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NEW METHOD OF ELECTRODE PLACEMENT FOR DETERMINATION OF CARDIAC OUTPUT USING IMPEDANCE CARDIOGRAPHY

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Abstract : In thirty eight young healthy adult subjects, cardiac output was determined non-invasively by using two methods of electrode placement viz. vertical (uses silver braided wires in a band shape) and horizontal (conventional stick-on type surface ECG electrodes), using the technique of Impedance Cardiography. The recordings were taken in supine position on the same day in two separate sets with 30.0 min interval between two sets. In each set of recording, five successive recordings, each at an interval of five minutes were taken. The mean values of cardiac out put by two methods were compared. For the set I, the respective values (Mean±SD) of cardiac output by horizontal and vertical methods for the each of the five recordings were 4.87±0.77 and 5.03±0.64 for the first, 4.87±0.71 and 4.91±0.66 for the second, 4.99±0.67 and 5.00±0.70 for the third, 4.78±0.69 and 4.98±0.61 for the fourth, 4.84±0.69 and 4.98±0.62 for the fifth recording in supine position. The respective P values for these pairs for between the group comparisons were 0.33, 0.50, 0.96, 0.17, and 0.36. In addition, to see the repeatability for each method, within the group comparison was done, the P values were 0.71 and 0.91 for the horizontal and vertical methods, respectively. The mean value of cardiac output did not differ significantly between two methods for recordings of set II in supine position. The cardiac output measurement by placing four spot electrodes horizontally, gave consistent result on repeated measurements and their values showed concordance with the cardiac output values obtained by conventional four band electrodes tied around the chest.

Key words : impedance cardiography cardiac output electrode placement

INTRODUCTION

For many patients in ICU or in emergency medicine unit or those being investigated for some cardiovascular complaint, simply measuring heart rate (HR) and blood pressure does not provide adequate data on their haemodynamic state.

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Cardiac output (CO) is the functional expression of cardiovascular performance and can be used to confirm the need for, or efficacy of treatment. Determination of cardiac output is an important procedure in interventional cardiology and also used in cardiothoracic surgery (1). To estimate CO in clinical practice, several invasive methods are available. These are the Fick's method, dye-dilution and thermo-dilution techniques. Currently, thermo-dilution technique is used most commonly for measurement of cardiac output. These requires catheterization of the patient which itself adds to morbidity and sometimes mortality of patient. It gives only intermittent measurement of cardiac output of the patient. Alternatively, the method of Impedance Cardiography with its several advantages is a promising method to measure cardiac output (2, 3, 4). Currently existing impedance based cardiac output monitors operate by emitting a low voltage (2.5 to 4 mA), high-frequency (50 to 100 kHz), alternating electrical current through the thorax via spot or band electrodes. The electrical impedance changes according to changes in the volume and velocity of the blood flow, in the thoracic aorta within the thorax are detected by sensing electrode as pulsatile decreases in impedance (dZ), which can be further expressed as its derivative (dZ/dt). This derivative has been shown to proportional to the stroke volume. Along with heart rate it gives us CO of the patient.

There are various types of electrodes and their method of placement across the chest wall. The indigenously developed 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. 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. It is cumbersome and very uncomfortable to the patient. Purpose of this study was to search a convenient method of electrode placement using standard stic-on type surface ECG electrodes for cardiac output determination using noninvasive impedance cardiography. For this we compared the vertical electrode placement method using band electrodes with the horizontal electrode placement method using conventional stick on type surface ECG electrodes.

