Improving risk stratification after acute myocardial infarction : focus on emerging applications of echocardiography

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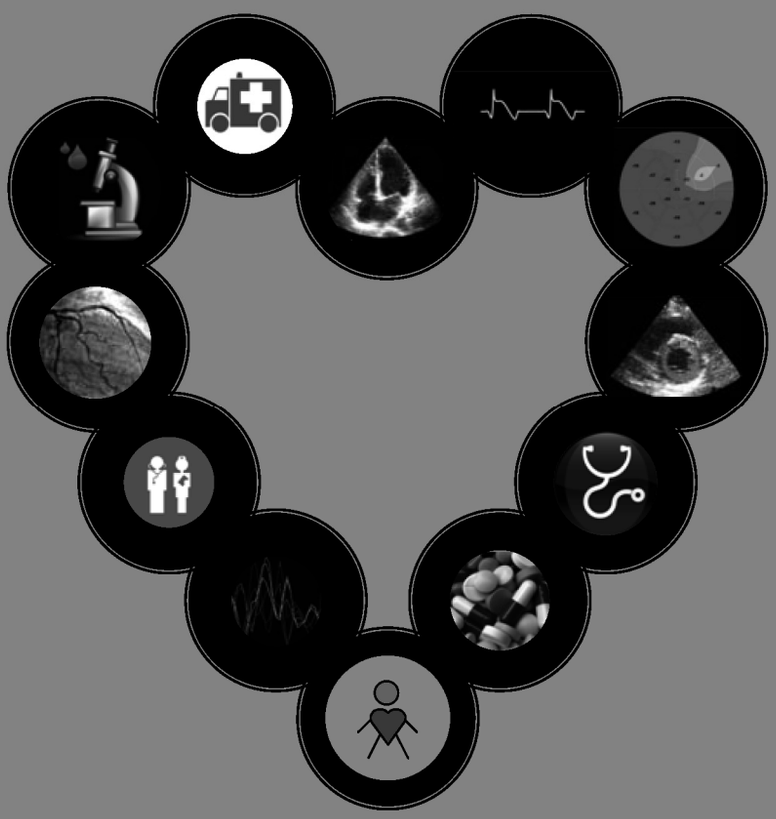

Chapter 9

Prognostic Value of Right Ventricular Function in Patients after Acute Myocardial Infarction Treated with Primary Percutaneous Coronary Intervention

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Abstract

Objectives

Data on the association between right ventricular (RV) function and adverse events after acute myocardial infarction (AMI) are scarce. The purpose of the current study was to evaluate the relation between RV function and adverse events, in patients treated with primary percutaneous coronary intervention (PCI) for AMI.

Methods and results

Consecutive patients admitted with AMI treated with primary PCI underwent echocardiography within 48 hours of admission to assess left ventricular and RV function. RV function was quantified with RV fractional area change (RVFAC), tricuspid annular plane systolic excursion (TAPSE) and RV strain. The endpoint was defined as a composite of all-cause mortality, reinfarction and hospitalization for heart failure. All patients (n = 621) were followed prospectively and during a mean follow-up of 24 months, 86 patients reached the composite endpoint. RVFAC, TAPSE and RV strain were all univariable predictors of worse outcome. After multivariable analysis, only RVFAC (HR 0.96, 95%CI 0.92–0.99) and RV strain (HR 1.08, 95%CI 1.03–1.13) independently predicted the composite endpoint. In addition, RV strain provided incremental value to clinical information, infarct characteristics, left ventricular function and RVFAC.

Conclusions

RV function provides strong prognostic information in patients treated with primary PCI for AMI.

