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Ventricular Myocardial Fat: An Unexpected Biomarker for Long-term Survival?

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Abstract

Purpose To examine the association between myocardial fat, a poorly understood finding frequently observed on non-contrast CT, and all-cause mortality in patients with and without a history of prior MI.

Materials and methods A retrospective cohort from a diverse urban academic center was derived from chronic myocardial infarction (MI) patients (n = 265) and three age-matched patients without MI (n = 690) who underwent non-contrast chest CT between 1 January 2005-31 December 2008. CT images were reviewed for left and right ventricular fat. Electronic records identified clinical variables. Kaplan-Meier and Cox proportional hazard analyses assessed the association between myocardial fat and all-cause mortality. The net reclassification improvement assessed the utility of adding myocardial fat to traditional risk prediction models.

Results Mortality was 40.1% for the no MI and 71.7% for the MI groups (median follow-up, 6.8 years; mean age, 73.7 ± 10.6 years). In the no MI group, 25.7% had LV and 49.9% RV fat. In the MI group, 32.8% had LV and 42.3% RV fat. LV and RV fat was highly associated (OR 5.3, $p < 0.001$). Ventricular fat was not associated with cardiovascular risk factors. Myocardial fat was associated with a reduction in the adjusted hazard of death for both the no MI (25%, $p = 0.04$) and the MI group (31%, $p = 0.018$). Myocardial fat resulted in the correct reclassification of 22% for the no MI group versus the Charlson score or calcium score ($p = 0.004$) and 47% for the MI group versus the Charlson score ($p = 0.0006$).

Conclusions Patients with myocardial fat have better survival, regardless of MI status, suggesting that myocardial fat is a beneficial biomarker and may improve risk stratification.

Key Points

- *Myocardial fat is commonly found on chest CT, yet is poorly understood*
- *Myocardial fat is associated with better survival in patients with and without prior MI and is not associated with traditional cardiovascular risk factors*
- *This finding may provide clinically meaningful prognostic value in the risk stratification of patients*

Keywords Biomarkers · Myocardium · Risk assessment · Tomography, x-ray computed · Outcomes research

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Abbreviations

CAD	Coronary artery disease
CT	Computed tomography
LV	Left ventricle
MI	Myocardial infarction
NRI	Net reclassification improvement
RV	Right ventricle

Introduction

Adipose tissue within the ventricular myocardium has been observed histologically and on imaging in a variety of

settings. Right ventricular (RV) fat is commonly considered to be physiologic [1–3] and left ventricular (LV) fat is associated with myocardial infarction (MI) and ischemia [3–5]. The cellular processes that lead to adipocytes in the location of prior infarction are not well understood. One hypothesis is that revascularized ischemia leads to enhanced transdifferentiation of myocardial mesenchymal progenitor cells into adipocytes [6], suggesting that the heart is not a post-mitotic organ [7]. A more complex biologic process is suspected as ventricular fat has been observed in numerous other pathologies including dilated cardiomyopathy [8], arrhythmogenic right ventricular cardiomyopathy, tuberous sclerosis, muscular dystrophy [9], sarcoidosis [10], and Proteus syndrome [11].

Myocardial fat deposition is readily depicted on non-contrast computed tomography (CT) without electrocardiographic gating, including examinations for the coronary calcium score and lung cancer screening. On CT, myocardial fat appears as low attenuation within the ventricular wall (Fig. 1), with adipose tissue typically demonstrating an attenuation of -80 to -30 Hounsfield units [12]. Recent observational studies of patients who underwent CT have found the prevalence of LV fat to be 19% among those without coronary artery disease (CAD) [13] and 34% among those with prior MI [14], while RV fat has been reported in 17% of asymptomatic patients [15].

Little is known about the predisposing factors or prognostic implications of myocardial fat among patients with or without MI. As chest CTs are performed for numerous indications, including lung cancer screening, the clinical meaning of incidental cardiac findings requires active investigation. The purpose of the present study was to examine the association between myocardial fat seen on non-contrast chest CT and all-cause mortality in patients with and without a history of prior MI.

Material and methods

Cohort selection

The study population comprised patients aged ≥ 50 years who underwent non-contrast chest CT at our multisite urban academic medical center, January 1, 2005-December 31, 2008. Imaging sites included two hospitals (caring for both in- and outpatients) as well three outpatient imaging facilities. CT scanner models and protocol specifications varied. Patients were identified using Looking Glass Clinical Analytics (Streamline Health), which integrates clinical and administrative data sets, including the Social Security Death Index (SSDI), through November 1, 2011.

Two subgroups were selected from this population: (1) those without a history of prior MI (no MI group) and (2) those with a history of MI ≥ 3 years prior to their index CT (MI group). The 3-year threshold was chosen for the MI group because myocardial fat was described to develop gradually post infarction and is most reliably detected after 3 years [16].

