Real-time 3D echocardiography and tissue Doppler echocardiography in the assessment of right ventricle systolic function in patients with right ventricular myocardial infarction

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Aims
Knowledge of right ventricular (RV) function may be crucial in diagnosis and proper management of patients with suspected acute myocardial infarction (MI). Standard echocardiography has several drawbacks, tissue Doppler echocardiography (TDE) and real-time three-dimensional echocardiography (RT3DE) could be used for evaluation of the RV performance. The purpose of this study was to assess RV function in patients with inferior wall acute MI with both TDE and RT3DE.

Methods and results
Study group consisted of 85 patients in the acute phase of MI complicated with right ventricular myocardial infarction (RVMI) admitted for primary coronary intervention (PCI). Control group was formed from 85 patients with isolated inferior wall infarction matched to RVMI group. Before PCI all of the patients underwent echocardiographic examination with the assessment of RV function by TDE and RT3DE. TDE derived peak systolic velocity $S'_T$, peak early diastolic velocity $E'_T$ of RV free wall differed significantly between groups. Three-dimensional reconstruction and calculation of the right ventricular ejection fraction (RVEF) showed that in RVMI patients RVEF values were lower than in the controls ($41.7 \pm 6.03$ vs. $52.7 \pm 2.3\%$, respectively). RVEF < 51% allowed diagnosis of RVMI with sensitivity 91% and specificity 80%.

Conclusion
Three-dimensional echocardiography is a useful method in the estimation of RVEF, however does not perform better than TDE $S'_T$ in diagnosis of RVMI. Threshold of RVEF < 51% may be used for diagnosing of RVMI with adequate sensitivity and specificity.

Keywords
Right ventricular infarction • Three-dimensional echocardiography

Introduction
The assessment of ventricular systolic function is one of the most crucial tasks of echocardiography. Evaluation of the right ventricle (RV) function has a very significant role in prognosing the outcome of patients with myocardial infarction (MI), especially in those with right ventricular myocardial infarction (RVMI). Imaging of the RV is difficult owing to its complex crescent-shaped structure, heavy trabeculation, and retrosternal location.1 Conventional two-dimensional echocardiography does not provide exact images of this chamber. Therefore, tissue Doppler echocardiography (TDE) and especially real-time three-dimensional echocardiography (RT3DE) are gaining importance in the assessment of RV performance. They become more commonly used owing to their accuracy, feasibility, and reliability. The accuracy and reliability of these methods may be compared with the Cardiac Magnetic Resonance (CMR) imaging,2-5 ventriculography, and thermodilution,6 but they are far more accessible, safer and easier to perform.
The aim of this study was to assess and compare usefulness of TDE and RT3DE in the evaluation of RV function in patients with inferior wall acute MI complicated with RVMI.

Methods
Subjects for this study were selected from patients admitted to the Second Chair and Department of Cardiology of Medical University of Lodz during years 2007–09. All patients underwent standard echocardiography, and then were referred for coronary angiography followed by coronary angioplasty (PCI). The inclusion criteria were as follows: acute coronary syndrome (STEMI—ST segment elevation MI of inferior wall) with pain onset of no more than 12 h before admission, elevated cardiac biomarkers levels (Troponin I and creatine phosphokinase), specific to inferior wall infarction (IWMI) changes in ECG—ST segment elevation in II, III, and aVF. Diagnosis of RVMI was made with criteria recommended by The Task Force on the Management of Acute Myocardial Infarction of the European Society of Cardiology in 2003 when in patients with IWMI ST segment elevation ≥0.1 mV in the right precordial leads, particularly V4R, and tricuspid annular plane systolic excursion (TAPSE) <20 mm was found.

