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Right Ventricular Dysfunction Assessed by Cardiovascular Magnetic Resonance Imaging Predicts Poor Prognosis Late After Myocardial Infarction

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Objectives We sought to determine whether right ventricular (RV) function late after myocardial infarction (MI) impacts long-term prognosis.

Background Right ventricular failure predicts early mortality in patients with acute MI. The prognostic impact of RV function late after MI is not well defined. Accordingly, we determined whether RV dysfunction late after MI influences survival beyond traditional risk predictors, including patient age, left ventricular ejection fraction (LVEF), and infarct size.

Methods We studied 147 consecutive patients >30 days after MI (mean age of infarct 6.7 ± 8.2 years) who were referred for contrast-enhanced cardiovascular magnetic resonance imaging. We assessed hazard ratios for death by RV ejection fraction (RVEF). The association of RVEF with mortality adjusted to traditional risk predictors was examined by using multivariable Cox proportional hazards regression models.

Results A total of 26 deaths occurred during a median follow-up of 17 months (range 6 to 53 months). By univariable analysis, RVEF <40% was strongly associated with mortality (unadjusted hazard ratio 4.02; p = 0.0007). By multivariable analysis that adjusted for patient age, left ventricular (LV) infarct size, and LVEF, RVEF <40% remained a significant independent predictor of mortality (adjusted hazard ratio 2.86; p = 0.03).

Conclusions Right ventricular ejection fraction quantified late after MI is an important predictor of prognosis adjusted for patient age, LV infarct size, and LVEF. Accordingly, evaluation of RVEF using cardiovascular magnetic resonance imaging can improve risk-stratification and potentially refine patient management after MI. (J Am Coll Cardiol 2007;49:855–62) © 2007 by the American College of Cardiology Foundation

Patients with right ventricular (RV) dysfunction complicating acute myocardial infarction (MI) have a more than 4-fold increased risk for in-hospital mortality compared with those without RV dysfunction (1). Nevertheless, as a result of the low nutrient needs of its thin wall, elaborate collateral circulation, and direct endocardial diffusion of oxygen (2), RV dysfunction associated with acute MI has a high likelihood of recovery (3,4). Whether RV dysfunction late after MI also portends poor prognosis remains unclear. Although echocardiographic assessment of tricuspid annular excursion (5) and radionuclide technique (6) can both assess the RV in this setting, cardiac magnetic resonance imaging (CMR) can provide an improved quantitative and volumetric method of assessing RV size and function (7–9). Furthermore, late gadolinium-enhanced CMR is the current clinical standard for the assessment of left ventricular (LV) infarct size (10,11). Therefore, we tested the hypothesis that persistent RV dysfunction assessed by CMR late after MI increases long-term post-MI mortality, beyond established prognostic markers, including patient age, LV infarct size, and left ventricular ejection fraction (LVEF). We also sought to identify potential underlying mechanisms of RV dysfunction in this clinical setting.

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Methods

Study population. We enrolled 153 consecutive patients >30 days after acute MI who were referred for CMR for an assessment of their LV function and myocardial viability. The Brigham and Women's Hospital Institutional Review Board approved the study protocol, and informed consent

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Abbreviations and Acronyms

CMR = cardiovascular magnetic resonance imaging
EF = ejection fraction
ESVi = indexed end-systolic volume
HR = hazard ratio
LA = left atrium
LGE = late gadolinium enhancement
LV = left ventricular
LVEF = left ventricular ejection fraction
MI = myocardial infarction
RV = right ventricular
RVEF = right ventricular ejection fraction

