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RĪGA STRADIŅŠ UNIVERSITY

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Evaluation of the Right Ventricle Function Conducted in Patients after Acute Myocardial Infarction, Using Threedimensional Echocardiography and Myocardial Strain Analysis

Summary of the Doctoral Thesis
for obtaining a doctoral degree (*Ph.D.*)

Sector – Clinical Medicine
Sub-sector – Internal Medicine

Riga, 2021

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LIST OF ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
ASE/EACVI	American Society of Echocardiography and European Association of Cardiovascular Imaging
AUC, AUROC	Area under the curve, area under the receiver operating characteristics
BSA	Body Surface Area
CI	Cardiac Index
CI	Confidence Interval
Contr	Control Group
Echo	Echocardiography
ECG	Electrocardiography
EDV	End Diastolic Volume
EF	Ejection Fraction
ESV	End Systolic Volume
FAC	Fractional Area Change
FW	Free Wall
GLS	Global Longitudinal Strain
LV	Left Ventricle
LAD	Left Anterior Descending artery
LCx	Left Circumflex artery
LS	Longitudinal Strain
MI	Myocardial Infarction
MRI	Magnetic Resonance Imaging
NPV	Negative Predictive Value
NT-proBNP	N-terminal pro-B-type Natriuretic Peptide
PA ACT	Pulmonary Artery Acceleration Time

PPV	Positive Predictive Value
RAVI	Right Atrium Volume Index
RCA	Right Coronary Artery
ROC curve	Receiver Operating Characteristic Curve
RV	Right Ventricle
RVD	Right Ventricle Diameter
RVOT	Right Ventricle Outflow Tract
RVSP	Right Ventricular Systolic Pressure
Sax	Short axis view
SE	Sensitivity
SI	Systolic Index
SP	Specificity
ST	ST segment in electrocardiography
SV	Systolic Volume
TAPSE	Tricuspid Annular Plane Systolic Excursion
TR	Tricuspid Regurgitation
TV	Tricuspid Valve
TA S'V	Peak Systolic Velocity of Tricuspid Annulus
WMI	Wall Motion Score Index

INTRODUCTION

According to the official statistics of Eurostat, the statistical office of the European Union, for a number of years Latvia has been one of the countries with the highest standardised mortality rates due to the coronary artery disease. One of its clinical variations is an acute ST-segment elevation myocardial infarction (MI). Despite improvement in the ST-segment elevation treatment tactics in recent years and decrease in mortality, it is still the cause of intra-hospital death in about 4–12 % of patients (the number varies among member states of the European Society of Cardiology), whereas one-year mortality is around 10 % (Ibanez et al., 2018).

The extent, depth, and localisation of myocardial damage in patients with ST-segment elevation MI also determine the risk of many acute and chronic complications such as an acute or chronic cardiac insufficiency, mechanical complications, as well as heart rhythm and conduction disorders (Ibanez et al., 2018). Therefore, after reperfusion, it is essential to evaluate the consequences of MI and to timely identify patients with a high risk of adverse events such as rehospitalisation or death.

For risk assessment following the ST-segment elevation MI, early transthoracic echocardiography (Echo) is indicated for all patients prior to discharge from hospital: recommendation class I, level of evidence B (Ibanez et al., 2018). The main targets of echocardiographic assessment are the size of the infarcted area, localisation, and the left ventricular (LV) ejection fraction (EF). High-risk indicators, in this case, are LV EF < 40 % and anterior LV MI. In the selection of further therapy, it is also aimed at reduction of remodeling of LV (Ibanez et al., 2018). We must recognise that these factors are very important in determining a patient's prognosis; however, they unduly distract attention from the involvement and function of the right ventricle (RV). Indeed, in contrast to the anterior MI, the left ventricle inferior wall infarction is most often with a

preserved LV EF. Nevertheless, it should also be borne in mind that in the case of inferior MI, RV is also frequently affected, and at an allegedly minor LV damage with a preserved EF, at the same time, may severely interfere with the RV systolic function with cavity dilation, rhythm disturbances and even cardiogenic shock (Vargas-Barrón et al., 2007).

The current recommendations do not emphasise the incidence of RV MI, merely considering the issue as a complication of LV MI. This observation, however, in essence, is incorrect, as the myocardium of both ventricles is simultaneously affected in the case of ischemic damage, and in rare cases, an isolated RV MI condition can occur (Goldstein, 2012). The most common incidence of RV MI in combination with LV inferior wall MI (Ibanez et al., 2018) is merely indicated, as its diagnostic accuracy is highly dependent on the chosen method: clinically, using ECG, Echo or with magnetic resonance imaging (MRI), etc. Heart MRI recognises RV myocardial involvement in as many as 57 % of cases of the LV inferior ST-elevation MI (Kumar et al., 2006).

Apart from direct ischemic myocardium damage, it is possible that the function of RV can be suppressed for other reasons as well. For example, increase in afterload, phenomenon of robbing of coronary arteries, humoral and metabolic mediators from the ischemic area that suppress contractility of healthy myocardium, may be the cause of the RV global dysfunction (Marmor et al., 1981). Considering the foregoing, the main conclusion is that the RV systolic function should be determined in MI of any localisation.

Reconsidering the essential issue of the risk assessment for the patients after ST-elevation MI, it should be taken into account that in several practically applied cardiovascular risk charts at the time of their development the parameters of RV function were neither determined nor included in the analysis at all (Lee et al., 1995; Morrow et al., 2000; Fox et al., 2007). At the time when the core scientific research in the area was conducted, the procedure of RV

function determination was rather cumbersome. The two-dimensional (2D) Echo parameters were not as accurate owing to the fact that the RV function was determined indirectly, the radiological or invasive method was not always accessible for the acute MI patients; moreover, the data concerning the importance of its evaluation was considerably less.

Instead, a great number of studies conducted in recent years confirm that the RV involvement in the case of MI is associated with a threefold increase in cardiogenic shock, ventricular arrhythmias, atrioventricular blocks, and mechanical complication risk within intra-hospital and subsequent periods alike. The intra-hospital mortality rate is significantly higher among patients with the inferior LV MI and the RV involvement than without RV involvement (Mehta et al., 2001; Hamon et al., 2008). During the late post-myocardial infarction period, RV dysfunction similar to LV dysfunction is an independent prognostic factor for all causes of mortality, cardiovascular mortality and heart failure development (Zornoff et al., 2002). Biventricular dysfunction increases the risk of mortality and heart failure even further (Skali et al., 2005).

Newer Echo techniques provide the ability to conduct direct and accurate evaluation of the RV systolic function, which is useful not only for MI but also for patients with several other cardiac and non-cardiac pathologies. Early changes in the RV function can be determined by 2D longitudinal strain (LS) measurements. Normally, the RV pump function occurs mainly in the longitudinal direction, which is based on the arrangement of myocardial fibers in the muscle layer. This distinguishes RV from LV. RV LS in pathological conditions decreases first. 2D Echo LS parameters also provide the ability to indirectly evaluate the RV function both globally and segmentally, especially when the RV EF is still preserved. In the case of MI, it correlates better with RV EF, determined by MRI (Lemarié et al., 2015), as well is an independent predictive value of mortality and hospital admission risk (Antoni et al., 2010).

The gold standard for the RV EF determination, considering its complex anatomical structure and encumbered imagining, is the cardiac MRI. However, in recent years, Echo has been able to offer a fast, cheap, non-invasive, and MRI-validated alternative, namely 3D Echo, by which RV 3D-reconstruction provides a tool to directly determine volumes and EF. Decreased RV EF, as determined by MRI, is a significant prognostic mortality predictor, regardless of LV infarct size and LV EF. Therefore, the 3D Echo method with RV reconstruction option is very promising and possesses a great potential benefit in MI patient management. Nowadays, it has not been studied sufficiently in patients with acute ST-elevation MI.

Hypotheses of the Thesis

1. Reduction of the right ventricular ejection fraction can be statistically significant in the case of acute coronary artery lesion of different localisation.
2. Reduction of the myocardial longitudinal strain of the right ventricle free wall can be statistically significant in the case of acute coronary artery lesion of different localisation.

Aims of the Thesis

1. By 3D Echo and myocardial strain evaluation, to assess the direct and indirect changes of the right ventricular systolic function, and thus determine the possible involvement of the right ventricle in the patients with documented acute ST-elevation myocardial infarction.
2. Select the most informative Echo parameters of RV size and function putting it into daily medical practice by creating an RV assessment algorithm for patients with acute ST-elevation myocardial infarction.

Objectives of the Thesis

1. Determine the RV longitudinal strain parameters and 3D EF for healthy individuals and patients with acute ST-elevation MI.
2. Evaluate the RV EF determination possibilities with 3D Echo reconstruction for patients after acute ST-elevation MI.
3. Determine echocardiographically the incidence of RV involvement in acute ST-elevation MI.
4. Investigate changes in the right ventricular systolic function in acute ST- elevation MI of different localisation.
5. Identify the RV longitudinal strain and EF cut-off values for diagnostics of RV involvement in acute MI.

Scientific Novelty of the Study

RV and its function play an increasingly important role in the cardiac imaging. Nevertheless, studies to combine the newer Echo methods to determine RV dysfunction in patients with acute ST-elevation MI have not been performed so far. This is the first study to clarify the incidence of RV involvement in MI using the newer and more sensitive Echo techniques such as 3D echocardiography and the RV free wall (FW) strain measurements.

In Latvia, this scientific work is the first study dedicated to the echocardiographic evaluation of RV. For the first time in the country, RV 3D echocardiography and strain measurements were conducted in the framework of the study, involving a proposal of an algorithm for their adoption into clinical practice.

Approbation of the Thesis

The approbation of the Thesis was carried out on 19 January, 2021 at the meeting of the Department of Internal Diseases of Rīga Stradiņš University.

1 METHODS

1.1 Research Design, Procedure, and Research Population

Prospective monocentric cohort research was conducted at Riga East Clinical University Hospital from 2014 to 2016. Prior to the commencement of the research, on 10 July, 2014 a positive approval No. 8-A/14 of Riga East Clinical University Hospital Support Foundation's Medical and Biomedical Research Ethics Committee for compliance with ethical regulatory standards set out for scientific research was obtained.

Healthy volunteers were invited to participate in the assessment carried out from December, 2014 to May, 2015. A total of 32 participants who fully met the criteria for inclusion in the control group were selected. The patient group was formed from May, 2015 to August, 2016 according to the selection criteria. The inclusion of participants to the control group as well as the patient group was done upon voluntary consent, which the designated participants certified by signing the informed consent form.

1.1.1 Control Group

Inclusion criteria (the candidate must fully satisfy the following criteria):

1. age from 30 to 60 years (inclusive);
2. normal body mass index (18.5–25 kg/m^2);
3. normal 12 lead ECG;
4. normal Echo finding;
5. voluntary signed participation consent.

Exclusion criteria (if the candidate satisfies any of the following criteria):

1. pregnancy;
2. engagement in professional sports activities;

3. any cardiovascular complaints or a positive medical history of cardiovascular disease;
4. any other chronic diseases;
5. bad echo-visualisation.

1.1.2 Patient Group

Inclusion criteria (the candidate must fully satisfy the following criteria):

1. age 30 to 60 years (inclusive);
2. confirmed first time acute ST-elevation MI (clinically, with ECG, with myocardial necrosis markers and coronarography data);
3. coronary angiography performed;
4. voluntary signed participation consent.