Introduction

The prognosis of patients after acute myocardial infarction (AMI) is determined by the interaction of a large number of factors. Besides the importance of clinical parameters, several studies have described the use of two-dimensional (2D) echocardiography for the identification of patients who are at risk of adverse outcome.[1] These investigations revealed that the presence of left ventricular (LV) dysfunction, on 2D-echocardiography shortly post-AMI, is one of the most important prognostic parameters.[2 3] Therefore, noninvasive assessment of LV function has become essential for post-AMI risk stratification. The relevance of right ventricular (RV) function, on the other hand, is poorly defined in post-AMI patients. The involvement of the RV during inferior AMI has been defined as a strong predictor of major complications and in-hospital mortality.[4 5] Some evidence is available that RV dysfunction is associated with an adverse prognosis in post-AMI patients with moderate to severe LV dysfunction.[6 7] In patients who undergo primary percutaneous coronary intervention (PCI), however, the degree of LV dysfunction is generally mild and the clinical relevance of RV dysfunction in that currently growing population of post-AMI patients is unknown. Therefore, the aim of the current study was to investigate the relation between RV function and adverse events, in post-AMI patients treated with primary PCI. In addition to traditional measurements that are recommended to quantify RV function with 2D-echocardiography, RV strain was assessed. This novel technique enables direct quantification of myocardial deformation and is a sensitive tool to detect RV dysfunction.[8-11]

Methods

Patient selection and study protocol

Since February 2004, consecutive patients admitted with AMI, treated with primary PCI were included in an ongoing registry. All patients were treated according to the institutional AMI protocol, which is driven by the most recent guidelines.[1] This protocol, designed to improve care around AMI, includes structurized medical therapy and outpatient follow-up, as described previously.[12] In addition, 2D-echocardiography is performed within 48 hours of admission. This echocardiogram was used to assess LV and RV function. All patients were followed prospectively and the occurrence of adverse events was noted. Patients of

whom more than 6 months follow-up data were lacking, were considered as lost to follow-up, and excluded from further analysis.

Echocardiography

Images were obtained with patients in the left lateral decubitus position using a commercially available system (Vivid 7, General Electric-Vingmed, Horton, Norway). Data acquisition was performed at a depth of 16cm in parasternal and apical views using a 3.5-MHz transducer. Analysis was performed offline using dedicated software (EchoPac version 108.1.5, General Electric-Vingmed). The reference limits of all echocardiographic parameters were defined according to the American Society of Echocardiography's Guidelines.[13] The LV end-systolic volume (LVESV), end-diastolic volume (LVEDV) were assessed and LV ejection fraction (LVEF) was calculated using the biplane Simpson's method.[13] In addition, the LV was divided into 16 segments and each segment was analyzed individually and scored based on its motion and systolic thickening (1 = normokinesis, 2 = hypokinesis, 3 = akinesis, 4 = dyskinesis). Subsequently, wall motion score index (WMSI) was calculated as the sum of the segment scores divided by the number of segments scored.[13] Left atrial (LA) size was quantified by calculating the volume according to the ellipsoid model.[13] Severity of mitral regurgitation (MR) was graded semiquantitatively from the jet area of color-flow Doppler data and by measuring the width of the vena contracta. MR was characterized as: mild=jet area/LA area < 20% and vena contracta width < 0.3 cm, moderate=jet area/LA area 20% to 40% and vena contracta width 0.3–0.69 cm, and severe=jet area/LA area > 40% and vena contracta width ≥ 0.7 cm.[14] Tricuspid regurgitation (TR) severity was graded based on jet/right atrial area ratio. When the jet area occupied < 10% of the right atrial area, TR was graded as trivial, when it occupied 10% to < 20% as mild, when it occupied 20% to < 33% as moderate, and when it occupied ≥ 33% as severe.[15] In addition, the diameter of inferior vena cava and its respiratory variation were measured 1.0–2.0 cm from the junction with the right atrium in the subcostal view, as recommended by the guidelines.[13] Peak early (E) and late (A) diastolic velocities and deceleration time (DT) were measured. The E/E'-ratio was obtained by dividing E by E', which was measured using color-coded tissue Doppler imaging at the septal side of the mitral annulus in the apical 4-chamber view.[16-18]

