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Original Article

Correlation between Coronary Angiography and Impedance Cardiography

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Abstract

Aims and Objectives: The aims of the study were to find out the correlation between coronary angiographic findings and hemodynamic parameters derived from impedance cardiography (ICG) and echo-Doppler study.

Patients, Materials and Methods: A total of 200 patients of acute myocardial infarction having chest pain, ST elevation in two or more contiguous leads of electrocardiogram (ECG), biomarker positivity, echocardiographic evidence of regional wall motion abnormality (RWMA), and coronary angiographic evidence of coronary lesions were recruited. Subjects unwilling to participate, 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. The left ventricular ejection fraction (LVEF), stroke volume (SV), RWMA, diastolic function, etc., were observed. ICG measured LVEDV, LVESV, LVEF, and other parameters particularly amplitudes of the different waves. Coronary angiography (CAG) was done in the Cath Lab having "Siemens™ Axiom Artis Zee (floor)" equipment.

Results and Analysis: Results-analysis revealed there is negative correlation (Pearson's correlation coefficient, $r = -0.8$) between augmentation pressure and coronary angiographic stenosis percentage and P value is also significant ($P = 0.034$). Pulse pressure (PP) also is positively correlated ($r = -0.78$) with coronary angiographic stenosis percentage and P value is also significant ($P = 0.027$). There is a negative correlation ($r = -0.259$) between augmentation index (AIx) and coronary angiographic lesions and that is statistically significant ($P = 0.03$).

Conclusion: There is a positive correlation between ICG -derived hemodynamic parameters and the percentage stenosis of coronary arteries. Rise of augmentation pressure and PP in the ICG waveform is associated with coronary artery disease severity. AIx is negatively correlated with severity of coronary arterial stenosis.

Key words: Artificial neural network, Augmentation index, Coronary angiography, Impedance cardiography, Left ventricular ejection fraction, Left ventricular end-diastolic volume, Left ventricular end-systolic volume, Regional wall motion abnormality, Stroke volume

INTRODUCTION

Electrocardiogram (ECG) can detect myocardial ischemia, injury, and infarction by picking up the changes in voltage. ST-segment elevation of anterior wall is largely attributable to occlusion of the left anterior descending artery, inferior wall mostly attributable to occlusion of the right coronary artery, and lateral wall attributable to occlusion of the left circumflex artery. There are many ECG algorithms for predicting the culprit coronary artery occlusion in ST-elevation myocardial infarction patients. Impedance cardiography (ICG) another electrical instrument has also the potential of being contributory like ECG in acute myocardial infarction. However, coronary angiography (CAG) is the gold standard in identification and quantification of the coronary artery disease.

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In recent years, there is renewed interest in evaluating the role of ICG in cardiac diseases. We have also worked on ICG. The basic principles and technical details of the ICG device used 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] Many hemodynamic parameters such as stroke volume (SV), left

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ventricular ejection fraction (LVEF), and augmentation index (AIx) can be derived from ICG waveforms. AIx is the ratio between augmentation pressure and pulse pressure (PP). Augmentation pressure is the difference between two peaks of the systolic pressure and is attributable to the contribution of the reflected wave, left ventricular ejection time, etc. PP is the difference between the systolic pressure and the diastolic pressure identified in the ICG waveform. AIx can be estimated by applanation tonometry and by ICG. Radial tonometry-derived AIx has been shown to correlate with the extent of the coronary artery disease,[3] LV hypertrophy,[4] urinary albumin excretion,[5] maximal aortic intima-media thickness,[6] cardiovascular events,[7] and all-cause mortality.[8-10] In the present work, we have studied the ICG of patients undergoing CAG (for cardiac reason) for the purpose of searching correlation between ICG and CAG.

Aims and Objectives

The aims of the study were to collect (1) hemodynamic parameters predicted by impedance cardiography (ICG) instrument and cardiac echo-Doppler studies from patients of acute myocardial infarction and (2) find out the correlation between coronary angiographic findings and hemodynamic parameters derived from ICG and echo-Doppler study.

PATIENTS MATERIALS AND METHODS

Patients

Inclusion and exclusion criteria of the diseased subjects: Inclusion criteria: Classical chest pain (angina of coronary origin), ECG changes such as ST elevation in two or more contiguous leads, biomarker positivity (CPK-MB or troponin T), and echocardiographic evidence of regional wall motion abnormality (RWMA), and coronary angiographic evidence of coronary lesions were included in the study. Exclusion criteria: Subjects unwilling to participate after knowing that ICG is an experimental tool and is not going to contribute to the treatment process were excluded from the study. Moribund, critically ill subjects, and patients with concomitant heart failure, arrhythmia, and valvular lesions were excluded from the study. Materials and Methods: GE™ Vivid 7 Dimension echo-Doppler machine was used
AQ3 for acquisition of ECG-gated echo-Doppler imaging. LVEF RWMA, Diastolic function. LVEDV, LVESV, LVEF, LVET, SV, etc., were recorded. 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 1 shows that C1and C2 are excitation electrodes and R1-R2 are voltage-sensing electrodes placed on skin overlying the course of radial artery. Figure 2 shows the waveform. The waveforms were differentiated, processed to derive SV, LVEF, AIx, etc., parameters. CAG was done in our Cath Lab having "Siemens™ Axiom Artis Zee (floor)," with a power rating of 100 kW at 100 kV. The power of the X-ray generator is 100 kW, with a penetration depth of 92 cm. CAG pictures [Figure 3] thus acquired were utilized for qualitative and quantitative estimation of coronary artery disease. All the 200 subjects recruited in this study, underwent coronary angiogram due to cardiac indication. The coronary angiogram was analyzed to ascertain the location and degree of stenosis.

