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Seismocardiography — a non-invasive method of assessing systolic and diastolic left ventricular function in ischaemic heart disease

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Abstract

Background: *Seismocardiography (SCG) is a new non-invasive method which can assess left ventricular function (LVF) during exercise testing based on cardiac time intervals (CTI). There are no data assessing cardiac time intervals during exercise ischaemia in patients with coronary artery disease. The aim of the study was to assess systolic and diastolic CTI in patients after myocardial infarction (MI) with ischaemia during the exercise tolerance test (ETT).*

Material and methods: *Sixty post-MI patients were included in the study and subdivided into two groups, A and B. Group A consisted of 30 patients aged 61.7 ± 6 with normal left ventricular systolic function and left ventricular diastolic dysfunction based on Echo. Group B consisted of 30 patients aged 60.1 ± 6 with normal left ventricular systolic and diastolic function. During SCG the following parameters were analysed: pre-ejection period (PEP) in ms, left ventricular ejection time (LVET) in ms, PEP/LVET, myocardial performance index (MPI) and isovolumetric relaxation time (IVRT) in ms at rest and immediately after exercise. During ETT the following parameters were analysed: ETT duration in minutes, blood pressure (BP), heart rate (HR) and ST depression in mm.*

Results: *In group A on SCG exercise-induced ischaemia changed PEP from 115 ± 13 to 116 ± 17 ms, LVET from 298 ± 22 to 290 ± 26 ms, PEP/LVET from 0.39 ± 0.05 to 0.40 ± 0.08, MPI from 0.39 ± 0.1 to 0.42 ± 0.1, IVRT from 67 ± 21 to 72 ± 21 ms and MO-RF from 115 ± 39 to 85 ± 20, $p < 0.001$, which suggests a deterioration of the left ventricular systolic and diastolic function. In group B on SCG exercise-induced ischaemia changed PEP from 116 ± 18 to 118 ± 15 ms, LVET from 305 ± 25 to 294 ± 27, PEP/LVET from 0.38 ± 0.07 to 0.40 ± 0.07, MPI from 0.37 ± 0.8 to 0.40 ± 0.09, IVRT from 59 ± 14 to 66 ± 17 and MO-RF from 112 ± 39 to 85 ± 28, $p = 0.001$, also suggesting a deterioration in left ventricular*

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systolic and diastolic function in spite of the normal function at rest. There were no inter-group differences in ETT duration, HR and BP; only ST depression in group B was longer, 1.7 vs. 1.4 mm ($p = 0.027$).

Conclusion: *Seismocardiography is a helpful method of assessing left ventricular systolic and diastolic function in patients with exercise-induced ischaemia.* (Folia Cardiol. 2006; 13: 319–325)

seismocardiography, systolic and diastolic cardiac time intervals

Introduction

Seismocardiography (SCG) records low-frequency (below 50 Hz) precardiac waves generated by heart work and transmitted to the surface of the chest via an accelerometer in a standard exercise ECG test, the exercise tolerance test (ETT). The accelerations and decelerations of the heart within the chest cavity produce compression waves that vibrate the sternum. These compression waves are primarily produced by movements of the ventricular wall. Many of these movements correlate with the valvular timing (since the opening and closing of the valves are produced by ventricular wall movements). Acceleration gives more detailed information on the motion of the myocardium. Pressure is defined as force per unit area. In other words, pressure in the ventricle is proportional to force, if we assume that the area of the inner ventricular wall is approximately constant. It has been established, according to Newton's Second Law, that force is proportional to acceleration. Because left ventricular pressure (dp/dt) variations depend on contractility, acceleration is thought to represent a change in contractility as well. Thus SCG enables left ventricular systolic and diastolic function at rest and immediately after exercise testing to be assessed non-invasively by recording cardiac time intervals (CTI) [1–9].

According to Crow et al. [10], SCG is comparable with ECHO-2D in patients with dilated cardiomyopathy. Since SCG is conducted together with an exercise stress test, a comprehensive assessment of cardiac performance with respect to perfusion and left ventricular systolic and diastolic function is possible in patients with ECG signs of myocardial ischaemia [6, 7]. In patients with normal left ventricular function (LVF), if heart rate increases, the pre-ejection period (PEP), isovolumetric contraction time (IVCT) and isovolumetric relaxation time (IVRT) shorten, whereas left ventricular ejection time is prolonged [11, 12]. To date there is no data detailing cardiac time intervals in patients with stable coronary artery disease and ECG signs of myocardial ischaemia using SCG and ECHO assessment.

The aim of our study was to assess systolic and diastolic CTI in post-myocardial infarction (MI) patients with exercise-induced ischaemia.