ICD-9 codes were used to identify both groups. The MI group was defined as patients who were admitted with acute or initial episodes of MI (ICD-9 codes 410.x0, 410.x1). The no MI group comprised patients without ICD-9 codes for MI admission or a history of previous MI (410.x, 411.0, 412). Patients were excluded from the no MI group if they had prior abnormal cardiac enzyme levels (troponin T ≥ 0.11 ng/ml or CK-MB ≥ 5.1 ng/ml) or significant CAD requiring revascularization.

Patients with a history of cancer (except non-melanoma skin cancer), or cancer diagnosed within 6 months after index CT, documented in the Montefiore Cancer Registry, were excluded as they have a significant competing risk for mortality.

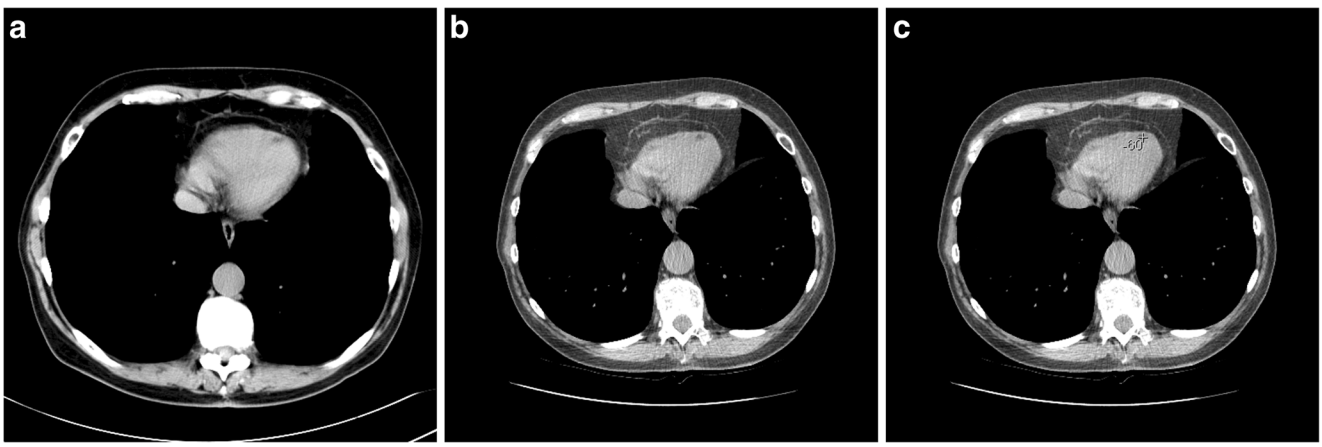

Fig. 1 Non-contrast 5-mm axial CT demonstrates subendocardial left ventricular myocardial fat in the apical interventricular septum and in the right ventricular free wall in a 68-year-old female without a history of MI (**a**). Nine years later, the same distribution of myocardial fat is noted on a non-contrast 2.5-mm axial slice (**b**). The area of myocardial fat in the left ventricle has an attenuation of -60 Hounsfield units, corresponding to fat density (**c**)

Examinations that did not include 5-mm axial slices or thinner were excluded.

There were 11,846 non-contrast chest CTs in patients ≥ 50 years, January 1, 2005-December 31, 2008; 299 patients met the initial inclusion criteria for the MI group and 7,731 patients met the initial inclusion criteria for the no MI group. To maintain a feasible number of CT scans for image review, three patients were randomly selected from the no MI group to match each patient in the MI group for the year-quarter that the CT was performed and for age within a 3-year window. Thus, the no MI group and the MI group were comparable for age, which is strongly associated with mortality, and for CT technology, which may impact the detection rate.

Patients were excluded at this stage primarily for lack of access to archived images for review and presence of cancer that was not documented in the cancer registry. The final study cohort comprised 690 patients in the no MI group and 265 in the MI group (Fig. 2). The median time since prior MI, for the MI group, was 5.4 years (IQR 4.0, 7.1).

The study was approved by the Institutional Review Board of the Albert Einstein College of Medicine, and a waiver of informed consent was granted for this HIPAA compliant study.

Image review

CT images were reviewed in random order by two members drawn from a panel of six fellowship-trained cardiothoracic radiologists, blinded to clinical information. The presence of myocardial fat was evaluated in consensus by visual inspection of the myocardium for foci of low attenuation matching subcutaneous fat within the myocardium. If consensus was not easily achieved, a third panel member served as a tiebreaker. The ordinal coronary calcium score [17] was determined for patients without a visible coronary artery stent or prior coronary artery bypass graft (CABG).

Indications for the CT, site, and CT detector row number were recorded. Given similar outcomes between patients whose examinations were done on an inpatient or emergency basis, those categories were combined. CT scanners were classified as low detector row (1, 4, 6) and high detector row (16, 64).