Right ventricular function analysis

RV fractional area change (RVFAC) was analyzed by tracing the RV end-diastolic area (RVDA) and end-systolic area (RVSA) in the apical 4-chamber view using the formula: (RVDA−RVSA)/RVDA×100.[13] Tricuspid annular plane systolic excursion (TAPSE) was measured in the RV free wall. In the 4-chamber view, the M-mode cursor was placed through the tricuspid annulus in such a way that the annulus moved along the M-mode cursor and the total displacement of the RV base from end-diastole to end-systole was measured.[19] Peak systolic longitudinal strain of the RV free wall was measured in the 4-chamber view using speckle-tracking analysis.[20] This novel software analyzes motion by tracking frame-to-frame movement of natural acoustic markers in 2 dimensions. All images were recorded with a frame rate of > 40fps for reliable analysis. The RV endocardial border was manually traced at end-systole and the automatically created region of interest was adjusted to the thickness of the myocardium. Peak systolic longitudinal strain was determined in the 3 segments of the RV free wall (basal, mid and apical) and RV strain was calculated as the mean value of all segments. Segments were discarded if tracking was of poor quality. Strain analysis was feasible in 85% of segments.

Statistical analysis

Continuous data are presented as mean±standard deviation and categorical data are presented as frequencies and percentages. Differences in characteristics between patient groups were evaluated using the unpaired Student's *t*-test and chi-square test.

The primary aim was to assess the association between RV function and adverse events after adjusting for clinical and echocardiographic covariates. Separate multivariable models were constructed for RVFAC, TAPSE and RV strain using Cox proportional hazards analysis to evaluate the individual prognostic importance of the different RV function measurements. Selection of parameters for consideration for entry in the multivariable models was based both on clinical judgment and univariable statistical significance. Based on these considerations, adjustments in the multivariable models were made for age, Killip class ≥ 2, right coronary artery (RCA) as culprit vessel, multivessel disease, peak cardiac troponin T (cTnT) level, LVEF, WMSI, E/E'-ratio and moderate or severe MR. Peak creatine phosphokinase level and LVESV were not included in multivariable analyses to

avoid co-linearity with peak cTnT level and LVEF. In addition, multiple variable analysis was performed for all events individually. Nonfatal reinfarction was defined based on criteria of typical chest pain, elevated cardiac enzyme levels, and typical changes on the electrocardiogram.[21] Hospitalization for heart failure (HF) was defined as hospitalization for new onset or worsening HF. As only a small number of 29 patients reached the endpoint of HF, no further subdivision was made for the cause of HF. To further investigate the clinical relevance of RV dysfunction, the population was stratified into 2 groups according to RV function. For RVFAC and TAPSE, cut-offs were defined according to the guidelines; 32% and 1.5 cm, respectively.[13] The normal value of RV strain has been reported to be -29.3±3.6%.[22] Patients were therefore divided according to the mean value plus 2SDs, which is the lower limit of normal RV strain (-22.1%). Event rates were plotted in Kaplan-Meier curves for the composite endpoint and the study population divided by the previously mentioned cut-offs, and groups were compared using the log-rank test. The date of last contact for patients without events was used in Kaplan-Meier analysis. Finally, univariable and multivariable Cox proportional hazards analyses were performed for RVFAC, TAPSE and RV strain, dichotomized by the cut-offs. The incremental value of RV function in addition to known risk factors for adverse outcome (age, Killip class ≥ 2, RCA as culprit vessel, multivessel disease, peak cTnT level, LVEF, WMSI, E/E'-ratio and moderate or severe MR), was established. For this purpose, those characteristics were entered in the Cox proportional hazard model in a stepwise fashion. Subsequently, RVFAC and RV strain were entered individually. In addition, RV strain was entered into the model of RVFAC, to test further incremental value. Global chi-square values including significance levels were calculated. All statistical tests were two-sided, and a *P* value <0.05 was considered statistically significant.

Results

Patient characteristics and follow-up

A total of 682 patients were included. Nine (1.3%) patients died before echocardiographic assessment could be performed, and in 22 (3.2%) patients echocardiographic assessment was not available within 48 hours of admission due to logistic reasons. Thirty patients (4.4%) were lost to follow-up and were excluded from further analysis. The study

