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Original

Early and late changes in myocardial function and heart rate variability in patients after myocardial revascularisation

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Abstract

BACKGROUND: The purpose of the study was to evaluate the effect of myocardial revascularisation and associated improvement of left ventricular systolic function on heart rate variability in patients after myocardial infarction.

MATERIAL AND METHODS: The study population consisted of 35 patients, who within the previous 6 months had suffered from myocardial infarction and in whom low dose dobutamine ventriculography revealed hibernating myocardium, whereas coronary angiography provided indications to revascularisation. CABG was performed in 22 patients, PTCA of the infarct-related artery in 13 patients. At baseline, 3 months and 3 years after the procedure radionuclide ventriculography, myocardial perfusion scintigraphy and 24hr continuous ECG recording were performed.

RESULTS: After initial improvement of systolic function in ventriculography (EF = 48.63 ± 11.6 *v.* 52.37 ± 11.27 at $p < 0.001$) it slightly but not significantly decreased at long-term follow-up (EF = 51.8 ± 10.77). The remaining parameters of systolic function behaved in a similar way in radionuclide ventriculography. Diastolic function parameters did not change significantly at early and long-term follow-up. HRV measures did not change at 3 months but at 3 years both sympathetic- and parasympathetic-related parameters and global autonomic activity were diminished. At 3 years global autonomic activity and parasympathetic activity were diminished with their values similar in both groups.

CONCLUSIONS: It seems that HRV measures diminish at long-term follow-up. The type of revascularisation procedure is only of short-range value with the parameters stabilising on a similar level at long-term follow-up.

Key words: radionuclide ventriculography, revascularisation, heart rate variability

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Introduction

Myocardial ischaemia as a result of atherogenic changes in coronary vessels leads to myocardial damage, which can be pronounced at various degrees. The consequence of this process is always impairment of contractile function. With the recent development of invasive techniques and the introduction of revascularisation procedures, it has been observed that some of the uncontractile myocardium may present with some degree of function recovery. Further studies resulted in the development of two concepts: hibernating and stunned myocardium. One of the most important features of hibernating myocardium is the presence of contractile reserve, which can be detected during echocardiography or radionuclide ventriculography dobutamine test. The identification of segments of the myocardium which promise the recovery of contractile function is important for both therapeutic and prognostic reasons.

Patients with myocardial infarction also have autonomic dysfunction both in the first weeks after the event [1] and in long-term follow-up [2]. Within the first hours of myocardial infarction sympathetic activity increases whereas parasympathetic activity is

decreased. It has been demonstrated that rapid reperfusion of the infarct-related artery causes lesser myocardial damage and markedly improves the autonomic function. Later during the course of myocardial infarction autonomic dysfunction is dependent on the infarct size, location, left ventricular systolic performance, pharmacological treatment and rehabilitation [1, 3, 4]. It seems however that the most important prognostic factor is systolic function and its relationship with the autonomic function [5].

The autonomic activity is most frequently measured by heart rate variability (HRV), taking into account time- and frequency-domain measures [6]. The results of studies on HRV have demonstrated decreased activity of the nervous system with predominantly blunted parasympathetic activity in patients with myocardial infarction.

There was a positive correlation between decreased HRV and increased risk of death due to cardiac arrhythmias. Evidence shows that myocardial revascularisation improves the clinical state and left ventricular systolic function. Some investigators [8, 9] show that the improvement occurs in the first year after the procedure, others [10] show that revascularisation improves HRV measures immediately after the surgical procedure. The effect of the procedure on HRV measures is also discussed.

The purpose of our study was to evaluate the effect of myocardial revascularisation (PTCA, CABG) on systolic and diastolic function and time-domain heart rate variability in patients after myocardial infarction in long-term follow-up.