Demographic and clinical data

Demographic data included age at CT, sex, race, and socioeconomic status. Those with missing race documentation were considered non-white given the non-white majority in our population. Clinical information included: date of first prior MI for the MI group, body mass index (BMI), and comorbidities such as hypertension and CAD. Most recent lipid panel within 5 years and statin pharmacotherapy were recorded. The modified Charlson score was calculated based on administrative data [18].

Mortality data

Those without a recorded death in Looking Glass™ or SSDI were censored on December 31, 2014 or later based on institutional clinical activity. Vital status of patients alive after November 1, 2011 but without institutional clinical activity was obtained from the National Death Index (NDI).

Statistical analysis

Statistical analysis was performed using Stata version 13.1 (StataCorp). Two-tailed $p < 0.05$ indicated statistical significance. We evaluated LV and RV fat as separate dichotomous variables, and fat in either ventricle as a single dichotomous variable.

Bivariate associations were compared by using the Student's t test or Wilcoxon rank sum test for continuous variables and Pearson χ^2 test or Fisher exact test for categorical variables, as appropriate. Multivariate logistic regression for factors associated with myocardial fat was employed using a forward stepwise approach; covariates with a p value < 0.15 on bivariate analysis were considered for inclusion and kept if they maintained significance at 0.05.

Survival analysis was performed separately for the no MI group and the MI group. Kaplan-Meier statistics were used for univariate survival analysis, with statistical significance at < 0.05 on the log-rank test. Cox proportional hazard models were constructed with all-cause mortality as the outcome variable and observations censored at December 31, 2014 or last encounter at a medical system, whichever was most recent. Forward stepwise selection where covariates reached a significance level of 0.15 was considered for the model. Entry criteria were defined as either a ≥ 10% change in the coefficient of the variable of interest or statistical significance of the coefficient for the covariate at 0.05. First-order interactions with the variable of interest were evaluated and considered present for $p < 0.10$. Confounding was considered significant for a 20% difference in the coefficient of interest. Proportional hazard assumptions were assessed for all models using log-log, Kaplan-Meier, and predicted survival plots and Schoenfeld residuals.

We assessed the classification of risk using the continuous net reclassification improvement (NRI) [19], a method frequently used to assess novel risk markers in cardiovascular diseases [20]. With the addition of ventricular fat to a base Cox proportional hazard model, each individual's risk of death at the median follow-up time (7.1 years-no MI group, 3.4