RESULTS AND ANALYSIS

The present study was a hospital-based cross-sectional study conducted in 200 patients admitted in the Cardiology

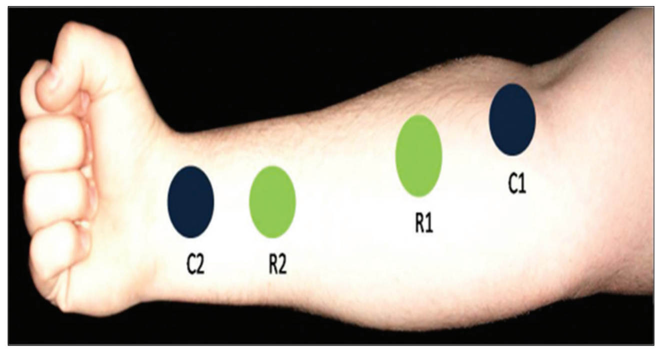

Figure 1: Electrode placement on the forearm of the subject

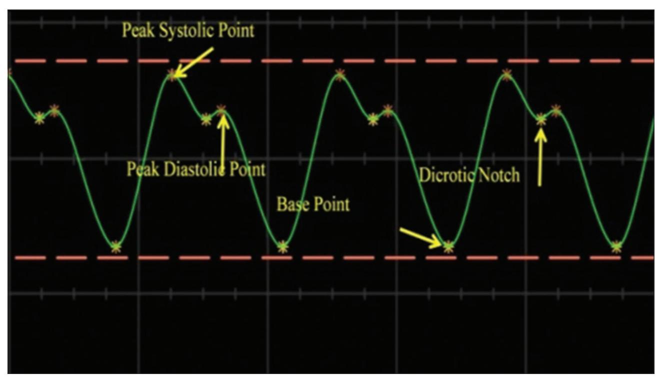

Figure 2: ICG signal after filtering

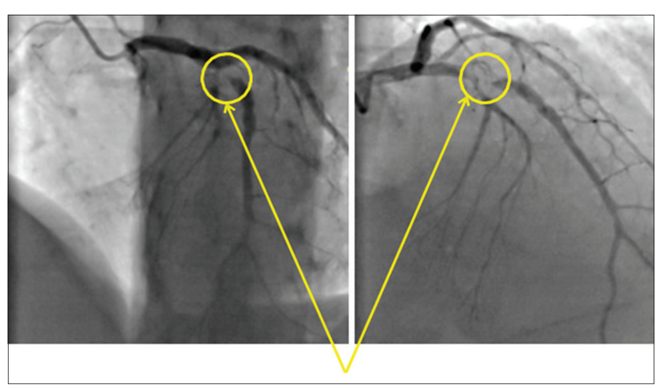

Figure 3: Coronary angiographic lesion

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 were 64.94 ± 8.348 kg and 24.1182 ± 3.11, respectively. The
AQ6 mean BSA of patients was 1.7073 ± 0.1269. 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. All the cases selected were having ST elevation Myocardial Infarction as evidenced by ECG. This was in consonace with inclusion criteria of patients. According to ECG in our study population, there was an involvement of wall as follows: Anerolateral in 23% 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%, inferior with RVMI in 2% of cases, global in 4%, and lateral 6%. Troponin T was positive in all cases. Among the other biochemical parameters, both of CPK and CPK-MB were elevated in 90% of cases.

DISCUSSION

Before going into the discussion of correlation between ICG and CAG, 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 (CO) 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 the flow of current depends mainly on the instantaneous impedance attributable to the blood within the artery and the impedance depends less on the tissues surrounding the artery. Blood contains electrolytes and charged particles or ions. Blood flows through arteries. This arterial flow is pulsatile in nature. There is variation or change in the volume of blood in the arteries in respect of time and that is attributable to the systole and diastole. Variation of blood volume results in variation of quantity of charged particles or ions in a given segment of vessel under study in respect of time. This variation of volume and hence the quantity of ions results in variation of impedance (to the current injected from outside by the ICG device). This 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. Majority of initial researchers worked on thoracic impedance plethysmography and the volume changes in aorta and inferior vena cava were studied in great detail. Vessel segment in the limbs has also 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}).

