catheter.

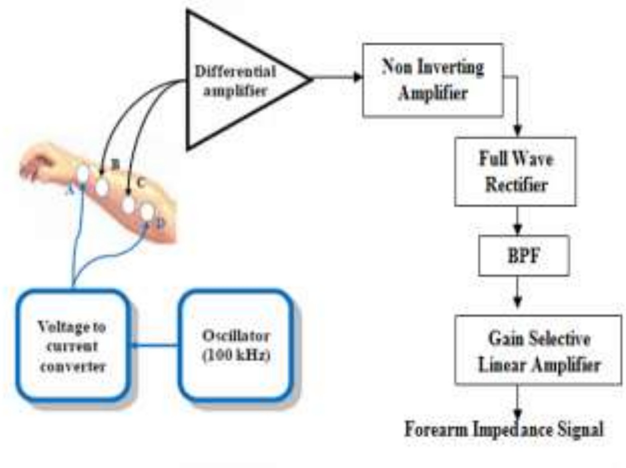
The symbols utilized for impedance is denoted as 'Z'. The impedance measurement is mapped as the electrical resistance in the human body. Here 'R' is denoted as the resistance and 'V' is denoted as voltage. As per the relation of Ohm's law it is known that $R = V / I$

In this proposed technique, the measurement over the electrical impedance at any section of human body is made by passing the small amount of current (in the range of microampere) and the resulting amplified signal is acquired as the IPG waveform with which the

International Journal of Aquatic Science
ISSN: 2008-8019
Vol 12, Issue 03, 2021

measurement is considered after the eradication of noise. The realization between the variation in voltage and resistivity is recorded along with the percentage variation in estimating the accuracy of changes. Since blood is the best conductor of electric current, the total quantity or the volume of blood delivered at one particular segment of body is made inversely reflected to the electrical impedance of the segment of the body [4]. The heart pumps the pure blood with which the blood volume as a result of pumping is attained by the periodic circulation of blood that causes the proportionate reduction in the electrical impedance. As a result, changes in the electrical impedance yields the relevant information regarding the circulation of blood in any of the sectional segment of the body that too mainly in the blood vessels and the cardiac muscle.

The constant amount of current is being sent through the essential segment of the body with the aid of two current electrodes [5]. In the impedance plethysmography hardware circuit, totally 4 electrodes have been used. Among, the two pairs of electrodes one pair are denoted as the voltage or sensing electrode and the other pair is called as current electrode. The position of electrode is designated with 1 and 3 for current electrode and 2 and 4 for the sensing voltage electrodes.After sensing the signal, the measured amplitude is made proportionate to the electrical impedance of the segment of body. The sequence of amplifying the signal and detecting the signal produces the instantaneous value of electrical impedance(Z) of the segment of body. The instantaneous value of electrical impedance is subtracted from the electrical impedance initial value (Z0) that produces a change in impedance as a derivative of timing function denoted as the waveform corresponding to $\Delta Z(t)$. The initial impedance derivative (dZ/dt) is acquired to produce the rate of impedance variation. With the aid of (dZ/dt) that has been utilized in the equation of Kubicek the measurement of stroke volume could be made. The IPG set up is depicted in figure 1 and its hardware test set up is depicted in figure 2.



International Journal of Aquatic Science
ISSN: 2008-8019
Vol 12, Issue 03, 2021

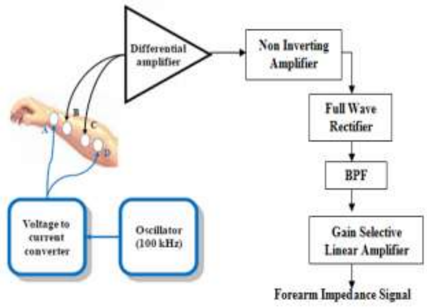


Fig. 1. Impedance Plethysmography Circuit

Fig. 2. Impedance Plethysmography -Hardware Implementation Circuit

There are various sorts of electrode types and their individual location methods are dependent based on their characteristics surrounding the wall of chest. The monitoring process of cardiac output which has been carried out by BARC (Baba Atomic Research Centre) utilizes the electrode band arrangement with 4 in number and it has used the method of neck abdomen vertically in placing it on the surface of the skin [6] [7]. This technique determines the requirement over specific sorts of electrode bands that has been manufactured by silver in a braided structure. The main moto for this proposed study is to enumerate the comparison with the previous studies that has been undergone by B. Barde Pradeep and his associate workers with which the application of these band electrodes are being made in the vertical fashion. In this proposed study, the traditional IPG technique the electrode placement is being done in the vertical fashion is the sort of Nacl metallic electrodes [8]. This sort of arrangement is made for estimating the measurement of cardiac output by the development of impedance cardiography in the non-invasive manner [9]. Moreover, most of the studies in the previous literatures have been made for comparing the techniques between the invasive and non-invasive strategies in various cardiac patients. In this study, it is aimed for establishing the basic data obtained from the experimentation from the clinical setting that has been related to the functioning of heart in the normal healthy subjects.