Material and methods

The study included 35 patients, 31 men and 4 women, aged from 35 to 74 years (mean age 51.7 $\pm$ 9.6 years) with coronary artery disease who had suffered from myocardial infarction within the previous 6 months. Non-Q-wave infarction was diagnosed in 12 patients, Q-wave infarction in 23 patients. There were 17 patients with anterior infarction, 4 with antero-lateral infarction, 12 with inferior infarction and 2 with posterior infarction.

Of the fundamental coronary risk factors, lipid disorders were found in 23 patients, diabetes in 8, obesity (BMI $>$ 25) in 13, smoking in 16 patients. All patients reported mild or moderate arterial hypertension with the mean duration of 4.3 $\pm$ 6.1 years.

Entry criteria included wall motion disorders in radionuclide ventriculography at rest and hibernating myocardium in low-dose dobutamine ventriculography. Based upon coronary angiography 13 patients were selected for percutaneous transluminal coronary angioplasty, 22 for coronary artery bypass grafting. PTCA was performed in left anterior descending artery, whereas surgical revascularisation mainly in left coronary artery. Bypass grafts were placed in the following vessels: left anterior descending artery — 17, diagonal artery — 9, intermediate artery — 2, circumflex artery — 9, marginal artery — 16, right coronary artery — 4, posterior interventricular artery — 6.

The patients were followed up for 3 years with examinations before revascularisation, at 3 months and 3 years after the procedure. Baseline and control examinations were performed in 30 patients (18 patients after CABG and 12 patients after PTCA). Of the initial 35 patients, 3 patients died suddenly (patients after CABG, 2 within a year and one at 2 years after the procedure), 2 patients were lost at follow-up leaving Poland (one patient after PTCA, one after CABG). During 3 years of follow-up all patients received comparable treatment. In the light of the effect of beta blockers and angiotensin converting enzyme inhibitors on HRV measures, the patients received only metoprolol and enalapril.

In all patients at baseline, 3 months and 3 years after revascularisation the following examinations were performed: 1) radionuclide ventriculography, 2) 24 h continuous ECG recording.

Radionuclide ventriculography

Systolic and diastolic parameters and left ventricular segmental fractions before and after revascularisation were measured by radionuclide ventriculography [12]. The study was performed using the gamma camera Orbiter 7500S Digitrac (Siemens, Erlangen, Germany) with the field of view 38.7 cm. Image acquisition and subsequent analysis were performed by a Microdelta computer using original Siemens-Nuclear — Chicago GAMPRO software. Radionuclide ventriculography was performed with the gating technique using labelled erythrocytes in vivo. The patient received intravenously a standard dose of stannous pyrophosphate containing 1 mg of cyanine ion followed (15 min later) by intravenous administration of 20 mCi (740 MBq) of technetium-99m sodium pertechnetate [13]. Data acquisition was set up at 3 mln counts in 26 frames per cardiac cycle for the matrix size 64 $\times$ 64. Evaluation was performed using the gamma camera in the left anterior oblique projection LAO 20° — LAO 50° with the best possible ventricular separation. During data processing the regions of interest were assigned manually for the left ventricle at end diastole and end systole. In analysing the data the region of interest was assigned manually for the left ventricle at end diastole and systole (Fig.1). In order to obtain pure chamber activity counts we subtracted the extra cardiac background, assigned laterally to the ventricle. Dobutamine ventriculography was performed using dobutamine infusion (a dose of 5 μg/kg/min for 5 min followed by 10 μg/kg/min for 5 min). Acquisition was started at 3 min of the study. We analysed left ventricular ejection fraction. A significant change in ejection fraction was considered at the cut-off value of 5%. The following systolic and diastolic parameters of the left ventricle were measured:

— ejection fraction — EF (%);
— 1/3 ejection fraction — 1/3 EF (%);