Exclusion criteria were previous hospitalization with history of ACS, presence of significant valvular heart disease, pulmonary hypertension, chronic obstructive pulmonary disease, myocardial hypertrophy, venous thromboembolism, left or right bundle branch block, and atrial fibrillation. Patients, who underwent unsuccessful PTCA and those with coronary vessels anomalies, were also excluded. After taking into consideration inclusion and exclusion criteria we qualified for the study 94 patients with RVMI. Patients with poor quality of acoustic window in whom assessment of RV volumes with three dimensional echocardiography was impossible to obtain were excluded from the study. Finally, study group was composed of 85 patients with RVMI in whom coronaryography revealed proximal occlusion of right coronary artery (RCA). Control group consisted of 85 patients with isolated IWMI matched by sex, age, left ventricle ejection fraction, risk factors, and therapeutic regimen to RVMI group.

Authors declare that this study complies with the Declaration of Helsinki. The research protocol is approved by the locally appointed ethics committee and the informed consent of the subjects was obtained.

On admission to the Hospital before PCI, all of the patients underwent echocardiographic examination, which was performed with the patient lying in the left decubitus position. All measurements were performed by single experienced ultrasonographist in accordance with the guidelines established by the American Society of Echocardiography.8 Transthoracic two-dimensional echocardiography was performed using General Electric Vivid 7 system with phased array transducer. TAPSE was measured using M-Mode imaging. Peak systolic (S′), and diastolic velocities (early E′ and late velocity A′) of RV free wall basal segment were registered with use of TDE. Image acquisition was performed in parasternal long-axis projection. S′ was defined as the maximum speed of the tricuspid valve annulus towards apex of the heart. Filter level was chosen to eliminate the Doppler signals from blood flow through the tricuspid valve. From tissue Doppler examination of RV time intervals, such as the duration of systolic excursion time (ET), duration of isovolumetric contraction time (ICT), and isovolumetric relaxation time (IRT). Registration of three-dimensional images was made with use of three-dimensional real-time reconstruction designated transducer—J 3V. Images of the RV were taken in the apical four-chamber projection. In order to obtain images of the highest quality, echocardiographic transducer was located laterally in relation to standard four-chamber apical position. Imaging axis has been twisted in order to focus the ultrasound beam towards the RV outflow tract. ECG gating was used and patients were ordered to hold their breath during image acquisition.

The recorded data were sent to the workstation, working under the control of TomTec Imaging Systems GmbH RV-Function 4D(1) software. Before analysis, it was necessary to determine the centre of mitral and tricuspid valves. Then the imaging axis was moved towards the left ventricular apex, to select the centre of the apex. In the next stages of the analysis, the contours of the RV in systole and diastole were draw. Previously marked contours were verified and automated analysis of RV volumes was done, with subsequent calculation of right ventricular ejection fraction (RVEF).

As diameter and volume of RV could have influence on RV myocardial systolic velocities a parameter, which described normalized values of RV systolic performance, was calculated—RVnorm = S′/end-diastolic volume (EDV) × 100.

The result of each measured parameter was presented as an average value calculated from three consecutive measurements. All statistical analyses were made by using program Statistica 6.0 PL (Stat Soft, Inc. Tulsa, OK, USA).

Results
Groups characteristics
Group 1 (RVMI) consisted of 85 patients with infarction of inferior wall and RVMI. Average age in this group was 58 ± 8 years. There were 34 (40%) women and 51 men among patients. Twenty-three (27%) of them were smokers, 15 (17.5%) were treated for arterial hypertension, and 12 (14%) had diabetes.

Group 2 (IWMI) comprised of 85 patients with average age of 58 ± 9 years. Thirty-five (41%) of them were women, 27 (31.5%) of them were smokers, 16 (19%) were treated for arterial hypertension, and 13 (15%) had diabetes. Systolic and diastolic blood pressure was higher in this group when compared with the first one. Detailed characteristics of these groups are presented in Tables 1 and 2.

Tissue Doppler echocardiography
In the Group 1, systolic velocity S′ and early diastolic velocity of the tricuspid valve annulus were significantly lower in comparison with the patients from Group 2. Late diastolic velocity A′ did not differ significantly between groups. The analysis of cardiac cycle subperiods showed that in the Group 1 patients’ duration of ICT was significantly longer than in the inferior wall MI patients, while IRT and time of systolic excursion E′ were similar. Detailed results are presented in the Table 3. In patients with RVMI S′ strictly depended on the duration of ischaemia (Figure 1). Comparing with left ventricle, RV isovolumic contraction time is shorter because RV systolic pressure rapidly exceeds the low pulmonary artery diastolic pressure. However, in case of significant RV damage ICT increases. We observed significant difference in ICT between both patients’ groups (Figure 2). Moreover in analysis of ICT behaviour, it was found that after 3 h of pain duration ICT raised in much more steep way when compared with first 180 min of RV infarction (Figure 2).

