Milano - 17 - 19 giugno 2009
3° Congresso Nazionale di Ecocardiochirurgia

Avviciniamoci a TC e RM

…per renderci conto di quanto siamo naturalmente vicini a queste metodiche

Cosa scegliere per caratterizzare il tessuto: peculiarità e limiti dell'eco 2D, TC e RM.

L. Cacciavillani
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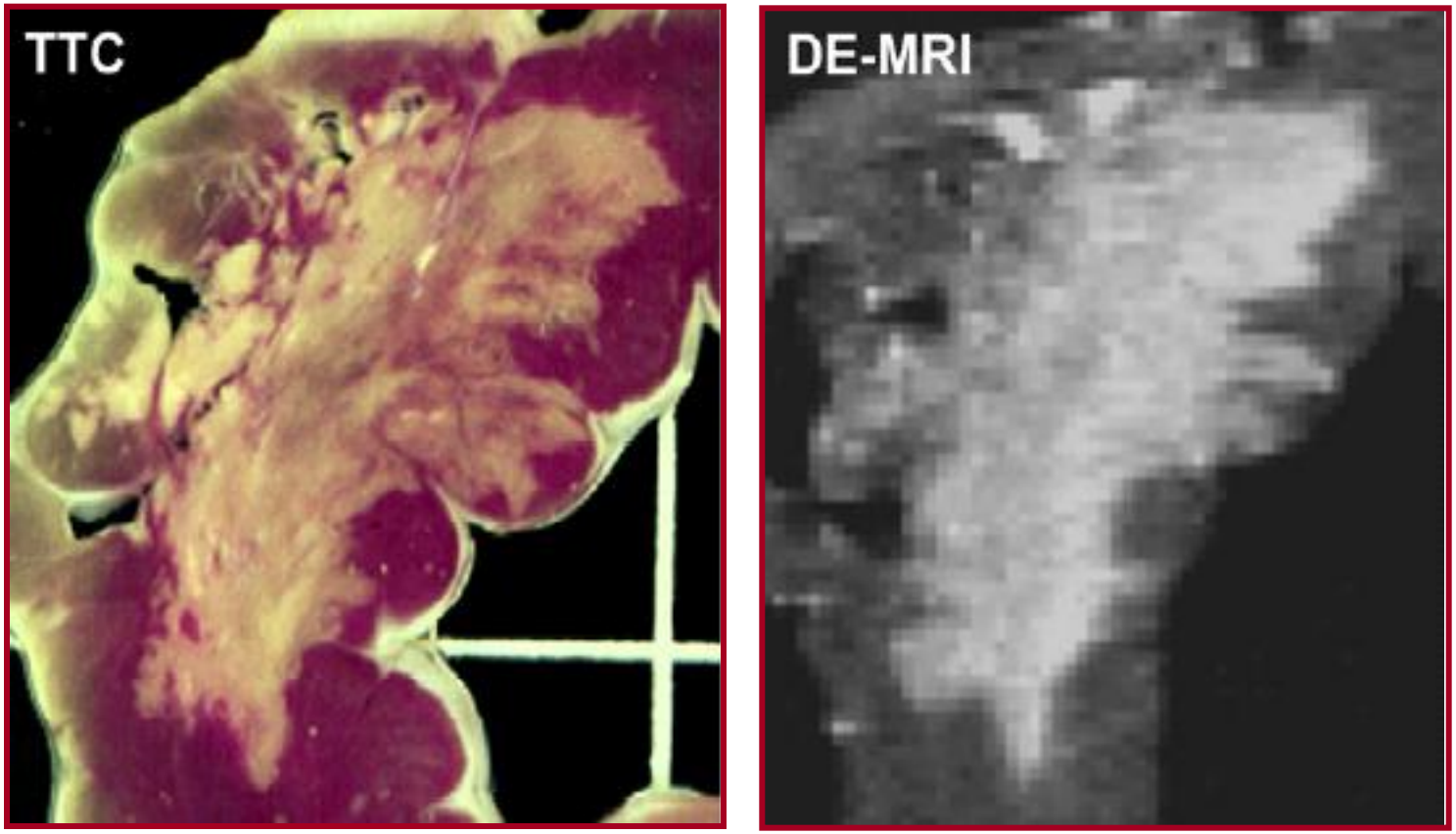
Avviciniamoci a TC e RM….