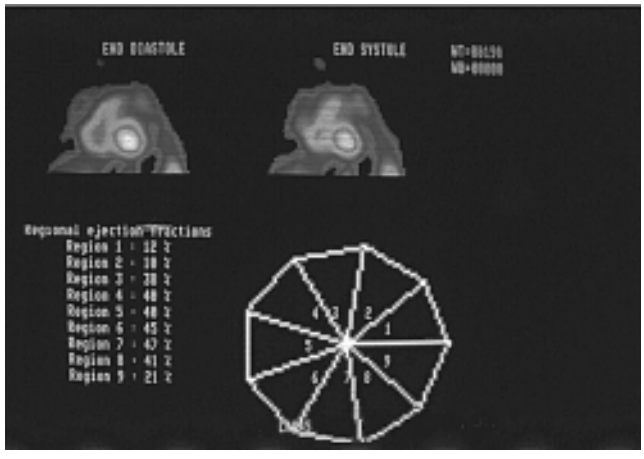


Figure 1. Left ventricular radionuclide ventriculography segmental ejection fractions.

— maximal emptying rate — MER [EDV/s];
— average emptying rate — AER [EDV/s];
— time to peak emptying — TTPE [ms];
— 1/3 filling fraction — 1/3 FF;
— maximal filling rate — MFR [EDV/s];
— average filling rate — AFR [EDV/s];
— time to peak filling — TTPF [ms].

Evaluations of MER, AER, MFR and AFR parameters were performed according to norms published by Adam et al. [11].

24 hr continuous ECG recording with time-domain heart rate variability

ECG recording was performed using Marquette Electronics analogue tape recorders. Analysis was done using a computer and original DRG software. We evaluated the presence and type of cardiac arrhythmias and the following time-domain measures:
— SDNN — standard deviation of all normal-normal intervals;
— SDANN — standard deviation of the averages of NN interval for all five-minute segments;
— SDNN Index — mean of SD of all NN intervals for all five-minute segments;
— rMSSD — square root of the mean of the sum of the squares of differences between adjacent NN intervals;
— pNN50 — number of pairs of adjacent NN intervals differing by > 50 ms.

Statistical analysis

Paired Student's t-test was used to test for differences in mean EF. Non-parametric Wilcoxon's test was used to assess differences in perfusion and wall motion parameters in low-dose dobutamine test. The value of low-dose dobutamine ventriculography for the prediction of improvement after revascularisation chi square and Pearson's correlation tests were used. Data were computed using the Statistica 5.0, StatSoft, Inc. [(1995). STATISTICA for Windows. Tulsa, OK: StatSoft, Inc].

Results

Radionuclide ventriculography

At baseline radionuclide ventriculography revealed the presence of systolic and diastolic left ventricular dysfunction (Table 1). The mean left ventricular ejection fraction was decreased, emptying was impaired and filling was also decreased but to a lesser degree. Wall motion disorders (Table 2) were demonstrated. Low-dose dobutamine test revealed a significant increase in the mean left ventricular ejection fraction (48.6 ± 11.6 *v.* 52.4 ± 11.3 at $p < 0.001$) and systolic parameters (MRE — 2.1 ± 0.6 *v.* 2.6 ± ± 0.9, ARE — 1.7 ± 0.5 *v.* 2.1 ± 0.8). Diastolic function was slightly impaired, which was significant only for the mean rate of filling adjusted for the count (0.96 ± 0.26 *v.* 1.14 ± 0.49) (Table 1). Based upon improved segmental ejection fraction in low dose dobutamine test (Table 2) the patients were selected for CABG or PTCA.

At 3 months after revascularisation radionuclide ventriculography revealed improved ejection fraction (48.63 ± 11.6 *v.* 52.3 ± ± 9.7 at $p < 0.01$), improved systolic parameters (MRE — 2.12 ± ± 0.62 *v.* 2.33 ±0.46, ARE — 1.66 ±0.47 *v.* 1.82 ± 0.49 at $p < 0.02$), and slight impairment of diastolic function (Table 3). As for segmental ejection fraction there was significant improvement in segments corresponding to circumflex artery (S1, S9) and right coronary artery (S7, S8) territory. There was also a slight increase in segmental ejection fraction in anterior interventricular artery territory (S2–S6) (Table 4). The ejection fraction in low dose dobutamine ventriculography was correlated with EF after the procedure ($r = 0.85$ at $p < 0.05$). There were also other correlations between the corresponding segmental EF (S1 — $r = 0.7$, S2 — $r =$ $= 0.66$, S3 — $r = 0.60$, S4 — $r = 0.5$, S5 — $r = 0.7$, S6 — $r =$ $= 0.63$, S7 — $r = 0.7$, S8 — $r = 0.84$, S9 — $r = 0.8$). We also compared segmental EF in low dose dobutamine test and after revascularisation calculating the sensitivity and specificity of low dose dobutamine ventriculography in predicting left ventricular improvement (Table 5).