We also assessed usefulness of TDE in diagnostic of RVMI. For this purpose, both test groups were combined and then cut-off
value of $S'_T$ based on receiver operating characteristic curve (ROC) was set.

During analysis of the $S'_T$ value, $S'_T = 11.9 \text{ cm/s}$ was considered as the threshold which allowed the identification of RVMI with a sensitivity of 86% and specificity of 98%. The positive predictive value was 90% and negative predictive value 87% (area under the ROC curve 0.95) (Figure 3).

**Right ventricular ejection fraction assessment with use of three-dimensional echocardiography**

After a three-dimensional reconstruction and calculation of the RVEF, we observed significant differences between both groups. In patients from the Group 1, RVEF values were significantly lower (41.7 ± 6.03 vs. 52.7 ± 2.3% $P < 0.01$). Results showed increased diastolic and systolic volume of the RV and reduced RVEF among patients from Group 1 (Table 4). After analysis, it was discovered that the time to reperfusion was independent parameter, which significantly determined RVEF (Figure 4).

In patients with RVMI with the increase of reperfusion time significantly raised RV EDV and ESV, these findings were not observed in patients with inferior wall MI (Figure 5).

In the next step, threshold value of RVEF that can be useful in diagnosing patients with RVMI was calculated. For this purpose, both groups were combined and then calculation of sensitivity and specificity was performed, then ROC curve was plotted (Figure 3). RVEF < 51% was set as a threshold value that allows identification of RV systolic dysfunction accompanying RVMI. Sensitivity of the test was 91%, specificity 80%, positive predictive value 81%, and negative predictive value 89%. Area under curve ROC = 0.95. Also strong correlation between $S'_T$ velocity and RVEF was found (Figure 6).

$RV_{\text{norm}}$ which should describe normalized values of RV function was significantly higher in patients with isolated inferior wall MI when compared with those with concomitant RVMI (15.1 ± 2.1 vs. 10.8 ± 2.7). In diagnosis of RVMI, threshold value of...
RVnorm = 14.8 was characterized with sensitivity 83%, specificity 87%, positive predictive value 86 and negative predictive value of 87. ROC area under curve was 0.93 (Figure 3).

Discussion

In our study, we demonstrated that three-dimensional echocardiography accompanied by TDE could be used for the evaluation of RV function and assessment of RV ejection fraction with diagnosis of RV infarction.

In order to diagnose RV dysfunction various echocardiographic techniques are used. The most commonly used method is TDE with measurement of RV free wall systolic velocity.9 – 12 TDE is also used in the detection of RV dysfunction with high sensitivity and specificity.13 – 16 It was proved that RVEF calculated with the use of magnetic resonance imaging closely correlates with the peak systolic speed of the tricuspid valve annulus. In this study, we used that parameter (S′T) as marker of RV systolic function. Similar to previous studies13 – 17, we found that in patients with RVMI S′T velocity is significantly reduced when compared with patients with MI limited to left ventricular inferior wall. In our study, patients with RVMI presented S′T values lower than 11 cm/s.

This threshold is described in literature as a borderline value that allows the identification of RV systolic dysfunction in the course of infarction.18 However, in a small percentage of patients in whom angioplasty was performed during the first hour from pain onset, S′T values were the highest, sometimes exceeding the value of 11 cm/s. The RV diastolic dysfunction may be diagnosed when value of early diastolic velocity (E′T) of the RV is reduced. RV diastolic dysfunction is one of the mechanisms leading to several negative consequences in the course of RVMI. Reduced value of E′T was also reported by other authors.11,14,19 These results demonstrate that impaired compliance of RV myocardium, in combination with reduced ventricular contractility may contribute to more frequent cardiogenic shock development in these patients.