population consisted of the remaining 621 consecutive patients admitted with AMI treated with primary PCI. Tables 1 and 2 summarize the clinical and echocardiographic characteristics of the population. Mean age was 60 ± 12 years and most patients were men (78%). Mean LVEF, RVFAC, TAPSE and RV strain were 45 ± 8%, 37 ± 9% and 1.7 ± 0.2 cm and -22 ± 7%, respectively. Fifty-seven patients (10%) presented with congestive HF defined as Killip class ≥ 2. Patients with congestive HF had significantly lower TAPSE (1.6 ± 0.2 cm vs. 1.7 ± 0.2 cm, p = 0.01) and RV strain (-19 ± 6% vs. -22 ± 7%, p = 0.02). No differences were observed in RVFAC and patients with and without congestive HF (37 ± 10% vs. 37 ± 9%, p = 0.71). The RCA was the culprit vessel in 217 patients (35%). No differences in RVFAC (36 ± 9% vs. 38 ± 9%, p = 0.07), TAPSE (1.7 ± 0.2 cm vs. 1.7 ± 0.2 cm, p = 0.28) and RV strain (-21 ± 7% vs. -22 ± 7%, p = 0.38) were observed in patients with and without inferior AMI. LV dysfunction (defined as LVEF < 40%) was observed in 151 patients (24%). When comparing RV function in patients with and without LV dysfunction, no significant differences were observed in RVFAC (37 ± 9% vs. 38 ± 9%, p = 0.31) and RV strain (-21 ± 7% vs. -22 ± 7%, p = 0.09). However, TAPSE was significantly lower in patients with LV dysfunction compared to patients without LV dysfunction (1.6 ± 0.2 cm vs. 1.7 ± 0.2 cm, p = 0.02). TAPSE was the only RV function measurement that differed significantly in patients with multivessel disease compared to patients without multivessel disease (1.6 ± 0.2 cm vs. 1.7 ± 0.2, p = 0.03). During a mean follow-up of 24 ± 15 months, 86 patients (14%) reached the composite endpoint: 51 patients died (8%), 16 patients (3%) had a nonfatal reinfarction and 29 patients (5%) were hospitalized for HF. Differences in clinical and echocardiographic characteristics between patients who reached the composite endpoint and patients who remained event-free are shown in Tables 1 and 2.

Right ventricular function and association with outcome

Table 3 shows the significant univariable predictors of the composite endpoint. In addition to clinical characteristics and echocardiographic measurements of LV function, RV function significantly predicted worse outcome. RVFAC, TAPSE and RV strain were univariable predictors of the composite endpoint. After adjusting RVFAC, TAPSE and RV strain for other variables that predicted adverse outcome, RVFAC and RV strain

independently predicted the occurrence of the composite endpoint (Tables 4 and 5). However, TAPSE did not remain significant in the multiple variable analysis (HR 0.88, 95%CI 0.16–4.81, p = 0.88).

Table 1.Baseline clinical characteristics

	All Patients (N = 621)	*Event (N = 86)*	*Event-free (N = 535)*	*P*
Age (years)	60 ± 12	65 ± 14	60 ± 11	0.001
Male gender	486 (78%)	67 (78%)	419 (78%)	0.93
Killip class ≥ 2	57 (10%)	26 (33%)	31 (6%)	<0.001
Current smoking	313 (51%)	42 (49%)	271 (51%)	0.83
Diabetes	61 (10%)	14 (16%)	47 (9%)	0.03
Family history of CAD	253 (41%)	28 (33%)	225 (42%)	0.11
Hyperlipidemia	125 (20%)	19 (22%)	106 (20%)	0.64
Hypertension	190 (31%)	34 (40%)	156 (29%)	0.05
Prior myocardial infarction	45 (7%)	13 (15%)	32 (6%)	0.002
RCA culprit vessel	217 (35%)	22 (26%)	195 (36%)	0.05
Multivessel disease	300 (49%)	53 (63%)	247 (46%)	0.004
TIMI flow				0.11
0–1	5 (1%)	2 (2%)	3 (1%)	
2	28 (5%)	6 (7%)	22 (4%)	
3	588 (95%)	78 (91%)	510 (95%)	
Peak CPK level (U/l)	2508 ± 2116	4014 ± 3046	2266 ± 1815	<0.001
Peak cTnT level (µg/l)	7.1 ± 7.0	12.8 ± 11.3	6.2 ± 5.5	<0.001
Medication at 6-months follow-up				
ACE inhibitor/ARB	575 (98%)	55 (98%)	520 (98%)	0.82
Antiplatelets	588 (100%)	56 (100%)	532 (100%)	1.00
Beta-blocker	538 (92%)	52 (93%)	486 (91%)	0.70
Statin	578 (98%)	55 (98%)	523 (98%)	0.96

ACE: angiotensin-converting enzyme; ARB: angiotensin receptor blocker; CAD: coronary artery disease; CPK: creatine phosphokinase; cTnT: cardiac troponin T; RCA: right coronary artery; TIMI: thrombolysis in myocardial infarction.