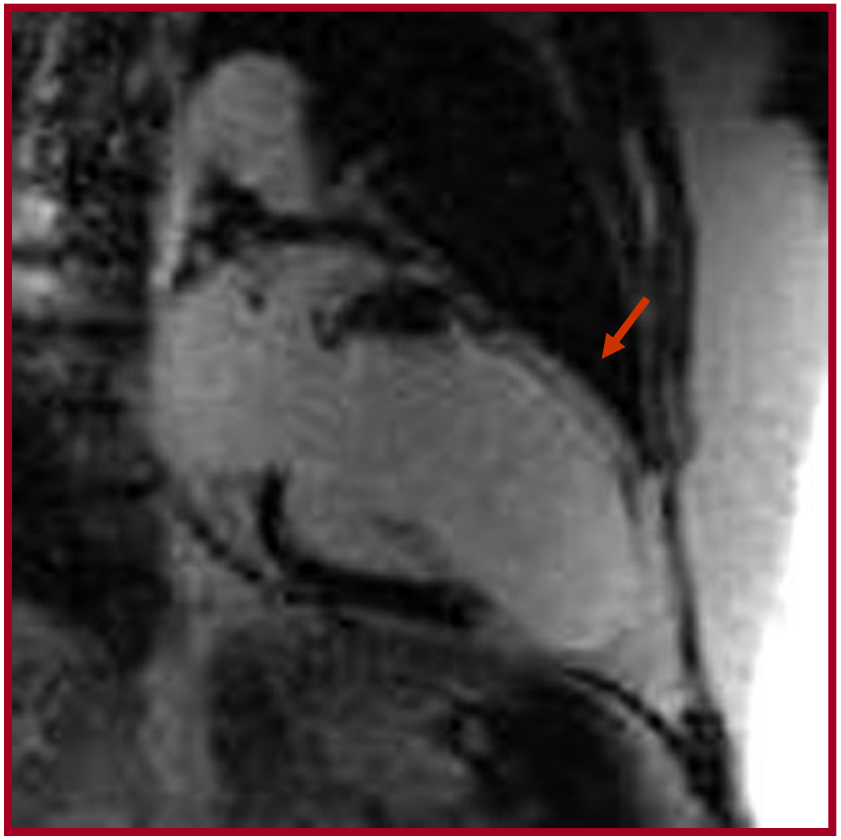
Cosa scegliere per caratterizzare il tessuto:

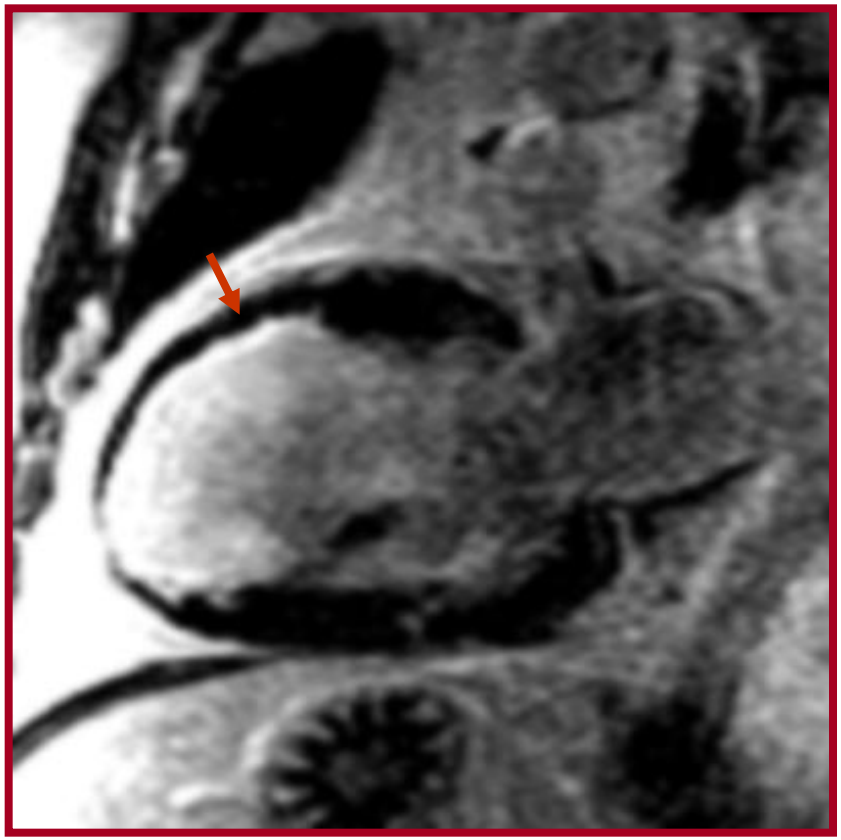
- Ischemic and Primary Dilated Cardiomyopathy