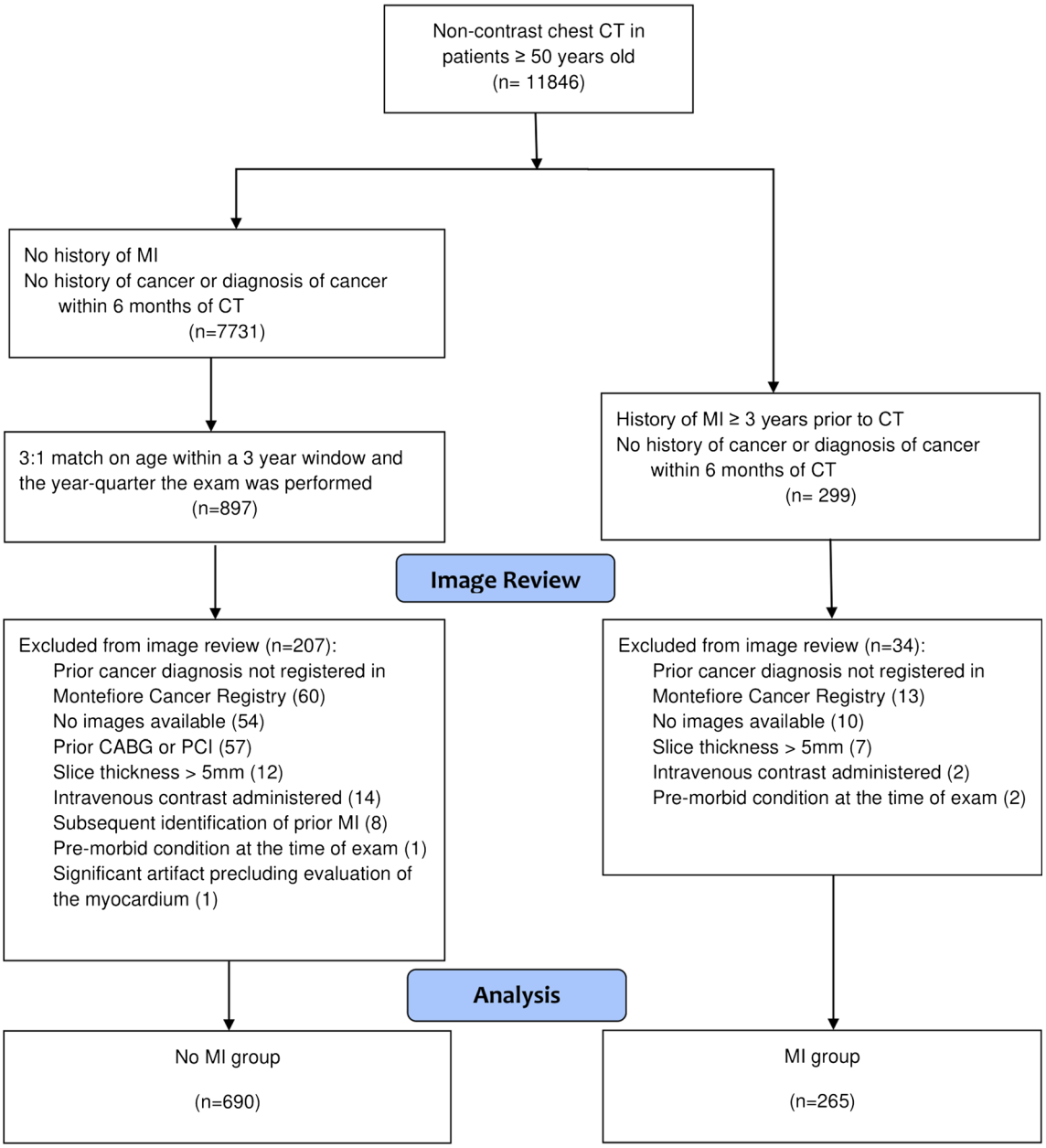

Fig. 2 Flowchart of the study cohort with patient selection and exclusion points. CT computed tomography, CABG coronary artery bypass graft, MI myocardial infarction, PCI percutaneous coronary intervention

years-MI group) was reclassified; the relative improvement in classification was reported.

Results

The study cohort comprised 955 patients, 690 patients in the no MI group and 265 patients in the MI group (Table 1). The MI group demonstrated a higher proportion of males and co-morbidities associated with cardiovascular disease than the no MI group. The overall poorer health among the MI group was demonstrated by a higher Charlson score and the observation that index CTs usually took place in the inpatient or emergency department setting. Of note, obesity was not more prevalent among the MI group.

Forty-nine percent (467/955) of the study cohort died over the 10-year follow-up period. As expected, the no MI group had a substantially lower mortality rate [40.1% (277/690)] compared with the MI group [71.7% (190/265)] (Fig. 3). In the no MI group, LV myocardial fat was present in 177 (25.7%) and RV fat in 344 (49.9%). In the MI group, LV fat was present in 87 (32.8%) patients and RV fat in 112 (42.3%). Those with LV fat had higher odds of also demonstrating RV fat in both the no MI (OR 6.8; 95%

Table 1 Cohort characteristics

	No MI group (n = 690)	MI group (n = 265)
Age	73.7 ± 10.7	73.8 ± 10.5
Female	452 (65.5)	115 (43.4)
Race		
White	220 (31.9)	95 (35.8)
Black	210 (30.4)	57 (21.5)
Hispanic	185 (26.8)	94 (35.5)
Asian	19 (2.6)	12 (4.5)
Unknown	56 (8.1)	7 (2.6)
Indication for CT		
Lung or pleural disease	330 (47.8)	137 (51.7)
Concern for malignancy	228 (33.0)	72 (27.2)
Mediastinal abnormality	16 (2.3)	7 (2.6)
Evaluation of aorta	53 (7.7)	18 (6.8)
Chest pain	9 (1.3)	3 (1.1)
Other	54 (7.8)	28 (10.6)
Socioeconomic status[a]	-2.0 (-5.7, -0.8)	-2.2 (-5.4, -0.8)
Body mass index[b]	26.7 ±7.0	26.8 ± 6.4
Hypertensive	412 (59.7)	237 (89.4)
Prior coronary artery disease	96 (13.9)	247 (93.2)
Diabetes[c]	167 (27.7)	151 (57.9)
Stroke/TIA[c]	66 (11.0)	81 (31.0)
Peripheral vascular disease[c]	67 (11.1)	88 (33.7)
Congestive heart failure[c]	90 (15.0)	185 (70.9)
Statin prescription	209 (30.3)	228 (86.0)
Charlson score	4 (3, 6)	8 (6, 10)
High detector row CT scanner	406 (58.8)	164 (61.9)
Inpatient/ED examination	287 (41.6)	179 (67.6)
Overall mortality	277 (40.1)	190 (71.7)
LV fat present	177 (25.7)	87 (32.8)
RV fat present	344 (49.9)	112 (42.3)

CT computed tomography, MI myocardial infarction, TIA transient ischemic attack, ED emergency department, presented as mean ± SD, n (%), or median (interquartile range)

[a] Missing in 36 (5%) of the no MI group and 13 (5%) of the MI group

[b] Missing in 124 (18%) of no MI group and in 12 (5%) of the MI group

[c] Missing in 88 (13%) of the no MI group and 4 (2%) of the MI group

CI, 4.5-10.4; $p < 0.001$) and MI group (OR 3.6; 95% CI, 2.3-6.8, $p < 0.001$).

