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A Retrospective Study of Hemodynamic Changes in Patients After Off-Pump Coronary Artery Bypass Graft Surgery Using Impedance Cardiography

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Background: This study aimed to investigate the role of impedance cardiography (ICG) to evaluate hemodynamic changes in patients after off-pump coronary artery bypass graft (OPCABG) surgery.

Material/Methods: One-hundred and sixty patients who had undergone OPCAGB were enrolled and assessed using New York Heart Association NYHA functional class (II, II, and IV). ICG was used to measure the stroke volume (SV), stroke volume index (SI), cardiac output per minute (CO/min), cardiac index (CI), end-diastolic volume (EDV), pre-ejection period (PEP), left ventricular ejection time (LVET), systolic time ratio (STR), left ventricular ejection fraction (LVEF), acceleration index (ACI), systemic vascular resistance (SVR), and thoracic fluid content (TFC). The ICG parameters were correlated with brain natriuretic peptide (BNP) and echocardiography parameters using multivariate regression analysis.

Results: The levels of CO, ACI, TFC, SVR, and BNP compared with ICG showed differences between NYHA functional class, with CO showing a significant difference (p<0.05). There were no significant differences between SV, SI, EDV, and LVEF before and after OPCAGB. Using ICG, the parameters of CI, LVEF, EDV, and TFC showed no significant correlation with BNP. SV, SI, CO, ACI, and LVET, which were negatively correlated with BNP. SVR, PEP, and STR were positively correlated with BNP (P<0.05).

Conclusions: In patients who had OPCABG, the findings from ICG were significantly correlated with BNP levels and the results from echocardiography for the evaluation of cardiac hemodynamic changes. ICG might have a role in the assessment of cardiac function in clinical practice.

MeSH Keywords: **Biochemistry • Hemodynamics • Hypertension**

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Background

Coronary heart disease (CHD), or ischemic heart disease (IHD), is a common disease in the elderly population and results in significant morbidity and mortality [1]. Off-pump coronary artery bypass graft (OPCABG) surgery can rapidly improve cardiac blood supply following occlusive or stenotic lesions of the coronary artery and is one of the main methods of treatment for CHD [2]. OPCABG not only avoids the complications of cardiopulmonary bypass but is also associated with more rapid recovery after surgery [2]. OPCABG can also improve clinical outcome and reduce the length of hospital stay [3]. However, cardiac dysfunction may occur while the heart is manipulated during OPCABG [4]. Therefore, the assessment of cardiac function and timely treatment of any complications would improve patient recovery after OPCABG [5].

Recently, several noninvasive methods have been developed in the field of cardiac function testing. Impedance cardiography (ICG), is a noninvasive method of evaluating the hemodynamic changes of cardiac function that measures impedance. Clinically, ICG has been widely used due to its simplicity of operation, its wide range of applications, and low cost of use [6,7]. In 2005, the American College of Cardiology (ACC) and the American Heart Association (AHA) supported the use of ICG and echocardiography in the diagnosis and treatment of chronic heart failure (CHF) [8].

In 2003, Lasater et al. [9] reported the findings from a study of a thoracic impedance method to monitor cardiac function in patients with chronic heart failure (CHF) and showed that the cardiac index (CI) and systemic vascular resistance (SVR) identified using ICG were significantly associated with the improvement in cardiac function and clinical symptoms. Several studies have analyzed the clinical application of ICG in the diagnosis and monitoring of heart failure [10,11]. The results have shown significant correlations between ICG, echocardiography, and brain natriuretic peptide (BNP). For example, when monitoring patients with heart failure, ICG data that included cardiac output (CO), the systolic time ratio (STR) were found to correlate with the left ventricular ejection fraction (LVEF) [11]. A significant association between ICG data and CO have also been shown [12]. previously published studies have shown a significant correlation between LVEF and STR [13,14]. Therefore, ICG is a feasible method for use in the diagnosis and monitoring of heart failure. Heart impedance tracing has advantages of being a non-invasive, dynamic, continuous monitoring method and for these reasons, the use of ICG is highly recommended.