In addition, analysis was performed for RVFAC, TAPSE and RV strain dichotomized according to normal and abnormal RV function with the above described cut-offs. Univariable analysis performed with the cut-offs demonstrated a HR of 2.22 (95%CI 1.39–

3.54, p = 0.001) for RVFAC. For TAPSE and RV strain, HRs of 4.00 (95%CI 2.45–6.53, p <0.001) and 3.43 (95%CI 1.87–6.29, p <0.001) were observed, demonstrating better discriminative power than RVFAC. Multiple variable analysis performed with the cut-offs showed smaller HRs of 1.97 (95%CI 1.10–3.55, p = 0.02) for RVFAC, 2.19 (95%CI 1.17–4.12, p = 0.02) for TAPSE and 2.18 (95%CI 1.10–4.29, p = 0.03) for RV strain.

Table 2. Baseline echocardiographic characteristics

	All Patients (N = 621)	*Event (N = 86)*	*Event-free (N = 535)*	*P*
LVESV (ml)	58 ± 22	67 ± 32	56 ± 20	0.006
LVEDV (ml)	105 ± 34	111 ± 43	104 ± 33	0.20
Left ventricular ejection fraction (%)	45 ± 8	41 ± 9	46 ± 8	<0.001
Wall motion score index	1.5 ± 0.3	1.7 ± 0.3	1.5 ± 0.3	<0.001
E/A-ratio	1.0 ± 0.4	1.0 ± 0.4	1.0 ± 0.4	0.10
Deceleration time (ms)	211 ± 74	199 ± 68	213 ± 75	0.11
E/E'-ratio	13 ± 6	15 ± 8	13 ± 5	0.05
Moderate or severe MR	44 (7%)	14 (17%)	30 (6%)	<0.001
Moderate or severe PR	2 (0.3%)	0 (0%)	2 (0.4%)	0.60
Moderate or severe TR	24 (4%)	5 (7%)	19 (4%)	0.17
Left atrial volume index (ml/m^2)	16 ± 6	17 ± 6	16 ± 6	0.29
Right ventricular diastolic area (cm^2)	15 ± 4	17 ± 5	15 ± 4	0.001
Right ventricular systolic area (cm^2)	10 ± 4	11 ± 4	9 ± 3	<0.001
RVFAC (%)	37 ± 9	33 ± 8	38 ± 9	<0.001
TAPSE	1.7 ± 0.2	1.6 ± 0.3	1.7 ± 0.2	0.07
Right ventricular strain (%)	-22 ± 7	-17 ± 7	-22 ± 7	<0.001

E/A: mitral inflow peak early velocity (E) / mitral inflow peak late velocity (A); E/E': mitral inflow peak early velocity (E) / mitral annular peak early velocity (E'); LVEDV: left ventricular end-diastolic volume; LVESV: left ventricular end-systolic volume; MR: mitral regurgitation; PR: pulmonary regurgitation; RVFAC: right ventricular fractional area change; TAPSE: tricuspid annular plane systolic excursion; TR: tricuspid regurgitation.

Kaplan-Meier curves for the cut-offs of RVFAC, TAPSE and RV strain and the composite endpoint are shown in Figure 1. The 4-year event rate in patients with RVFAC < 32% (n = 145) was 29% compared to 16% in patients with RVFAC ≥ 32% (n=454, p = 0.01). The

incidence of adverse events at 4 years was 45% in patients with TAPSE < 1.5 cm (n = 180) and 9% in patients with TAPSE ≥ 1.5 cm (n = 411, p <0.001). Patients divided in RV strain < -22.1% (n = 256) and ≥ -22.1% (n = 273) demonstrated a 4-year event rate at of 23% and 7%, respectively (p <0.001).