In the no MI group, myocardial fat was associated with white race, higher socioeconomic status, absence of known CAD, higher ordinal calcium score, and outpatient index CT (Table 2). Multivariable logistic regression analysis (Table 3) confirmed the higher prevalence of LV fat in patients with white race, absence of CAD, higher ordinal calcium score, and outpatient CT.

In the MI group, ventricular fat was more prevalent among patients without a history of stroke, with a lower Charlson score, and with an outpatient index CT (Table 2). In multivariable logistic regression analysis, a lower Charlson score and outpatient index CT remained significant (Table 3).

In the no MI group, Kaplan-Meier analysis demonstrated improved survival among patients with LV fat compared with those without LV fat (Fig. 4a). In the MI group, the difference in mortality was even greater (Fig. 4b). RV fat was also associated with improved survival in both groups (Fig. 5). Furthermore, myocardial fat in either the left or the right ventricle was associated with improved survival, with a greater difference seen in the MI group (Fig. 6).

In the no MI group, a multivariable Cox proportional hazard model demonstrated a 25% reduction in hazard of death among patients with ventricular myocardial fat (HR

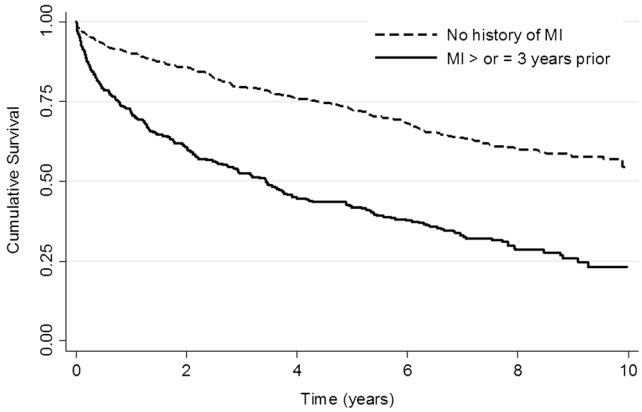

Fig. 3 Kaplan-Meier survival curves for the no MI and MI groups

0.75; 95% CI, 0.58-0.99; p = 0.04; Table 4). In the MI group, the presence of fat had an even stronger association with improved survival (HR 0.69; 95% CI, 0.51-0.94, p = 0.02).

In the no MI group, adding myocardial fat to a model consisting of the age, sex, and ordinal calcium score yielded an NRI of 0.22 (p = 0.004). Adding myocardial fat to the combined Charlson score and sex also demonstrated a statistically significant net improvement in classification (NRI 0.22, p = 0.004). Among patients with prior MI, including myocardial fat in a model with the sex and combined Charlson score resulted in the net reclassification of 47% of patients (p < 0.001).

Discussion

Our group previously postulated that LV fat in patients without a known prior MI suggests that a silent MI has occurred [21]. We anticipated that patients with LV myocardial fat and without a history of MI would have worse mortality compared with patients without LV fat. We further hypothesized that RV fat would not be associated with mortality. Surprisingly, and contrary to our original hypotheses, myocardial fat was strongly associated with better survival, in patients both with and without prior MI. Our hypothesis was that LV fat in

Table 2 Characteristics of the cohort groups by ventricular myocardial fat status