was obtained from participants before their enrollment for follow-up of clinical events. In this study cohort, 78 patients (53%) were included in a prior report by Yan et al. (12). Myocardial infarction was confirmed by both documentation in clinical records and by presence of abnormal late gadolinium enhancement (LGE) on CMR consistent with MI. Exclusion criteria included any known clinical condition that might affect RV function independently of the MI, including severe chronic obstructive pulmonary disease and interstitial lung disease, pulmonary embolism, primary pulmonary hypertension, congenital heart disease, and moderate or severe mitral or tricuspid valve diseases (either stenosis or regurgitation). Patients with noncardiac diseases that carry increased risk of mortality including renal or hepatic failure, advanced respiratory disease, or cancer not in complete remission also were excluded. All patients provided a detailed history at the time of CMR. Family history of premature coronary artery disease was defined by a diagnosis of coronary artery disease in a first-degree male relative <45 years or female <55 years. A history of dyslipidemia was defined by fasting low-density lipoprotein cholesterol >100 mg/dl or current treatment with cholesterol-lowering medications. Hypertension was defined by persistent resting systolic blood pressure >140 mm Hg, diastolic blood pressure >90 mm Hg, or current treatment with blood pressure-lowering medications. Significant tobacco use was defined as >10 pack-years of cigarette smoking. Age of MI was defined by intervals: 3 to 6 months, 6 to 12 months, 12 to 24 months, or >24 months.

Electrocardiographic assessment. Twelve-lead electrocardiograms were obtained within 1 month of CMR and interpreted by a single experienced investigator blinded to CMR, coronary angiography, and clinical information. The presence of MI was determined according to the Minnesota Code (codes 1-1 through 1-2, except 1-2-8) (13,14). Underlying cardiac rhythm including heart block and left ventricular hypertrophy (Sokolow-Lyon index) were recorded as binary variables, whereas corrected QT and QRS interval were recorded as continuous variables.

Measure of ventricular systolic and diastolic functions and LV and RV infarct size by CMR. Imaging was performed with a 1.5-T scanner (Signa CV/i, General Electric Healthcare, Milwaukee, Wisconsin). All acquisitions were obtained with a 4- or 8-element cardiac phased-array surface coil with the patient supine. Electrocardiographic gating and breath holding in expiration were used as much as feasible. After rapid cardiac localization, cine imaging of cardiac function was performed by steady-state free precession gradient echo technique in 8–14 parallel short-axis (8-mm thickness, 0-mm skip) and 3 radial long-axis planes. Typical cine imaging parameters included TR/TE of 3.4/1.2 ms, flip angle 45°, NEX of 1, with in-plane spatial resolution of 1.6 × 2 mm, and views per segment of 12, providing a temporal resolution of approximately 40 ms. Late gadolinium-enhanced imaging of infarcted myocardium was acquired in matched short and long-axis planes using a previously validated T1-weighted segmented inversion-recovery pulse sequence (TR/TE 4.8/1.3 ms, inversion time 200 to 300 ms to null normal myocardium, at 10 to 15 min after the addition of 0.15 mmol/kg cumulative gadolinium-diethylenetriamine pentaacetic acid intravenously) (15,16).

Cine function analysis was performed off-line with validated software (CineTool 3.9.2, General Electric Healthcare) (17). The cardiac phase that demonstrated the largest LV cavity size was defined as end-diastole and the smallest LV cavity size as end-systole. A single experienced observer manually traced the endocardial contours of the RV and the LV at end-diastole and -systole in all cine studies (Fig. 1). The papillary muscles were included in the ventricular cavity volume. If the basal slice contained both ventricular and atrial myocardium, the contours were drawn up to the junction of the atrium and the ventricle and joined by a straight line through the blood pool. The RV and LV end-diastolic and -systolic volumes and the ejection fraction (EF) were computed using the Simpson's rule. Right and left ventricular volumes were adjusted to body surface area by using the Dubois Formula (18) to yield the respective volume indices. In the basal slice, both in end-diastole and -systole, if the pulmonary valve was visible, only the portion of the volume surrounded by trabeculated myocardium below the level of the pulmonary valve was included. For the inflow portion of the RV, the blood volume was excluded from the RV volume if the surrounding wall was thin and not trabeculated, as it was considered to be in the right atrium.