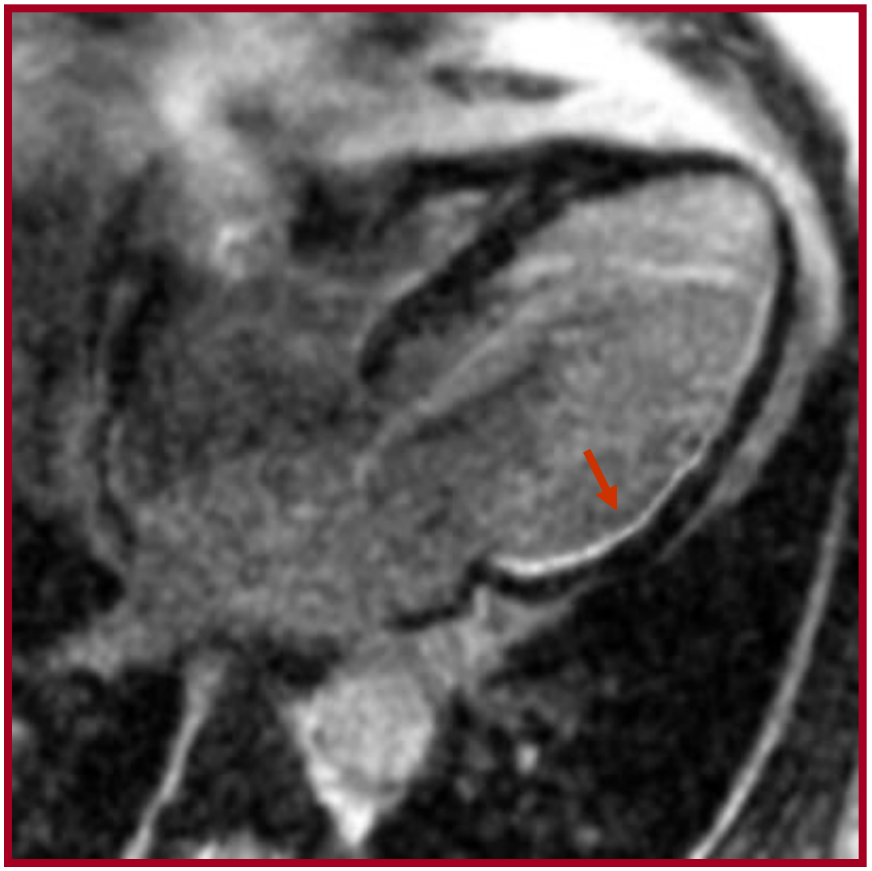
CONTRAST ENHANCED MRI

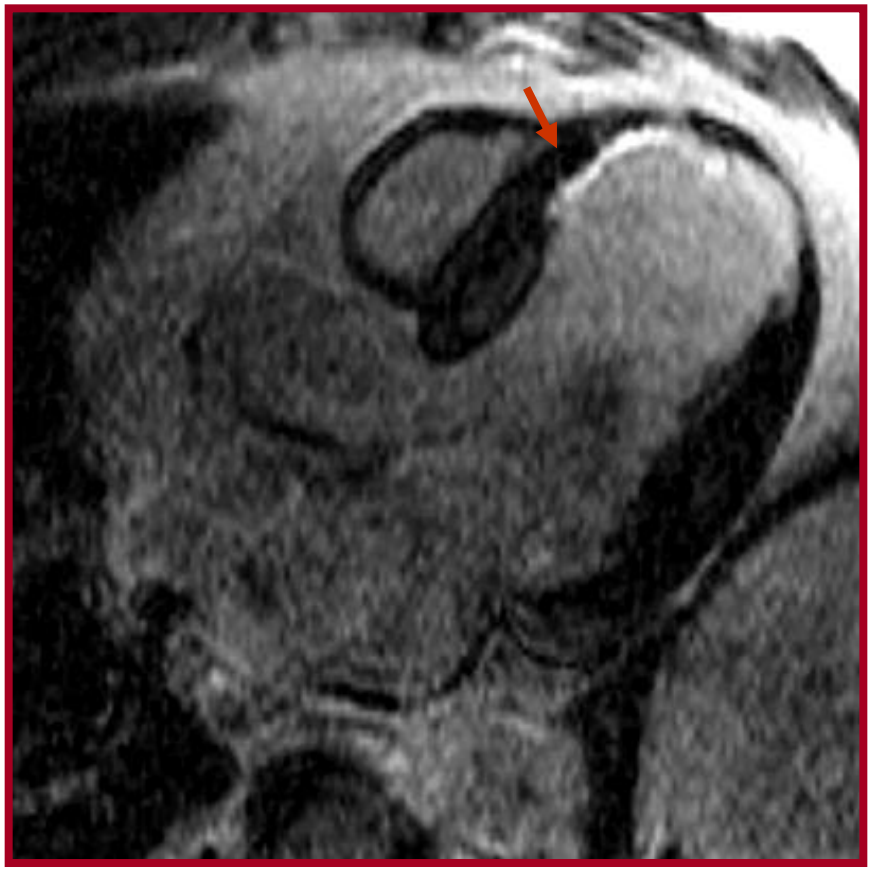
Kim et al Circulation. 1999;100:1992-2002