Table 3.Cox univariable predictors for the composite endpoint

	Hazard Ratio	***95%CI***	***P***
Age	1.05	1.02–1.07	<0.001
Killip class ≥ 2	5.05	3.15–8.08	<0.001
Prior myocardial infarction	2.57	1.42–4.65	0.002
Multivessel disease	1.88	1.21–2.92	0.005
Peak creatine phosphokinase level (per 100-U/l)	1.02	1.02–1.03	<0.001
Peak cardiac troponin T level	1.08	1.06–1.10	<0.001
Left ventricular end-systolic volume (per 5-ml)	1.07	1.03–1.12	0.001
Left ventricular ejection fraction	0.93	0.91–0.96	<0.001
Wall motion score index	10.95	5.02–23.90	<0.001
E/A-ratio	1.87	1.09–3.21	0.02
E/E'-ratio	1.05	1.02–1.09	0.003
Moderate or severe mitral regurgitation	3.38	1.90–6.02	<0.001
RVFAC	0.94	0.92–0.97	<0.001
RVFAC < 32%	2.22	1.39–3.54	0.001
TAPSE	0.10	0.03–0.38	0.001
TAPSE < 1.5 cm	4.00	2.45–6.53	<0.001
Right ventricular strain	1.10	1.06–1.14	<0.001
Right ventricular strain < -22.1%	3.43	1.87–6.29	<0.001

E/A: mitral inflow peak early velocity (E) / mitral inflow peak late velocity (A); E/E': mitral inflow peak early velocity (E) / mitral annular peak early velocity (E'); RVFAC: right ventricular fractional area change; TAPSE: tricuspid annular plane systolic excursion.

With the exception of nonfatal reinfarction, multiple variable analysis showed that RVFAC and RV strain were independent predictors of all events. RVFAC demonstrated HRs of 0.93 (95%CI 0.90–0.97, p = 0.001) and 0.94 (95% CI 0.89–0.99, p = 0.05), and RV strain HRs of 1.10 (95%CI 1.03–1.16, p = 0.003) and 1.16 (95%CI 1.07–1.26, p = 0.001) for all-cause mortality and hospitalization for HF, respectively. In addition, when early deaths (defined

as deaths occurring during index hospitalization) were excluded from multiple variable analysis, RVFAC and RV strain remained independent predictors of all-cause mortality (HR 0.93, 95%CI 0.89–0.97, p = 0.001 and HR 1.07, 95%CI 1.01–1.14, p = 0.04, respectively).

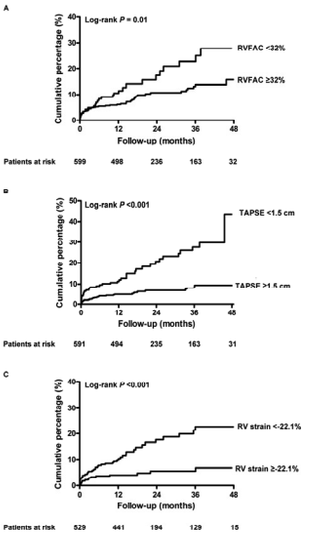

Figure 1.
Cumulative incidence of adverse events Patients stratified by right ventricular fractional area change (panel A), tricuspid annular plane systolic excursion (panel B) and right ventricle strain (panel C).

Table 4.Cox model with right ventricular fractional area change

	Hazard Ratio	*95%CI*	*P*
Killip class ≥ 2	2.99	1.51–5.92	0.002
Multivessel disease	1.92	1.04–3.56	0.04
Peak cardiac troponin T level	1.05	1.01–1.08	0.008
Left ventricular ejection fraction	0.95	0.91–0.99	0.01
Right ventricular fractional area change	0.96	0.92–0.99	0.007

Table 5.Cox multivariable model with right ventricular strain

	Hazard Ratio	*95%CI*	*P*
Killip class ≥ 2	3.18	1.58–6.41	0.001
Multivessel disease	2.03	1.07–3.86	0.03
Peak cardiac troponin T level	1.06	1.01–1.10	0.01
Left ventricular ejection fraction	0.95	0.91–0.99	0.01
Right ventricular strain	1.08	1.03–1.13	0.002