Radionuclide ventriculography was repeated at 3 years after revascularisation. There were no differences in left ventricular ejection fraction as compared with the values immediately after revascularisation (52.3 ± 9.7 *v.* 51.8 ± 10.77). There were no changes in systolic left ventricular function (MRE — 2.33 ± 0.46 *v.* 2.19 ± ± 0.47, ARE — 1.82 ± 0.49 *v.* 1.74 ± 0.43), and diastolic function (Table 3). Segmental wall motion was diminished in S1, S7–S9 corresponding to circumflex artery territory and right coronary artery territory. Segments corresponding to left anterior descending artery territory showed no changes or a tendency towards increased values (Table 4).

Time-domain heart rate variability

Analysis of time-domain heart rate variability before and after myocardial revascularisation revealed a slight decrease of all values dependent both on sympathetic and parasympathetic activity (Table 6). Additionally analysis of patients after CABG and PTCA was performed separately. It was found out that after PTC SDNN and SDANNI decreased only at follow-up remaining unchanged early after the procedure (Table 7). Simultaneously we observed increased parasympathetic activity (pNN50 and rMSSD) at 3 months followed by decrease at 3 years. A more linear decrease in SDNN and SDANNI was observed in patients after CABG (Table 8). There was also a significant decrease in values dependent on parasympathetic activity (rMSSD, pNN50), which showed a tendency towards improvement at late follow-up.

Discussion

Use of any medical diagnostic procedure requires that its effectiveness be studied with regard to diagnostic accuracy and its impact on therapy. Low dose dobutamine ventriculography is an established modality for the evaluation of left ventricular function providing information on further diagnostic and therapeutic procedures [14]. The infusion of dobutamine, α_1-, β_2-receptor agonists, and first of all β_1-adrenergic receptors showing positive inotropic and chronotropic activity affects the myocardium similar to physical effort [15]. Positive inotropic stimulation generally increases contractility of all viable segments, that is both normally vascularised myocardium and hibernating myocardium in hypoperfused segments.

The number of studies regarding postoperative ventricular function and the impact of hibernation has so far been limited. Felipe et al. [16] discussed the role of first-pass and equilibrium radionuclide ventriculography. With the improvement assumed to

Table 1. Systolic and diastolic left ventricular function in radionuclide ventriculography at baseline and after low dose dobutamine test

n = 30	EF (%)	1/3 EF (%)	MRE [EDV/sec]	ARE [EDV/s]	TTPE [ms]	1/3 FF	MRF [EDV/s]	ARF [EDV/s]	TTPF [ms]
Baseline	48.63 ± 11.6	19.03 ± 5.44	2.12 ± 0.62	1.66 ± 0.47	101.6 ± 40.0	0.37 ± 0.08	1.63 ± 0.5	0.96 ± 0.26	183.7 ± 47.11
p	< 0.001	< 0.001	< 0.002	< 0.001	NS	NS	NS	< 0.05	NS
Low dose dobutamine test	52.37 ± 11.27	23.33 ± 6.81	2.55 ± 0.88	2.07 ± 0.78	89.83 ± 35.84	0.36 ± 0.09	1.9 ± 0.84	1.14 ± 0.49	203.47 ± 48.09