Both bipolar and tetrapolar electrodes have been used for research. In case of tetrapolar electrodes as 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 1]. The signal so acquired from a segment of vessel under study is processed and filtered. Demodulation and differentiation of the signal thus acquired are followed by the extraction of the features. The ICG signal thus acquired resembles conventional aortic pulse waveform (obtained by direct invasive transaortic measurement/or non-invasive applanation tonometry of peripheral arteries) in many ways. The extracted features of ICG waveform are broadly categorized into four major types: Pressure features, time features, area features, and amplitude features. Algorithm deployed in the ICG device is usually designed in such a way so that it detects only the complete cardiac cycles and discards incomplete cardiac cycles. Feature points such as peak systolic point, dicrotic notch, peak diastolic point, and baseline point are of paramount importance [Figure 2]. The difference between the first two peak values may be termed as augmented pressure which is attributable to reflected wave and LVET. The PP is the difference between systolic and diastolic pressures. The ratio between augmented pressure and PP is called AIx. The differentiated ICG waveforms may be used to extract many other remaining feature points such as SV and LVEF. SV is the absolute volume of blood ejected by concerned ventricle during systole and CO is the product of SV and heart rate. Applanation tonometry has been widely used in assessment of pulse-wave velocity, central aortic waveforms, and AIx. ICG has also been used in the assessment of hemodynamic parameters. However, studies on correlation between ICG and applanation tonometry in the measurement of pulse-wave velocity[11] despite being limited in number reveal that they are in good agreement with each other. Radial

Table 1: Correlation between coronary angiography and echo-derived hemodynamic parameters

Hemodynamics	r and *P* values	Coronary	Angiographic	Stenosis	Percentage
		Left anterior descending artery	Right coronary artery	Left circumflex artery	Left main coronary artery
Echo left ventricular ejection fraction	Pearson correlation	+0.110	+0.016	+0.32	+0.209
	P-value	0.275	0.876	0.749	0.037
Echo stroke volume	Pearson correlation	+0.269	+0.218	+0.456	+0.014
	P-value	0.007	0.029	0.001	0.04

Table 2: Correlation between coronary angiography and ICG-derived hemodynamic parameters

Hemodynamics	r and *P* values	Coronary	Angiographic	Stenosis	Percentage
		Left anterior descending artery	Right coronary artery	Left circumflex artery	Left main coronary artery
ICG left ventricular ejection fraction	Pearson correlation	+0.075	+0.102	+0.189	±178
	P-value	0.041	0.04	0.049	0.076
ICG stroke volume	Pearson correlation	+0.15	+0.306	+0.325	+0.058
	P-value	0.008	0.002	0.001	0.04

Table 3: Correlation (r) between coronary angiographic lesion site (s) and ICG-derived augmentation pressure, PP, and augmentation index

Parameters	r and *p*	Left main coronary artery	Left anterior descending artery	Left circumflex artery	Right coronary artery
Augmentation pressure (peak 1-peak 2)	r	−0.8	−0.9	−0.8	−0.9
	p	0.034	0.029	0.036	0.0198
PP (SBP-DBP)	r	+0.78	+0.69	+0.86	+0.883
	p	0.027	0.047	0.06	0.021
Augmentation index augmentation index (P1-P2)/(PP)	r	−0.259	−0.42	−0.63	−0.204
	p	0.03	0.048	0.021	0.04

PP: Pulse pressure

tonometry-derived AIx has been shown to correlate with the extent of the coronary artery disease,[7] LV hypertrophy,[8] urinary albumin excretion,[9] maximal aortic intima-media thickness, cardiovascular events,[9] and all-cause mortality[10,12,13] SV has been estimated by ICG by previous workers as well.[14] In the present study, Table 1 reveals that there is a negative correlation (Pearson's correlation coefficient, r) between percentage of coronary angiographic stenosis and the echo-Doppler-derived hemodynamic parameters such as stroke volume ($r = -0.269$ and $P = 0.007$) and left ventricular ejection fraction ($r = -0.110$ and $P = 0.275$) and P values are significant. Table 2 reveals that similarly, there is a negative correlation and P values are also significant between the percentage of coronary angiographic stenosis and the ICG-derived hemodynamic parameters such as stroke volume ($r = -0.15$ and $P = 0.008$) and left ventricular ejection fraction ($r = -0.075$ and $P = 0.041$). Table 3 reveals that there is a positive correlation (Pearson's correlation coefficient, $r = +0.8$) between augmentation pressure (P1-P2) and coronary angiographic stenosis percentage and P value is also significant ($P = 0.034$). PP also is positively correlated ($r = +0.78$) with coronary angiographic stenosis percentage and P value is also significant ($P = 0.027$). There is a negative correlation ($r = -0.259$) between AIx and coronary angiographic lesions and that is statistically significant ($P = 0.03$). The AIx of the subjects with angiographically proved coronary artery disease ranged between −1.65 and +1.24. Higher the value of ICG-derived AIx, worse is the status of the coronary artery disease.

CONCLUSION

There is a positive correlation between ICG-derived hemodynamic parameters and the percentage stenosis of coronary arteries. Rise of augmentation pressure and pulse pressure in the ICG waveform is associated with coronary artery disease severity. However, AIx is negatively correlated with severity of coronary arterial stenosis, i.e., as there is increase in the percentage stenosis of coronary lesions and increase in the number of coronary arteries involved, the AIx is increased. However, further large-scale studies are required to explore the potential of ICG.

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