Exclusion criteria (if the candidate satisfies any of the following criteria):

1. hemodynamically unstable condition;
2. non-coronary causes of the acute myocardial damage;
3. confirmed lung disease (obstructive/restrictive ventilatory defect);
4. congenital cardiac pathology/cardiac valve pathology/chronic cardiovascular disease other than history of coronary heart disease/prior pulmonary or cardiac surgery;
5. heart rhythm disorders during the examination;
6. chronic kidney disease;
7. confirmed system connective tissue, accumulation or infiltrative diseases;
8. pregnancy;
9. engagement in professional sports activities;
10. bad echo-visualisation.

Thirty-two participants were included in the control group. The patient group was formed of 73 participants. According to the specially designed

questionnaire, demographic, anamnesis data, analysed 12 lead ECG were collected from the control group members, as well as a transthoracic Echo was performed. Clinical, biochemical data, coronary angiography examination results were additionally collected in the patient group.

1.2 Research Protocol

Within the study, various types of data sets were collected and documented for subsequent analysis:

- demographic, medical history data;
- clinical data;
- biochemical values;
- 12 lead ECG;
- results of coronary angiography examination;
- Echo.

Echo was performed once, in patients with acute MI at the time of hospital admission as soon as the patient's clinical condition permitted its transfer to the Diagnostic Cardiology Department. All Echo examinations were performed using the same ultrasound machine and one version of the software package for data analysis at all times. Participants were excluded from the study if the quality of the acquired Echo images was poor, i.e. insufficient imagining of cardiac structures to perform accurate 2D image measurements, 2D strain analysis or 3D RV reconstruction.

1.3 Acquisition of Echocardiographic Images and Principles of Measurements

Recording and subsequent analysis of all examinations were performed by one certified specialist, excluding the variability of inter-specialist measurement and interpretation. Single ultrasonograph – GE Healthcare Vivid

E9 – was used to capture and process images, and a workstation with one software package version, which at the time of the study was available on the site of the Diagnostic Cardiology Department of the Gaiļezers Clinic of Riga East Clinical University Hospital.

1.3.1 Two-dimensional Echocardiography and Doppler Imagining

For the acquisition of images, M5S-D probe and 2D mode, 2D controlled M-mode, continuous wave and pulse wave Doppler imagining as well as tissue Doppler imagining were used. Recordings were performed at the parasternal and apical standard positions: left parasternal long axis view, parasternal short axis view at valve level, ventricular basal level and ventricular mid segment level, apical four-chamber view, LV two-chamber and three-chamber view.

Several additional positions were used for the RV assessment: subxiphoid long axis view, parasternal RV inflow tract view, RV focused apical four-chamber view, and modified apical four-chamber view. Cineloops of three heart cycles were recorded at each view when a participant was asked to maintain a breath-hold and saved with a possibility of offline access. Particular attention was paid to the correct angle of view in the apical window so that the ventricles of the heart would be fully visible. Also, image optimisation options were used where required: depth change, sector width adjustment, focus change, gain correction, the Nyquist limit selection for Doppler signal optimisation.

All Echo entries were performed with a simultaneous ECG record. The 2D Echo study and measurements were performed in line with the uniform methodology laid down in the guidelines of 2015 established by ASE/EACVI "Recommendations for Cardiac Chamber Quantification by Echocardiography in Adults" (Lang et al., 2015) and Echocardiographic Working Group

Methodological Recommendations in Transthoracic echocardiography elaborated by the Latvian Society of Cardiology (Latvijas Kardiologu biedrības Ehokardiogrāfijas darba grupa, 2015), which were relevant at the time of the study. Standard measurements have been performed according to the protocol of the Transthoracic Echocardiography Examination of the Republic of Latvia and additional measurements required for the study.

LV, right atrium volumes, LV systolic volume and cardiac output were indexed to body surface area (BSA).

Echo variables

Visual assessment of the LV and RV segmental systolic function – presence of hypokinesia, akinesia, localisation, Wall motion score index (WMI).

WMI was scored by visual determination of the LV segmental contractility disorders. The contractility of each segment is denoted numerically (normokinesia – 1, hypokinesia – 2, akinesia – 3, dyskinesia – 4). The sum of the numbers of all segments was divided by the total number of the LV segments – 16. The WMI norm is equal to 1, hence the higher the WMI, the more severely the LV contractility is impaired.

2D and 2D controlled M-mode measurements:

- LV end-diastolic volume index (LV EDV ind., ml/m^2);
- LV end-systolic volume index (LV ESV ind., ml/m^2);
- LV ejection fraction (LV EF, %);
- Right atrium volume index (RAVI, ml/m^2);
- RV outflow tract diameter in parasternal short axis view (RVOT sax, mm);
- RV basal diameter (RVD basal, mm);
- Mid-cavity diameter of RV (RVD mid, mm);

- RV length (RV L, mm);
- Tricuspid annular plane systolic excursion (TAPSE, mm);
- RV fractional area changes (FAC, %).

Doppler imagining parameters (continuous wave, pulse wave, and tissue Doppler imagining):

- LV systolic volume index (SI, ml/m^2);
- cardiac output index (CI, l/min/m^2);
- pulmonary artery acceleration time (PA ACT, m/s);
- tricuspid valve regurgitation maximal velocity (TR V max, m/s);
- RV systolic pressure (RVSP, mmHg);
- peak systolic velocity of tricuspid annulus (TA S'V, cm/s).

1.3.2 Two-Dimensional Measurements of the Right Ventricle Strain

RV focused four-chamber view has been chosen to evaluate the RV LS. For the analysis a workstation software package (EchoPac PC, GE Healthcare, Norway), and a semi-automatic mode was used. The QRS cycle start markers were adjusted as needed in the ECG curve. The pulse wave Doppler signal of the pulmonary valve was registered, and its opening and closing timings were marked. The endocardial border of RV was manually traced. The programme automatically added a mark to the opposite epicardium border. Where applicable, the borders were adjusted manually, making sure that the RV myocardium is adequately perceived during the heart cycle.

Automatically, RV FW, which is in the area of interest, was split into three segments – apical, mid segment and basal segment. Based on the analysis of the natural acoustic myocardial marker motion in the B-mode grayscale imaging, several myocardial strain parameters were automatically calculated, from which the RV total FW LS and RV FW segmental LS were registered for

the study, expressed as a percentage (a negative variable as it denotes shortening).

2D strain indicators:

- LV global longitudinal strain (LV GLS, %);
- RV FW LS (%);
- RV FW basal segment LS (%);
- RV FW mid segment LS (%);
- RV FW apical segment LS (%).

1.3.3 Three-Dimensional Right Ventricle Echocardiography

Real-time 3D full-volume image acquisition was performed at the end of the 2D examination while the patient was lying down in the left side position. In the 2D mode, the apical RV focused four-chamber position was found laterally from the standard apical four-chamber view. GE Vivid E9 4V probe was used. Record performed during 4–6 consecutive heart cycles, while the patient held breath intake. Wherever required, an image was optimised by size, gain, and depth. The processing of the obtained data was performed offline, using a workstation with a commercially available software package (TomTec 4D-RV Analysis, Germany), validated to a heart MRI.

The sequence of actions was performed following the recommendations of the programme provided for the reconstruction of RV. Notably, the right ventricle EDVs and ESVs were calculated semi-automatically throughout the cardiac cycle, manually correcting the RV endocardium where it was required. The RV systolic volume (SV) and EF were mathematically calculated from the volumes obtained.

3D RV Echo reconstruction parameters:

- 3D RV EF (%);

- 3D RV end-diastolic volume (3D RV EDV, ml);
- 3D RV end-systolic volume (3D RV ESV, ml);
- 3D end-diastolic volume indexed to the RV body surface area (EDV/BSA, 3D RV EDV ind., ml/m^2);
- 3D end-systolic volume indexed to the RV body surface area (ESV/BSA, 3D RV ESV ind., ml/m^2);
- 3D RV systolic volume (3D RV SV, ml);
- 3D RV systolic index (SV/BSA, 3D RV SI, ml/m^2).

1.4 Statistical Analysis

Statistical data processing was performed using IBM SPSS Statistics 20.0 software package. Prior to applying the statistical tests to the data obtained, compliance with the normal distribution was visually verified according to a graphical representation, quantitative characterisation of the variables, and checked using the Kolmogorov-Smirnov test. Considering that the results of the patient group were split into subgroups with a smaller number of participants, the data distribution was not normal; therefore, to these parameters non-parametric statistical tests were applied.

Descriptive statistical methods were used to characterise the research groups. Data with normal distribution used the arithmetic mean and standard deviation (SD) for characterisation, but the median and interquartile range (IQR; Q1–Q3) were used for data without normal distribution. For the comparison of quantitative variables between the two groups, in the case of a normal distribution observance, an independent samples t-test was used. Effect size determination was performed using Cohen's d index: small – 0.2–0.5; medium – 0.5–0.8; large ≥ 0.8.

Quantitative variables with a non-normal distribution were analysed between the groups by non-parametric statistical tests. Kruskal-Wallis H test

was used when more than two groups were compared. A comparison has been performed between the two groups, applying Mann-Whitney U test, also determining the effect size r: small – 0.1–0.3; medium – 0.3–0.5; high ≥ 0.5.

In the case of nominal variables, a percentage was shown. In comparison of these parameters in groups, Pearson's chi-square test was used. Determined effect size Phi (φ), if the parameter between the two groups was compared: small – 0.1–0.3; medium – 0.3–0.5; high ≥ 0.5. If there were more than two groups, there was determined Cramer's V effect size: small – 0.1–0.3; medium – 0.3–0.5; high ≥ 0.5.

In accordance with generally accepted principles, p-value < 0.05 was considered to be the threshold for statistical significance of bilateral test results.

A Receiver Operating Characteristic curve, i.e. ROC curve analysis was carried out to assess the diagnostic accuracy and to determine the diagnostic thresholds of the tested new Echo parameters. Evaluating the area under the curve (AUC), the following levels were used: 0.9 < AUC < 1.0 – excellent diagnostic accuracy; 0.8 < AUC < 0.9 – good; 0.7 < AUC < 0.8 – moderate; 0.6 < AUC 0.7 – poor; 0.5 < AUC < 0.6 – failed diagnostic method.

2 RESULTS

2.1 Description of Study Groups

The study consisted of 105 participants: 32 healthy participants in the control group and 73 acute ST-elevation MI patients in the study group were included. The demographic description of the groups is summarised below (Table 2.1). In the patient group, the prevalence of males is strong (78 %), whereas in the control group the gender-spread is equal. The average age of the patients is 52, while in the control group it is 46.

Table 2.1

Demographic description of the study groups

Parameters	Control group (N = 32)	Patient group (N = 73)	p-value	Effect size	95 % CI
Gender, Females/Males	17 (53 %) / 15 (47 %)	16 (22 %) / 57 (78 %)	0.002	0.3 (medium)	-
Age, years M; SD	46.3; 6.8	52.2; 6.4	< 0.001	0.89 (large)	− 3.17–− 8.66
Height, m M; SD	1.74; 0.19	1.76; 0.08	0.185	0.14 (small)	− 0.06–0.01
Weight, kgs M; SD	70.2; 10.3	84.3; 17.2	< 0.001	0.99 (large)	− 7.58–− 20.6
BSA, m^2 M; SD	1.85; 0.19	1.99; 0.22	0.002	0.68 (medium)	– 0.06–− 0.24
BMI, kg/m^2 M; SD	23.2; 2.0	27.0; 4.2	< 0.001	1.1 (large)	– 2.32–− 5.41
Smoker	9 (28 %)	42 (59 %)	0.004	0.28 (small)	-

Additionally, clinical data and biochemical parameters were summarised (Table 2.2). Echo examinations were performed on average in 3.4 days from the date of hospital admission.