METHODS

We carried out cardiac output determination in thirty-eight young, healthy male adults (mean age-28 yrs, range 22–34 yrs), without history of any disease. Two methods of electrode placement i.e. Vertical (Neck-abdomen) method and newly proposed horizontal method were used. We measured cardiac output by Cardiac Output Monitor indigenously developed by Bhabha Atomic Research Center (BARC), Mumbai (5). For the vertical method (Fig. 1b) the Cardiac Output Monitor was connected to subject via four band electrodes, which are silver braided long strips, soaked in water just before use. Among four band electrodes used, two were current injecting electrodes (I_1, I_2) and other two were voltage-sensing electrodes (V_1, V_2). The lower thoracic voltage-sensing electrode (V_1) was placed at the level of the xiphisternum and cervical sensing electrode (V_2) was positioned at the base of neck. The current injecting electrodes delivering an alternating current 4 mA at 50 kHz were placed with one (I_1) at top of the neck 5 cm above the cervical sensing electrode and the other (I_2) 5 cm, below the thoracic sensing electrode. During the recording procedure the band electrodes were made wet with the help of cotton swab soaked in water to ensure proper electrical contact with the body surface. In horizontal method, (Fig. 1a) two current injecting spot electrodes (I_1, I_2) were placed on mid arm laterally one on right (I_1) and other on left (I_2) side and the voltage sensing spot electrodes were placed at 2nd intercostal space along the anterior axillary line which

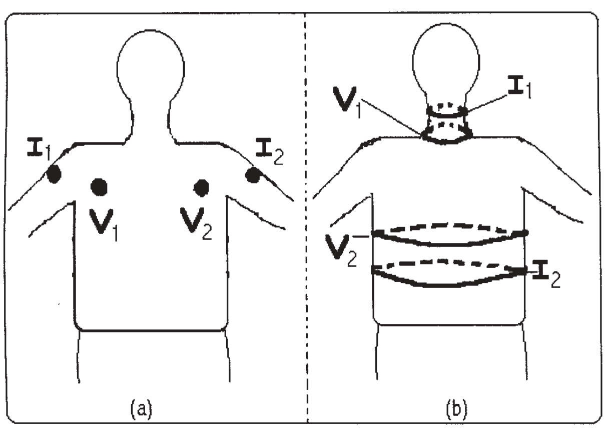

Fig. 1 : Placement of electrode on the body surface for determination of cardiac output using Impedance Cardiography (a) For horizontal placement of electrodes and (b) For vertical placement of electrodes. Four electrodes, two current injecting electrodes (I_1, I_2) and two voltage sensing electrodes (V_1, V_2) were used. In vertical placement of electrodes four band electrodes were used, V_1 is placed at the base of neck and I_1 is placed 5 cm above it at the top of neck, V_2 is placed at the level of Xiphisternum and I_2 is placed 5 cm below it. In horizontal placement of electrodes four standard ECG surface electrodes were used. The current injecting electrodes I_1 and I_2 placed on the mid-arm laterally, one on each side and the voltage sensing electrodes (V_1, V_2) were placed at the second inter costal space along anterior axillary line, one on each side.

is anatomically corresponds the level of aortic arch. The electrodes used were standard stick on surface ECG electrodes. The Cardiac Output Monitor estimated the stroke volume (SV) from the impedance signal recorded from the inner pair of electrodes using Kubiceks equation as, $SV = \rho \quad L^2 LVET \quad (dz/dt)m/Z_0^2$, where ρ = resistivity of blood in Ω-cm, L = distance between two sensing electrodes in cm, Z_0 = mean basal thoracic impedance in Ω, (dz/dt) m = maximum rate of change of impedance in Ω/sec. While all the recordings, the value of basal impedance was kept around '28±3 Ω' by ensuring proper electrical contact of electrodes with body surface, and also by adjusting the inter electrode distance for the sensing electrodes. The cardiac output was calculated as the product of stroke volume and heart rate. The Cardiac Output Monitor automatically averages stroke volume over ten cardiac cycles and displays cardiac output.

In two separate sets namely Set I and Set II, five successive recordings were taken at the interval of five minutes using both method of electrodes placement. After completing the set I recording, the electrodes were not removed. There was interval of 30 min between set I and set II recordings. Thus, total time required to complete recording of one subject was about 90–100 min. This recording protocol provided an opportunity to see the repeatability of the method by measurement of cardiac output over extended period of about 90–100 min.

The data analysis was done using SAS 8.0 statistical package. Descriptive statistics has been calculated for both the method at each point time. To see difference between the two methods at each time point the student t test was used and to see the trend for each method, repeated measure ANOVA was used. The above study was approved by medical ethics committee of All India Institute of Medical Sciences, New Delhi – 110 029.