Three-dimensional echocardiography in assessing right ventricular ejection fraction

In the available literature, there are studies comparing the accuracy of the three-dimensional echocardiography imaging and magnetic resonance imaging (CMR) in assessing the volume of the RV.13,20 – 22 These articles have shown that results of RVEF calculated by RT3DE are very close to that obtained with the CMR23 – 29 and the accuracy of this method is significantly higher than two-dimensional echocardiography.30 Despite of previously described usefulness of this new technique in the assessment of RV systolic function, it is rarely used in clinical practice. This situation may be due to the fact that systems capable of RT3DE are not widely available.31,32 In this study, we used an external workstation to reconstruct the RV volume based on the received data. Our research was the first attempt to analyse RV function in patients with acute MI on the basis of echocardiographic three-dimensional imaging research technique. One of the most important observations from this study is analysis of RVEF assessed by three-dimensional reconstruction. The lowest values of the RVEF were observed in patients with the longest time to successful angioplasty. These observations are similar with previously published results, which found that RV systolic function in patients with prolonged time to recanalization of occluded artery is significantly reduced.30 In further analysis of collected data, RVEF < 51% was set as a threshold value that allows identification of RV systolic dysfunction accompanying RVMI. Sensitivity of the test was 91% and specificity 80%.
Then the question should be asked whether we should use $S_T$ or RVEF or may be both parameters to detect RVMI. TDE is easier and faster to perform than three-dimensional reconstruction of RV and it also requires less advanced equipment. Despite of encouraging results, one should remember the known limitations of TDI-like angle dependency or assessment of only long-axis function. Because TDI interrogates motion at a single point in the myocardium with reference to a point outside the heart (the transducer), it is influenced by translational motion, velocity gradients between base and apex of the RV and tethering (normal apical segments pull an abnormal basal segment towards the apex). Moreover, single-point interrogation does not fully capture true myocardial mechanics. The angle of beam does influence timing of TDI events when angles exceed 20°.\(^{33}\) Despite its undoubted advantages, the three-dimensional echocardiography has also some drawbacks. First is the requirement of modern echocardiographic systems and because of that the cost of study increases. Secondly, the examination should be performed by an experienced echocardiographist, who was previously trained in the three-dimensional image acquisition. Another limitation is the necessity of sending three-dimensional images to the workstation and manual data analysis. This results in a longer time needed to obtain RVEF value. However, registration of the requested data takes about 5–10 min (patients with a difficult ‘window’ in echocardiography examination) and does not significantly prolong testing time. Calculation of RVEF was made parallel with angioplasty. It should be noted that we had to exclude 10% of preselected patients with RV infarction because of poor echocardiographic conditions. However, thanks to this effort we have data on RV volumes and RV ejection fraction. As described

![Figure 3 ROC curve in diagnostic of RVMI with the use of RVEF, $S_T$ and RVnorm (TPF, sensitivity; FPF- 1, specificity).](image)

**Table 4** RVEF calculated with three-dimensional echocardiography

<table>
<thead>
<tr>
<th></th>
<th>Group 1</th>
<th>Group 2</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RVEF (%)</td>
<td>41.7 ± 6.03</td>
<td>52.7 ± 2.3</td>
<td>$&lt; 0.001$</td>
</tr>
<tr>
<td>EDV (mL)</td>
<td>85.5 ± 7</td>
<td>76.8 ± 5</td>
<td>$&lt; 0.001$</td>
</tr>
<tr>
<td>End-systolic volume (ESV) (mL)</td>
<td>49.9 ± 8</td>
<td>36.7 ± 9</td>
<td>$&lt; 0.001$</td>
</tr>
<tr>
<td>Ejection volume (mL)</td>
<td>35.6 ± 9</td>
<td>40.1 ± 8</td>
<td>$&lt; 0.001$</td>
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</tbody>
</table>
In this study, both TDE and RT3DE performed accurately in obtaining data on RV systolic function.