	No MI group			MI group		
	Fat absent (n = 313)	Fat present (n = 377)	p value	Fat absent (n = 122)	Fat present (n = 143)	p value
Age	73.5 ± 11.3	73.8 ± 10.2	0.69	74.0 ± 11.3	73.6 ± 9.7	0.78
Female	195 (62.3)	257 (68.2)	0.11	54 (44.3)	61 (42.7)	0.79
Non-white race	229 (73.2)	241 (63.9)	0.01	83 (68.0)	87 (60.8)	0.22
Socioeconomic status[a]	-2.2 (-6.0, -1.0)	-1.8 (-5.1, -0.8)	0.05	-2.1 (-5.8, -1.0)	-2.2 (-5.4, -0.8)	0.65
Body mass index[b]	26.7 ± 7.4	26.6 ± 6.6	0.84	26.7 ± 7.2	26.8 ± 5.7	0.12
Hypertension	195 (62.3)	217 (57.6)	0.21	111 (91.0)	126 (88.1)	0.45
Coronary artery disease	56 (17.9)	40 (10.6)	0.006	N/A	N/A	N/A
Ordinal calcium score	2 (0,5)	3 (1,6)	0.04	N/A	N/A	N/A
Diabetes[c]	77 (28.1)	90 (27.4)	0.86	76 (62.8)	75 (53.6)	0.13
Stroke/TIA[c]	34 (12.4)	32 (9.8)	0.30	46 (38.0)	35 (25.0)	0.02
Peripheral vascular disease[c]	29 (10.6)	38 (11.6)	0.70	46 (38.0)	42 (30.0)	0.17
Congestive heart failure[c]	49 (17.9)	41 (12.5)	0.07	92 (76.0)	93 (66.4)	0.09
Statin prescription	92 (29.4)	117 (31.0)	0.22	109 (89.3)	119 (83.2)	0.15
Charlson score	4 (3, 6)	4 (3, 6)	0.34	8 (6, 11)	7 (6,9)	0.002
High detector row CT scanner	195 (62.3)	211 (56.0)	0.09	83 (68.0)	81 (56.6)	0.06
Inpatient/ED examination	165 (52.7)	122 (32.4)	<0.001	104 (85.3)	75 (52.5)	<0.001
Time since MI (months)	N/A	N/A	N/A	61.6 (47.5, 83.7)	66.4 (48.7, 86.9)	0.38
Total cholesterol (mg/dl)[d]	N/A	N/A	N/A	159 ± 47	164 ± 42	0.36
Overall mortality	144 (46.0)	133 (35.3)	0.004	100 (82.0)	90 (62.9)	0.001

CT computed tomography, MI myocardial infarction, N/A not applicable, TIA transient ischemic attack, ED emergency department, presented as mean ± SD, n (%), or median (interquartile range)

[a] Missing in 36 (5%) in the no MI group and in 13 (5%) in the MI group

[b] Missing in 124 (18%) of the no MI group and in 12 (5%) of the MI group

[c] Missing in 88 (13%) of the no MI group and in 4 (2%) of the MI group

[d] Missing in 18 (7%) of the MI group

Table 3 Multivariate logistic regression model for variables associated with ventricular myocardial fat

	Odds ratio	95% CI	*p* value
No MI group (n = 690)			
Non-white race	0.68	0.48-0.95	0.03
Coronary artery disease	0.52	0.33-0.83	0.005
Ordinal calcium score (per point)	1.07	1.01-1.12	0.02
Inpatient/ED examination (ref: outpatient)	0.42	0.31-0.57	< 0.001
MI group (n = 265)			
Charlson score (per point)	0.91	0.84-0.99	0.03
Inpatient/ED examination (ref: outpatient)	0.21	0.11-0.38	< 0.001

CI confidence interval, ED emergency department, MI myocardial infarction

patients without prior MI would indicate prior silent MI and would be associated with a higher mortality, approaching that of the MI group and similar to the mortality effect of silent MI on cardiac MRI [22]. The granular data also do not support this hypothesis. LV fat was not associated with traditional cardiovascular risk factors such as age, sex, obesity, hypertension, diabetes, stroke, or hyperlipidemia and far exceeded published estimates of silent MI in the general population [23, 24]. These results not only refute our hypothesis, but also suggest that another process is taking place.

RV fat was present in one-half of the no MI group and was also associated with better survival. LV and RV fat was highly correlated, suggesting the same physiologic process is occurring throughout the myocardium. These results support the role of myocardial fat as either intrinsically protective or as a biomarker of a protective physiologic process. The survival benefit associated with myocardial fat was even greater for patients with prior MI, in whom previous studies attributed fat to an infarct scar with the expectation of worsened prognosis [25]. While ischemic injury may be a cause of myocardial fat deposition, the present study suggests that this is not the predominant mechanism; it explains neither the high