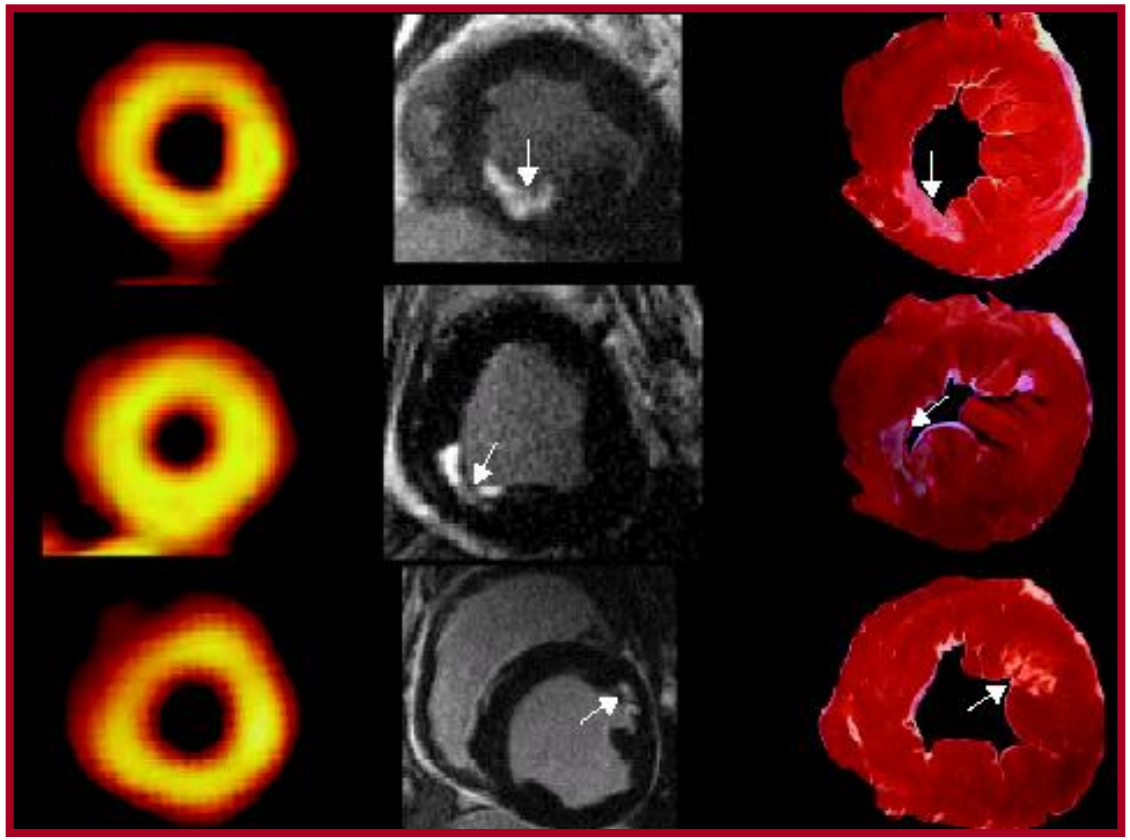






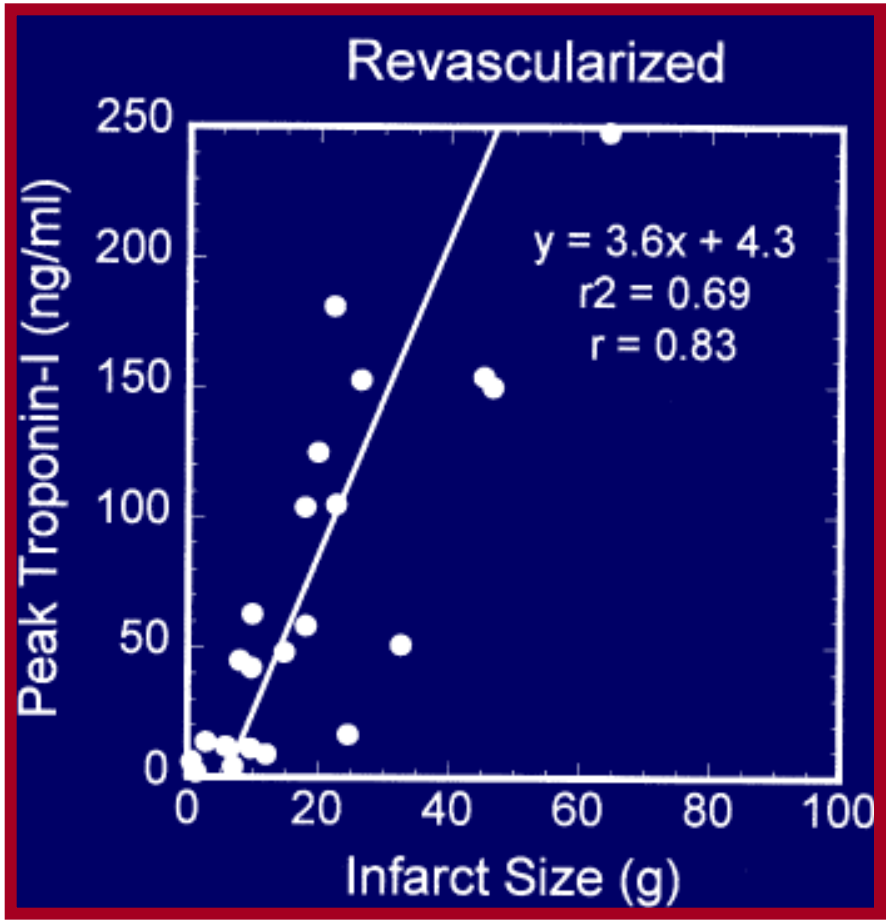
MRI vs SPECT for detection of subendocardial myocardial infarcts