LVEF — left ventricular ejection fraction, 1/3 EF — 1/3 ejection fraction, MRE — maximal emptying rate, ARE — average emptying rate, TTPE — time to peak emptying, 1/3 FF — filling fraction, MRF — maximal filling rate, ARF — average filling rate, TTPF — time to peak filling

Table 2. Segmental ejection fraction in radionuclide ventriculography at baseline and in low dose dobutamine test

n = 30	S1	S2	S3	S4	S5	S6	S7	S8	S9
Baseline	54.0 ± 13.36	53.13 ± 13.57	43.53 ± 12.01	31.7 ± 12.27	28.6 ± 11.66	39.77 ± 12.8	45.46 ± 14.08	48.93 ± 16.31	54.97 ± 15.81
p	< 0.001	< 0.05	NS	NS	NS	< 0.01	< 0.002	< 0.001	< 0.001
Low dose dobutamine test	60.33 ± 13.04	56.76 ± 12.24	44.27 ± 10.62	33.23 ± 10.83	29.6 ± 11.42	44.23 ± 14.28	49.8 ± 15.3	54.63 ± 17.72	61.03 ± 16.7

S2, S3 — anterior segments corresponding to left anterior descending artery territory; S4, S5 — septal segments; S6 — apical-septal segment; S1, S9 — inferolateral segments corresponding to circumflex artery territory; S7 — inferoapical segment; S8 — inferolateral segment corresponding to right coronary artery territory

Table 3. Systolic and diastolic left ventricular function in radionuclide ventriculography at baseline, 3 months and 3 years after revascularisation

n = 30	EF (%)	1/3 EF (%)	MRE [EDV/s]	ARE [EDV/s]	TTPE [ms]	1/3 FF	MRF [EDV/s]	ARF [EDV/s]	TTPF [ms]
Baseline	48.63 ± 11.6	19.03 ± 5.44	2.12 ± 0.62	1.66 ± 0.47	101.6 ± 40.0	0.37 ± 0.08	1.63 ± 0.5	0.96 ±0.26	183.7 ± 47.11
p	< 0.01	< 0.02	< 0.02	< 0.02	NS	NS	< 0.05	< 0.05	NS
After revascularisation	52.3 ± 9.7	22.0 ± 6.05	2.33 ± 0.46	1.82 ± 0.49	100.63 ± 49.56	0.36 ± 0.09	1.78 ± 0.48	1.07 ± 0.3	178.56 ± 61.5
p	NS	NS	< 0.05	NS	NS	NS	NS	NS	NS
At 3 years	51.8 ± 10.77	21.47 ± 4.99	2.19 ± 0.47	1.74 ± 0.43	100.47 ± 36.98	0.37 ± 0.09	1.72 ± 0.49	1.09 ± 0.36	179.76 ± 72.34

LVEF — left ventricular ejection fraction, 1/3 EF — 1/3 ejection fraction, MRE — maximal emptying rate, ARE — average emptying rate, TTPE — time to peak emptying, 1/3 FF — filling fraction, MRF — maximal filling rate, ARF — average filling rate, TTPF — time to peak filling

Table 4. Segmental ejection fraction in radionuclide ventriculography at baseline, 3 months and 3 years after revascularisation

n = 30	S1	S2	S3	S4	S5	S6	S7	S8	S9
Baseline	54.0 ± 13.36	53.13 ± 13.57	43.53 ± 12.01	31.7 ± 12.27	28.6 ± 11.66	39.77 ± 12.8	45.46 ± 14.08	48.93 ± 16.31	54.97 ± 15.81
p	< 0.02	NS	NS	NS	NS	NS	NS	< 0.005	< 0.02
After revascularisation	57.93 ± 10.46	56.13 ± 11.41	44.43 ± 12.62	34.0 ± 11.98	31.83 ± 11.78	41.9 ± 12.62	48.5 ± 13.15	54.87 ± 14.2	59.97 ± 12.34
p	NS	NS	NS	NS	NS	NS	NS	< 0.05	< 0.05
At 3 years	56.6 ± 9.39	54.6 ± 10.76	44.43 ± 12.3	35.4 ± 12.35	33.73 ± 13.46	40.77 ± 13.69	45.97 ± 13.2	51.63 ± 14.0	56.87 ± 12.2