Table 2.2

Description of the patient group by clinical/biochemical parameters

Parameters	Patient group (N = 73)
Time from the admission to Echo, days M; SD; 95 % CI	3.4; 1.1; 3.13–3.67
Thrombolysis, N (%)	23 (32)
Angioplasty, N (%)	70 (96)
Events, N (%): - not stated	56 (77)
- ventricular tachycardia	5 (7)
- ventricular fibrillation	5 (7)
- cardiogenic shock	7 (9)
Troponin T-hs, pg/ml Me [Q1–Q3]; (min–max)	4493 [2258–7455]; (12–20784)
NT-proBNP, pg/ml; N = 35 Me [Q1–Q3], (min–max)	1035 [474–2043]; (109–5400)

All participants of the patient group underwent acute coronary angiography. In 68 (93.2 %) cases, the right type of perfusion was determined, in 2 (2.7 %) cases the left type of perfusion was determined and 3 cases (4.1 %) of a balanced type of perfusion were found. Acute right coronary artery (RCA) damage was found in 34 (46.6 %), whereas left anterior descending artery (LAD) was damaged in 30 (41.1 %) and left circumflex artery (LCx) in 9 (12.3 %) patients.

No statistically significant association was found between the incidence of life-threatening events in the study, which were ventricular tachycardia, fibrillation or cardiogenic shock, and acutely damaged artery according to the results of the Pearson's Chi-square test ($p = 0.076$) (Table 2.3).

Table 2.3

Frequency of life-threatening events according to the acutely damaged artery

	Acutely damaged artery				p-value/ effect size
	RCA (N = 34)	**LAD** (N = 30)	**LCx** (N = 9)	**Total** (N = 73)	
Events, N (%)	12 (35 %)	4 (15 %)	1 (13 %)	17 (30 %)	0.076/0.27
Ventricular tachycardia	4	1	0	5	-
Ventricular fibrillation	3	1	1	5	-
Ventricular shock	5	2	0	7	-

Considering the biochemical values, only the NT-proBNP levels were statistically significantly different between the groups depending on the acutely damaged artery (p = 0.017) (Table 2.4).

Table 2.4

Levels of biochemical parameters according to the acutely damaged artery

Biochemical parameters	Acutely damaged artery				Group comparison
	RCA	**LAD**	**LCx**	**p-value**	**p-value/ effect size**
Troponin T-hs, pg/ml, N = 73 Me [IQR]; (min–max)	4784 [5218]; (161–20784)	4525 [4193]; (12–11000)	2596 [10936]; (402–15791)	0.75	-
NT-proBNP, pg/ml, N = 35 Me [IQR]; (min–max)	1035 [1022]; (198–2474)	1510 [1957]; (584–5400)	2098 [2417]; (109–4069)	0.017	RCA/LAD 0.031/0.41 RCA/LCx 0.018/0.47 LAD/LCx 0.38/0.21

From Mann-Whitney U test analysis, it is evident that RCA and LAD groups (p = 0.031; r = 0.41) and the RCA and LCx groups (p = 0.018; r = 0.47) differ statistically significantly and with medium effect size, with the lowest median NT-proBNP level exactly in the case of RCA damage.

2.2 Echocardiographic Assessment of the Groups

Pursuant to the exclusion criteria, the study involved participants with good (50 % control and 53 % patient group) or moderate RV echo-visualisation.

2.2.1 Echocardiographic Assessment of the Left Ventricle

Segmental systolic function evaluation is the analysis of wall motion by segments, which is mostly performed qualitatively, i.e. visually. Akinesia was singled out, considering that it usually has a deeper myocardial injury, which in turn could potentially indicate a more pronounced dysfunction. In patients with RCA damage, this was observed in 79.4 %, in the LAD group – 100 % and in the LCx group – 88.9 %.

LV quantifiable parameters to be analysed are wall motion index (WMI), indexed volumes, EF, GLS, SI and CI (Table 2.5). The inclusion criteria in the control group (contr) indicate that the Echo finding is normal for the participants.

In relation to the GLS, it should be clarified that this value is negative in the norm, but in order to avoid interpretation difficulties and inaccuracies, within the study, it was registered without a minus sign. The higher the GLS number, the better the longitudinal deformation of the myocardium.

LV parameters were compared in groups arranged according to the acutely damaged artery. Statistically significant differences between the groups were observed for all parameters except for LV indexed EDV. Overall, the control group is statistically different from the MI groups. In LV WMI, indexed ESV, GLS, and SI, statistically significant differences were also observed between groups with the artery damage. The GLS was statistically significantly higher in the RCA group compared to LAD ($p < 0.001$) with a high effect size

(r = 0.5). Likewise, the RCA group statistically significantly but with medium effect size is different from other MI groups by WMI, indexed ESV and SI.

Table 2.5

LV parameters in different groups of participants (in control group, in patients with acutely damaged RCA, LAD or LCx)

LV parameter	Group	Me [IQR] (min–max)	p	Groups with significant differences (p < 0.05)/ effect size	Groups with no significant differences (p > 0.05)/ effect size
LV WMI	contr N = 32	1.0	< 0.001	contr/RCA (< 0.001)/0.9 contr/LAD (< 0.001)/0.93 contr/LCx (< 0.001)/0.91 RCA/LAD (< 0.001)/0.48 RCA/LCx (0.013)/0.38	LAD/LCx (0.591)/0.09
	RCA N = 34	1.5 [0.188] (1.0–1.688)			
	LAD N = 30	1.625 [0.375] (1.313–2.5)			
	LCx N = 9	1.625 [0.188] (1.0–2.125)			
LV EDV ind, ml/m^2	contr N = 32	54 [15] (32–75)	0.398		contr/RCA (0.508)/0.08 contr/LAD (0.296)/0.14 contr/LCx (0.862)/0.03 RCA/LAD (0.089)/0.22 RCA/LCx (0.858)/0.03 LAD/LCx (0.395)/0.14
	RCA N = 34	50 [15] (32–71)			
	LAD N = 30	54 [20] (35–142)			
	LCx N = 9	48 [18] (41–75)			
LV ESV ind, ml/m^2	contr N = 32	19 [7] (10–25)	< 0.001	contr/RCA (0.001)/0.42 contr/LAD (< 0.001)/0.63 contr/LCx (0.002)/0.49 RCA/LAD (0.038)/0.26	RCA/LCx (0.288)/0.16 LAD/LCx (0.620)/0.08
	RCA N = 34	23 [10] (12–39)			
	LAD N = 30	26,5 [11] (15–93)			
	LCx N = 9	25 [9] (15–35)			
LV EF, %	contr N = 32	64.5 [5] (60–71)	< 0.001	contr/RCA (< 0.001)/0.78 contr/LAD (< 0.001)/0.84 contr/LCx (< 0.001)/0.61	RCA/LAD (0.09)/0.22 RCA/LCx (0.178)/0.20 LAD/LCx (0.79)/0.04
	RCA N = 34	54 [8] (43–74)			
	LAD N = 30	51 [9] (33–62)			
	LCx N = 9	48 [12] (38–65)			

Table 2.5 continued

LV para-meter	Group	Me [IQR] (min–max)	p	Groups with significant differences (p < 0.05)/ effect size	Groups with no significant differences (p > 0.05)/ effect size
LV GLS, %	contr N = 32	20.9 [2.9] (18.3–26.0)	< 0.001	contr/RCA (< 0.001)/0.81 contr/LAD (< 0.001)/0.86 contr/LCx (< 0.001)/0.63 RCA/LAD (< 0.001)/0.5 RCA/LCx (0.016)/0.37	LAD/LCx (0.684)/0.07
	RCA N = 34	15.4 [2.8] (11.7–21.5)			
	LAD N = 30	13.5 [3.8] (5.7–18.1)			
	LCx N = 9	11.1 [5.3] (9.4–21.2)			
LV SI, ml/m^2	contr N = 32	39.4 [8.4] (28.9–63.9)	< 0.001	contr/RCA (0.03)/0.27 contr/LAD (< 0.001)/0.49 contr/LCx (0.009)/0.41 RCA/LAD (0.016)/0.31	RCA/LCx (0.143)/0.22 LAD/LCx (0.956)/0.01
	RCA N = 34	37.1 [7.1] (23.0–52.5)			
	LAD N = 30	33.5 [10.8] (15.5–51.3)			
	LCx N = 9	32.3 [12.5] (20.5–43.7)			
LV CI, l/min/ m^2	contr N = 32	2.77 [0.74] (1.91–4.15)	0.001	contr/RCA (0.008)/0.32 contr/LAD (< 0.001)/0.48 contr/LCx (0.016)/0.38	RCA/LAD (0.175)/0.17 RCA/LCx (0.540)/0.09 LAD/LCx (0.855)/0.03
	RCA N = 34	2.48 [0.91] (1.44–3.42)			
	LAD N = 30	2.32 [0.85] (1.31–3.09)			
	LCx N = 9	2.12 [0.72] (1.72–3.77)			

2.2.2 Echocardiographic Assessment of the Right Ventricle

Initially, RV was assessed visually for certain segmental systolic dysfunctions (hypokinesia, akinesia, or dyskinesia). Overall, the RV function impairments in this fashion were determined in 19 (26 %) patients out of 73. The statistical analysis of the Pearson's Chi-square showed a statistically significant ($p = 0.022$) association with a medium effect size (Cramer's $V = 0.32$) between the acutely damaged artery and the presence of the RV segmental systolic dysfunction, which was visually determined.

In the case of RCA damage, impairment of the RV segmental systolic function was assessed visually more than three times more frequently than in the LAD and LCx groups. In the control group, according to the selection

criteria, all patients had a normal finding, i.e. no impairment of RV function was determined. By combining the visual assessment of the RV segmental systolic function with the RV dysfunction indices found by the standard Echo, it was possible to detect more cases of the RV involvement in patients with acute MI – 26 (36 %). A statistically significant association was also confirmed between the RV dysfunction and the acutely damaged artery (p = 0.015) with a medium effect size (Cramer's V = 0.34) (Table 2.6).

Table 2.6

RV dysfunction frequency in the patient groups formed according to acutely damaged artery

	Acutely damaged artery			
	RCA (N = 34)	**LAD** (N = 30)	**LCx** (N = 9)	**p-value / effect size**
RV segmental systolic function impairment by visual assessment				
Present, N (%)	14 (41.2 %)	4 (13.3 %)	1 (11.1 %)	0.022/0.32
Absent, N (%)	20 (58.8 %)	26 (86.7 %)	8 (88.9 %)	
RV segmental systolic function impairment by visual assessment and RV dysfunction detected by conventional parameters				
Present, N (%)	18 (52.9 %)	6 (20 %)	2 (22.2 %)	0.015/0.34
Absent, N (%)	16 (47.1 %)	24 (80 %)	7 (77.8 %)	
RV segmental systolic function impairment by visual assessment + RV dysfunction by conventional parameters + RV dysfunction by new parameters in compliance with the current recommendations				
Present, N (%)	19 (55.8 %)	8 (26.7 %)	4 (44.4 %)	0.06/0.27
Absent, N (%)	15 (44.2 %)	22 (73.3 %)	5 (55.6 %)	

Following a visual assessment in combination with both conventional parameters and new study parameters (RV 3D EF and RV FW LS) in line with the thresholds laid down in the Recommendations of 2015 (Lang et al., 2015) for the RV dysfunction assessment, 31 cases (42 %) of the RV involvement were determined. The association between the RV dysfunction and damaged artery was also statistically significant in this case, but with a small effect size (Cramer's V = 0.27).