To reflect common practice in the clinical setting, LVEF and RVEF were recorded as continuous variables and also dichotomized as "normal" or "abnormal." Abnormal RVEF was defined as <40% based on a mean − 3 SD of reported age-adjusted normal using the steady-state free precession cine technique (19,20). The location and size of LV and RV infarct were determined by LGE imaging. Infarcted myocardium was quantitated by semiautomatic detection of any region with signal intensity 2 SD above the mean signal intensity of the remote myocardium as previously validated (21). Left ventricular infarct size was reported in grams as well as calculated as a percent of total LV mass. Right ventricular LGE consistent with RV infarction was identified by a consensus agreement among 2 cardiologists who were experienced in CMR interpretation and blinded to

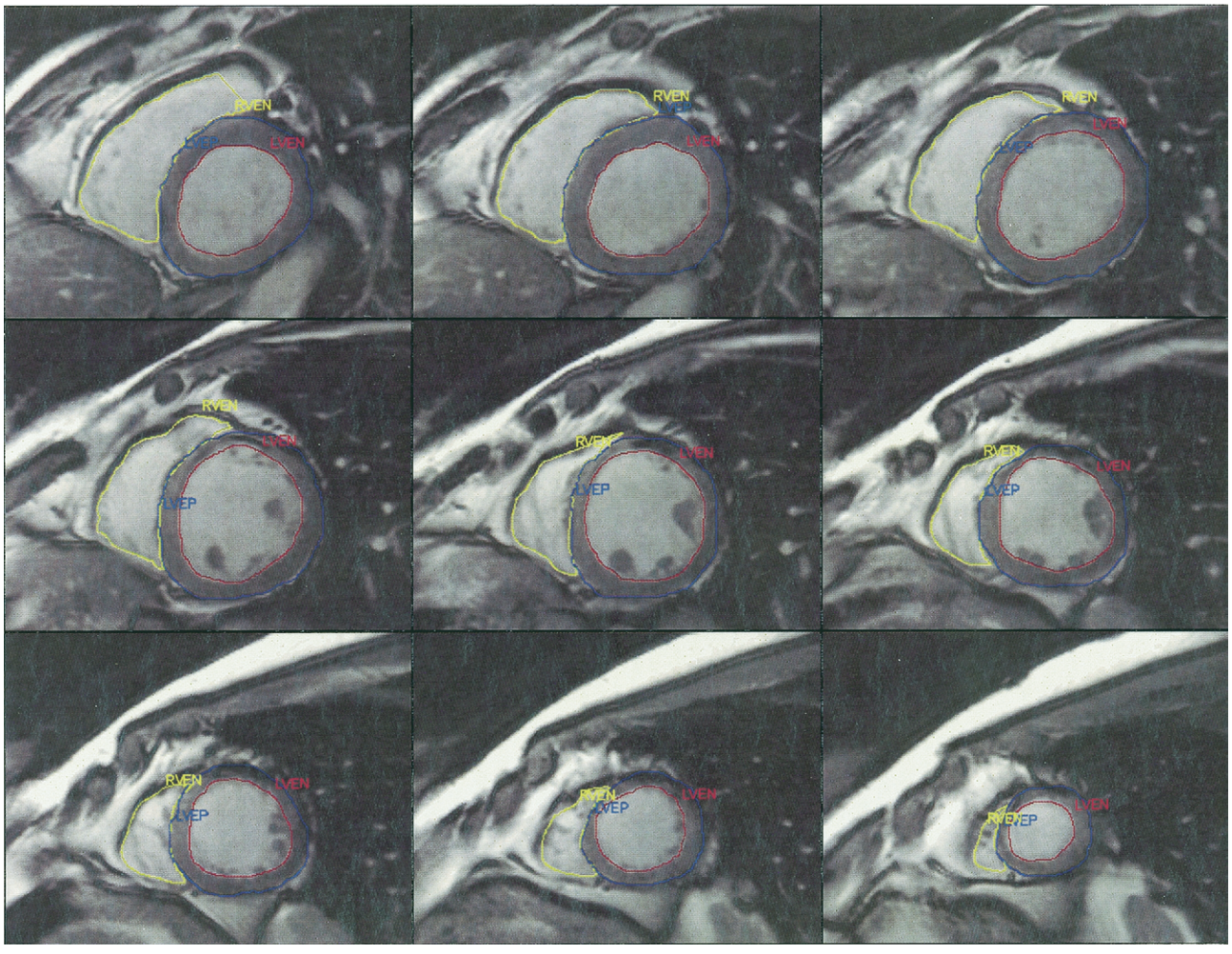

Figure 1 **Example of Volumetric Determination of RV and LV Ejection Fraction**

Endocardial borders are delineated manually for right ventricular (RV) (RVEN, **yellow line**) and left ventricular (LV) (LVEN, **red line**) every 8 mm from atrioventricular valve to apex to determine cavity areas at end-systole and -diastole (end-diastole shown here). Consecutive areas are summed by Simpson's method to calculate end-systolic and -diastolic volumes and calculate ejection fraction. In this example, an RV ejection fraction was measured at 35% and LV ejection fraction at 61%. LVEN = left ventricle endocardial border; LVEP = left ventricle epicardial border; RVEN = right ventricle epicardial border.

RVEF, LVEF, and clinical outcome. Infarct size in the RV was assessed by the number of infarcted segments on a 9-segment model described by Tandri et al. (22). Left atrial dimension represents a preload independent marker of LV diastolic function and provides prognostic information in population-based studies (23). The left atrial size was measured at mid-anterior-posterior dimension from the 3-chamber cine imaging view at end-ventricular systole.