Anja Wagner; *Lancet 2003; 361: 374-79*



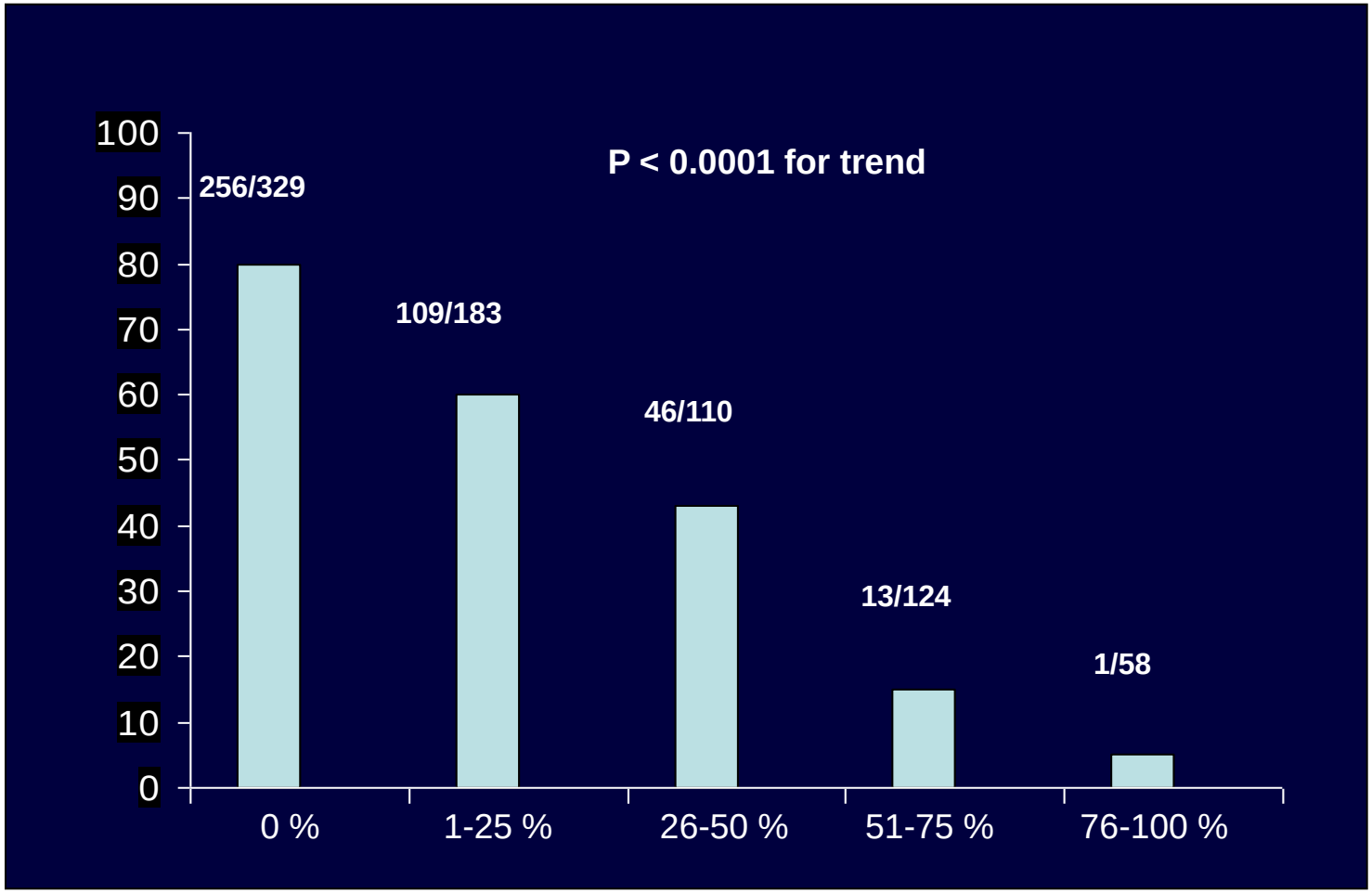
Relationship of infarct size by MRI to peak Troponin I