2. MATERIALS REQUIRED AND METHODOLOGIES

Under the clinical setting arrangement, the experimentation is being incorporated in two different age groups as mentioned. The first age group which has been considered is between (15 to 24) years and the second age group is between (25 to 34) years of age. In this each group is consisting of totally 9 healthy subjects and the execution of this experiment is being made in the supine state after acquiring the data of anthropocentricity [10]. For establishing the experiment and enumerating the comparison of targeted impedance cardiography, the 4-electrode arrangement is switched to 8 electrodes setting and the experiment is carried on. Among the utilization of 8 electrodes, four electrodes were considered as the sensing voltage electrodes and the remaining 4 electrodes were considered as the current electrodes. The current electrodes are represented as $I1, I2, I1'$& $I2'$ and similarly the sensing voltage electrodes are denoted as $V1, V2, V1'$ & $V2'$. The bottom thoracic voltage sensing electrodes ($V2, V2'$) are being sticked at the xiphisternum level on either side at the line of axillary in the anterior section and the voltage cervical electrodes that too in the supine position ($V1, V1'$) are being positioned at the neck base [12]. The current electrodes ($I1, I1'$) are being positioned at the top surface of the neck above the cervical voltage electrodes on one end and ($I2, I2'$) are the next pair of current electrodes placed at the other end surface of neck with which 5mA current is given as the input in order to disturb the resistivity of the body.

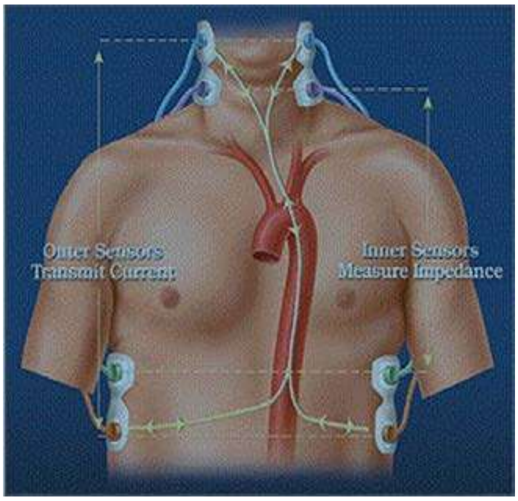


Fig. 3. Electrode arrangement for the setup of Impedance Cardiography [2]

As on the other way, the estimation of stroke volume (SV) is being made from the inner electrodes pair utilizing the equation formulated by Kubiceik [2] [13].

$$Stroke\ Volume\ (SV) = kp\ (\frac{L}{Z0})^2[LVET\ \left(\frac{dz}{dt}\right) max] \quad (2.1)$$

Where k is declared as constant that accounts for changes in the body composition on the basis of gender, age, relative content of fat and circumference of chest etc. L is declared as the length between the inner electrodes. ‘p’ is declared as the computational variable of specific blood resistivity and LVET is the Left Ventricular Ejection time with which its measurement is shown in the following figure. Figure 3 depicts the illustration of ICG in estimating the stroke volume.

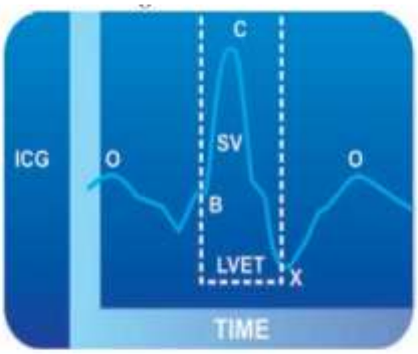


Fig. 4 Illustrating the measurement of ICG in estimating the SV[2]

The normal value for the calculation of heart rate is being made as 60 beats per minute correlated with the interval of R-R measured in sec as the ECG signal parameter for estimating the value of cardiac output as the derivative of stroke volume (SV) holds with the product of heart rate. The calculated values are acquired automatically by loading the mean values of CO and SV acquired from the set up. Along with these parameters, the weight and height of each individual male subjects are loaded in order to acquire the BSA values in predicting the value of Cardiac Index (CI). The determination of the estimation of Stroke Volume is being considered as the derivative of dZ/dt with which its measurement is obtained from the amplitude of ICG waveform in realizing its timing interval that has been calculated from Kubiceik's equation [2] [14].