Coronary angiography. Coronary angiography was performed in 65 patients within 6 months of CMR per discretion of the attending physicians. An experienced investigator blinded to CMR findings and clinical events assessed the presence of coronary stenoses in 2 orthogonal views of each BARI-defined segment by quantitative coronary angiography using validated software (CMS-QCA, Medis, the Netherlands) (24). Significant stenoses were defined as ≥70% luminal narrowing in the most severe view (≥50% for left main stenosis).

Follow-up. After CMR, subjects were prospectively followed for a median of 17 months (range 6 to 53 months). Clinical follow-up based on a standard questionnaire was obtained from telephone interviews with the patients or relatives, physicians, or from hospital records. Survival status was obtained through a query of the National Social Security Death Index (25).

Statistical analysis. Baseline patient characteristics stratified by RVEF are displayed in Table 1. Two-tailed *t* test and Fisher exact test were used as appropriate. We fitted Cox proportional-hazards survival models to estimate unadjusted hazard ratios (HRs) and the 95% confidence intervals of all the variables. We performed 2 multivariable analyses to assess for any incremental prognostic value of

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Table 1 Demographic Characteristics of the Study Population

	Overall (n = 147)	RVEF ≥40% (n = 122)	RVEF <40% (n = 25)	p Value
Age, yrs	63 ± 11	63 ± 10	64 ± 12	NS
Male gender, %	78	77	84	NS
Diabetes, %	37	34	48	NS
Hypertension, %	63	66	52	NS
Dyslipidemia, %	89	90	84	NS
Smoking, %	33	32	36	NS
Family history premature CAD, %	33	34	28	NS
History of prior PCI, %	41	43	32	NS
History of prior CABG, %	37	39	28	NS
Revascularization after CMR	37	29	8	NS
Infarct location by DE, %				
LAD territory	33	31	40	NS
RCA territory	43	43	44	NS
LCx territory	8	9	0	NS
Mixed territories	17	17	16	NS
ASA therapy, %	90	91	88	NS
Statin therapy, %	85	87	73	NS
Beta-blocker therapy, %	81	87	52	0.002
ACE inhibitor therapy, %	64	65	60	NS
Calcium channel blocker therapy, %	10	12	0	NS

ACE = angiotensin-converting enzyme; ASA = acetylsalicylic acid; CABG = coronary artery bypass graft; CAD = coronary artery disease; CMR = cardiovascular magnetic resonance; DE = delayed enhancement; LAD = left anterior descending; LCx = left circumflex; PCI = percutaneous coronary intervention; RCA = right coronary artery; RVEF = right ventricular ejection fraction.