W. Patricia Ingkanisorn, J Am Coll Cardiol 2004;43:2253–9



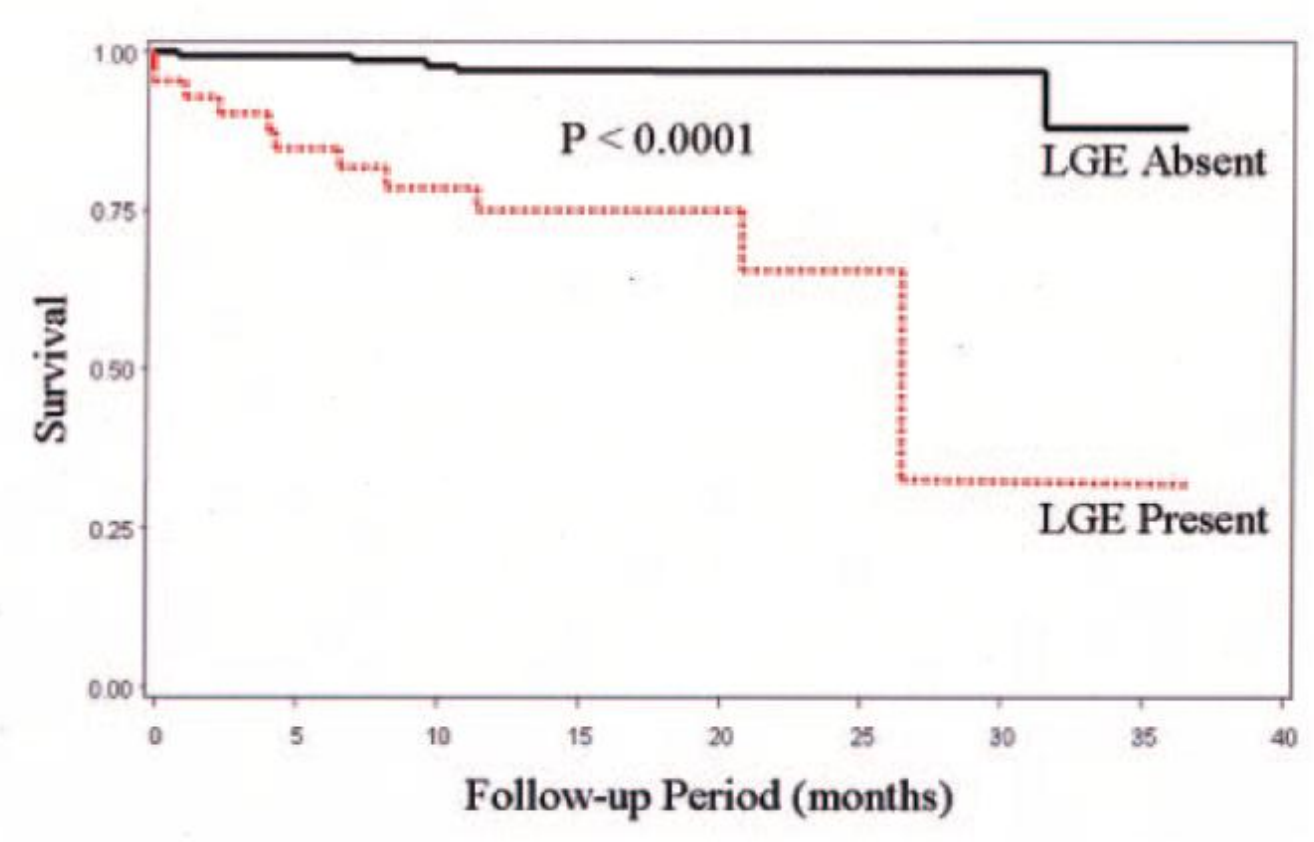
Prediction of Wall Motion Improvement

Raymond J. Kim; NEJM 2000;343:1445-53



IMPACT OF UNRECOGNIZED MYOCARDIAL SCAR DETECTED BY CMRI ON SURVIVAL

Circulation. 2006;113:2733-2743



Kaplan-Meier curves for cardiac mortality

Contrast-enhanced cardiovascular magnetic resonance in primary and ischemic dilated cardiomyopathy

Chiara Calore[a], Luisa Cacciavillani[a], Giovanni Maria Boffa[a], Caterina Silva[a], Enrico Tiso[a], Martina Perazzolo Marra[a], Enrico Bacchiega[a], Francesco Corbetti[b] and Sabino Iliceto[a]

Objectives Differentiation between primary dilated cardiomyopathy and ischemic cardiomyopathy has an important clinical significance. Contrast-enhanced cardiovascular magnetic resonance can play a role in this task, identifying myocardial scarring or fibrosis as presence of delayed enhancement. The aim of the present study was to evaluate the diagnostic potential of contrast-enhanced cardiovascular magnetic resonance in differentiating dilated cardiomyopathy from ischemic cardiomyopathy.

Methods Contrast-enhanced cardiovascular magnetic resonance was performed in 100 patients with left ventricular dilatation and reduced systolic function: 24 had normal coronary arteries (dilated cardiomyopathy group) and 76 had significant coronary artery disease (ischemic cardiomyopathy group), with or without previous myocardial infarction.

Results In the dilated cardiomyopathy group, only seven (29%) patients showed delayed enhancement and its pattern was characterized by mid-wall, patchy or diffuse location. All patients with ischemic cardiomyopathy and prior myocardial infarction (54 subjects) showed delayed enhancement with subendocardial ($n = 4$) or transmural ($n = 50$) extension. Among the 22 patients with ischemic cardiomyopathy but without previous myocardial infarction, 13 (59%) showed either subendocardial ($n = 4$) or transmural ($n = 9$) delayed enhancement.

Conclusions Patterns of delayed enhancement are different in dilated cardiomyopathy and ischemic cardiomyopathy, reflecting the presence of scarring or various degrees of fibrosis in left ventricular myocardium. The presence of subendocardial or transmural delayed enhancement at contrast-enhanced cardiovascular magnetic resonance allowed distinction between dilated cardiomyopathy and ischemic cardiomyopathy with high sensitivity (88%) and specificity (100%). Integration of cardiovascular magnetic resonance results with angiographic information can be useful in the identification of pathogenic mechanisms underlying left ventricular dysfunction. *J Cardiovasc Med* 8:821–829 © 2007 Italian Federation of Cardiology.