Therefore, this study aimed to investigate the role of impedance cardiography (ICG) to evaluate hemodynamic changes in patients after off-pump coronary artery bypass graft (OPCABG) surgery.

Material and Methods

Patient clinical data

A retrospective study was conducted at a single center and included 160 patients who had undergone off-pump coronary artery bypass graft (OPCABG) surgery who were assessed using the New York Heart Association NYHA functional class (I–IV), and clinically diagnosed with coronary heart disease (CHD) based on the 2013 European Society of Cardiology (ESC) guidelines [15]. Prior written informed consent was obtained from all study participants. The study was approved by the local Ethics Review Board of the Peoples' Hospital of Xinjiang, Uygur Autonomous Region.

Inclusion and exclusion criteria

Patients were included if they were aged 18–80 years old, diagnosed with CHD, had undergone OPCABG surgery and signed the informed consent. Patients were excluded if they their height was <135 cm or >190 cm, if they had pleural effusion, a permanent pacemaker implant, a life-threatening comorbidity such as severe heart failure, a metabolic disease such as diabetes or hyperthyroidism, malignant tumors or autoimmune diseases, a history of allergy or serious adverse reactions, or if they had incomplete clinical data.

Enzyme-linked immunoassay (ELISA)

Peripheral blood was collected from each patient before surgery, in the morning of surgery, and during the following three mornings after surgery. Serum was isolated from the peripheral blood samples. Levels of brain natriuretic peptide (BNP) in the serum were measured using a BNP enzyme-linked immunoassay (ELISA) kit (Biosite Incorporated, San Diego, California, USA), according to the manufacturer's instructions.

Impedance cardiography (ICG)

Following OPCABG surgery, all patients were admitted to the intensive care unit (ICU), and received routine mechanical ventilation, vasoactive drugs, moderate rehydration, low molecular weight heparin, and underwent blood gas analysis. Postoperative treatment included dopamine, nitroglycerin, phosphate creatine, and electrolytes. ICG was performed to monitor the hemodynamic changes. Monitoring of mechanical ventilation, drug therapy, fluid management, and electrolyte balance, was performed before and after surgery. ICG was performed using a BioZ Dx Impedance Cardiograph (Cardio Dynamics, San Diego, CA, USA) with eight electrodes. ICG was performed at the same time as echocardiography. Before ICG examination, patients were rested for 10 minutes. The patients were in the supine position during ICG and the sensors

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measured the baseline impedance of the thorax. The sensing electrodes were placed at the left and right sides of the neck, and the intersection between the anterior axillary line and the lower edge of the costal arch. The following parameters were recorded: the stroke volume (SV); the stroke volume index (SI); the cardiac output (CO) per minute; the cardiac index (CI); the end-diastolic volume (EDV); the pre-ejection period (PEP); the left ventricular ejection time (LVET); the systolic time ratio (STR); the left ventricular ejection fraction (LVEF); the acceleration index (ACI); the systemic vascular resistance (SVR); and the thoracic fluid content (TFC).

Echocardiography

Echocardiography was performed using the Philips ClearVue 350 (Shanghai Hanfei Medical Devices Co., Ltd., China) to monitor the hemodynamic changes before surgery and at the same time as ICG after surgery. The cardiac parameters of LVEF, SV, CO, ESV, and LVET, EDV, SI, CI, STR were measured. The average of three measurements of each variable was used.

Statistical analysis

SPSS version 19.0 (IBM, Chicago, IL, USA) was used for statistical analysis. All measurement data were expressed as the mean ± standard deviation (SD). The paired t-test was used for comparison between data before and after treatment. Analysis of variance (ANOVA) was used for comparison between groups. Multivariate regression analysis was used for the parameters of BNP, ICG, and echocardiography. Spearman correlation's analysis and Bland-Altman analysis was used for consistency evaluation. A P-value <0.05 was considered to be statistically significant.