RV dysfunction for all-cause mortality late after MI in addition to known prognostic markers. First, we aimed to build the best-overall parsimonious model for mortality late after MI. We performed stepwise forward selection considering any clinical or imaging variables listed in Tables 1 and 2. Significant levels of covariate entry or stay were both set at p = 0.05. Second, we assessed the association of RVEF ≥40% to mortality adjusted to known post-MI predictors, including patient age, LV infarct size (per 10% LV mass), and LVEF (per 10% LVEF). The validity of the proportional-hazards assumption was tested by adding a time-dependent interaction variable to each of the final models for each of the predictors in the models. All predictors in the final models fulfilled the validity of the proportional-hazards assumption. Spearman correlation assessed the relationship of RVEF to parameters of LV function (LV indexed end-systolic volume [ESVi], LVEF, and left atrial size). Analyses were performed using SAS version 9.1 (SAS Institute, Cary, North Carolina).

Results

We enrolled 153 consecutive subjects >30 days after MI referred for CMR assessment of ventricular function and myocardial viability. Assessment of vital status was complete in all patients. Six patients were excluded from further analysis because of severe mitral regurgitation (n = 3) or poor image quality (n = 3). All 6 patients were alive at the

Table 2 Electrocardiographic Features of the Study Population

	Overall (n = 147)	RVEF ≥40% (n = 122)	RVEF <40% (n = 25)	p Value
Normal sinus rhythm, %	97	98	91	NS
Resting heart rate >100 beats/min, %	3	2	8	NS
Left ventricular hypertrophy, %	6	7	0	NS
Significant Q waves, %	36	32	59	0.03
Prolonged QRS >200 ms, %	22	21	27	NS
Left bundle branch block, %	13	12	18	NS
Right bundle branch block, %	7	6	9	NS
Prolonged corrected QT >440 ms, %	43	43	41	NS
ST-segment depression, %	23	23	23	NS
T-wave inversion, %	33	33	36	NS
Any ECG abnormality, %	81	79	91	NS

ECG = electrocardiogram; RVEF = right ventricular ejection fraction.

end of study follow-up. The remaining 147 patients (115 men, mean age 63 ± 11 years) constituted the study cohort. Mean interval between MI and CMR study was 6.7 ± 8.2 years (10%: 3 to 6 months, 3%: 6 to 12 months, 8%: 12 to 24 months, and 79%: >24 months after MI). Twenty-six patients died after a median follow-up of 17 months (range 6 to 53 months). Univariable associations with post-MI mortality are presented in Table 3. Kaplan-Meier analysis demonstrated that RVEF <40% was associated with a markedly reduced survival ($p < 0.0001$) (Fig. 2). Within 6 months of the CMR study, significant angiographic coronary stenosis (≥70% diameter stenosis by quantitative coronary angiography) was noted in 57 (39%) of subjects, including significant RCA stenosis in 39 patients (27%). Indices of RV and LV function of the cohort are reported in Table 4. Right ventricular ejection fraction (per each 10% decrease) and RVEF <40% (by dichotomous analysis) demonstrated a strong association with mortality (unadjusted HR 1.45, $p = 0.005$ and 4.02, $p = 0.0007$, respectively) (Table 3). Although LVEF also was significantly associated with mortality late after MI, LV infarct size (by gram or % LV mass) was not (Table 4). Other significant univariate predictors of mortality included corrected QT, left atrium (LA) size, resting tachycardia, and nonsinus

