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Original Article

Correlation between Three Methods of Blood Pressure Measurement (Impedance Cardiography, Sphygmomanometry, and Invasive Methods)

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Abstract

Aims and Objectives: The aims of the study were to find out the correlation between three methods of blood pressure (BP) measurement with impedance cardiography (ICG) device, conventional non-invasive sphygmomanometer, and cath lab-based invasive arterial pressure (AP) study.

Patients Materials and Methods: Patients who had definite indications for coronary angiography (CAG) or coronary intervention due to cardiac reasons were selected for the measurement of BP by three methods, namely, by transducer-based invasive central aortic pressure study, by ICG, and by conventional sphygmomanometry. One hundred patients of acute myocardial infarction having chest pain, ST elevation in two or more contiguous leads of electrocardiogram (ECG), biomarker positivity, and echocardiographic evidence of regional wall motion abnormality were selected. Transfemoral or radial access of the ascending aorta allowed the measurement of central aortic pressure during invasive procedure. CAG was done in the cath lab having "Siemens™ Axiom Artis Zee (floor)" equipment. The subjects who were unwilling to participate, who were moribund, critically ill subjects, and patients with concomitant heart failure, arrhythmia, and valvular lesions were excluded from the study. GE™ Vivid 7 Dimension machine was used for ECG-gated echo-Doppler studies. ICG-derived BP values (systolic BP [SBP], diastolic BP [DBP], mean AP [MAP], and pulse pressure) were recorded for comparison with similar pressure data obtained from two other methods.

Results and Analysis: Analysis of results show a comparison of data on SBP, DBP, and MAP measured by three methods by sphygmomanometry, invasive, and ICG methods. The analysis also shows the values of correlation coefficients – all of which are significantly positive correlations. ICG has been found to have positive correlation with both sphygmomanometric and invasive methods of BP measurement. It also shows a graphical presentation of the correlation between SBP, DBP, and MAP measured by three methods by sphygmomanometry, invasive, and ICG methods.

Conclusion: There is a significant correlation between three methods of BP measurement with ICG device, conventional non-invasive sphygmomanometer-based method, and cath lab-based invasive AP study.

Key words: Augmentation index, Coronary angiography, Diastolic blood pressure, Impedance cardiography, Mean arterial pressure, Pulse pressure, Systolic blood pressure

INTRODUCTION

Blood pressure (BP) can be measured in many non-invasive and invasive ways. The most commonly clinically used technique is auscultatory technique using mercury-based sphygmomanometers. Oscillometric techniques are also used in BP measuring devices. All these are big size devices. Non-invasive photoplethysmography (optoelectronic) based technique and impedance plethysmography based estimation of BP are still at experimental level and need further validation before wide use in clinical practice. Invasive intra-arterial BP estimation is done in the cardiac cath labs, operation theaters, and intensive care units for different indications.

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Despite the availability of many established pre-existing techniques, the BP measurement by newer impedance cardiography (ICG) device bears the potential of some extra advantages inclusive of wearability and portability – that is why in recent years, there is renewed interest in evaluating the role of ICG. We have been also working on the hemodynamic aspects of ICG. The basic principles and technical details of the ICG device used by us were designed by Ghosh *et al.*, from School of Medical Science and Technology (SMST), Indian Institute of Technology (IIT), Kharagpur, and have been discussed earlier.[1,2]

Aims and Objectives

The aims of this study was to record each of systolic BP (SBP), diastolic BP (DBP), mean arterial pressure (MAP), and pulse pressure (PP) predicted by ICG, invasive method, and sphygmomanometry from patients of acute myocardial infarction (AMI) and find out correlation between three methods and validation of the data derived from ICG. The objective of selecting only patients of AMI was that invasive coronary angiography (CAG) (with or without intervention) was indicated on medical ground and not for research purpose only. This provided the facility of measuring invasive method of measuring BP within ethical boundary.