Results

Patient clinical characteristics

There were 180 patients with coronary heart disease (CHD) who were admitted to the intensive care unit (ICU) of the Peoples' Hospital of Xinjiang Uyghur Autonomous Region from January 2015 to October 2017, and 160 of them underwent off-pump coronary artery bypass graft (OPCABG) surgery and were included in this study. The clinical data are shown in Table 1. There were 90 men and 70 women, aged between 38–79 years (mean, 58.31±15.42 years). The patients' body weight ranged from 45–82 kg (mean, 61.61±12.82 kg). Based on the New York Heart Association (NYHA) functional classification, there were 0 cases of class I, 42 cases of class II, 105 cases of class III, and 13 cases of class IV heart failure.

Table 1. Clinical characteristics of the patients who underwent off-pump coronary artery bypass graft (OPCABG) surgery following impedance cardiography (ICG).

Parameters	Mean (± standard deviation)
Gender (M/F)	90/70
Age (years)	58.31±15.42
BMI (Kg/m^2)	21.32±3.45
Systolic blood pressure (mmHg)	135.2±4.7
Diastolic blood pressure (mmHg)	88.8±3.9
(NYHA) (II/III/IV)	42/105/13
LVEF (pre-operation)	51.31±12.21
Arrhythmia (pre-operation)	62/160
Number of lesions	3.12±0.64
Time of operation (minutes)	171.32±17.15

BMI – body mass index; NYHA – the New York Heart Association functional classification; LVEF – left ventricular ejection fraction.

Comparison of impedance cardiography (ICG) and brain natriuretic peptide (BNP) between the patient groups with different NYHA functional classes after OPCABG surgery

To compare the differences for in the parameters of the stroke volume (SV), the stroke volume index (SI), the cardiac output (CO) per minute, the cardiac index (CI), the end-diastolic volume (EDV), the pre-ejection period (PEP), the left ventricular ejection time (LVET), the systolic time ratio (STR), the left ventricular ejection fraction (LVEF), the acceleration index (ACI), the systemic vascular resistance (SVR), the thoracic fluid content (TFC), and the BNP between patients with different NYHA functional classes, the patients were divided into three groups (class II, class III and class IV). As shown in Table 2, the parameters of BNP, CO, ACI, TFC, and SVR were significantly different between the three functional groups ($p<0.05$). With the increase in cardiac insufficiency, the CO and ACI decreased, whereas the TFC, SVR, and BNP increased.

Multivariate regression analysis for the parameters of BNP, ICG, and echocardiography between the three groups with different NYHA classes (II, III, and IV) after OPCABG surgery

Multivariate regression analysis evaluated the parameters of BNP, ICG, and echocardiography, which included SV, SI, CI, CO, STR, LVET, PEP, LVEF, EDV, ACI, TFC, and SVR between the three groups with different NYHA classes (II, III, and IV) after OPCABG. As shown in Table 3, the CO was significantly different between

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Table 2. Distribution of impedance cardiography (ICG) and brain natriuretic peptide (BNP) data in the patient groups according to New York Heart Association (NYHA) functional class after off-pump coronary artery bypass grafting (OPCABG) (mean ± standard deviation).

ICG data	NYHA class II (n=42)	NYHA class III (n=105)	NYHA class IV (n=13)	p-Value
SV (ml)	42.1±18.86	31.3±23.59	25.3±5.35	0.054
SI (ml/m²)	4.12±18.53	3.04±23.14	2.79±5.28	0.212
CI (l/min/m²)	4.32±1.12	2.69±1.30	3.04±0.84	0.063
CO (l/min)	4.48±1.38#	3.02±1.13*	2.61±1.52*#	0.033
STR (–)	23.2±0.16	29.7±0.15	33.9±0.17	0.294
LVET (ms)	331±0.05	354±0.08	242±0.1	0.065
PEP (ms)	18.9±0.03	32.6±0.04	31.9±0.05	0.127
LVEF (–)	37.5±0.02	28.6±0.03	30.6±0.04	0.443
EDV (ml)	115.34±23.12	121±24.34	125±25.43	0.364
SVR (dyne×s×cm⁻⁵)	1571.6±221.03#	1687±180.56*	1798±179.08*#	0.001
ACI (/100/s²)	51.64±3.15#	45.34±2.88*	39.67±3.12*#	0.005
TFC (/kOhm)	14.8±2.32#	26.9±3.06*	38.8±3.11*#	0.001
BNP (ng/ml)	66.3±1.02#	326±2.35*	367±3.53*#	<0.001