The unpaired T test is utilized for comparing these parameters taken for the study with the previous sets of experimentations and also for enumerating the validation of comparison between these two age clusters. Moreover, the Pearson correlation coefficient is being used for each individual age group to view the relationship between Cardiac Output and Body Surface Area (BSA).

3. RESULTS AND DISCUSSIONS

The age cluster with the first category (15 to 24) years and the second category (25 to 34) each consisting of 9 healthy subjects. For all the healthy subjects the calculation is being made in the term of Mean added with Standard Deviation (Mean+SD).

The average value of the Cardiac Output (CO) which is measured in Liters per minute for the first and second age group is obtained as 5.09±0.89 and 4.9±0.65 respectively. The Cardiac Index (CI) is measured in terms of Liters per minutes per square meter. The acquired value of Cardiac Index for both the age groups are seen to be 2.89±0.54 and 2.67±0.23 respectively. The average value of Stroke Volume for both the age groups are seen to be as 52.3±7.8 & 56.6±8.4 respectively. From the previous study the acquired value of Cardiac Output, Cardiac Index and the Stroke Volume with whichits measurement has been obtained from the 8 band of electrodes are observed as 5.14±0.61, 3.05±0.24 & 65.03±8.46 respectively with n value of thirty-eight [1]. Table 1 corresponds to the mean and related standard deviation values of previous and the proposed study [1] [15].Table 2 determines the computation of t-test unpaired values and correlation coefficient value in both the methods. Table 3 depicts Computation of t-test unpaired values and correlation coefficient value between two proposed age clusters.

Table 1: Representation of Mean and its associated SD Values

Previous Study Data			Proposed Study Data					
Age: 21 to 35 years			Age: 15 to 24 years			Age: 25 to 34 years		
n=38			n=27			n=27		
CO	CI	SV	CO	CI	SV	CO	CI	SV
5.14±0.61	3.05±0.24	65.03±8.46	5.09±0.89	2.89±0.54	52.3±7.8	4.9±0.65	2.67±0.23	56.6±8.4

The above acquired t-test unpaired values are being applied for probabilistic calculation. The value of correlation coefficient (p value) for the parameters Cardiac Output (CO), Cardiac Index (CI) and Stroke Volume (SV) are being explored to the comparison with the previous study and the proposed study with which for both the age clusters it is being attained with 0.16, 0.08 and 0.04 respectively.Also, the analysis has been extended for the illustration of p values in determining cardiac output, cardiac index and stroke volume between the two proposed age groups are 0.21, 0.15 and 0.15 respectively.

Table 2: Computation of t-test unpaired values and correlation coefficient value in both the methods

Parameters	Comparison between previous study (21 to 35 years) & proposed study (15 to 24 years)	Comparison between previous study (21 to 35 years) & proposed study (25 to 34 years)
Cardiac Output	t=0.243	t=1.345
	p=0.79	p=0.16
Cardiac Index	t=0.524	t=1.6
	p=0.58	p=0.08
Stroke Volume	t=1.06	t=2.36
	p=0.23	p=0.04

Table 3: Computation of t-test unpaired values and correlation coefficient value between two proposed age clusters.

Parameters	Comparison between Current study between 2 age groups
Cardiac Output	t=1.26
	p=0.21
Cardiac Index	t=1.58
	p=0.15
Stroke Volume	t=1.46
	p=0.15

The Pearson coefficient of correlation is also being realized between the parameters of Body Surface Area (BSA) and Cardiac Output that has been acquired based on computation. The linear correlation coefficient of r value is computed for both the parameters in 2 age groups. Table 4 determines the relationship of correlation coefficient (r).

Table 4: Computation of Correlation Coefficient between two proposed age clusters.

Body Surface Area (BSA) & Cardiac Output (CO)	**Age Cluster 1**	**Age Cluster 2**
Correlation Coefficient 'r'	0.386	0.81

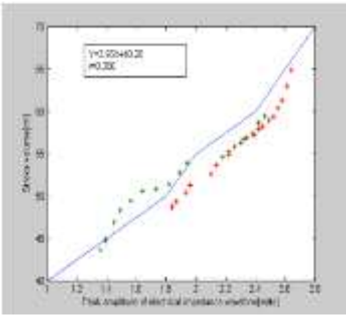


Fig. 5 Linear regression analysis between IPG & SV

In the current proposed study, the comparison is made between the parameters for which the cardiac output is being measured under the 4 band electrodes arrangement and correlated with the IPG apparatus in detecting the peak amplitude for estimating the stroke volume. Table 2 determines the comparison with previous studies with the present cluster of age groups with both t-test unpaired values and correlation coefficient values. It is seen that the p value is 0.21, 0.15 & 0.15 for CO, CI and SV when the comparison is made between 2 different clusters of age groups. The simulated screens of Peak amplitude and SV is being represented in the following figure 5 and figure 6 with the linear evaluation of correlation coefficient. The linear regression value of r is attained to be as 0.386.