The association between RV dysfunction (visually and according to conventional parameters) and localisation of the coronary artery damage (proximal, mid or distal) was not determined (p = 0.24; Cramer's V = 0.33).

The study included several standard Echo values for the right heart that were compared between the groups according to the acutely damaged artery (Table 2.7). Statistically significant differences were observed in the case of RAVI, RVOT sax, TAPSE, FAC, PA ACT, TR V max, RVSP, and TA S'V. Of these, RVOT sax, TAPSE, PA ACT, TR V max, RVSP, and TA S'V was statistically significantly different only when making a comparison between the control group and the MI groups. Among the groups with the acutely damaged artery, these parameters did not show a statistically significant difference. In contrast, RAVI differed between RCA and LAD statistically significantly and with moderate effect size (p = 0.005; r = 0.36), while FAC differed statistically significantly but with a small effect size (p = 0.035; r = 0.27).

Table 2.7

Standard Echo RV parameters in the control group and groups of patients according to the acutely damaged artery

Para-meter	Group	Me [IQR] (min–max)	p	Groups with significant differences (p < 0.05)/ effect size (r)	Groups with no significant differences (p > 0.05)/ effect size (r)
RAVI, ml/m²	contr N = 32	18 [6] (12–30)	0.022	contr/LAD (0.031)/0.28 RCA/LAD (0.005)/0.36	contr/RCA (0.309)/0.13 contr/LCx (0.327)/0.16 RCA/LCx (0.141)/0.23 LAD/LCx (0.741)/0.06
	RCA N = 34	20 [8] (13–45)			
	LAD N = 30	17 [5] (7–26)			
	LCx N = 9	17 [8] (10–28)			
RVOT sax, mm	contr N = 32	31 [5] (20–36)	0.014	contr/RCA (0.003)/0.36 contr/LCx (0.038)/0.32	contr/LAD (0.277)/0.14 RCA/LAD (0.065)/0.24 RCA/LCx (0.928)/0.01 LAD/LCx (0.158)/0.23
	RCA N = 34	34 [6] (26–44)			
	LAD N = 30	33 [5] (25–42)			
	LCx N = 9	34 [4] (30–42)			

Table 2.7 continued

Para-meter	Group	Me [IQR] (min–max)	p	Groups with significant differences (p < 0.05)/ effect size (r)	Groups with no significant differences (p > 0.05)/ effect size (r)
RVD basal, mm	contr N = 32	34.5 [7] (30–41)	0.853		contr/RCA (0.782)/0.03 contr/LAD (0.426)/0.10 contr/LCx (0.924)/0.01 RCA/LAD (0.518)/0.08 RCA/LCx (0.952)/0.09 LAD/LCx (0.589)/0.09
	RCA N = 34	35 [5] (28–52)			
	LAD N = 30	34 [6] (25–44)			
	LCx N = 9	35 [6] (30–39)			
RVD mid, mm	contr N = 32	25 [5] (18–33)	0.128		contr/RCA (0.368)/0.11 contr/LAD (0.217)/0.16 contr/LCx (0.117)/0.25 RCA/LAD (0.069)/0.23 RCA/LCx (0.072)/0.27 LAD/LCx (0.901)/0.02
	RCA N = 34	25 [6] (16–39)			
	LAD N = 30	23.5 [8] (15–35)			
	LCx N = 9	23 [3] (19–27)			
RV L, mm	contr N = 32	74 [9] (63–84)	0.663		contr/RCA (0.528)/0.08 contr/LAD (0.722)/0.05 contr/LCx (0.377)/0.14 RCA/LAD (0.761)/0.04 RCA/LCx (0.268)/0.17 LAD/LCx (0.312)/0.17
	RCA N = 34	73.5 [11] (58–88)			
	LAD N = 30	75 [13] (61–93)			
	LCx N = 9	73 [6] (59–82)			
TAPSE, mm	contr N = 32	26 [3] (19–33)	< 0.001	contr/RCA (< 0.001)/0.75 contr/LAD (< 0.001)/0.70 contr/LCx (0.002)/0.49	RCA/LAD (0.359)/0.12 RCA/LCx (0.255)/0.17 LAD/LCx (0.463)/0.12
	RCA N = 34	20.5 [6] (10–26)			
	LAD N = 30	21 [2] (16–29)			
	LCx N = 9	22 [8] (16–27)			
FAC, %	contr N = 32	49.5 [6] (40–63)	0.003	contr/RCA (< 0.001)/0.44 contr/LCx (0.065)/0.29 RCA/LAD (0.035)/0.27	contr/LAD (0.139)/0.19 RCA/LCx (0.530)/0.10 LAD/LCx (0.385)/0.14
	RCA N = 34	43 [13] (10–62)			
	LAD N = 30	48 [8] (26–82)			
	LCx N = 9	43 [15] (34–59)			

Table 2.7 continued

Para-meter	Group	Me [IQR] (min–max)	p	Groups with significant differences (p < 0.05)/ effect size (r)	Groups with no significant differences (p > 0.05)/ effect size (r)
PA ACT, ms	contr N = 32	152 [24] (116–181)	< 0.001	contr/RCA (< 0.001)/0.61 contr/LAD (< 0.001)/0.61 contr/LCx (< 0.001)/0.68	RCA/LAD (0.553)/0.08 RCA/LCx (0.326)/0.15 LAD/LCx (0.184)/0.22
	RCA N = 34	116 [31] (77–177)			
	LAD N = 30	120 [33] (66–164)			
	LCx N = 9	106 [17] (92–123)			
TR V max, m/s	contr N = 32	2.14 [0.4] (1.5–2.8)	0.003	contr/RCA (0.018)/0.29 contr/LAD (< 0.001)/0.46	contr/LCx (0.077)/0.28 RCA/LAD (0.161)/0.18 RCA/LCx (0.591)/0.08 LAD/LCx (0.467)/0.12
	RCA N = 34	2.44 [0.4] (1.8–2.9)			
	LAD N = 30	2.37 [0.7] (1.8–3.3)			
	LC*x* N = 9	2.2 [0.8] (2.0–3.4)			
RVSP, mmHg	contr N = 32	20.0 [7.5] (10.0–32.5)	< 0,001	contr/RCA (< 0.001)/0.48 contr/LAD (< 0.001)/0.59 contr/LCx (0.007)/0.42	RCA/LAD (0.237)/0.15 RCA/LCx (0.804)/0.04 LAD/LCx (0.676)/0.07
	RCA N = 34	27.5 [10.0] (15.0–55.0)			
	LAD N = 30	27.5 [13.8] (20.0–47.5)			
	LC*x* N = 9	22.5 [15.0] (22.5–47.5)			
TA S'V, cm/s	contr N = 32	14 [2] (12–18)	0.003	contr/RCA (0.004)/0.35 contr/LAD (< 0.001)/0.48	contr/LCx (0.494)/0.11 RCA/LAD (0.799)/0.03 RCA/LCx (0.346)/0.15 LAD/LCx (0.357)/0.15
	RCA N = 34	12 [5] (5–19)			
	LAD N = 30	12.5 [4] (8–16)			
	LCx N = 9	12.5 [7] (8–21)			

Real-time 3D RV reconstruction was used to determine the RV volumes as well as SV and EF. The RV volumes and SV were indexed per BSA, similar to the LV parameters (Table 2.8). No statistically significant differences between groups were observed in the RV diastolic volumes. RV ESV and indexed ESV differ statistically significantly with a medium effect size between

the control and RCA group, and between the RCA and LAD groups. In the RCA group, the systolic volumes were greatest.

Table 2.8

RV parameters by 3D reconstruction in different groups of participants

RV parameter	Group	Me [IQR] (min – max)	p	Groups with significant differences (p < 0.05)/ effect size (r)	Groups with no significant differences (p > 0.05)/ effect size (r)
3D RV EDV, ml	contr N = 32	105.4 [33.6] (61.9–156.6)	0.667		contr/RCA (0.419)/0.10 contr/LAD (0.505)/0.09 contr/LCx (0.975)/0.005 RCA/LAD (0.262)/0.15 RCA/LCx (0.571)/0.09 LAD/LCx (0.711)/0.06
	RCA N = 34	118.9 [51.6] (62.8–209.9)			
	LAD N = 30	96.7 [47.6] (54.3–182.4)			
	LCx N = 9	110.2 [43.5] (65.5–146.0)			
3D RV ESV, ml	contr N = 32	44.2 [14.2] (27.1–80.5)	0.002	contr/RCA (< 0.001)/0.49 RCA/LAD (0.012)/0.34	contr/LAD (0.568)/0.08 contr/LCx (0.070)/0.28 RCA/LCx (0.157)/0.23 LAD/LCx (0.470)/0.12
	RCA N = 34	62.7 [22.2] (18.7–124.5)			
	LAD N = 30	47.0 [27.5] (20,2–104.2)			
	LCx N = 9	51.5 [17.0] (30.5–80.1)			
3D RV SV, ml	contr N = 32	58.6 [27.2] (33.8–91.8)	0.067	contr/*RCA* (0.013)/0.32	contr/*LAD* (0.072)/0.24 contr/*LCx* (0.147)/0.23 *RCA/LAD* (0.510)/0.09 *RCA/LCx* (0.804)/0.04 *LAD/LCx* (0.876)/0.03
	RCA N = 34	48.7 [23.2] (25.5–85.4)			
	LAD N = 30	54.8 [20.3] (25.0–92.1)			
	LCx N = 9	54.4 [30.4] (35.0–76.1)			
3D RV EDV ind, ml/m^2	contr N = 32	56.8 [13.3] (37.7–85.2)	0.457		contr/RCA (0.534)/0.08 contr/LAD (0.108)/0.21 contr/LCx (0.395)/0.13 RCA/LAD (0,423)/0,11 RCA/LCx (0.671)/0.07 LAD/LCx (0.800)/0.04
	RCA N = 34	56.3 [19.2] (34.7–111.1)			
	LAD N = 30	51.2 [17.4] (31.2–89.9)			
	LCx N = 9	55,1 [19.2] (38.1–65,8)			

Table 2.8 continued

RV parameter	Group	Me [IQR] (min – max)	p	Groups with significant differences (p < 0.05)/ effect size (r)	Groups with no significant differences (p > 0.05)/ effect size (r)
3D RV ESV ind, ml/m²	contr N = 32	24.4 [5.7] (5.8–41.3)	0.008	contr/RCA (0.001)/0.42 RCA/LAD (0.013)/0.34	contr/LAD (0.822)/0.03 contr/LCx (0.123)/0.24 RCA/LCx (0.339)/0.16 LAD/LCx (0,.20)/0.17
	RCA N = 34	29.6 [12.9] (10.3–65.9)			
	LAD N = 30	24.0 [9.3] (11.6–51.3)			
	LCx N = 9	26.5 [8.6] (17.7–33.5)			
3D RV SI, ml/m²	contr N = 32	31.5 [12.9] (20.6–49.5)	0.001	contr/RCA (< 0.001)/0.47 contr/LAD (0.009)/0.35 contr/LCx (0.025)/0.35	RCA/LAD (0.167)/0.19 RCA/LCx (0.645)/0.08 LAD/LCx (0.520)/0.11
	RCA N = 34	24.3 [11.0] (14.1–45.2)			
	LAD N = 30	27.4 [9.8] (12.5–40.0)			
	LCx N = 9	27.3 [12.3] (19.3–39.2)			
3D RV EF, %	contr N = 32	58.0 [11] (46–71)	< 0,001	contr/RCA (< 0.001)/0.66 contr/LAD (0.043)/0.27 contr/LCx (0.004)/0.46 RCA/LAD (0.001)/0.48	RCA/LCx (0.111)/0.26 LAD/LCx (0.143)/0.25
	RCA N = 34	45.4 [13] (28–70)			
	LAD N = 30	55.1 [9] (37–68)			
	LCx N = 9	46.4 [10] (41–60)			

3D RV EF is statistically significantly different between the control group and each of the patient groups, as well as between the RCA and LAD groups. In the case of RCA damage, 3D RV EF proved to be the smallest (45 %). However, despite statistically significant EF differences observed between the control and LAD group, the effect size was small. In other cases, it was medium or large.