Table 3 Unadjusted Analysis of Hazard Ratio for All-Cause Mortality

	Hazard Ratio for Death (n = 26)	95% Confidence Interval	p Value
Age, yrs	0.90	0.62 to 1.3	NS
Female gender	1.79	0.77 to 4.16	NS
History of PCI	0.47	0.20 to 1.13	0.09
History of CABG	1.14	0.49 to 2.64	NS
History of hypertension	0.70	0.32 to 1.54	NS
History of diabetes	1.09	0.47 to 2.55	NS
History of hypercholesterolemia	0.95	0.22 to 4.06	NS
History of smoking	1.82	0.81 to 4.09	NS
Family history of CAD	1.3	0.58 to 2.94	NS
Aspirin use	1.04	0.24 to 4.44	NS
Statin use	0.99	0.30 to 3.31	NS
Beta-blocker use	0.51	0.23 to 1.16	0.11
ACE inhibitor use	0.72	0.33 to 1.62	NS
Resting tachycardia (rate >100 beats/min)	7.34	1.67 to 32.2	0.008
Nonsinus rhythm	5.03	1.50 to 16.9	0.009
LVH on ECG	0.75	0.1 to 5.56	NS
QRS >200 ms	1.17	0.46 to 2.96	NS
LBBB	1.29	0.44 to 3.79	NS
RBBB	1.70	0.50 to 5.75	NS
Corrected QT >420 ms	2.47	1.08 to 5.63	0.03
Q wave	0.74	0.32 to 1.75	NS
ST-segment depression	0.93	0.35 to 2.48	NS
T-wave inversion	0.5	0.19 to 1.34	NS
>70% coronary stenosis of RCA	1.9	0.86 to 4.19	0.11
>70% coronary stenosis of any vessel	1.21	0.55 to 2.67	NS
LVEF (per 10%)	0.77	0.60 to 0.98	0.03
LVESVi (per 10 ml/m^3)	1.05	0.97 to 1.14	NS
LVEDVi (per 10 ml/m^2)	1.03	0.95 to 1.13	NS
LA size (per mm)	1.09	1.04 to 1.15	0.0009
LV mass (per every 10 g)	1.09	0.99 to 1.19	0.07
LV infarct size (per 10% of LV mass)	1.03	0.79 to 1.34	NS
LV infarct size (per every 10 g)	1.06	0.89 to 1.26	NS
RVEF <40%	4.02	1.80 to 8.96	0.0007
RVEF (per 10% decrease)	1.45	1.12 to 1.85	0.005
RVESVi (per 10 ml/m^3)	1.14	0.96 to 1.34	NS
RVEDVi (per 10 ml/m^2)	1.02	0.85 to 1.23	NS
RV infarct (presence or absence)	2.44	0.82 to 7.23	0.11
RV infarct size (per number of segments)	1.54	1.17 to 2.04	0.003

ACE = angiotensin-converting enzyme; CABG = coronary artery bypass grafting; CAD = coronary artery disease; ECG = electrocardiogram; LA = left atrium; LBBB = left bundle-branch block; LV = left ventricular; LVEDVi = indexed LV end-diastolic volume; LVEF = left ventricular ejection fraction; LVESVi = indexed LV end-systolic volume; LVH = left ventricular hypertrophy; PCI = percutaneous coronary intervention; RBBB = right bundle-branch block; RCA = right coronary artery; RV = right ventricular; RVEDVi = indexed RV end-diastolic volume; RVEF = right ventricular ejection fraction; RVESVi = indexed right systolic volume.

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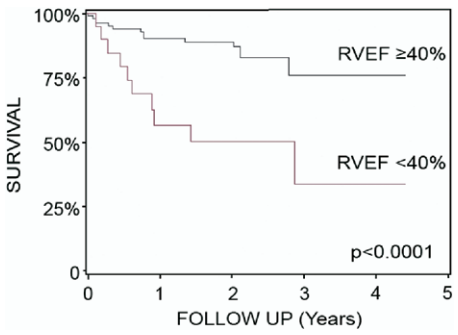

Figure 2 Kaplan-Meier Survival of Study Cohort Stratified by RVEF of 40%

RVEF = right ventricular ejection fraction.

rhythm. Right ventricular ejection fraction correlated modestly with LVEF ($r = 0.39$, $p < 0.0001$), LVESVi ($r = -0.37$, $p < 0.0001$), and LA size ($r = -0.17$, $p < 0.05$). Image quality of LGE imaging was adequate and allowed assessment of RV MI in 144 subjects, among them 13 demonstrated LGE of the RV consistent with RV MI. Only 4 patients with RVEF <40% demonstrated RV MI by LGE imaging (p = NS). Univariable analysis revealed that although the size of RV MI (by number of RV segments involved) was associated with post-MI mortality (hazard ratio 1.54, 95% confidence interval 1.17 to 2.04, $p = 0.003$), the presence of RV MI did not significantly predict mortality (HR 2.44, $p = 0.11$).