SV – stroke volume; SI – stroke volume index; CI – cardiac index; CO – cardiac output; STR – systolic time ratio; LVET – left ventricular ejection time; PEP – pre-ejection period; LVEF – left ventricular ejection fraction; EDV – end-diastolic volume; BNP – brain natriuretic peptide (detected by ELISA); ACI – acceleration index; TFC – thoracic fluid content; SVR – systemic vascular resistance. Compared with NYHA Class II, * P<0.05. Compared with NYHA class III, # P<0.05.

the three patient groups (p<0.05), while other parameters were not significantly different. Using multivariate regression analysis, CO was a determinant of cardiac NYHA functional class.

Comparisons between the ICG parameters and BNP before and after OPCABG surgery in the three groups with different NYHA classes (II, III, and IV)

To compare the hemodynamic parameters before and after treatment, ICG was used. The treatment of cardiac failure with use of diuretics, and rehydration, and reduction of peripheral vascular resistance were used. After treatment, there was no difference in SV, SI, EDV, and LVEF. However, there were significant differences in STR, LVET, PEP, BNP, ACI, TFC, CO, CI, and SVR (p<0.05) before and after treatment (Table 4). The CO, LVET and ACI increased, and PEP, BNP, TFC, and SVR decreased. This data suggests that when myocardial contraction was increased, cardiac output increased.

Linear correlation analysis between ICG data and BNP after OPCABG surgery

The correlation between ICG data and BNP were analyzed by Spearman's correlation. As shown in Table 5, there was no significant correlation between BNP and the ICG data for CI, LVEF, EDV, and TFC. SV, SI, CO, ACI, and LVET were negatively correlated with BNP, while SVR, PEP, and STR were positively correlated with BNP. This data suggests that when cardiac function improved and cardiac output increased, BNP decreased. However, when the cardiac function was impaired and peripheral resistance increased, BNP levels increased.

Consistency analysis of ICG and echocardiography after OPCABG surgery

The consistency between the data from ICG and echocardiography was determined by Bland–Altman analysis. There was consistency between the ICG and echocardiography parameters, including the LVEF, SV, SI, CO, CI, and STR (P<0.05) (Tables 6, 7). No consistency was found for EDV, LVET, and PEP. These data suggest that the ICG detection parameters and echocardiography parameters showed good consistency.

Discussion

Recently, the incidence of cardiovascular disease has increased with the aging population and due to changes in lifestyles [16]. Coronary artery stenosis results in insufficient myocardial blood supply and leads to progressive cardiac ischemia,

Table 3. Multivariate regression analysis for the parameters of brain natriuretic peptide (BNP), impedance cardiography (ICG) and echocardiography among the patient groups with different New York Hear Association (NYHA) functional classes after off-pump coronary artery bypass grafting (OPCABG).

		Parameter estimation			
Parameter	**Variance**	**Estimation**	**Standard error**	**Wald χ^2**	**Pr >χ^2**
Intercept	1	−1.1118	585.4695	0.1513	0.59
SV	1	−0.2276	158.4367	0.1165	0.51
SI	1	3.4451	206.7463	0.1204	0.49
STR (–)	1	−2.0357	612.2286	0.2433	0.44
CI	1	−1.4094	467.5372	0.1565	0.46
CO	1	−0.1376	22.7515	3.3565	0.04
LVET	1	−1.005	161.7357	0.1186	0.5
PEP	1	−1.25	378.283	0.3213	0.45
SVR	1	−1.3341	267.8761	0.1342	0.46
TFC	1	−2.0342	362.7541	0.2812	0.38
BNP	1	−1.3452	447.3231	0.1451	0.45
ACI	1	−1.9653	279.0431	0.1431	0.45
EDV	1	–	–	–	–
LVEF	1	–	–	–	–

SV – stroke volume; SI – stroke volume index; CI – cardiac index; CO – cardiac output; STR – systolic time ratio; LVET – left ventricular ejection time; PEP – pre-ejection period; LVEF – left ventricular ejection fraction; EDV – end-diastolic volume; BNP – brain natriuretic peptide (detected by ELISA); ACI – acceleration index; TFC – thoracic fluid content; SVR – systemic vascular; '–' – not indicated.