Material and methods

Sixty post-MI male patients, mean age 60 ± 6 years, with stable coronary artery disease (CAD) and positive ETT were included in the study. All the patients underwent ECHO, ETT and seismocardiography (SCG) and were subdivided into two groups, A and B. Group A consisted of 30 patients, aged 61.7 ± 6 years, with normal left ventricular systolic function and left ventricular diastolic dysfunction based on ECHO. Group B consisted of 30 patients, aged 60.1±6 years, with normal left ventricular systolic and diastolic function.

Echocardiography

Standard echocardiography with Doppler imaging was performed using the Vingmed apparatus on the same day as SCG. Resting left ventricular dimensions and ejection fraction were measured in the supine position by the two-dimensionally guided M mode according to the guidelines of the Polish Cardiac Society [13]. Left ventricular diastolic function was assessed by pulse-wave Doppler echocardiography to interrogate the transmitral flow-velocity curve [14, 15].

The following parameters were assessed:

- ejection fraction (EF%);
- E/A — defined as transmitral, early to atrial filling velocity ratio;
- DT — deceleration time of early filling in ms;
- IVRT — isovolumetric relaxation time in ms;
- left ventricular diastolic dysfunction was classified as an abnormal relaxation pattern: $E/A < 1$ and $DT > 200$ ms and $IVRT \geq 100$ ms.

Exercise stress test

All patients underwent a symptom-limited ETT on a cycloergometer (Ergometric 800 s, Margot Medical Ergo-Line) connected to the computer system (Case 12, Marquette). The exercise workload started from 50 W and increased every three minutes by 50 W. The test was terminated when the target, 85% of the predicted maximal heart rate, was achieved or when any of the following occurred: severe angina, dyspnoea, fatigue, complex ventricular arrhythmia or ST-segment depression ≥ 2 mm. Horizontal or downsloping ST-segment depression of ≥ 1 mm, 80 ms after the J point was approved as a positive result of the ETT.

During ETT the following parameters were analysed: duration in minutes, blood pressure (BP), heart rate (HR) and ST depression in mm.

Seismocardiography

SCG was performed simultaneously with resting supine 12-lead electrocardiography before and immediately after a symptom-limited ETT, using a Seismocardiograph 2000 (Seismed Instruments Incorporated). With the patient in the supine position the accelerometer was placed on the sternum just above the xiphoid process. Each recording lasted one minute. When all the recordings were completed, a final SCG report was printed.

The following parameters were analysed for the patient at rest and immediately after exercise:

— left ventricular systolic parameters [ms]:
  - PEP — pre-ejection period (Q-AO, Q wave on ECG-aortic valve opening on SCG);
  - LVET — left ventricular ejection time (AO-AC, aortic valve opening-aortic valve closure);
  - PEP/LVET — contractility coefficient;
  - IVCT — isovolumetric contraction time (MC-AO, mitral valve closure-aortic valve opening);

— left ventricular diastolic parameters [ms]:
  - MO-MC — left ventricular filling time (MO-MC, mitral valve opening-mitral valve closure);
  - IVRT — isovolumetric relaxation time (AC-MO, aortic valve closure-mitral valve opening);
  - MO-RF — rapid ventricular filling time (mitral valve opening-peak of rapid ventricular filling wave on SCG);

— global myocardial performance indices:
  - MPI — myocardial performance index (IVCT + IVRT)/LVET;
  - G value — acceleration of left ventricular movement (1 g = 9.81 m/s^2).

The study protocol had been approved by the Institutional Ethics Committee and each patient's informed written consent had been obtained.

Statistical analysis

All data were expressed as mean ± standard deviation. The differences in the means between variables were compared by means of a paired or unpaired t test. Relationships between parametric variables were determined by correlation analysis. A p value ≤ 0.05 was considered significant.

Results

The baseline characteristics of 60 patients are listed in Table 1. There were no inter-group differences with regard to age, number and localisation of MI and pharmacotherapy. On the basis of ECHO assessment all patients showed normal left ventricular systolic function, although only patients in

Table 1. Patient characteristics

	Group A (n = 30)	Group B (n = 30)	p
Age	61.7 ± 6	60.1 ± 6	NS
Anterior myocardial infarction	11 (36.6%)	10 (33.3%)	NS
Inferior myocardial infarction	19 (63.3%)	20 (66.6%)	NS
Post myocardial infarction follow up (years)	3.6 ± 3	4.6 ± 4	NS
NYHA II	19 (63%)	17 (57%)	NS
NYHA I	11 (37%)	13 (43%)	NS
Hypertension	17 (57%)	16 (53%)	NS
Beta-blockers	93 (%)	29 (97%)	NS
ACE inhibitors	23 (77%)	25 (83%)	NS
Statins	23 (77%)	25 (83%)	NS
Fibrates	3 (10%)	1 (3%)	NS

Table 2. Results of echocardiography in groups A and B

	Group A	Group B	p
Ejection fraction	57 ± 13%	61 ± 10%	NS
Deceleration time [ms]	197 ± 100	177 ± 57	NS
E/A	0.7 ± 0.2	1.2 ± 0.2	< 0.001
Isovolumetric relaxation time [ms]	102 ± 15	95 ± 15	0.03

group B had normal left ventricular diastolic function (Table 2). Table 3 shows the ETT results. No differences in any of these were found between groups A and B. However, ST segment depression at peak exercise was significantly greater in group B in comparison with group A (1.7 vs. 1.4, p = = 0.027). As with the ECHO data, the SCG variables assessing left ventricular systolic function at rest were normal in both study groups (Table 4). Importantly, on SCG a deterioration in left ventricular systolic function in response to exercise-induced ischaemia was observed in both groups (Table 5).