4. CONCLUSION AND FUTURE WORK

Impedance Plethysmography and impedance cardiography are advantageous in more aspects in estimating the functioning of heart to aid the decision for the requirement of correct treatment to proceed with. The validation is being made with the linear regression analysis of estimating the stroke volume in predicting the cardiac output and cardiac index and this can be extended for many research studies by using the machine learning algorithms in future in predicting the different states of cardiac arrhythmias that can be incorporated in future work.

5. REFERENCES

[1] Pradip Barde, Ghanshyam Jindal, Rajvir Singh & Kishore Deepak. New method of electrode placement for determination of cardiac output using Impedance Cardiography. Indian J PhysiolPharmacol 2006; 50 (3) : 234–240

[2] Kubicek WG. Development and evaluation of an impedance cardiac output system. Aerosp Med 1966; 12: 1208–1212

[3] Belardini R, Cimpani N, Costani C, Blandini A, Purcara A. Comparison of impedance cardiography with thermodilution and direct Pick methods for non-invasive measurement of cardiac output during incremental exercise in patients with ischemic cardiomyopathy. Am J Cardiol 1996; 77: 1293–1301

[4] Richard L Summers, LouAnn H Woodward, and W Franklin Peacock. A report - Role for Impedance Cardiography in the Diagnosis and Management of Acute Heart Failure. Emergency medicine & critical care review 2006.
[5] Rachna Parashar, Manish Bajpai, Manish Goyal, Shraddha Singh, Sunita Tiwari, V. S. Narayan. Impedance cardiography for monitoring changes in cardiac output. Indian J PhysiolPharmacol 2012; 56(2) : 117 – 124
[6] MD Kelkar, Padmashree R Bharadwaj, GD Jindal and GB Parulkar : Impedance Plethysmography in Arterial Occlusive Disease : Correlation with Arteriography. Indian Heart Journal 1983; 35; 2: 94-97.
[7] Jindal GD, Pednekar SA, Nerurkar SN, Masand KL, Gupta DK, Deshmukh HL, Bapu JP and Parulkar GB: Dignosis of venous disorders using impedance plethysmography. J Postgrad Med 1990;36:158.
[8] Raines, J. K., 1972, "Diagnosis and Analysis of Arteriosclerosis in the Lower Limbs from the Arterial Pressure Pulse." Ph.D. Thesis, Massachusetts Institute of Technology.
[9] Van De Water, J. M., Dove, C. B., Mount, B. E. and Linton: Application of bioelectric impedance to the measurement of arterial flow. J. Surg. Res., 1973, 15: 22-29.
[10] Majumder, S.; Mondal, T.; Deen, M.J. Wearable sensors for remote health monitoring. Sensors 2017, 17, 130. [CrossRef] [PubMed]
[11] Medtronic Cardiac Diagnostics & Monitoring for Healthcare Professionals, SEEQ MCT System. Available online: http://www.medtronicdiagnostics.com/us/cardiac-monitors/seeq-mct-system/index. htm (accessed on 8 April 2017).
[12] Park, J.H.; Jang, D.G.; Park, J.; Youm, S.K. Wearable sensing of in-ear pressure for heart rate monitoring with a piezoelectric sensor. Sensors 2015, 15, 23402–23417. [CrossRef] [PubMed]
[13] Chandrasekaran, V.; Dantu, R.; Jonnada, S.; Thiyagaraja, S.; Subbu, K.P. Cuffless differential blood pressure estimation using smart phones. IEEE Trans. Biomed. Eng. 2013, 60, 1080–1089. [CrossRef] [PubMed]
[14] Liu, S.H.; Cheng, D.C.; Lin, C.M. Arrhythmia identification with two-lead electrocardiograms using artificial neural networks and support vector machines for a portable ECG monitor system. Sensors 2013, 13, 813–828
[15] M. C. Cho, J. Y. Kim and S. H. Cho, “A Bioimpedance Measurement System for Portable Monitoring of Heart Rate and Pulse Wave Velocity Using Small Body Area,” Circuits and Systems, pp.3106-3109, 2009