In patients with MI, contractile function of affected myocardial wall is diminished, what results in depressed wall motion velocities and subsequently lowered ejection fraction. As we found in three-dimensional examination, in patients with RVMI volume of the RV increased. Because RV geometry (size and volumes) has influence on displacement and velocity of RV wall, we used normalized parameter which incorporates both contractile function and RV volume—RVnorm = S'/EDV × 100. This parameter incorporated measurements from tissue Doppler (S') and three-dimensional echocardiography (RV EDV). Creation of ‘normalized’ parameter as RVnorm did not significantly increased the frequency of diagnosis of RV infarction. Sensitivity of this parameter was lower than S' and RVEF however specificity of RVnorm was higher than RVEF. Therefore, this parameter was not as good as RVEF and S' in detection of RV infarction. Presented data indicate that S', RVEF or RVnorm is better in prediction of outcome in patients with RV infarction.

Impact of time to reperfusion on right ventricle performance

Another important observation is a fact that both S', ICT and RVEF significantly correlated with the time from the onset of symptoms to successful reperfusion. These results are consistent with the results of studies describing the course of left ventricular myocardial infarction.34–37 In previous studies, it was proved that early recanalization of occluded coronaries by fibrinolysis or angioplasty (PCI) significantly improves the outcome and also preserves the normal function of the myocardium affected with infarction.34,38–40 Therefore, while analysing the values of S', we should take into consideration that situation in which the intervention has been taken before myocardial damage could be detected by TDE. This phenomenon has been observed in three patients (3.5%) of the analysed group. It should be noted that in each of

Figure 4 Impact of the time to reperfusion on the RVEF.

Figure 5 Impact of the time to reperfusion on the RV EDV and ESV in patients with RVMI compared with patients with isolated IWMI.
these cases, we observed characteristic ECG changes in leads from above the RV. However in this small group of patients, we observed significant reduction of RV ejection fraction calculated from three-dimensional echocardiography with values lower than 45% what clearly indicated on RV dysfunction. In this study, we demonstrated that the degree of RV systolic function impairment depends on the duration of ischaemia in a manner similar to that observed in left ventricular infarctions.41,42

Analysing the impact of the duration of pain to the degree of RV damage, we found strong relationship between time to reperfusion and measured parameters—$S_T$ and RVEF. Collected data indicate that RV damage develops in a similar way to that in the left ventricle. Prolonged time needed to take effective interventions leads to the more severe damage, despite differences in blood supply, load and energy expenditure of RV. In this study, we demonstrated that reperfusion time over 3 h causes significantly greater impairment of RV systolic function.35 These data indicate that primary angioplasty should be performed as fast as possible because shorter time to coronary artery recanalization is very important for salvage of the RV systolic function.

**Limitations**

RVMI was diagnosed in patients with ST segment changes in right precordial leads especially V4R. This method of the diagnosis of RVMI was recommended by The Task Force on the Management of Acute Myocardial Infarction of the European Society of Cardiology in 2003, therefore was used in our study. Diagnosis of RV infarction based only on ECG changes has several limitations, mainly in terms of limited specificity and high dependence from a delay of examination from the onset of symptoms. In order to overcome this limitation, all diagnostic procedures were performed within 12 h from pain onset. To improve specificity, diagnosis of RV infarction and RV systolic dysfunction was confirmed with two-dimensional echocardiographic measurement of TAPSE. It should be stated that the golden standard for assessing RVEF is CMR; however, this method cannot be used in acute phase of infarction. In this study, we used RT3DE, which gives us accurate and reliable values of ejection fraction very close to that obtained by means of CMR, what was shown in literature.

In this study, we analysed results only from strictly selected patients. In further trials, more varied patients with diagnosed RVMI should be enrolled in the study to ascertain clinical value of RVEF in assessing outcome in all patients.

**Conclusion**

Three-dimensional echocardiography is a useful method in the estimation of RVEF, however, does not perform better than TDE $S_T$ in diagnosis of RVMI. Threshold of RVEF < 51% may be used for diagnosing of RVMI with adequate sensitivity and specificity.

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