RV strain is also a relatively new parameter of the systolic function that was analysed as a part of the study (Table 2.9). It should be recalled that for a better perception these indicators are expressed with positive values. A higher value indicates better myocardial strain.

Statistically significant differences among the groups were observed in the case of all strain values. RV FW strain, basal and mid segment LS was the worst in the RCA group (23.7 %, 22.0 %, and 25.5 % respectively). Conversely, the strain of the apical segment of the RV FW was the smallest in the case of LAD MI (21.5 %) due to RV blood supply pattern. All RV strain parameters with high effect size are statistically significantly different between the control and RCA groups.

Table 2.9

Evaluation of the RV free wall longitudinal strain in different groups of participants according to the damaged artery

RV para-meter	Group	Me [IQR] (min–max)	p	Groups with significant differences (p < 0.05)/effect size (r)	Groups with no significant differences (p > 0.05)/ effect size (r)
RV FW LS, %	contr N = 32	32.0 [3.7] (26.0–37.3)	< 0.001	contr/RCA (< 0.001)/0.70 contr/LAD (< 0.001)/0.47 contr/LCx (00.05)/0.44 RCA/LAD (0.002)/0.39	RCA/LCx (0.161)/0.22 LAD/LCx (0.494)/0.11
	RCA N = 34	23.7 [9.9] (5.0–35.0)			
	LAD N = 30	27.5 [7.6] (200–33.7)			
	LCx N = 9	28.3 [10.4] (17.0–34.3)			
RV FW basal segm. LS, %	contr N = 32	30.0 [7.0] (22.0–39.0)	< 0.001	contr/RCA (< 0.001)/0.59 RCA/LAD (< 0.001)/0.61	contr/LAD (0.67)/0.055 contr/LCx (0.085)/0.27 RCA/LCx (0.072)/0.28 LAD/LCx (0.074)/0.29
	RCA N = 34	22.0 [16.0] (– 5.0–34.0)			
	LAD N = 30	31.5 [7.0] (23.0–38.0)			
	LCx N = 9	27.0 [9.5] (19.0–40.0)			
RV FW mid segm. LS, %	contr N = 32	33.0 [4.0] (28.0–44.0)	< 0.001	contr/RCA (< 0.001)/0.67 contr/LAD (0.003)/0.38 contr/LCx (0.003)/0.48 RCA/LAD (< 0.001)/0.45	RCA/LCx (0.147)/0.23 LAD/LCx (0.216)/0.20
	RCA N = 34	25.5 [10.8] (– 4.0–39.0)			
	LAD N = 30	30.0 [6.0] (22.0–38.0)			
	LCx N = 9	30.0 [9.5] (22.0–34.0)			

Table 2.9 continued

RV parameter	Group	Me [IQR] (min–max)	p	Groups with significant differences (p < 0.05)/effect size (r)	Groups with no significant differences (p > 0.05)/ effect size (r)
RV FW apical segm. LS, %	contr N = 32	30.0 [5.0] (23.0–39.0)	< 0.001	contr/RCA (< 0.001)/0.64 contr/LAD (< 0.001)/0.71 contr/LCx (0.001)/0.56	RCA/LAD (0.424)/0.10 RCA/LCx (0.950)/0.01 LAD/LCx (0.726)/0.056
	RCA N = 34	22.0 [5.0] (10.0–34.0)			
	LAD N = 30	21.5 [6.3] (5.0–30.0)			
	LCx N = 9	24.0 [14.0] (7.0–29.0)			

The primary aim of the study is to diagnose RV involvement and its dysfunction in any localisation of MI, using the new Echo methods. Therefore, as a standard for the determination of RV systolic dysfunction, for conducting the ROC curve analysis, changes in the traditional RV Echo parameters (TAPSE, TA S'V, FAC) were adopted, namely, assuming values of the abnormality thresholds in compliance to the recommendations in force at the time the analysis (Table 2.10).

Table 2.10

Number of patients with changes in each of the standard parameters, as well as abnormally reduced 3D RV EF and RV FW LS

RV function parameter	Abnormality threshold	Number of patients (%) (N = 73)	RV function parameter	Abnormality threshold	Number of patients (%) (N = 73)
TAPSE, mm	< 17	9 (12)	**3D RV EF, %**	< 45	18 (25)
TA S'V, cm/s	< 9.5	10 (14)	**RV FW LS, %**	< 20	14 (19)
FAC, %	< 35	10 (14)			

From the RV 3D volume parameters, the statistically significant ROC curve is composed of ESV, indexed ESV and EF (p < 0.001), whereas only the

last two form a good diagnostic model (AUC = 0.81 and 0.88 respectively) (Table 2.11). 3D RV indexed ESV > 28.8 ml/m^2 diagnoses RV involvement with 77 % sensitivity and 77 % specificity, while 3D RV EF < 49 % – with 73 % sensitivity and 78 % specificity.

Table 2.11

ROC curve analysis of RV 3D parameters used in the RV dysfunction diagnostics in patients with MI

RV parameter	AUC (95 % CI)	p-value	Cut-off value	Se % (95 % CI)	Sp % (95 % CI)	PPV % (95 % CI)	NPV % (95 % CI)
3D RV EDV, ml	0.63 (0.48–0.77)	0.077	-	-	-	-	-
3D RV ESV, ml	0.79 (0.68–0.91)	< 0.001	56.3	73 (50–89)	73 (61–83)	44 (34–56)	90 (82–95)
3D RV SV, ml	0.62 (0.48–0.75)	0.1	-	-	-	-	-
3D RV EDV ind, ml/m^2	0.61 (0.47–0.75)	0.115	-	-	-	-	-
3D RV ESV ind, ml/m^2	0.81 (0.7–0.93)	< 0.001	28.8	77 (55–92)	77 (66–86)	50 (38–62)	92 (84–96)
3D RV SI, ml/m^2	0.68 (0.55–0.80)	0.012	-	-	-	-	-
3D RV EF, %	0.88 (0.79–0.96)	< 0.001	49.0	73 (50–89)	78 (67–87)	50 (38–62)	91 (83–95)

All RV strain parameters represent statistically significant ROC curves ($p < 0.001$) for RV dysfunction in patients with MI of any localisation (Table 2.12). Excellent models consist of RV FW LS (AUC = 0.95; cut-off value = 24.5 %; sensitivity 88 %; specificity 89 %) and RV FW mid segment LS (AUC = 0.92; cut-off value = 27.5 %; sensitivity 88 %; specificity 86 %). The other parameters represent good diagnostic models ($0.8 \leq AUC \leq 0.9$).

Table 2.12

ROC curve analysis of RV LS parameters used in the RV dysfunction diagnostics in patients with MI

RV parameter	AUC (95 % CI)	p-value	Cut-off value	Se % (95 % CI)	Sp % (95 % CI)	PPV% (95 % CI)	NPV % (95 % CI)
RV FW LS, %	0.95 (0.89–1.0)	< 0.001	24.5	88 (70–98)	89 (80–95)	74 (60–85)	96 (89–99)
RV FW basal LS, %	0.88 (0.79–0.96)	< 0.001	26.5	76 (55–85)	76 (65–85)	51 (40–63)	91 (83–95)
RV FW mid LS, %	0.92 (0.84–0.99)	< 0.001	27.5	88 (69–97)	86 (76–93)	67 (53–78)	96 (88–98)
RV FW apical LS, %	0.88 (0.80–0.95)	< 0.001	22.0	85 (65–96)	74 (62–83)	52 (42–62)	93 (85–97)

2.3 Analysis of Clinical, Biochemical Data and Standard Echocardiographic Parameters of the Right Ventricle in the Groups According to the Presence of the Right Ventricle Systolic Dysfunction

Taking into account the newly acquired cut-off levels of the studied parameters, i.e. RV 3D EF and RV FW LS, and combining them with visual assessment and diagnostics according to standard parameters, RV involvement was found in 44 (60 %) patients with MI. The association between RV dysfunction and damaged coronary artery (LAD, LCx or RCA), in this case, was not statistically significant (p = 0.086) (Table 2.13).

Table 2.13

RV dysfunction in patients with MI, visually assessed in combination with conventional parameters and new parameters, as defined by the study cut-off levels, classified according to the damaged artery

RV dysfunction	Acutely damaged artery			p-value/ effect size
	RCA (N = 34)	LAD (N = 30)	LCx (N = 9)	
Present	25 (73.5 %)	14 (46.7 %)	5 (55.6 %)	0.086/0.25
Absent	9 (26.5 %)	16 (53.3 %)	4 (44.4 %)	

The association between the presence of life-threatening events and damaged artery has been previously analysed (Table 2.3), without having been detected (p = 0.76; Cramer's V effect = 0.27, small). In contrast, by studying the relationship between events and presence of RV dysfunction (diagnosed using a combination of new and standard parameters), the Pearson Chi-square test reveals a statistically significant association (p = 0.034; φ effect size = 0.3, mean).

Biochemical parameters were also analysed depending on the RV dysfunction, but no statistically significant differences were found.

From RV Echo standard parameters, according to the Mann-Whitney U test, a statistically significant difference between patient groups with and without RV dysfunction presented RAVI, RVD basal, RVD mid, RV L, TAPSE, FAC, and PA ACT. The most important of these are FAC (effect size = 0.58, large), RVD mid and TAPSE (medium effect size, 0.31 and 0.37 respectively) (Table 2.14).