S2, S3 — anterior segments corresponding to left anterior descending artery territory; S4, S5 — septal segments; S6 — apical-septal segment; S1, S9 — inferolateral segments corresponding to circumflex artery territory; S7 — inferoapical segment; S8 — inferolateral segment corresponding to right coronary artery territory

Table 5. Predictive values of dobutamine radionuclide ventriculography test

Result of dobutamine test	Result of revascularisation		
	Improved contractility	No improvement	Total segments
Improved contractility	106	33	139
No improvement	57	74	131
Total segments	163	107	270

Sensitivity — (106/163) 65.03%, specificity (74/107) — 69.16%, positive predictive value — (106/139) 76.26%, negative predictive value — (74/131) 56.49%

exceed 5% during exercise the investigators estimated its sensitivity to be 76% and specificity 88%. Using the same principle in the present study, that is considering as significant the improvement of systolic function when regional ejection fraction in low dose dobutamine test was increased by a minimum of 5%, we were able to identify 139 segments suitable for revascularisation. Of them 106 improved, yielding the sensitivity of 65% and specificity of 69%. This accounts also for the findings of Spinnelli et al. [17] that not all revascularised hypokinetic areas improve after the procedure. The investigators evaluated Tc-99 sestamibi scintigraphy, low dose dobutamine echocardiography and radionuclide ventriculography in the prediction of improvement, both spontaneous and induced by revascularisation in patients after myocardial infarction. The investigators included in the study 49 patients (mean age 52 ± 10 years, i.e. comparable with our study) of whom 19 underwent revascularisation and 30 received pharmacological treatment. The study was performed at baseline and 8 months after revascularisation. In the group undergoing revascularisation 56% of akinetic segments showed improved contractility. What is interesting, 16 of 23 segments (70%), which were negative in low dose echocardiography were viable in SPECT after successful revascularisation. In our study a similar effect (no improvement in low dose dobutamine ventriculography followed by return of contractility after revascularisation) was observed in 57 of 163 segments showing improvement (35%). These results on the one hand indicate the higher value of SPECT as compared with low-dose dobutamine test, on the other hand they provide evidence to confirm the hypothesis that viable myocardium is not always characterised by the presence of contractility reserve.

Table 6. Time-domain heart rate variability before and at 3 months after revascularisation

n = 30	SDNN	SDANNI	SDNNI	rMSSD	pNN50
Baseline	105.03 ± 32.03	95.37 ± 30.94	46.65 ± 16.43	30.03 ± 15.67	7.58 ± 9.45
p	NS	NS	NS	NS	NS
After revascularisation	99.1 ± 27.32	90.31 ± 28.55	43.17 ± 11.91	24.44 ± 10.85	5.86 ± 8.0
p	< 0.001	< 0.002	< 0.05	< 0.02	< 0.05
At 3 years	81.68 ± 31.79	74.06 ± 33.96	39.03 ± 10.88	24.1 ± 10.51	4.45 ± 5.35

SDNN — standard deviation of all normal-normal intervals, SDANN — standard deviation of the averages of NN interval for all five-minute segments, SDNN Index — mean of SD of all NN intervals for all five-minute segments, rMSSD — square root of the mean of the sum of the squares of differences between adjacent NN intervals, pNN50 — number of pairs of adjacent NN intervals differing by > 50 ms

Table 7. Time-domain heart rate variability at long-term follow-up in patients after PTCA

n = 12	SDNN	SDANNI	SDNNI	rMSSD	pNN50
Baseline	105.54 ± 21.88	97.45 ± 24.29	43.54 ± 13.01	27.36 ± 12.7	6.63 ± 9.03
p	NS	NS	< 0.02	< 0.02	< 0.005
At 3 months	105.09 ± 32.18	94.82 ± 31.67	49.18 ± 14.11	31.45 ± 13.9	11.0 ± 10.57
p	NS	NS	NS	NS	NS
At 3 years	83.09 ± 23.54	76.63 ± 21.27	40.81 ± 13.36	25.18 ± 12.62	4.27 ± 4.92