PATIENTS MATERIALS AND METHODS

Patients who had definite indications for CAG or coronary intervention due to cardiac reasons were selected for the measurement of BP by three methods, namely, by transducer-based invasive central aortic pressure study, by ICG, and by conventional sphygmomanometry. One hundred patients of AMI having chest pain, ST elevation in two or more contiguous leads of electrocardiogram (ECG), biomarker positivity, and echocardiographic evidence of regional wall motion abnormality were selected. Transfemoral or radial access of the ascending aorta allowed the measurement of central aortic pressure during invasive procedure. CAG [Figure 1] was done in the cath lab having "Siemens™ Axiom Artis Zee (floor)" equipment. The subjects who were unwilling to participate, who were moribund, critically ill subjects, and patients with concomitant heart failure, arrhythmia, and valvular lesions were excluded from the study. GE™ Vivid 7 Dimension machine was used for ECG-gated echo-Doppler studies. ICG measured amplitudes of the different peaks of the ICG waves and the augmentation index (AIx). ICG predicted SBP, DBP, mean arterial BP, and PP were recorded for comparison with similar pressure data obtained from two other methods. ICG device used in this study was designed and developed by Ghosh *et al.,* in the SMST, IIT, Kharagpur, and the details of the device have already been published in Artificial Intelligence in Medicine.[1] Figure 2 shows that C1 and C2 are excitation electrodes and R1–R2 are voltage-sensing electrodes placed on skin overlying the course of radial artery. Figure 3 shows the waveform. The waveforms were differentiated, filtered, and again differentiated. The difference between the two crests (second order and first order) was rendered by the subtractor inbuilt and the divider integrated divided that by the first crest amplitude. The technical details of the device are beyond the scope of this clinical publication.

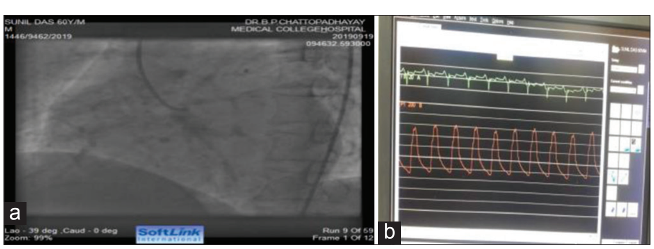

Figure 1: (a and b) Invasive catheter in ascending aorta and pressure tracing

RESULTS AND ANALYSIS

The present study was a hospital-based cross-sectional study conducted on 100 patients admitted in the

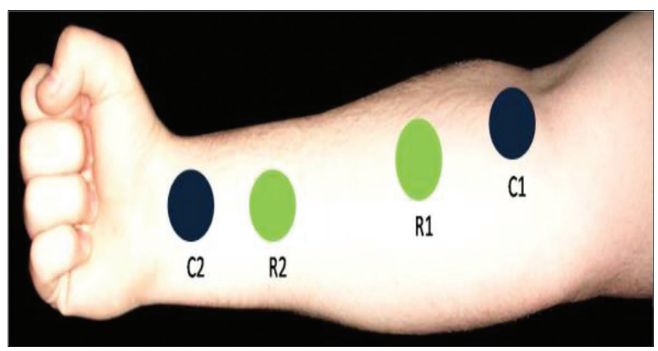

Figure 2: Electrode placement on the forearm of the subject

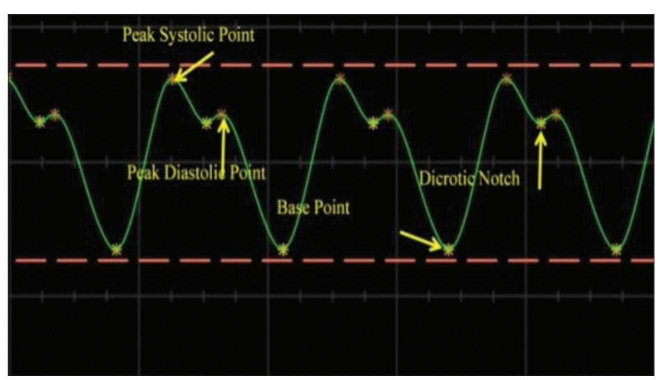

Figure 3: Impedance cardiography signal after filtering

cardiology department of medical college and hospital, Kolkata. In our study, 48% were female and 52% were male. The mean ± standard deviation (SD) age was 50.32 ± 8.125 years. Mean height mean ± SD was 163.85 ± 8.158 cm among the population. Mean weight and body mass index was 64.94 ± 8.348 kg and 24.1182 ± 3.11, respectively. Among the study population, 51% of patients are previously diagnosed hypertensive and 49% are normotensive. Among the study population, 35% had diabetes, either type 2 or type 1 and 65% were non-diabetic. About 29% of the study subjects were suffering from dyslipidemia. About 42% of the study population had a positive family history of diabetes. About 34% had a positive family history of hypertension and 21.6% had a history of AMI among family members. ECG wise, there were 100% of cases of ST-elevation MI and troponin T was positive in all cases in consonance with the inclusion criteria. According to ECG in our study population, there was involvement of wall as follows: Anerolateral in 28% of cases, anterior wall in 26%, inferior wall in 21%, anterior with inferior in 3% of cases, anteroseptal 7%, septal 3%, inferior with posterior wall 5%, 2% cases, global in 4%, and lateral 6%.