Table 2.14

RV standard Echo parameters in patients with ST-elevation MI according to the presence of RV dysfunction

Right heart parameter	RV dysfunction	Me [IQR]; (min–max)	p-value / effect size
RAVI, ml/m^2	**- present**	19 [8]; (7–45)	0.031/0.25
	- absent	17 [6]; (10–27)	
RVOT sax, mm	**- present**	34 [6]; (25–44)	0.113/0.18
	- absent	33 [5]; (25–43)	
RVD basal, mm	**- present**	36 [5]; (25–52)	0.015/0.28
	- absent	34 [4]; (28–42)	
RVD mid, mm	**- present**	26 [7]; (15–39)	0.006/0.31
	- absent	23 [5]; (16–31)	
RV L, mm	**- present**	77 [10]; (58–93)	0.036/0.24
	- absent	73 [8]; (59–84)	
TAPSE, mm	**- present**	20 [5]; (10–27)	0.002/0.37
	- absent	22 [4]; (14–29)	
FAC, %	**- present**	41 [12]; (15–82)	< 0.001/0.58
	- absent	50 [8]; (37–62)	
PA ACT, ms	**- present**	112 [33]; (66–177)	0.039/0.24
	- absent	123 [27]; (82–162)	
TR V max, m/s	**- present**	2.41 [0.3]; (1.9–3.3)	0.513/0.07
	- absent	2.35 [0.6]; (1.8–3.4)	
RVSP, mmHg	**- present**	27.5 [10.0]; (17.5–55.0)	0.466/0.08
	- absent	30.0 [10.0]; (17.5–47.5)	
TA S'V, cm/s	**- present**	12 [5]; (5–21)	0.728/0.04
	- absent	13 [3]; (8–18)	

2.4 Analysis of the Right Ventricle Three-Dimensional Echocardiographic Parameters and Longitudinal Strain of the Right Ventricle in Groups According to the Presence of Right Ventricle Systolic Dysfunction

According to the Mann-Whitney U test (Table 2.15), in patients with RV systolic dysfunction has been observed statistically significantly higher 3D RV ESV ($p < 0.001$; effect size = 0.46, medium) and indexed 3D RV ESV ($p < 0.001$; effect size = 0.51, high).

Likewise, statistically significant difference, however, with small effect size was observed in case of 3D RV SI, which was smaller in the RV dysfunction group ($p = 0.027$; effect size = 0.28). Dependence of RV 3D EF on the presence of RV dysfunction was not analysed because it served as one of the criteria for determining this dysfunction.

Table 2.15

RV 3D Echo parameters for patients with ST-elevation MI according to the presence of RV dysfunction

RV parameter	RV dysfunction	Me [IQR]; (min–max)	p-value / effect size
3D RV EDV, ml	**- present**	114.9 [53.3]; (64.0–209.9)	0.118/0.20
	- absent	104.9 [37.5]; (54.3–156.6)	
3D RV ESV, ml	**- present**	60.7 [25.0]; (28.3–124.5)	< 0.001/0.46
	- absent	44.3 [17.6]; (18.7–80.5)	
3D RV SV, ml	**- present**	49.1 [26.8]; (25.0–92.1)	0.203/0.16
	- absent	56.5 [21.1]; (33.8–91.8)	
3D RV EDV ind, ml/m^2	**- present**	55.5 [19.4]; (33.4–11.0)	0.139/0.19
	- absent	54.3 [15.5]; (31.2–85.2)	
3D RV ESV ind, ml/m^2	**- present**	29.7 [12.1]; (17.9–65.9)	< 0.001/0.51
	- absent	23.8 [6.4]; (10.3–41.3)	
3D RV SI, ml/m^2	**- present**	25.4 [9.4]; (12.5–45.1)	0.027/0.28
	- absent	30.7 [10.3]; (19.6–49.5)	

In the case of RV FW strain parameters, they were statistically significantly lower ($p < 0.001$) in patients with RV dysfunction, with large effect size (Table 2.16). RV TW total LS was not analysed because it served as one of the criteria for determining RV dysfunction.

Table 2.16

RV longitudinal strain values in patients with ST-elevation MI according to the presence of RV dysfunction

RV parameter	RV dysfunction	Me [IQR]; (min–max)	p-value /effect size
RV BS basal segment LD, %	**- present**	24.0 [11.0]; (– 5.0–35.0)	< 0.001/0.53
	- absent	31.0 [7.0]; (22.0–39.0)	
RV BS mid segment LD, %	**- present**	25.0 [10.0]; (– 4.0–35.0)	< 0.001/0.72
	- absent	33.0 [5.0]; (27.0–44.0)	
RV BS apical segment LD, %	**- present**	21.0 [6.0]; (5.0–34.0)	< 0.001/0.65
	- absent	28.0 [6.3]; (16.0–39.0)	

3 DISCUSSION

With the development of new Echo methods, RV non-invasive assessment has become more informative, more accurate, overcoming the difficulties caused by its anatomical structure and positioning. This has enabled to take a closer look at changes in RV size and function in the case of various pathologies. Within this study, particular emphasis has been given to the RV failure in the case of acute MI. Nowadays, there is very little research being done on RV MI or dysfunction, and their importance in a patient's prognosis is underestimated.

3.1 Demographic, Clinical and Biochemical Description of Study Groups

Analysing demographics of the control and patient groups, statistically significant differences were observed in a number of parameters with considerable effect size. In the group of patients, the number of males and smokers (small effect size) is higher, the average age and weight of patients are higher, therefore, contributing to higher BSA and BMI. It should be noted that under the age of 60, which is one of the criteria for inclusion, gender, and age (early manifestations in men), obesity and overweight are specific risk factors for atherosclerosis. Therefore, in the group of patients with MI, the findings are not unexpected. The groups were not unified according to the demographic parameters, taking into consideration the number of participants, as well as the fact that several Echo parameters were indexed by BSA. The gender differences between the Echo parameters are known and may influence comparisons of the control and patient group outcomes. It ought to be noted, however, that the differences by the gender distribution between the control and the patient group were statistically significant ($p = 0.002$), but the effect size is

medium, on the verge with low (φ effect size = 0.3). It should also be taken into account that the statistical parameter analysis was performed not merely by making a comparison between the control and patient groups but also within the group of patients, dividing it according to the damaged artery.

All patients had undergone coronary angiography and the patient group was divided into subgroups according to the acutely damaged artery with the aim of exploring the effect of MI of different localisation over RV. Depending on this, the majority of the registered parameters was analysed. In the LCx group, the number of patients in the group was the smallest, which could affect the accuracy of the results. According to the RV anatomy and perfusion studies, however, this artery is the least likely to perfuse RV and cause dysfunction specifically in the form of direct ischemic damage. In the study conducted among the patients with LCx damage, only one showed the left type of blood perfusion and possible RV perfusion from the circumflex artery, corresponding to 10–20 % of the data referred to in the literature (Abuchaim et al., 2009; Parikh et al., 2012). Therefore, in only one case RV MI in the LCx group is likely.

Upon examination of the ventricular arrhythmias and the overall incidence of cardiogenic shock, no statistically significant association between these events and the damaged artery was found. On the other hand, it should be noted at once that a statistically significant association with a medium effect size was found between the events and the presence of RV dysfunction. This is one of the reasons why the RV function should be carefully evaluated for MI of any localisation. This issue remains even more relevant given that in the medical community it is generally considered that only RCA damage can be the cause of RV dysfunction.

From the biochemical parameters, statistically significant differences depending on the damaged artery were found only in the case of NT-proBNP,

which was the lowest in the RCA group. While that brain type natriuretic peptides are secreted by ventricular muscle layer, which is significantly thicker in LV, their levels increase mostly in LV rather than RV overload. Analysing the differences in biochemical parameters depending on the presence of RV involvement, no statistically significant differences were found. The level of troponin T-hs showed a difference that is approximate to the statistically significant ($p = 0.057$), but it is more likely to indicate the extent of the damage. The greater the extent of damage, the higher the probability of the RV function being impaired. It has to be concluded that none of the biochemical parameters have a diagnostic value for the determination of RV dysfunction.

3.2 Echocardiographic Evaluation of the Left Ventricle

LV was evaluated according to the parameters provided in the Echo standard protocol, supplemented with LV WMI and GLS measurements. All LV parameters that directly or indirectly reflect its function have a statistically significant difference between the control and patient groups according to the acutely damaged artery. In the RCA group, according to all parameters, the LV systolic function was least disturbed compared to LAD and LCx damage. This finding often contradicts with the severe clinical condition that can accompany the LV inferior wall infarction. One of the reasons for this condition is rhythm disorders. Of these, ventricular arrhythmias are associated with the extent of RV involvement. The second reason is extensive RV MI accompanied by characteristic hypotension even up to cardiogenic shock.

3.3 Echocardiographic Evaluation of the Right Ventricle by Standard Parameters

RV standard parameters were evaluated in the control group and groups depending on the damaged artery, and re-analysed only in the group of patients

depending on the presence of RV dysfunction. The dysfunction was determined visually, according to the RV standard Echo parameters and new parameters, using the thresholds determined in the study.

In the comparison of the RV parameters between the control group and the patient groups formed according to the acutely damaged artery, the 2D RV size variables did not differ statistically, wherefrom it can be concluded that RV dilation in the case of MI is not typical for any damaged arteries. Other parameters, such as TAPSE, FAC, PA ACT, TR V max, RVSP, and TA S'V differ mainly between the control group and patient groups, but not making a comparison among the patient groups. This finding indicates a change in RV function in the case of MI overall, and these changes are also not dependent on the damaged artery.

In turn, the most appropriate standard parameters used for determining RV dysfunction are FAC ($p < 0.001$; effect size = 0.58, large) and TAPSE ($p = 0.002$; effect size = 0.37, medium). Median FAC and median TAPSE in patients with RV dysfunction proved to be higher than the threshold identifying pathology according to ASE/EACVI 2015 Recommendations for Cardiac Chamber Quantification by Echocardiography in Adults (Lang et al., 2015). In the case of FAC, it was 41 % versus the 35 % threshold specified in the guidelines, whereas in the case of TAPSE – 20 mm versus the 17 mm threshold. Furthermore, it should be kept in mind that the study group was subject to an age limit of up to 60 years according to the inclusion criteria that may affect the results obtained. Likewise, it should also be borne in mind the accuracy of both indicators in the assessment of RV systolic function has certain limitations, as measurements are made over one plane and are affected by LV. However, the most important component that explains the difference between the obtained indicators and the guidelines specified abnormality threshold is that by breaking down the patients according to the presence of RV

dysfunction, the RV longitudinal strain, which changes faster than the standard parameters, was used as a criterion.

Another parameter that is useful for studying the RV changes in MI patients is the mid-cavity RVD. In contrast to the analysis performed using breaking down by the artery, determining it in groups with and without RV dysfunction, the RVD mid shows a statistically significant difference ($p = 0.006$; effect size = 0.31, medium) indicating that RV tends to expand. Nevertheless, this measurement is ineffective in the diagnosis of RV dysfunction, as its median value in the study population falls within the norm values listed in the ASE/EACVI 2015 Recommendations for Cardiac Chamber Quantification by Echocardiography in Adults (Lang et al., 2015). Mid-cavity RVD is useful, provided the availability of its value in a patient prior to and after the MI or for the evaluation of the RV immediately after the MI and in the later follow-up control examinations.

3.4 Indicators of Three-Dimensional Volume and Longitudinal Strain of the Right Ventricle in the Group of Healthy Participants

Within the framework of the study after the reconstruction of 3D RV, RV volumes were determined by calculating indexed RV volumes and EF. From the study conducted in 2013, it is known that RV volumes tend to decrease by age, while RV EF has as a tendency to increase. There are also known some differences, depending on gender: volumes are expected to be smaller for women of any age, but EF is slightly higher or similar (D'Oronzio et al., 2012). However, the latest 2015 ASE/EACVI recommendations do not yet recommend the use of breakdowns by normal reference values according to age groups (Lang et al., 2015). In the context of this study, given the small number of participants, the control group was also not broken down by gender and age in the data analysis process.