Table 4. Impedance cardiography (ICG) parameters and brain natriuretic peptide (BNP) before and after treatment (mean ± standard deviation).

	SV (ml)	**SI (ml/m²)**	**CO (L/Min)**	**CI (l/min/m²)**	**STR**	**PEP (ms)**	**LVET (ms)**
Before treatment	64.7±9.8	3.355±1.91	3.0±0.9	2.29±0.12	0.54±0.1	96.74±12.1	302.1±9.0
After treatment	71.2±11.1	4.712±1.33	4.3±1.5	3.18±0.12	0.47±0.16	80.04±4.35	341±7.9
P-value	0.062	0.181	0.028	0.032	0.034	0.046	0.044

	EDV (ml)	**ACI**	**TFC (/kohm)**	**LVEF (–)**	**SVR (dyne·s·cm⁻⁵)**	**BNP (ng/ml)**
Before treatment	120.45±24.3	39.2±25.7	39.3±13.7	32.23±0.03	1967±575	1069±311
After treatment	113.2±22.1	50.6±17.3	33.4±7.8	28.34±0.02	1798±432	367±105
P-value	0.054	0.02	<0.001	0.061	0.042	0.033

SV – stroke volume; SI – stroke volume index; CI – cardiac index; CO – cardiac output; STR – systolic time ratio; LVET – left ventricular ejection time; PEP – pre-ejection period; EF – ejection fraction; EDV – end-diastolic volume; BNP – brain natriuretic peptide (detected by ELISA); ACI – acceleration index; TFC – thoracic fluid content; SVR – systemic vascular resistance.

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Table 5. Correlation analysis of impedance cardiography (ICG) data and brain natriuretic peptide (BNP).

ICG data		SV (ml)	SI (ml/m²)	CO (L/min)	CI (L/min/m²)	SVR (dyne·s·cm⁻⁵)	ACI
BNP	r	–0.898	–0.634	–0.351	–0.220	0.865	–0.025
	P value	<0.01	<0.01	<0.05	0.053	<0.05	<0.05
ICG data		**PEP (ms)**	**LVEF (-)**	**LVET (ms)**	**STR**	**TFC (/kohm)**	**EDV (ml)**
BNP	r	0.583	–0.544	–0.895	0.344	0.231	0.533
	P value	<0.01	0.62	<0.01	<0.01	0.56	0.58

r – linear correlation coefficient; SV – stroke volume; SI – stroke volume index; CI – cardiac index; CO – cardiac output; STR – systolic time ratio; LVET – left ventricular ejection time; PEP – pre-ejection period; EDV – end-diastolic volume; BNP – brain natriuretic peptide (detected by ELISA); ACI – acceleration index; TFC – thoracic fluid content; SVR – systemic vascular resistance.

Table 6. Limits of agreement (LOA) of echocardiography and impedance cardiography (ICG) by Bland-Altman analysis.

Index	n	LOA 95% CI	Mean	LOA lower limit value	LOA upper limit value	Number in LOA 95% CI
CI	160	–0.06–0.12	0.03 (0.02–0.04)	–0.05 (–0.06–0.03)	0.11 (0.09–0.12)	158 (99.03%)
CO	160	–0.21–0.24	0.01 (–0.01–0.03)	–0.18 (–0.21–0.15)	0.21 (0.17–0.24)	160 (100%)
EDV	160	–256.65–235.95	–10.35 (–31.12–10.42)	–221.14 (–256.65–185.62)	200.44 (164.92–235.95)	158 (99.03%)
LVEF	160	–0.82–1.09	0.13 (0.05–0.21)	–0.69 (–0.82–0.55)	0.95 (0.82–1.09)	151 (94.17%)
LVET	160	–647.71–706.37	29.33 (–27.76–86.42)	–550.09 (–647.71–452.46)	608.74 (511.11–706.37)	158 (99.03%)
PEP	160	–36.81–35.37	–0.72 (–3.76–2.32)	–31.6 (–36.81–26.4)	30.16 (24.96–35.37)	158 (99.03%)
SI	160	–0.05–0.09	0.02 (0.01–0.03)	–0.04 (–0.05–0.03)	0.08 (0.07–0.09)	158 (99.03%)
STR	160	–0.9–1.83	0.46 (0.35–0.58)	–0.71 (–0.9–0.51)	1.63 (1.44–1.83)	155 (97.09%)
SV	160	–0.95–1.56	0.3 (0.2–0.41)	–0.77 (–0.95–0.59)	1.38 (1.2–1.56)	149 (93.20%)