Results of the multivariable analyses are presented in Table 5. In the first multivariable approach, RVEF <40% and left atrial enlargement were the only variables selected in forming the best overall model for mortality in this study cohort. In the second multivariable approach, RVEF <40% maintained strong association with mortality, independent of patient age, LV infarct size, and LVEF (per 10% of LVEF) combined. After adjusting for patient age, LV infarct size, and LVEF, RVEF <40% incurred a near 3-fold adjusted hazard increase for mortality. Age of MI only demonstrated a trend association with mortality (HR 2.21, $p = 0.07$). Right ventricular ejection fraction <40% maintained a significant association with mortality adjusted to either RV infarct size or age of MI (adjusted HR 3.47, $p = 0.004$, and HR 3.34, $p = 0.004$, respectively).

Table 4 Cardiovascular Magnetic Resonance Imaging Measurements of the Study Population

	Overall (n = 147)	RVEF ≥40% (n = 122)	RVEF <40% (n = 25)	p Value
LVEF, %	45 ± 17	47 ± 16	32 ± 14	<0.0001
LVESVi, ml/m^2	65 ± 41	59 ± 39	94 ± 42	<0.0001
LVEDVi, ml/m^2	109 ± 39	104 ± 37	133 ± 37	<0.001
RVEF, %	52 ± 13	56 ± 8	31 ± 11	<0.0001
RVESVi, ml/m^2	34 ± 18	29 ± 11	60 ± 27	<0.0001
RVEDVi, ml/m^2	68 ± 22	65 ± 19	85 ± 30	<0.0001
LV mass, g	147 ± 43	148 ± 44	142 ± 37	NS
Any WMA, %	90	88	100	NS
LV infarct size, g	22 ± 21	21 ± 21	27 ± 26	NS
LV infarct size, %LV mass	16 ± 15	15 ± 15	19 ± 19	NS
Left atrial size, mm	42 ± 7	42 ± 8	45 ± 7	0.07

WMA = wall motion abnormality; other abbreviations as in Table 3.

Table 5 Multivariable Associations With All-Cause Mortality

	Hazard Ratio (95% Confidence Interval)	p Value
Best overall multivariable model		
Left atrial size, mm	1.07 (1.02–1.13)	0.007
RVEF <40%	3.54 (1.50–8.36)	0.004
Association of RVEF <40% adjusted for patient age, LV infarct size, and LVEF		
Patient age, yrs	0.85 (0.58–1.25)	0.41
LV infarct size (per 10% of LV mass)	0.91 (0.68–1.21)	0.50
LVEF (per 10% change)	0.82 (0.61–1.012)	0.21
RVEF <40%	2.86 (1.13–7.25)	0.03

LV = left ventricular; LVEF = left ventricular ejection fraction; RVEF = right ventricular ejection fraction.

Discussion

This study evaluated the prognostic implications of RV dysfunction late after MI, using volumetric quantification of RVEF by cine CMR. Our data indicate that RV dysfunction late after MI is the strongest multivariable predictor in the best overall model of post-MI mortality in our study cohort. In particular, RVEF <40% carries almost a 3-fold increase in mortality, after adjusting for patient age, LV infarct size, and LVEF. We also conclude that RV global dysfunction in this clinical setting likely reflects several possible mechanisms and cannot be accounted for by RV MI alone.

Controversies surrounding the prognostic weight of RV function. Right ventricular dysfunction has long been associated with in-hospital morbidity and mortality early after acute MI (26). Mehta et al. (27) demonstrated that RV dysfunction at the time of MI increases 6-month mortality independently of the extent of LV myocardial damage. However, most RV dysfunction during the acute phase resolves, and it remains controversial as to whether RV dysfunction identified outside the acute setting of MI independently predicts poor prognosis (2,28–31). Although some argued that dysfunction of the afterload-sensitive RV is merely a reflection of LV failure (32,33), Kaul et al. (34) have suggested that the effects of previous MI on RV function depend little on the extent of LV dysfunction.