SDNN — standard deviation of all normal-normal intervals, SDANN — standard deviation of the averages of NN interval for all five-minute segments, SDNN Index — mean of SD of all NN intervals for all five-minute segments, rMSSD — square root of the mean of the sum of the squares of differences between adjacent NN intervals, pNN50 — number of pairs of adjacent NN intervals differing by > 50 ms

Table 8. Time-domain heart rate variability at long-term follow-up in patients after CABG

n = 18	SDNN	SDANNI	SDNNI	rMSSD	pNN50
Baseline	104.72 ± 37.52	94.11 ±35.0	48.55 ± 18.31	31.66 ± 17.39	8.16 ± 9.9
p	NS	NS	< 0.03	< 0.01	< 0.02
At 3 months	95.44 ± 24.14	87.55 ± 27.02	39.5 ± 8.87	20.16 ± 5.39	2.72 ± 3.49
p	< 0.01	< 0.02	< 0.005	< 0.02	< 0.05
At 3 years	80.83 ± 36.55	72.5 ± 40.32	37.94 ± 9.31	23.44 ± 9.34	4.55 ± 5.73

SDNN — standard deviation of all normal-normal intervals, SDANN — standard deviation of the averages of NN interval for all five-minute segments, SDNN Index — mean of SD of all NN intervals for all five-minute segments, rMSSD — square root of the mean of the sum of the squares of differences between adjacent NN intervals, pNN50 — number of pairs of adjacent NN intervals differing by > 50 ms

According to many experimental and clinical studies the longer the time of hibernating myocardial hypoperfusion, the more degenerative and necrotic changes can be observed in myocardial tissue, which prolong the time of regaining its function upon successful revascularisation. Spinelli et al. [17] suggested that not every hibernating myocardium reacts to innotropic stimulation, and that the results of revascularisation could be a positive surprise for both patient and doctor. We may only speculate how significant would be the increase of systolic and diastolic function, and their influence on total haemodynamics of the heart. In our study we observed a significant increase in systolic function three months after revascularisation. Global left ventricular ejection fraction and segmental ejection fraction were increased. Similar results with regard to time after the revascularisation procedure were obtained by others. Barilla et al. [18] studied 21 patients after anterior wall myocardial infarction, who in the dobutamine stress echocardiography showed increased global and regional contractility. Ten patients underwent CABG, 3 patients underwent PCI of left coronary artery (LCA), while the remaining patients were treated pharmacologically. Radionuclide ventriculography performed in all the patients at six weeks revealed improvement of regional contractility in previously hypoperfused regions, but the increase was most pronounced in patients after revascularisation procedures. The authors emphasised not only the usefulness of dobutamine radionuclide ventriculography in patients after myocardial infarction but also the amount of improvement of systolic function after successful revascularisation. Monin et al. [19] studied 68 patients in short-term (21 $\pm$ 12 days) observation after myocardial infarction. As in our study they used radionuclide ventriculography as a method of identification of viable but hypoperfused myocardium and after that they identified changes in coronary arteries using standard coronary angiography. The whole group of 54 patients underwent either PTCA of infarct-related artery (43 patients) or CABG (11 patients). At 3–4 months they observed an increase of ejection fraction (52 $\pm$ 6% *v.* 57 $\pm$ 6% at $p = 0.004$). The authors indicated the impact of patency of infarct related artery after revascularisation procedure. They selected a group of 5 patients who had no improvement of left ventricular function, despite the observed improvement in dobutamine stress echocardiography. In these patients after coronary Angiography, reocclusion or a significant narrowing of the artery was observed. In our study the efficacy of revascularisation procedure was measured by radionuclide SPECT study, which was chosen as a non-invasive method characterised by both good sensitivity and specificity.