Incremental value of RV function in addition to traditional risk factors

Global chi-square scores were calculated to assess the incremental value of RV function. RV function quantified by RVFAC and RV strain provided incremental value to clinical information (age and Killip class ≥ 2), infarct characteristics (RCA as culprit vessel, multivessel disease and peak cTnT level) and LV systolic and diastolic function (LVEF, WMSI, E/E'-ratio and moderate or severe MR). In addition, RV strain was added to the RVFAC-model, which demonstrated to increase the predictive power of the model even further (Figure 2). Interestingly, TAPSE, did not have incremental value in addition to clinical information, infarct characteristics and LV function.

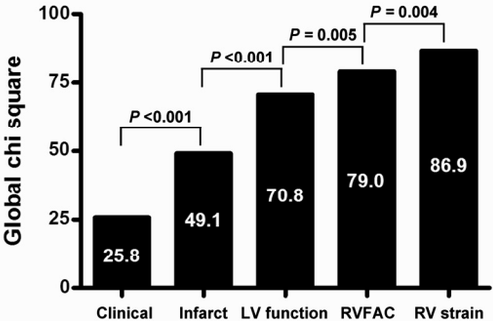

Figure 2.

Incremental value of right ventricular function The addition of right ventricular fractional area change and right ventricular strain provides incremental value to known risk factors for adverse outcome, related to clinical information, infarct characteristics and LV function.

Discussion

The major finding of the present study was that RVFAC, TAPSE and RV strain were strong predictors of the composite endpoint all-cause mortality, reinfarction and hospitalization for HF. In addition, the prognostic value of several traditional risk factors including Killip class, peak cardiac enzymes, multivessel disease and LV function, was again confirmed. After adjusting for known risk factors of adverse outcome after AMI, RVFAC (HR 0.96, 95%CI 0.92–0.99) and RV strain (HR 1.08, 95%CI 1.03–1.13) independently predicted the composite endpoint. In addition, the cut-off for RV strain at < -22.1% was associated with an adjusted HR of 2.18 for the occurrence of the composite end-point. Moreover, RV strain < -22.1% provided incremental value over clinical information, infarct characteristics, LV function and RVFAC for the prediction of adverse outcome in post-AMI patients. However, RV function failed to provide prognostic information for the prediction of nonfatal reinfarction individually.

Quantification of right ventricular function

Multiple methods have been described to quantify RV function with 2D-echocardiography. In clinical practice, qualitative assessment of RV function is usually performed, whether or not in combination with TAPSE or RVFAC.[13] Both measurements are simple to perform and associated with prognosis, particularly in patients with LV dysfunction after AMI.[6 7 19] In contrast to previous studies, the current study evaluated the importance of RV function in a large population of post-AMI patients, treated with primary PCI and relatively preserved LV function. In addition to TAPSE and RVFAC, we assessed RV strain. Although RVFAC, TAPSE, and RV strain are highly correlated, they measure different aspects of RV function. RVFAC is the most commonly used measurement to assess RV contractility. However, the measurement of RVFAC is experience-dependent and reproducibility is often poor. Therefore, RVFAC may not adequately reflect contractility. TAPSE is another frequently used measurement to assess RV function and reflects the longitudinal systolic excursion of the lateral tricuspid valve annulus, which may not fully reflect RV contractility. Strain is a novel technique that enables angle-independent measurement of active myocardial deformation. Previous studies indicated that subtle but clinically relevant decreases in ventricular function can be detected using strain and we therefore hypothesized that this may also apply for subtle changes in RV function post-AMI.[10 22-25] Peak RV longitudinal strain, which quantitates the maximal shortening in the RV free wall from apex to base, is likely to be a good estimator of RV function since 80% of the stroke volume is generated by longitudinal shortening of the RV free wall.[26] The results of the current study point out, for the first time, that reduced strain of the RV is a strong independent predictor of adverse events in post-AMI patients. RV strain, even after correction for clinical information, infarct characteristics and LV function, demonstrated to be of incremental value in addition to RVFAC. In addition, RV strain may detect RV dysfunction earlier than RVFAC as the Kaplan-Meier estimates showed earlier divergence for RV strain than RVFAC (Figure 1). TAPSE has been found to correlate with LVEF, which is an important predictor of adverse outcome in AMI patients and thus may explain the earlier separation on the graphs. This indicates that RV strain may be superior to traditional measures of RV function, for the prediction of adverse events after AMI.