Tables 1–3 show a comparison of data on SBP, DBP, and MAP measured by three methods by sphygmomanometry, invasive, and ICG methods. Table 4 shows the values of correlation coefficients, all of which are positive correlations. ICG has been found to have a positive correlation with both sphygmomanometric and invasive methods of BP measurement. Figure 4 shows graphical presentation of the correlation between SBP, DBP, and MAP measured by three methods by sphygmomanometry, invasive, and ICG methods.

Table 1: Comparison of SBP by sphygmomanometry, invasive, and ICG methods (*n*=100)

SPG-SBP		INV-SBP		ICG-SBP	
Mean	137.9375	Mean	138.85	Mean	138.225
Standard error	1.729705447	Standard error	1.670679768	Standard error	1.669151892
Median	140	Median	141	Median	140
Mode	140	Mode	142	Mode	140
SD	15.47095584	SD	14.94301412	SD	14.92934838
Sample variance	239.3504747	Sample variance	223.2936709	Sample variance	222.885443
Count	100	Count	100	Count	100
Confidence level (95.0%)	3.442892512	Confidence level (95.0%)	3.325404838	Confidence level (95.0%)	3.322363678

SBP: Systolic blood pressure, ICG: Impedance cardiography, SD: Standard deviation

Table 2: Comparison of DBP by sphygmomanometry, invasive, and ICG methods (*n*=100)

SPG-DBP		INV-DBP		ICG-DBP	
Mean	86.85	Mean	87.3125	Mean	87.125
Standard error	1.190296	Standard error	0.972012	Standard error	1.018092
Median	90	Median	90	Median	88
Mode	92	Mode	90	Mode	90
SD	10.64633	SD	8.693943	SD	9.106091
Sample variance	113.3443	Sample variance	75.58465	Sample variance	82.92089
Count	100	Count	100	Count	100
Largest (1)	110	Largest (1)	112	Largest (1)	110
Smallest (1)	60	Smallest (1)	60	Smallest (1)	60
Confidence level (95.0%)	2.369224	Confidence level (95.0%)	1.934742	Confidence level (95.0%)	2.026461

DBP: Diastolic blood pressure, ICG: Impedance cardiography, SD: Standard deviation

Table 3: Comparison of MAP by sphygmomanometry, invasive, and ICG methods (*n*=100)

SPG-MAP		INV-MAP		ICG-MAP	
Mean	86.85	Mean	87.3125	Mean	87.125
Standard error	1.190296	Standard error	0.972012	Standard error	1.018092
Standard deviation	10.64633	Standard deviation	8.693943	Standard deviation	9.106091
Sample variance	113.3443	Sample variance	75.58465	Sample variance	82.92089
Count	100	Count	100	Count	100
Largest (1)	110	Largest (1)	112	Largest (1)	110
Smallest (1)	60	Smallest (1)	60	Smallest (1)	60
Confidence level (95.0%)	2.369224	Confidence level (95.0%)	1.934742	Confidence level (95.0%)	2.026461

MAP: Mean arterial pressure, ICG: Impedance cardiography, SD: Standard deviation

DISCUSSION

Before going into the discussion of correlation between methods of the measurement of BP by ICG, invasive method, and sphygmomanometry, some basic facts about ICG will be reviewed. ICG is a relatively new tool, yet to be widely utilized. ICG can give information about the function of the heart. Kubicek *et al.*[3] were the pioneer to introduce ICG for measuring cardiac output, stroke volume (SV), and body fluid composition in 1966. ICG measures the ionic conduction of human body depending on the variation of impedance or resistance. When alternating current is injected to the tissue overlying a vessel, the ease or resistance to flow of current depends mainly on the instantaneous impedance attributable to the blood within the arteriovenous compartment underneath and the impedance depends relatively less on the other tissues surrounding the artery. Blood contains electrolytes and charged particles or ions. The variation of volume of arterial blood within a specific part of the body in respect of time is deemed responsible for variation of the static and transient values of electrical conductivity. Before Kubicek, the variation in impedance (ΔZ) obtained due to the pulsatile, peripheral blood flow of limbs has been mathematically related to the pulsatile change in volume by Nyboer *et al.*,[4] 1950. Vessels are considered as volume conductors. Vessel segment in the limbs has been studied and by application of transfer function central aortic waveforms, pulse wave velocity has been derived by many workers. In this connection, it is necessary to emphasize the importance of the rate of change of impedance (dz/dt) and the maximum rate of change of impedance (dz/dt_{max}).