Overall, the gender distribution in the groups was similar (53 % women), the average age – 46.3 years, SD 6.8. It should be noted that the median values of these parameters were calculated in the study, which slightly complicates the comparison with the averages indicated in the recommendations. However, the non-indexed RV volumes obtained, considering the indicative age, fall within the previously published norm with the difference between the medians of ~ 10–15 ml (D'Oronzio et al., 2012). Indexed volume values are more accurate because they exclude variability depending on BSA.

For the indexed RV EDV in the recommendations indicated the average norm values are 61 ml/m^2 (SD = 13) for males and 53 ml/m^2 (SD = 10.5) for females that match the median of the control group in the current study – 56.8 ml/m^2 (IQR = 13.3) without division by gender. In the case of indexed RV ESV, the finding is similar – 24.4 ml/m^2 (IQR = 5.7) in the control group, it corresponds to the recommended reference, i.e. 27 ml/m^2 (SD = 8.5) for men and 22 ml/m^2 (SD = 7) for women. In the case of RV EF, the gender breakdown is not recommended, and the recommendation indicates a total norm of 58 % (SD = 6.5). This is fully consistent with the RV EF median in the control group – 58 % (IQR = 11).

The longitudinal strain of RV was assessed over the entire length of FW, averaging, and separately for each segment. In the control group, total RV FW LS was 32 % (IQR = 3.7). The value is close to the average of 29 % (SD = 4.5 %) set out in the current recommendations (Lang et al., 2015). But a year later, following the issue of ASE/EACVI Recommendations of 2015, RV LS parameters were readjusted (Muraru et al., 2016). In Muraru's study, a new mean of RV FW LS was defined – 30.5 % (SD = 3.9), which differs from the control group obtained median only by 1.5 %. This slight difference could also be explained by the fact that the Italian researchers did not have an age limit for

participants in the analysis conducted, hence the oldest being 76 years old. In the present study, the age limit of 60 years was applied, which means that younger patients were included in the control group, and thus with a better RV strain.

In the control group the RV segmental LS almost did not differ from the results published in the study carried out in 2016 (– 30 % vs – 30 % in the basal segment, – 33 % vs – 34 % in the mid segment, and – 30 % vs – 29 % in the apical segment) (Muraru et al., 2016). Similar to the data from previous studies, there was a tendency identified for LS to be the greatest in the RV mid segment.

3.5 The Right Ventricle Systolic Dysfunction in Patients with ST-Elevation Myocardial Infarction

RV systolic dysfunction was determined by several indicators within the study. Initially, the assessment was visual in determining the disorders of the segmental systolic function. Such RV dysfunction was found in 26 % of patients.

In addition to the visual assessment, the RV dysfunction was also quantified by standard Echo parameters – TAPSE, TA S'V, and FAC by accepting as a pathological threshold the level specified in the ASE/EACVI recommendations of 2015. By combining both methods, indications of RV involvement in ST-elevation in the case of MI were already found in 36 % of the patients. The combination of these particular methods was accepted as the standard for the determination of the RV systolic dysfunction by analysing the new 3D Echo and LS parameters for patients with ST-elevation MI. The current ASE/EACVI recommendations of 2015 also set out the thresholds for new parameters for the RV dysfunction, but it should be noted that they are not abnormally specific. In 3D RV EF it is < 45 %, while in RV FW LS it is > – 20

% (Lang et al., 2015). Provided that in the selection of patients, these indicators were additionally considered, it was possible to diagnose RV dysfunction in 42 % of the cases.

Within this study, 3D RV volume and LS parameters were analysed in patients with ST-elevation MI age group for up to 60 years. As a standard in the determination of the RV systolic dysfunction, visual changes and changes in traditional Echo parameters were adopted. It turned out that of 3D RV volume indices indexed 3D RV ESV and 3D RV EF have a good diagnostic value with satisfactory sensitivity and specificity when determining RV involvement in the case of MI. Indexed ESV < 28.8 ml/m^2 and EF < 49 % best predicted RV systolic dysfunction.

While the recommendations do not provide thresholds for the detection of abnormal changes in 3D RV volumes, 3D RV EF appeared to be 4 % higher than the indicated pathological level. This is partly explained by the relatively younger group of patients involved in the study. When analysing 3D parameters according to the damaged artery, the most statistically significant change in RV parameters was observed in the case of RCA damage. In this group, compared to the control group, there were statistically largest 3D RV ESV and indexed 3D RV ESV and smallest 3D RV SV, 3D RV SI and 3D RV EF. This finding reflects a more pronounced RV systolic dysfunction at MI it the RCA blood pool, which corresponds to heart MRI findings (Kumar et al., 2006; Bodi et al., 2010), but does not deny the RV dysfunction in MI of other localisations, as 3D RV SI and 3D RV EF were statistically significantly different also when LAD and LCx arteries were damaged by reference to the control group values obtained.

Upon investigating changes in RV strain parameters, they showed a better diagnostic value compared to 3D RV volumes and EF. This is a natural finding, keeping in mind that RV systolic function is mainly provided by

longitudinal contraction, and RV LS responds to a pathological condition with decrease faster than volumes. Thereby, LS decrease alongside with reduced EF will show a more severe RV systolic dysfunction than isolated RV LS changes. All RV LS parameters ranged form good or excellent statistically significant models for detection of the RV systolic dysfunction in ST-elevation MI.

Excellent diagnostic models are total RV FW LS with a threshold of – 24.5 %, 88 % sensitivity and 89 % specificity, and RV FW mid segment LS with a threshold of – 27.5 %, 88 % sensitivity, and 86 % specificity. As in the case of 3D RV EF, the study obtained cut-off levels for RV FW LS is 4.5 % higher than that provided in the 2015 recommendations, but coincides directly with the norm lower threshold of – 29 % ± 4.5 (Lang et al., 2015). Nevertheless, when making a comparison between the obtained RV FW LS threshold and the one indicated in the expert opinion published in 2017 concerning the standardisation of the Echo protocol with the refinements of the mentioned guidelines of 2015, the difference is significantly smaller – 1.5 %, as the new recommended threshold for diagnosing the pathology is – 23 % (Galderesi et al., 2017). In general, it indicates the accuracy and reliability of measurements performed within the framework of the study.

Analysing the parameters of RV strain depending on the damaged artery, statistically significantly worse results were shown in the RCA group for almost all investigated parameters, similar to 3D RV volume and EF analysis. It should be noted that statistically significant differences were also observed when making a comparison between LAD and LCx damage groups with control group indices that confirm the possibility of RV dysfunction in the case of ST-elevation MI of any localisation. Interestingly, the most pronounced LS decrease in RV FW apical segment was observed in the case of LAD damages, due to the peculiarities of RV perfusion and indicates the likelihood of RV

segmental dysfunction also in the case of LV MI affecting the septum, the anterior wall, and the apex.

Pursuant to the RV 3D volume and LS analysis conducted within the study, patients were re-divided into groups with RV systolic dysfunction and without it, in addition to visual imaging and standard Echo parameters using 3D RV EF and RV FW total LS thresholds, detected in this study. As a result, RV involvement was discovered in 44 patients, representing 60 % of the patient group. Such a finding is much closer to autopsy research data showing the greatest rate of the RV involvement in the case of MI among all RV research methods, including the "gold standard" – heart MRI. Applying the new thresholds specified in the new parameters, the RV involvement, according on the damaged artery, was also reassessed, but no statistically significant association was found. This indicates the possibility of the RV systolic dysfunction in ST elevation MI of any localisation.

3.6 Limitations of the Study

The first and foremost constraint is the unavailability of cardiac MRI for the acute ST-elevation MI patients involved in the study. Heart MRI is the only method except autopsy, which sufficiently accurately is capable of identifying the presence of myocardial ischemia region, its localisation, width, myocardial edema, and the decrease in RV EF. It would be necessary to verify the new Echo parameter thresholds for detecting the RV dysfunction. Considering that RV dysfunction was initially determined according to the pathological thresholds of the standard Echo parameters, rather than by heart MRI, the limitations of these traditional methods also affect such selection. Therefore, it is not possible to completely exclude both inadequate and excessive diagnosis of RV dysfunction by standard parameters.

The number of patients should also be considered among other restrictions. Overall, the number of participants included in the study is sufficient for both the patient and the control group. However, dividing the patients into subgroups as part of statistical analysis, the number of patients in the LCx group is the lowest, which may affect the accuracy of the results. In the patient group, all participants were accepted one by one according to the selection criteria rather than the localisation of ST-elevation MI. The LCx pool infarctions proved to be the least common.

Imaging capabilities represent a limitation to any investigation method based on ultrasound use. Poor Echo visualisation of heart structures was a criterion for exclusion in the study, but imaging of moderate quality could also partially affect the accuracy of the measurements. On the bright side, by doing so, the study becomes more realistic and is closer to everyday practice.

The fast aging of the software package is not a limitation, but the circumstances that should be taken into account when conducting this type of research. The latest version of the RV 3D reconstruction programme was not available within the framework of the study. Different versions of software algorithms vary, and the RV reconstruction methodology also changes, which can result in a small measurement difference and show different calculated RV volumes for the same patient. This should be considered in the comparison of the results of the studies that were made using different versions of the data processing programme.

CONCLUSIONS

1. Normal RV LS and 3D EF values in healthy individuals aged 30 to 60 years were determined within the study. These measurements were used as reference values for the comparison with the values obtained from ST-elevation MI patients.
2. Echo-visualisation enabled to perform RV 3D reconstruction of sufficient quality to calculate RV volumes and EF in 88 % of cases.
3. Based on the results of the study, depending on the method of evaluating RV dysfunction, its involvement in ST-elevation MI was observed in 26–60 % of the cases. The least RV dysfunction was identified merely by visual assessment. The highest percentage of involvement is determined by combining visual assessment with standard Echo methods and new parameters such as 3D RV EF and RV FW LS.
4. Changes in the RV function, based on both traditional Echo parameters and new parameters, can be observed if any of the three coronary arteries is damaged. The most pronounced changes in RV were naturally observed in the case of RCA damage, namely, in patients with LV inferior ST-elevation MI. In the case of damage of LAD, special attention should be paid to the apical RV segments, because there may be local changes without reduction of 3D RV EF.
5. 3D RV EF < 49 % is a threshold that can be used for detecting the presence of dysfunction in patients with ST-elevation MI. In the case of RV FW LS, it is 24.5 %.

Hypotheses of the Thesis

The hypothesis “the reduction of the right ventricular ejection fraction can be statistically significant in the case of acute coronary artery lesion of different localisation” was confirmed in the study. Statistically significant differences in 3D RV EF were observed between the control group and each of the damaged artery groups.

The hypothesis “the reduction of the myocardial longitudinal strain of the right ventricle free wall can be statistically significant in the case of acute coronary artery lesion of different localisation” was also confirmed within the framework of the study. The statistically significant differences in the total LS of the RV FW were observed between the control group and each of the damaged artery groups.

PRACTICAL RECOMMENDATIONS

1. The RV 3D reconstruction method is effective and should be introduced in medical practice on a wider scale, especially for patients after ST-elevation MI, thereby determining the RV dysfunction according to RV volumes and EF. The method should also be considered for dynamic evaluation of RV function.
2. For patients with ST-elevation MI for detection of RV dysfunction, it is recommended to use RV 3D EF cut-off value of less than 49 %.
3. The RV LS method is effective and possesses great clinical utility and should be implemented on a great scale for early diagnosis of RV dysfunction in patients after ST-elevation MI. The method should be given to consideration for the dynamic evaluation of RV function.
4. For patients with ST-elevation MI for detection of RV dysfunction the use of RV FW LS values greater than – 24.5 % is recommended.
5. Methods for determining RV 3D EF and RV FW LS have to be used in combination with standard Echo methods.