SV – stroke volume; SI – stroke volume index; CI – cardiac index; CO – cardiac output; STR – systolic time ratio; LVET – left ventricular ejection time; PEP – pre-ejection period; EDV – end-diastolic volume; BNP – brain natriuretic peptide (detected by ELISA); ACI – acceleration index; TFC – thoracic fluid content; SVR – systemic vascular resistance; LOA – limits of agreement.

resulting in impaired cardiac function [16]. In this study, the hemodynamic changes resulting from coronary heart disease (CHD) in patients who had off-pump coronary artery bypass graft (OPCABG) surgery were evaluated by impedance cardiography (ICG) parameters. One-hundred and sixty patients who had undergone OPCAGB were enrolled and assessed using the New York Heart Association NYHA functional class and divided into three groups (II, II, and IV). The ICG parameters could be divided into overall evaluation parameters, myocardial contractility parameters, preload parameters, and postload parameters. The overall ICG evaluation parameters included stroke volume (SV), stroke volume index (SI), cardiac output (CO), and cardiac index (CI); the myocardial contractility parameters included left ventricular ejection time (LVET), systolic time ratio (STR), pre-ejection period (PEP), and acceleration index (ACI); the preload parameter was thoracic fluid content (TFC); and the postload parameter was systemic vascular resistance (SVR).

The findings from this study showed that there were significant differences in the CO, ACI, TFC, and SVR between patients in the three NYHA classes (II, III, and IV), with decreased levels

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Table 7. Regression analysis for impedance cardiography (ICG) and echocardiography.

Index		β	Standard error	t	P-value	R2
CI	Intercept	0	0.02	−0.19	0.8505	0.0373
	Mean value	0.01	0.01	1.98	0.0507	
CO	Intercept	0.12	0.05	2.54	0.0127	0.0507
	Mean value	−0.03	0.01	−2.32	0.0222	
EDV	Intercept	236.63	1.99	119.16	<0.0001	0.9945
	Mean value	−1.98	0.01	−135.49	<0.0001	
LVEF	Intercept	0.83	0.31	2.7	0.0081	0.0492
	Mean value	−0.02	0.01	−2.29	0.0243	
LVET	Intercept	−624.58	17.15	−36.41	<0.0001	0.9449
	Mean value	1.89	0.05	41.61	<0.0001	
PEP	Intercept	31.74	3.28	9.69	<0.0001	0.5215
	Mean value	−1.17	0.11	−10.49	<0.0001	
SI	Intercept	0.01	0.02	0.68	0.4964	0.0006
	Mean value	0	0.01	0.24	0.8108	
STR	Intercept	−0.05	0.37	−0.14	0.8879	0.0192
	Mean value	0.02	0.01	1.4	0.1631	
SV	Intercept	−0.44	0.3	−1.46	0.148	0.0579
	Mean value	0.02	0.01	2.49	0.0143	

SV – stroke volume; SI – stroke volume index; CI – cardiac index; CO – cardiac output; STR – systolic time ratio; LVET – left ventricular ejection time; PEP – pre-ejection period; EDV – end-diastolic volume; BNP – brain natriuretic peptide (detected by ELISA); ACI – acceleration index; TFC – thoracic fluid content; SVR – systemic vascular resistance.

of CO and ACI and increased levels of TFC and SVR. These findings may be explained as being due to the aggravation of symptoms of cardiac insufficiency, reduced cardiac output per minute, decreased myocardial contractility, and increased cardiac preload and afterload. Also, multivariate regression analysis of the parameters of BNP, ICG, and echocardiography showed that the CO was significantly different ($p<0.05$), while other parameters were not significantly different, indicating that CO was a determinant of cardiac NYHA functional class. There were also significant differences in the CO, CI, STR, LVET, PEP, BNP, ACI, TFC and SVR before and after OPCAGB surgery. After surgery, the CO, LVET, and ACI increased, while the PEP, BNP, TFC, and SVR decreased. This could be explained by the increase of myocardial contractility accompanied by an increase in the CO, while the cardiac preload and afterload decreased. These data indicate that ICG was useful in the detection of cardiac hemodynamics before and after OPCABG surgery.