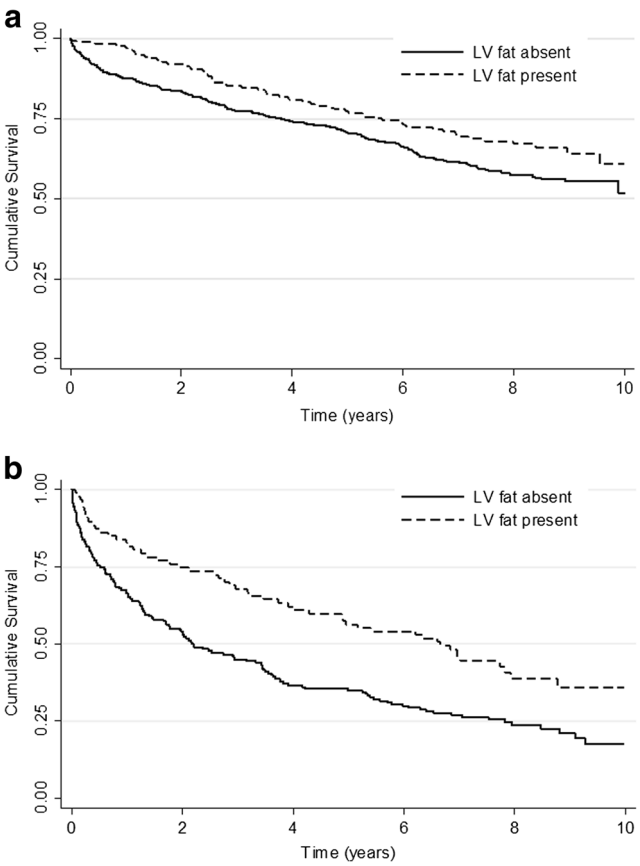

Fig. 4 Kaplan-Meier survival curves based on the presence of left ventricular (LV) myocardial fat in the no MI group (p = 0.025) (**a**) and in the MI group (p < 0.001) (**b**)

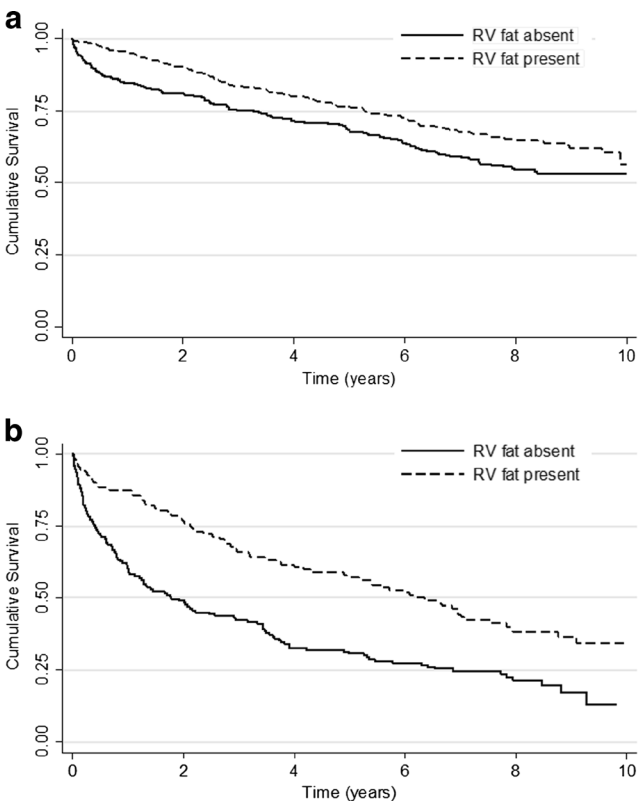

Fig. 5 Kaplan-Meier survival curves based on the presence of right ventricular (RV) fat in the no MI group (p < 0.001) (**a**) and in the MI group (p < 0.0001) (**b**)

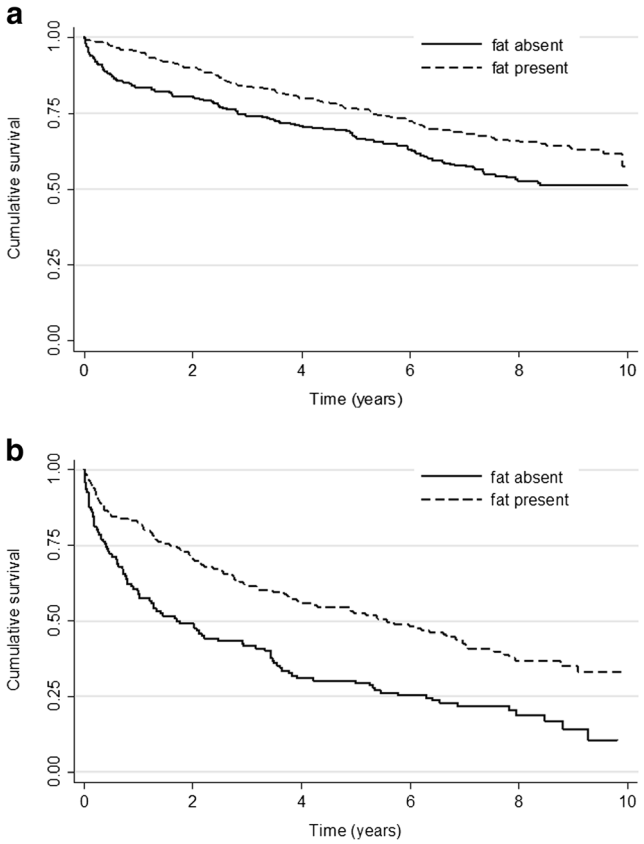

Fig. 6 Kaplan-Meier survival curves based on the presence of ventricular myocardial fat in either ventricle in the no MI group ($p = 0.007$) (**a**) and the MI group ($p < 0.0001$) (**b**)

prevalence of fat in the no MI group nor the better survival of patients with myocardial fat in both the no MI group and the MI group.