Role of CMR in RV function analysis. Compared with the LV, RV volume and RVEF quantification have been challenged by a complex geometric shape and RV wall thickness of mere 3 to 4 mm. Although echocardiography and nuclear medicine technique are valuable clinical tools in assessing global RV function and stratifying patient risk, geometric assumptions in modeling the complex RV shape

restricts the ability of these techniques in accurate and precise quantification of RV function. As a result, a wide range of "normal" values for RVEF has been reported by echocardiographic techniques (5,6,35,36). With tomographic scan planes, and high spatial and temporal resolution, CMR is the recognized clinical reference tool for RV structure and function in a spectrum of cardiac diseases involving the RV (7–9,37).

Independent impact of RV function on survival and the potential mechanisms of RV dysfunction. The prognostic significance of reduced LVEF has been investigated extensively in subjects with a history of clinical MI (38). Although we observed that LV infarct size demonstrated significant inverse correlation with LVEF ($r = -0.49$, $p < 0.0001$) as reported in previous studies (39), LV infarct size per se was not associated with all-cause mortality (p = NS). Although this lack of association may reflect the heterogeneous chronicity of MI of the study population or limited study power owing to the relatively small sample size, myriad neurohormonal factors beyond LV infarct size have been described that can mediate ventricular remodeling, arrhythmias, and impact on post-MI clinical outcomes (40). Important prognostic factors such as the presence and extent of myocardial hibernation and stunning may not be reflected by LV infarct size alone. Therefore, consistent with previous studies, we found that LVEF was a stronger predictor of all-cause mortality than was LV infarct size (HR 0.77, p = 0.03 vs. HR 1.06, p = NS, respectively) (41). Although LVEF predicts long-term mortality after MI, it does so only modestly and hence other factors that elevate risk of cardiac death late after MI need to be defined (42). Our study identified one such powerful factor, RVEF <40%, heralding increased mortality late after MI. Early after an acute MI, decreased RVEF may occur without impaired LVEF in inferior MI whereas decreased RVEF only occurs with impaired LVEF in anterior MI, suggesting that RV failure is associated with RV ischemia in inferior MI and overload in anterior MI (43). Later after MI, impaired RV function likely reflects a manifestation of common conditions, including RV infarction or ischemia, pulmonary hypertension secondary to LV dysfunction, or subclinical pulmonary thromboembolic disease. Our observation that only 16% of subjects with RV dysfunction late after MI actually have RV necrosis identified by LGE suggests that RV MI is not the sole mechanism underlying RV dysfunction in this setting. Although we noticed that RVEF was related to indices of LV function (LVEF, LVESVi, and LA dimension), the finding that RVEF maintained strong adjusted association with post-MI mortality beyond the indices of LV function may have important clinical implications. This may reflect the presence of other subclinical conditions, such as RV ischemia without infarction or pulmonary disease that affect RV function and have negative impact on patient prognosis.

Study limitations. The current study has several limitations. Although CMR is the best current standard for quantitation of RV function, it could be difficult to discriminate the RV from atrium at the level of the tricuspid valve in short-axis because of the dynamic through-plane motion of the atrioventricular groove during the cardiac cycle. This technical consideration was accounted for in our study by careful observation of the tricuspid valve and heart chambers in motion before obtaining measurements, coupled with the identification of atrium as the thinner-walled chamber devoid of trabeculations. Variability in RV measurements was reduced by relying on a single experienced operator to perform all measurements. Measurement of pulmonary arterial pressure by echocardiographic Doppler technique at the same time of the CMR could have contributed to explaining the mechanisms of RV dysfunction but were not available in most patients in this cohort. We did, however, evaluate for RV infarction by LGE and assessed the relationship of RVEF with indices of LV function, to further explore the mechanisms underlying RV dysfunction in this clinical setting. It should be emphasized that although volumetric CMR technique can quantify RVEF at high accuracy and reproducibility, RVEF is load-dependent and does not fully represent RV myocardial performance. Given the small sample size of this study cohort, the current findings should be replicated in a larger population.

Conclusions

This study demonstrates that RV function assessed late after clinical MI is an important predictor of post-MI mortality, independent of patient age, LV infarct size, and LVEF. Evaluation of RV function using CMR may improve the risk stratification of patients with MI beyond current practice and refine their medical management.

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