Table 6 shows the diastolic time intervals on SCG at rest and immediately after exercise. At rest in group A IVRT was significantly longer, confirming the left ventricular diastolic dysfunction. However, SCG performed immediately after an ETT interrupted because of myocardial ischaemia revealed a significant shortening of rapid ventricular filling (MO-RF) in both study groups. Global myocardial performance deteriorated during exercise-induced ischaemia in both study groups as evidenced by an increase in the MPI and insufficient acceleration of left ventricle movement (an improvement of less than double in the G value) (Table 7).

Table 3. Exercise stress test results in groups A and B

	Group A	Group B	p
Workload [W]	131 ± 32	123 ± 31	NS
Duration [min]	9 ± 3	10 ± 4	NS
HR/min at rest	73 ± 9	73 ± 11	NS
HR/min at peak of exercise	124 ± 15	123 ± 16	NS
SBP at rest	117 ± 24	128 ± 14	0,015
DBP at rest	80 ± 9	78 ± 8	NS
SBP at peak of exercise	183 ± 19	183 ± 31	NS
DBP at peak of exercise	92 ± 11	89 ± 12	NS
DP at rest	92 ± 16	94 ± 15	NS
DP at peak of exercise	228 ± 43	229 ± 47	NS
Reason for ETT termination-fatigue	16 (54%)	14 (46%)	NS
Reason for ETT termination-ischaemia	14 (46%)	16 (54%)	NS
ST depression [mm]	1.4 ± 0.4	1.7 ± 0.6	0.027

DP — double product; ETT — exercise tolerance test; HR — heart rate; SBP — systolic blood pressure; DBP — diastolic blood pressure

Table 4. Systolic and diastolic seismocardiographic parameters of the left ventricle — normal values

	Normal ranges*	
	Rest	Exercise
Isovolumetric contraction time [ms]	32–58	30–49
PEP [ms]	96–120	86–114
LVET [ms]	304–330	310–338
Contractility coefficient (PEP/LVET)	0.25–0.43	0.22–0.40
Isovolumetric relaxation time [ms]	49–90	38–80
Left ventricular filling time (MO-MC) [ms]	582–587	597–600
Rapid ventricular filling time (MO-RF) [ms]	78–102	80–88
Myocardial performance index	0.26–0.45	0.22–0.38

*Heart rate adjusted to 60 bpm; PEP — pre-ejection period; LVET — left ventricular ejection time

Table 5. Systolic time intervals in SCG at rest and immediately after exercise in groups A and B

	Group A	Group B	p
PEP at rest [ms]	115 ± 13	116 ± 18	NS
PEP at peak of exercise [ms]	116 ± 17	118 ± 15	NS
IVCT at rest [ms]	50 ± 14	54 ± 12	NS
IVCT at peak of exercise [ms]	49 ± 15	51 ± 10	NS
LVET at rest [ms]	298 ± 22	305 ± 25	NS
LVET at peak of exercise [ms]	290 ± 26	294 ± 27	NS
PEP/LVET at rest	0.39 ± 0.05	0.38 ± 0.07	NS
PEP/LVET at peak of exercise	0.40 ± 0.08	0.40 ± 0.07	NS

PEP — pre-ejection period; IVCT — isovolumetric contraction time; LVET — left ventricular ejection time; PEP/LVET — contractility coefficient

Table 6. Diastolic time intervals in SCG at rest and immediately after exercise in groups A and B

	Group A	Group B	p
IVRT at rest [ms]	67 ± 21	59 ± 14	0.038
IVRT at peak of exercise [ms]	72 ± 21	66 ± 17	NS
MO-RF at rest [ms]	115 ± 39	112 ± 39	NS
MO-RF at peak of exercise [ms]	85 ± 20*	85 ± 28**	NS
MO-MC at rest [ms]	585 ± 25	580 ± 24	NS
MO-MC at peak of exercise [ms]	580 ± 30	582 ± 23	NS

IVRT — isovolumetric relaxation time; MO-RF — rapid ventricular filling; MO-MC — ventricular filling time; *$p < 0.001$; **$p = 0.001$