RESULTS

Set I (Table I):

The mean value of cardiac output (L/min) for the five successive recordings in supine position by horizontal and vertical methods were 4.87±0.77 and 5.03±0.64 for the first, 4.87±0.71 and 4.91±0.66 for the second, 4.99±0.67 and 5.00±0.70 for the third, 4.78±0.69 and 4.98±0.61 for the fourth, 4.84±0.69 and 4.98±0.62 for the fifth recording respectively for each pair. For between the group comparisons at each time point, the respective P values for these pairs were 0.33, 0.50, 0.96, 0.17 and 0.36. Also to see the repeatability for each method within the group comparison was done, the P values were 0.71 and 0.91 for the horizontal and vertical methods respectively. Considering the importance of body surface area we also calculated the values for cardiac index. The cardiac index values (L/min/m^2) by horizontal and vertical method for five recordings were 2.90±0.61 and 3.00±0.63, 2.87±0.61 and 2.92±0.60, 2.98±0.70 and 2.98±0.63, 2.86±0.67 and 2.97±0.62, 2.89±0.62 and 2.97±0.60 respectively. The respective P values for these pairs were 0.48, 0.67, 0.96, 0.44, and 0.57. Also to see the repeatability for each method, within the group comparison was done, the P values were 0.85 and 0.93 for the horizontal and vertical methods respectively. Also the mean values for stroke volume (ml) the important determinant of cardiac output, by the horizontal and vertical methods respectively for five successive recordings were 69.55±12.06 and 69.03±10.42, 68.84±11.69 and 67.60±11.00, 71.49±12.96 and 68.45±9.80, 69.37±13.08 and 69.29±10.26, 68.82±12.36 and 68.69±10.54. The corresponding P values for these pairs were 0.84, 0.64, 0.25, 0.98 and 0.96. The within the groups comparison P value was 0.75 for the both groups. Thus the value of cardiac output by both the methods showed concordance among them. These values were also repeatable over a period of time during the same set for both the methods.

TABLE I: Cardiac output (L/min), CI: Cardiac Index (L/min/m^2) and SV: Stroke Volume (ml) values by Horizontal (H) Vertical (V) methods in set-I.

	Type	*(M±SD) 1*	*2*	*3*	*4*	*5*	*P*
	H	4.87±0.77	4.87±0.71	4.99±0.67	4.78±0.69	4.84±0.69	0.71
	V	5.03±0.64	4.91±0.66	5.00±0.70	4.98±0.61	4.98±0.62	0.91
CO	P	0.33	0.50	0.96	0.17	0.36	
	H	2.90±0.61	2.87±0.61	2.98±0.70	2.86±0.67	2.89±0.62	0.85
CI	V	3.00±0.63	2.92±0.60	2.98±0.63	2.97±0.62	2.97±0.60	0.93
	P	0.48	0.67	0.96	0.44	0.57	
	H	69.55±12.06	68.84±11.69	71.49±12.96	69.37±13.08	68.82±12.36	0.75
	V	69.03±10.42	67.60±11.00	68.45±9.80	69.29±10.26	68.69±10.54	0.75
SV	P	0.84	0.64	0.25	0.98	0.96	

TABLE II : Cardiac output (L/min), CI: Cardiac Index (L/min/m^2) and SV: Stroke Volume (ml) values by Horizontal (H) Vertical (V) methods in set-II.

	Type	*(M±SD) 1*	*2*	*3*	*4*	*5*	*P*
	H	4.96±0.57	4.71±0.56	4.81±0.73	4.83±0.55	4.87±0.49	0.65
	V	5.05±0.66	4.78±0.63	4.80±0.59	4.99±0.74	4.85±0.53	0.58
CO	P	0.54	0.67	0.94	0.27	0.87	
	H	2.69±0.66	2.81±0.64	2.98±0.71	2.88±0.64	2.90±0.60	0.59
CI	V	3.01±0.67	2.85±0.63	2.87±0.64	2.98±0.65	2.90±0.64	0.58
	P	0.75	0.83	0.96	0.53	0.97	
	H	70.59±12.03	68.72±10.04	68.65±11.94	69.84±12.35	69.98±11.22	0.98
	V	68.86±12.02	69.79±12.76	70.29±13.03	72.27±10.82	70.4±10.46	0.21
SV	P	0.53	0.69	0.57	0.37	0.86	