Based on the results of the study conducted, it is possible to identify the most sensitive of all available RV assessment parameters that should be used in daily practice, especially in patients with ST-elevation MI (Table 1). These include a visual assessment of the RV segmental and global systolic function, TAPSE, FAC, mid-cavity RVD, RV FW LS, and 3D RV EF.

Table 1

Echo methods and parameters recommended for the evaluation of the RV function

Method	Parameters	Echo view	Comments
I visual assessment (during standard Echo exam)	- segmental systolic function - global systolic function	- subxiphoid long axis - parasternal long axis - parasternal RV inflow view - parasternal short axis view: basal, mid-cavity, apical levels - apical 4 chamber view - RV focused 4 chamber view	- in case of inferior LV MI pay attention to RV inferior and lateral wall, especially basal and midsegments - in case of extensive anterior or apical LV MI pay attention to RV apical segments and anterior wall
II standard Echo	- TAPSE	- apical 4 chamber view	
	- FAC - mid RVD	- RV focused 4 chamber view	- mid RVD for RV evaluation in follow-up
III 2D deformation imaging	- RV FW LS	- RV focused 4 chamber view	
IV RV 3D Echo	- EF	- RV focused 4 chamber view	

It is possible to apply visual assessment of RV segmental and global dysfunction to Echo screening (Figure 1). If there are no visual signs of RV dysfunction, for its safer exclusion, the RV FW LS measurement is sufficient. When on the basis of the foregoing criteria suspicions are raised concerning the RV dysfunction, a focused complete evaluation of RV is required.

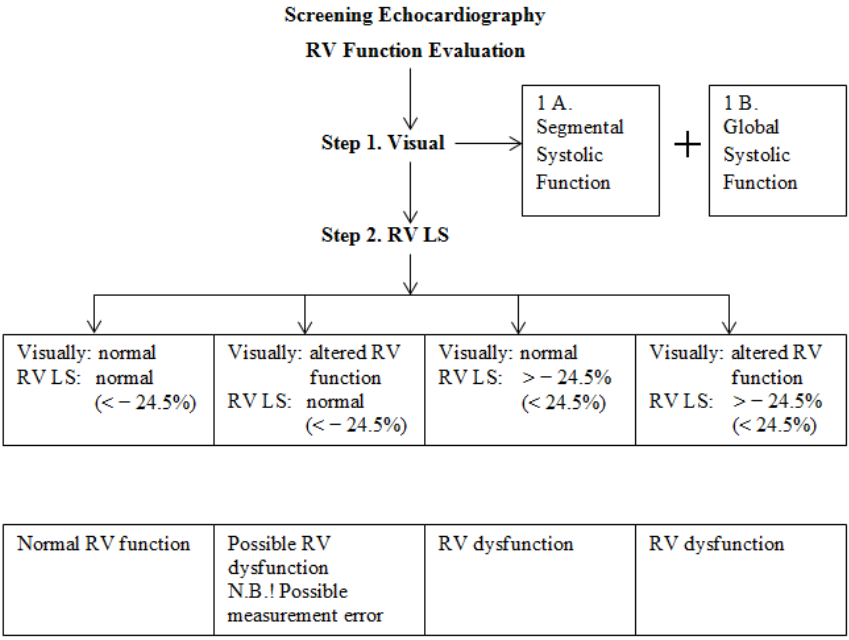

Fig. 1. **Algorithm for RV function evaluation during Echo screening**

RV – right ventricle; RV LS – longitudinal strain of the right ventricle

For conducting proper assessment of RV, the visual evaluation of systolic function, standard Echo measurements and new Echo parameters – RV LS and 3D RV EF (Figure 2) should be used. Dysfunction is assessed by taking into account all relevant parameters (Table 2).

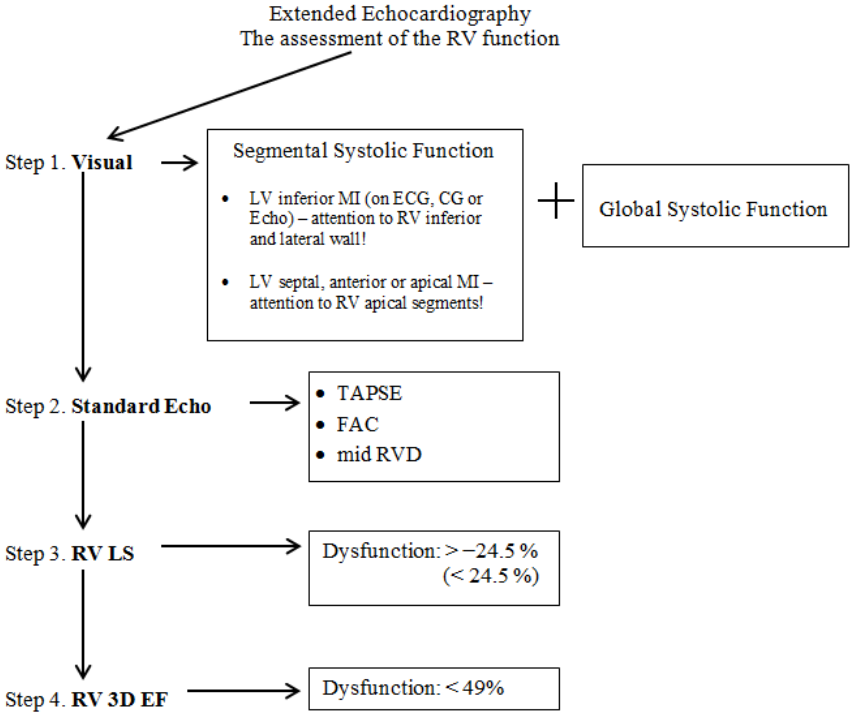

Fig. 2. **The algorithm for evaluating the RV function during the detailed Echo**

CG – Coronarography; ECG – electrocardiography; Echo – echocardiography; FAC – fractional area change; LV – left ventricle; MI – myocardial infarction; mid RVD – mid-cavity diameter of the right ventricle; RV – right ventricle; RV 3D EF – right ventricular ejection fraction, determined by three-dimensional echocardiography; RV LD – longitudinal deformation of the right ventricle; TAPSE – Tricuspid Annular Plane Systolic Excursion

Table 2

Determination of RV dysfunction by detailed Echo algorithm results

Visual: N Standard Echo: N RV LS: N RV 3D EF: N	Visual: N Standard Echo: Alt. RV LS: N RV 3D EF: N	Visual: N Standard Echo: N RV LS: Alt. RV 3D EF: N	Visual: N Standard Echo: Alt. RV LS: Alt. RV 3D EF: N
No RV dysfunction	**No RV dysfunction N.B.! possible measurement error in standard Echo parameters**	**Subclinical RV dysfunction**	**RV dysfunction**
Visual: Alt. Standard Echo: Alt. RV LS: Alt. RV 3D EF: N	Visual: Alt. Standard Echo: Alt. RV LS: Alt. RV 3D EF: Alt.	Visual: Alt. Standard Echo: N RV LS: N RV 3D EF: N	Visual: N Standard Echo: N RV LS: N RV 3D EF: Alt.
RV dysfunction	**RV dysfunction**	**Error in visual assessment**	**Measurement error**

Alt. – abnormally altered parameter; Echo – echocardiography; RV 3D EF – right ventricular ejection fraction, determined by three-dimensional echocardiography; RV LS – longitudinal strain of the right ventricle; N – the norm

PUBLICATIONS

1. Articles in international peer-reviewed journals:

- Pickure, Z., Kalinin, A., Lejnieks, A., Alekhin, M. N. 2017. Current Echocardiographic Techniques for Evaluation of the Right Ventricle. *Kardiologiia* 17 (9), 54–64. doi:10.18087/cardio.2017.9.10019.

- Pičkure, Ž., Kalinin, A., Lejnieks, A. 2021. Right ventricle involvement in patients with acute st elevation myocardial infarction: is echocardiography good enough in diagnosing it? *Proceedings of the Latvian Academy of Sciences*. (in press)

- Pickure, Z., Kalinin, A., Pickurs, K., Zakharova, E., Alekhin, M., Lejnieks, A. 2020. P1516 Detecting right ventricular systolic dysfunction in patients with acute ST-elevation myocardial infarction: echocardiography is good enough. *European Heart Journal - Cardiovascular Imaging.* 21(suppl1), jez319.940. doi: 10.1093/ehjci/jez319.940

2. Thesis in international conferences:

- Pickure, Z. Three-dimensional echocardiography and strain of the right ventricle [Трёхмерная эхокардиография и стрейн правого желудочка]. *Modern technologies of functional and ultrasound diagnostics in clinical medicine – 2018*, St. Petersburg, Russia, Apr. 26, 2018

- Pickure, Z., Kalinin, A., Pickurs, K., Lejnieks, A., Erts, R., Zakharova, E., Kasprzak, J. D. Right ventricular longitudinal strain abnormalities in acute myocardial infarction: beyond the right coronary artery. *EuroEcho-Imaging*, Dec. 6, 2017.

- Pickure, Z., Kalinin, A., Pickurs, K., Lejnieks, A., Erts, R., Zakharova, E., Kasprzak, J. D. Right ventricular involvement in acute myocardial infarction of different localisation - detection by three-dimensional echocardiography. *EuroEcho-Imaging*, Dec. 9, 2017.

- Pickure, Z, Kalinin, A., Pickur, K., Zaharova, E., Lejnieks, A. 2017. Determination of the right ventricular ejection fraction in patients with

acute myocardial infarction using three-dimensional echocardiography [Определение фракции выброса правого желудочка у больных с острым инфарктом миокарда с помощью трехмерной эхокардиографии]. *Abstracts of the reports of the VIII International Congress "Cardiology at the crossroads of sciences"*, Tyumen, Russia, pp. 209–210.

- Pickure, Z., Kalinin, A., Pickur, K., Zakharova, E., Lejnieks, A. 2017. Evaluation of the longitudinal strain of the right ventricle in patients with acute myocardial infarction [Оценка продольной деформации правого желудочка у больных с острым инфарктом миокарда. Тезисы докладов VIII Международного конгресса «Кардиология на перекрестке наук».] *Abstracts of the reports of the VIII International Congress "Cardiology at the crossroads of sciences",* Tyumen, Russia, pp. 210–211.

3. Thesis in local conferences in Latvia:

- Pičkure, Ž., Kalinin, A., Kalniņš, A., Erts, R., Lejnieks, A. 2017. Determination of the right ventricular ejection fraction in patients with acute myocardial infarction using three-dimensional echocardiography. *RSU Scientific Conference*, Riga, p.35.

- Pičkure, Ž., Kalinins, A., Kalniņš, A., Erts, R., Lejnieks, A. 2017. Echocardiographic evaluation of longitudinal strain of the right ventricle in patients with acute myocardial infarction. *RSU Scientific Conference,* Riga, p.39.

- Pičkure, Ž., Kalinins, A., Lejnieks, A. 2015. Evaluation of the right ventricle systolic function using three-dimensional echocardiography. *RSU Scientific Conference*, Riga, p.83.

- Pičkure, Ž. Acute myocardial infarction. How to look at the right ventricle. *Knowledge for Use in Practice*, RSU, Apr. 4, 2019.

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