Right ventricular function and outcome

In the past, the clinical importance of RV function has been underestimated. Although RV dysfunction was reported to recover to some extent after AMI, recently the value of RV function for the prediction of long-term outcome has been well recognized in patients with inferior AMI and LV dysfunction.[27 28] Mehta et al. showed in a meta-analysis that patients with RV involvement in inferior AMI were at increased risk of adverse events and demonstrated that RV involvement is not due to more extensive infarction of the LV.[29] In post-AMI patients with LV dysfunction, Zornoff et al. and Anavekar et al. confirmed that RV function is weakly correlated with LV function and demonstrated that RV function quantified with RVFAC was independently associated with an increased risk of mortality and HF.[6 7] In the current study, RV function was studied extensively with assessments currently used in clinical practice (TAPSE, RVFAC) and novel speckle-tracking derived strain. All measurements of the RV were related to adverse prognosis. After adjusting for other variables that predicted adverse outcome, RVFAC and RV strain independently predicted the occurrence of the composite endpoint (all-cause mortality, reinfarction and hospitalization for HF. TAPSE, on the other hand, was a strong univariate predictor of adverse events, but did not remain significant in multivariable analysis. The prognostic value of TAPSE in AMI patients was investigated by Samad et al. In 194 AMI patients TAPSE was an independent predictor of mortality after adjustment for LVEF and age.[19] However, in the GISSI-3 echo substudy which included 500 AMI patients, TAPSE was significantly associated with LVEF, which may explain why TAPSE did not provide incremental value to clinical information, infarct characteristics and LV function and why TAPSE was not an independent predictor of adverse outcome.[28]

Right ventricular strain

Although, strain was primarily developed for the measurement of LV deformation, previous reports have demonstrated the usefulness of RV strain in several populations to detect subtle changes in RV function.[9-11] Measurement of longitudinal strain of the RV is a reliable method for the assessment of RV function, since 80% of the stroke volume is generated by longitudinal shortening of the RV free wall.[30] To our best knowledge, this is the first study to examine the value of RV strain in post-AMI patients. RV strain provided

incremental value to traditional measurements of RV function and the quantification of RV strain is simple to perform and highly feasible.

Clinical implications

The results of the current study suggest that routine assessment of RV function should be implemented in the follow-up of AMI patients. RV strain measured early after AMI appeared to be superior to RVFAC and TAPSE for the risk stratification of AMI patients and could facilitate in the identification of patients who are at risk for adverse events.

Limitations

RV infarction complicates about 50 percent of inferior AMI. ST-segment elevations and Q-waves in the right precordial leads have shown to have a high diagnostic accuracy for RV infarctions. Unfortunately, in the present study right precordial leads were not applied during electrocardiography, however, no significant differences RV function parameters were observed in patients with and without inferior infarction. For the current study, the cut-off for RV strain was chosen at 2SDs from the normal RV strain in a group of 60 healthy subjects.[22] Normal limits of RV strain, derived from larger populations are currently lacking. Therefore, future research should aim at defining normal limits for RV strain and validating these cut-offs in relation to clinical endpoints. Although, RV function at baseline was a good predictor of outcome in AMI patients, the predictive value of RV function at different periods after AMI could not be addressed. Changes in RV function could occur in the first weeks after AMI and serial assessment of RV function would be interesting.

Conclusions

RV function provides strong prognostic information in AMI patients treated with primary PCI. RV strain is an independent predictor of all-cause mortality, reinfarction and hospitalization for HF. In addition, RV strain provides incremental value over clinical information, infarct characteristics, LV function and RVFAC. Quantitative assessment of RV function with RV strain may improve the risk stratification of patients after AMI.

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