The active role of adipose tissue in systemic disease has been of great recent interest in the medical community, with development of a more nuanced understanding of the negative effects of adiposopathy [26]. Large observational studies demonstrated that excess pericardial adipose tissue is associated with obesity, dyslipidemia, diabetes, hypertension, and metabolic syndrome [27–29]. These studies have consistently found pericardial fat to be associated with coronary artery calcium [27, 28, 30, 31], and one study found an association with increased mortality [32]. Clearly, myocardial fat represents a distinct entity from pericardial fat as it lacks the associated comorbidities and is associated with lower rather than higher mortality.

The association of myocardial fat with better survival is supported by basic research, which has found that adipose tissue contains adipose-derived mesenchymal stem cells, which are multipotent and migrate to infarct border zones if infused intravenously within 3 hours of acute MI [33]. When infused, adipose-derived mesenchymal stem cells decrease the infarct size and improve LV function in animal models. Mesenchymal stem cells, particularly those derived from adipose tissue, could be a source of cells for repair of myocardial damage [26, 34, 35]. This may be true not only after an acute MI, but also for micro-injuries sustained over time. The association of myocardial fat with a higher calcium score and, paradoxically, less documented CAD in our no MI group provides supportive evidence that low-level ischemic changes augment the development of adipose depots and prevent development of clinically meaningful CAD.

We found that myocardial fat improved patient risk stratification compared with the ordinal calcium score and Charlson comorbidity score. Direct comparison with widely used risk assessment models, such as the Framingham Risk Score, will be necessary in the future.

Limitations of the present study include incomplete serum lipid data, blood pressure measurements, and smoking status

Table 4 Cox proportional hazard analysis to determine association with all-cause mortality

	Hazard ratio	95% CI	*p* value
No MI group ($n = 602$)			
Ventricular fat	0.75	0.58-0.99	0.04
Age (per year)	1.06	1.05-1.08	< 0.001
Female sex (ref: male)	0.57	0.43-0.74	< 0.001
Inpatient/ED examination (ref: outpatient)	1.94	1.48-2.55	< 0.001
Ordinal Calcium Score (per point)	1.09	1.04-1.13	< 0.001
Congestive heart failure	1.88	1.39-2.54	< 0.001
MI group ($n = 261$)			
Ventricular fat	0.69	0.51-0.94	0.02
Age (per year)	1.03	1.02-1.04	< 0.001
Inpatient/ED examination (ref: outpatient)	1.61	1.12-2.31	0.01
Congestive heart failure	2.02	1.38-2.96	< 0.001
Chronic kidney disease	1.91	1.40-2.60	< 0.001

CI confidence interval, ED emergency department, MI myocardial infarction

for the no MI group, precluding inclusion in the multivariable analysis. Patients with chronically mildly elevated serum troponin levels were excluded. We lacked detailed data regarding the severity of the prior MI, including the vascular territory and cardiac function, prior to and during the admission and after recovery from the event. Additionally, a small proportion of patients (about 7%) were of unknown ethnicity or race. This study included patients 50 years of age or older, which limits the application of our findings to younger populations. This examination did not specifically study patients with other known causes of myocardial fat deposition such as lipodystrophy and arrhythmogenic right ventricular cardiomyopathy. Our analysis of ordinal calcium scores is not directly comparable to quantitative Agatston scores. Variation in the CT scanner type and imaging protocol and lack of cardiac gating allowed only qualitative visual evaluation and precluded a more standardized quantitative assessment of attenuation and volume, which will certainly be necessary in further studies including diagnostic criteria based on Hounsfield unit measurements. However, routine non-contrast chest CTs are used clinically with great frequency in the evaluation of numerous conditions, making this finding one that can be widely reported and therefore generalizable to a larger population.

The present study, to our knowledge, is the first to examine the association between myocardial fat and all-cause mortality. The large cohort size, 10-year follow-up period, and substantial mortality yielded a sufficiently powered analysis. The diversity of the US population is mirrored in this cohort, with white, black, and Hispanic subgroups well represented.

Ventricular myocardial fat is common, not related to traditional cardiovascular risk factors, and improves risk stratification compared with the ordinal calcium score and Charlson score. Myocardial fat on non-contrast chest CT is unexpectedly associated with better survival for both patients with and without a history of prior MI and may provide independent, clinically meaningful prognostic value.

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Compliance with ethical standards

Guarantor The scientific guarantor of this publication is Dr. Anna S. Bader.

Conflict of interest The authors of this manuscript declare relationships with the following companies: The spouse of L.B.H. is a board member of Kryon.

Statistics and biometry One of the authors has significant statistical expertise.

Informed consent The requirement for written informed consent was waived by the Institutional Review Board.

Ethical approval Institutional Review Board approval was obtained.

Methodology
- retrospective
- observational
- performed at one institution

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