Tetrapolar electrodes were used in our study. Low-intensity high-frequency steady current is injected through outer two electrodes (C1–C2) and the receiving of the signal of variation of impedance (dZ) at the electrode-skin as well as tissue-vessel interface is acquired by the inner two electrodes [R1–R2 of Figure 2]. The signal so acquired from a segment of vessel under study is processed and filtered. Figure 2 shows that C1 and C2 are excitation electrodes and R1–R2 are voltage-sensing electrodes placed on skin overlying the course of radial artery. Figure 3 shows the waveform. The waveforms were differentiated, filtered, and again differentiated. The difference between the two crests (second order and first order) was obtained from the subtractor (augmented pressure) and the augmented pressure was divided by the PP value (difference between systolic and diastolic pressures).

Studies on correlation between ICG versus applanation tonometry in the measurement of pulse wave velocity[5] despite being limited in number reveal that they are in good agreement with each other. Many hemodynamic parameters such as SV,[6] left ventricular ejection fraction (LVEF), and AIx can be derived from ICG waveforms. AIx is the ratio between augmentation pressure and PP. Augmentation pressure is the difference between two peaks of the systolic

Table 4: Correlation coefficients

Correlation between	Correlations		
	SBP (r)	DBP (r)	MAP (r)
Spygmo versus INV	0.96177147	0.878096024	0.943255
Spygmo versus ICG	0.9741539	0.918881483	0.962693
INV versus ICG	0.98630466	0.929906314	0.974367

ICG: Impedance cardiography, SBP: Systolic blood pressure, DBP: Diastolic blood pressure, MAP: Mean arterial pressure

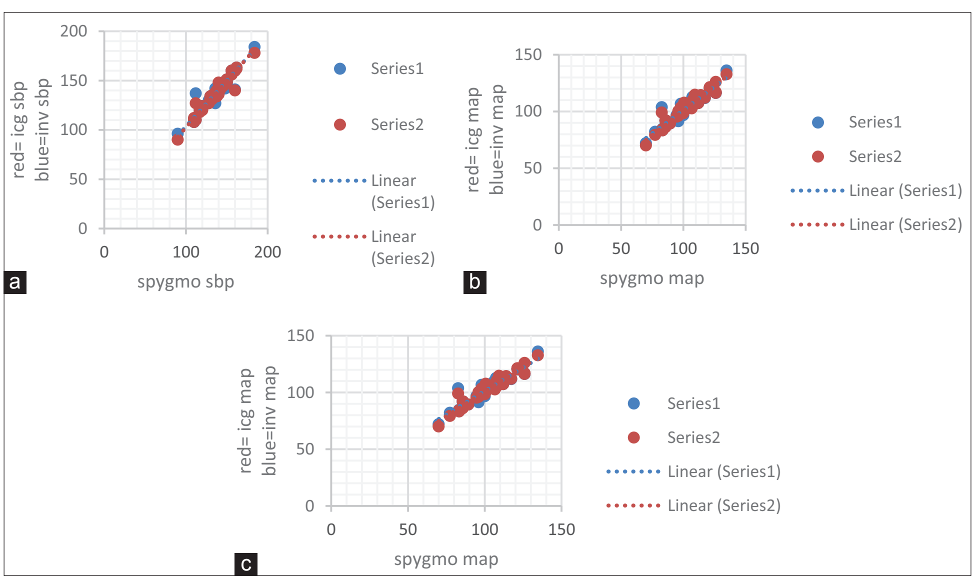

Figure 4: (a-c) Correlation between systolic blood pressure (BP), diastolic BP, and mean arterial pressure measured by three different methods (sphygmomanometry, invasive, and impedance cardiography)

pressure and is attributable to the contribution of the reflected wave. PP is the difference between the systolic pressure and the diastolic pressure identified in the ICG waveform. AIx can be estimated by applanation tonometry as well as by ICG.[5] Radial tonometry-derived AIx has been shown to correlate with the extent of the coronary artery disease,[3] LV hypertrophy,[4] urinary albumin excretion,[7] maximal aortic intima-media thickness,[8] cardiovascular events,[9] and all-cause mortality.[5,6,10-14] In the present work, we have studied the ICG-derived BP, invasive BP, and conventional sphygmomanometer-based BP.

The result and analysis of the data obtained reveal that ICG is well in agreement with the gold standard invasive method of BP measurement as well as conventional sphygmomanometric method of measurement.

CONCLUSION

There is a significant correlation between three methods of BP measurement with ICG device, conventional non-invasive sphygmomanometer, and cath lab-based invasive AP study. The ICG-derived BP data have been validated by this correlation. However, further large-scale studies are required.

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