Heart rate variability is an established technique to evaluate prognosis [3, 6, 20]. It has been demonstrated that increased mortality in patients after myocardial infarction is positively correlated with decreased heart rate variability [5, 7, 21]. HRV has been found to be a completely independent risk factor of sudden cardiac death. Odemuyiwa et al. [22] demonstrated that decreased heart rate variability is a more powerful predictor of death after myocardial infarction than ejection fraction. In contrast, Lanza et al. [23] found a significant correlation with both parameters, however a stronger relationship with left ventricular ejection fraction.

In the beginning of the 1990s Zipes [24] found out that ischaemic episodes, including myocardial infarction, cause changes in the autonomic system. Interest was focused on the effect of reperfusion on the autonomic system. Osterhues et al. [25] performed successful PTCA in 42 patients (20 patients after myocardial infarction) analysing HRV parameters 3–4 days and 6–8 months after the procedure. They also demonstrated decreased HRV parameters dependent on the parasympathetic component (rMSSD, pNN50) with simultaneously increased SDNN and SDANN, which were higher later on. It should be noted that at follow-up of 6–8 months the parameters dependent on parasympathetic activity were again increased. The investigators concluded that it was a result of slow improvement after revascularisation. In turn, Szydło et al. [26] performed PTCA of the infarct-related artery (time from the onset of myocardial infarction 2.5 $\pm$ 1.5 months) in 25 patients. At baseline and at 3–5 days after the procedure they determined time-domain and frequency-domain measures, demonstrating a significant increase of the parameters corresponding to global autonomic activity, but mainly parasympathetic-related indices. Bonnemeier et al. [8] analysed time-domain and frequency-domain measures in 123 patients undergoing PTCA after myocardial infarction. Directly after successful reperfusion they observed decreased parameters dependent on the parasympathetic component. Additionally the investigators compared early reperfusion ($<$ 12 hours from the onset of the infarction) with late reperfusion. In the latter group HRV parameters were improved to a lesser degree. A probable mechanism of this difference may be damaged parasympathetic receptors, thus inhibiting adequate recovery.

In our study in patients at 3 months after PTCA we observed a significant increase of rMSSD and pNN50. At 3 years all parameters were decreased without statistical significance.

In 1978 Airaksinen et al. [27] published a pioneer paper describing changes in HRV parameters in patients after CABG. The investigators demonstrated a significant increase of sympathetic activity and marked deterioration of parasympathetic activity. Osterhues et al. [28] also observed similar changes and concluded that it was most probably the result of the same procedure, suggesting the presence of mechanical damage due to bypass grafting and various degrees of damage to the vagal nerve. In another paper the same investigators [25] emphasised the need for separate analysis of changes in HRV parameters depending on the revascularisation procedure. In our study a group of patients after CABG showed a significant decrease of parasympathetic activity (Table 8). We did not observe the increase of parameters related to global autonomic activity. Also Demirel et al. [10] despite the initial decrease of HRV parameters observed a gradual improvement until the return of initial values at 3 months after the operation. This may account for the slight decrease or lack of changes in our study. Demirel et al. ended their follow-up at one year, demonstrating improvement of sympathetic and parasympathetic activity both in time- and frequency-domain measures. Follow-up of 3 years in our study has been the longest after revascularisation in the aspect of HRV. In our study the significant decrease of autonomic activity is not comparable with previous findings. It does not seem that it is related to classical states, in which these parameters are deteriorated. None of our patients had myocardial infarction or unstable anginal episode. Furthermore perfusion scintigraphy revealed not only good perfusion in the revascularised areas but also lack of new ischaemic changes.

Conclusions

1. Revascularisation of hypoperfused regions leads to favourable and persistent improvement of cardiac function.
2. HRV parameters despite initial lack of changes deteriorate at long-term follow-up.
3. The type of revascularisation procedure seems to have only a short-term value and at further follow-up the parameters are stabilised at a similar level.

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