In this study, the correlation of cardiac hemodynamic changes in patients after OPCABG between BNP and ICG were also analyzed. There was a significant correlation between the CO obtained by the ICG monitoring system and the CO obtained using the classic Swan-Ganz thermodilution catheter [17]. In this study, there was a negative correlation between the CO and BNP levels using ICG monitoring. Peripheral blood BNP levels have previously been shown to be a sensitive indicator for the diagnosis of chronic heart failure [18].

The systolic time ratio (STR) is a sensitive parameter that represents myocardial contractility [19] and is the ratio of PEP to LVET [6]. When there is reduced cardiac function and a compensatory increase in heart rate, the PEP will prolong, whereas LVET will decrease, indicating that an increase in STR indicates impaired myocardial contractile function [6]. In the present study, STR and BNP were positively correlated.

The acceleration index (ACI) is a unique ICG parameter that refers to the acceleration of blood flow in the ascending aorta and arch, with a normal range being 70–150 for men and 90–170 for women [6]. The ACI is more sensitive and accurate than LVEF in evaluating cardiac function [20]. The present study showed that there was a significant negative correlation between ACI and BNP. Thus, ACI can accurately assess the cardiac contractility in patients with heart failure, especially those with cardiomyopathy.

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A previously published study compared the correlation between the data from ICG and echocardiography and found that the data of the cardiac index (CI) and systolic time ratio (STR) obtained by ICG were significantly correlated with the LVEF obtained by echocardiography (r=0.85) [21]. Brenda et al. [22] showed that for patients with heart failure, the STR could replace LVEF in the evaluation of cardiac function (r=–0.55; P<0.001). Also, the sensitivity, specificity, positive rate, and negative rate of STR ≥0.50 in evaluating cardiac function were 92%, 85%, 95%, and 79%, respectively [22]. Therefore, STR ≥0.50 could be used as a cut-off point for evaluating left ventricular function. In assessing cardiac function in patients with heart failure, Thompson et al. found that the STR obtained by ICG was negatively correlated with LVEF by echocardiography (r=–0.54; P<0.001) [23]. This present study found that there was consistency between the findings from ICG and echocardiography, including for the SV, SI, LVEF, CO, STR, and CI. However, there was a lack of consistency for the EDV, LVET, and PEP. Using Bland–Altman analysis, the limits of agreement (LOA) between echocardiography and ICG using 95% confidence interval (CI) for the CO was the highest at 100.00%. These results indicate that the two methods of ICG and echocardiography showed a good consistency for the evaluation of cardiac function in patients with CHD.

However, this study had several limitations. This was a retrospective study conducted in a single center and the number of patients studied was small. Because the data obtained was dependent on the quality of data recorded in the medical records, there was a lack of detailed information regarding the pharmacological treatment history of the patients studied. Future large-scale prospective studies that include pharmacodynamics are required to further evaluate the role of ICG in patients with CHD before and after OPCABG.

Conclusions

This study investigated the role of impedance cardiography (ICG) in the evaluation of cardiac hemodynamic changes in patients after off-pump coronary artery bypass graft (OPCABG) surgery. The findings showed that ICG parameters were significantly different before and after OPCABG surgery and that ICG not only had a good correlation with serum levels of brain natriuretic peptide (BNP) but also has with echocardiography findings. The cardiac preload parameter of thoracic fluid content (TFC) and the cardiac afterload parameter of systemic vascular resistance (SVR) were specifically obtained by ICG. These findings indicate that ICG might supplement the gaps in the echocardiography parameters, and support that ICG may be used as an effective method for real-time evaluation of cardiac function in clinical practice.

Conflict of interest

None.

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