Table 7. Myocardial performance indices in SCG at rest and immediately after exercise in groups A and B

	Group A	Group B	p
G value at rest	39 ± 14	38 ± 11	NS
G value at peak of exercise	72 ± 28	74 ± 24	NS
MPI at rest	0.39 ± 0.1	0.37 ± 0.08	NS
MPI at peak of exercise	0.42 ± 0.1	0.40 ± 0.09	NS

G value — acceleration of left ventricular movement; MPI (myocardial performance index) = [(IVCT + IVRT)/LVET]

The correlation between the parameters of left ventricular systolic and diastolic function on ECHO and SCG were examined. A positive correlation was observed only between the G value and the EF at rest and following exercise in group A ($r = 0.391$, $p = 0.03$, $r = 0.348$, $p = 0.06$). Moreover, in group A IVRT on ECHO was significantly longer compared with IVRT on SCG (102 vs. 67 ms, $p < 0.001$).

Discussion

The SCG waveform is related to mechanical events in the cardiac cycle that produce the opening and closing of cardiac valves. Thus SCG is able to measure cardiac function simply and non-invasively by means of cardiac time intervals. Systolic and diastolic CTI may provide important information concerning myocardial performance at rest and after exercise. When left ventricular systolic function deteriorates, PEP is longer, LVET is shorter and PEP/LVET increases [16–19]. In patients with normal LVF PEP is shorter during exercise, LVET is longer and PEP/LVET decreases [11, 12]. Libonati et al. [20] assessed CTI on SCG in 51 healthy persons and found that ETT duration determined physical capacity and LVF. They showed a shortening of PEP and IVRT, a prolongation of LVET and a lowering of MPI. Our results confirmed the usefulness of SCG in the assessment of left ventricular systolic and diastolic function at rest and immediately after exercise in patients with CAD. The resting SCG systolic parameters, namely PEP, LVET and PEP/LVET, were normal in both study groups and corresponded with normal left ventricular systolic function on ECHO. However, exercise-induced ischaemia caused a deterioration in LVF by means of a prolongation of PEP, a shortening of LVET and an increase in PEP/LVET above the normal ranges. All these values changed in spite of an exercise-induced increase in heart rate.

In our previous study we compared CTI duration in patients with left ventricular dysfunction (EF about 37%) and in healthy subjects. In patients with left ventricular dysfunction PEP prolongation, PEP/LVET improvement and PEP shortening were observed immediately after exercise, whereas in healthy subjects PEP/LVET lowering was found [21, 22]. Ischaemia induces dyssynchrony of myocardial function, delay in mitral valve opening and a shortening of rapid ventricular filling [23]. In both study groups left ventricular diastolic function worsened immediately after exercise-induced ischaemia. IVRT prolongation and significant shortening of rapid ventricular filling were found.

Recently several studies have shown that MPI assessed on ECHO is a stronger predictor of survival than EF in post-MI patients [24, 25]. Analysis of one-year mortality has revealed that MPI values higher than 0.63 accounted for 37% survival, whereas MPI < 0.63 for 89% survival. Moreover, Bruch et al. [26] documented that MPI gives a very good sensitivity of 86% and specificity of 82% in detecting left ventricular dysfunction. MPI was independent of heart rate and blood pressure, whereas it significantly correlated with end-diastolic pressure ($r = 0.46$, $p < 0.01$) [26]. In our study MPI was examined on SCG. Immediately after exercise-induced ischaemia a deterioration in global myocardial function was found in both study groups. Moreover, insufficient acceleration of left ventricle movement was observed, suggesting deterioration of the LVF.

It should be stressed that the G value had a positive correlation with EF. Similarly, Koch et al. [27] found a positive correlation between the G value measured on SCG and EF on ECHO

($r = 0.87$, $p < 0.0001$). In our study IVRT obtained on SCG was shorter compared to that obtained on ECHO. Similarly, Crow et al. demonstrated that mean CTI values on SCG are shorter than on ECHO [3, 10].

It has been suggested, that a heart rate ranging from 50 to 110 bpm did not interrupt CTI assessment [16]. In our study CTI duration was adjusted to a heart rate of 60 bpm. In spite of an exercise-induced increase in heart rate, PEP and IVRT lasted longer and LVET was shorter, PEP/LVET and MPI increased, suggesting deterioration in the left ventricular systolic and diastolic function. Therefore the present study is consistent with previous findings that the diagnosis of left ventricular systolic and diastolic function based on SCG is very helpful in clinical practice [28, 29]. SCG is a simple and non-invasive method performed during the exercise stress test, which is accepted as the first step in the diagnosis of coronary artery disease. However, whether SCG provides sufficient data for reliable left ventricle performance analysis is an issue that requires further investigation.

Conclusion

Seismocardiography is a helpful method of assessing left ventricular systolic and diastolic function in patients with exercise-induced ischaemia.

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