Set II (Table II) :

The mean value of cardiac output (L/min) for the five recordings in supine position by horizontal and vertical methods respectively were 4.96±0.57 and 5.05±0.66, 4.71±0.56 and 4.78±0.63, 4.81±0.73 and 4.80±0.59, 4.83±0.55 and 4.99±0.74, 4.87±0.49 and 4.85±0.53. The corresponding P values for between the group comparisons of these pairs are 0.54, 0.67, 0.94, 0.27 and 0.87. Also the P values for within the group comparison for the vertical and horizontal method are 0.65 and 0.58 respectively. Similarly the mean value for cardiac index (L/min/m^2) for each recording were 2.90±0.61 and 3.00±0.63 2.87±0.61 and 2.92±0.60, 2.98±0.70 and 2.98±0.63, 2.86±0.67 and 2.97±0.62, 2.89±0.62 and 2.97±0.60 with respective P values 0.48, 0.67, 0.96, 0.44, 0.57. The P values for within the group comparison were 0.85 and 0.93 for the horizontal and vertical method respectively. The values for stroke volume (ml) for horizontal and vertical method were 70.59±12.03 and 68.86±12.02, 68.72±10.04 and 69.79±12.76, 68.65±11.94 and 70.29±13.03, 69.84±12.35 and 72.27±10.82, 69.98±11.22 70.4±10.46 with corresponding P values 0.53, 0.69, 0.57, 0.37, 0.86 respectively for each pair. The P values for the within the group comparison for horizontal and vertical method were 0.98, 0.21. The value of cardiac output by both the methods showed concordance among them. These values were also repeatable over a period of time during the same set for both the methods. Thus after 30 min interval in Set II, the cardiac output values showed similar pattern of measurement by both the methods.

DISCUSSION

The property of bioimpedance shown by biological tissue has been used extensively to measure vascular functions, motility of visceral organs, body composition and various impedance based functions to assess various systems of the body for the past seven decades (6, 7, 8). Jan Nyboer (9) introduced impedance pleththysmography in 1940 and impedance cardiography by Kubicek in 1966 (10, 11) to measure cardiac output. Large numbers of investigators in this field have validated these measurements (12, 13). Comparability of Impedance Cardiography method with other interventional procedures has also been validated (14).

In present study we compared the horizontal method of spot electrode placement with vertical method of band electrode placement. We found that the horizontal method gives similar cardiac output measurement as that of the vertical method. Thus, the value of cardiac output by both the methods showed concordance among them. These values were also repeatable over a period during the same set for both the methods. The recording over extended period starting from set I (~25 min) to set II (~25 min) with interval of 30 min between the two sets, showed consistent results using the surface electrodes method. On the contrary, when we used band electrodes over extended period they required frequent wetting with cotton swab soaked in water for proper electrical contact. Considering the approach and method of surface electrodes placement, this method is more convenient to the patient, technician and it spares the body parts for comfortable operability. This is of particular importance when the cardiac output is being monitored in a patient undergoing some diagnostic intervention (e.g. angiography) or any thoracic or abdominal surgical intervention when the body surface of the patient is less accessible to put the electrodes because it may interfere with the working field of the operating surgeon. This non-invasive method may have application for cardiac output measurement in pediatric age group in whom cardiothoracic surgery is being performed for improving their abnormal cardiac function due to presence of certain congenital abnormality. Currently there is no suitable method to quantify their cardiac function. This method with modification of electrode size and their placement may be used to quantify their cardiac function before and after intervention.

It is interesting to note that the two methods provide comparable results. Physiologically, this point can be explained. In the horizontal method of spot electrode placement, sensing electrodes were placed at the level of second intercostals space which nearly corresponds to the level of aortic arch (15) from where the impedance changes occurring due to change in blood flow with every cardiac cycle can be measured more accurately. Since this method is mainly based on blood flow in the aorta, its validity remains to be tested in certain conditions like coarctation of aorta.

We conclude that the horizontal method using Impedance Cardiography with four surface ECG electrodes is equally good to vertical method for measurement of cardiac output in humans.

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