Journal of Cardiovascular Medicine 2007, 8:821–829

Keywords: cardiovascular magnetic resonance, ischemic cardiomyopathy, primary cardiomyopathy

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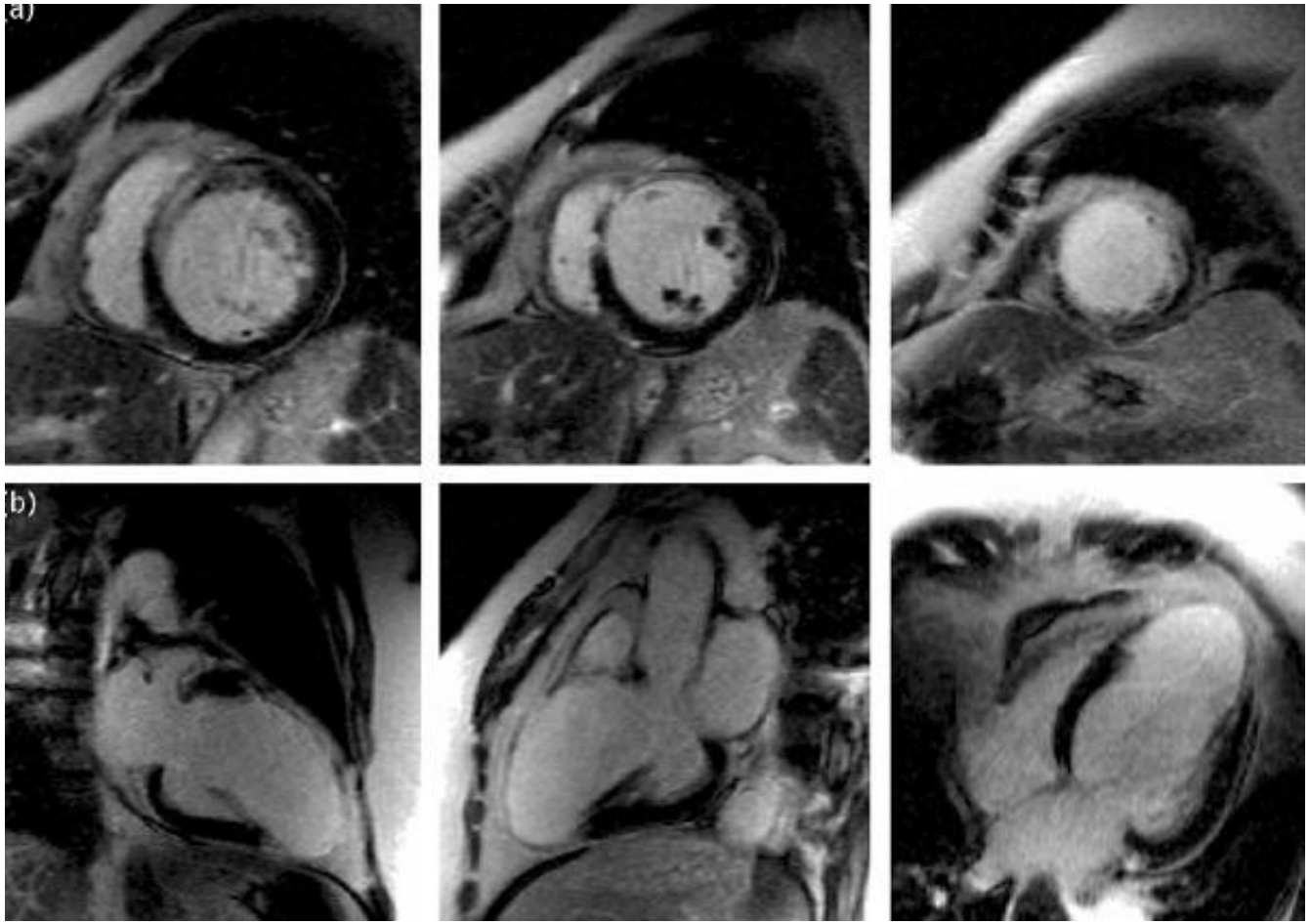
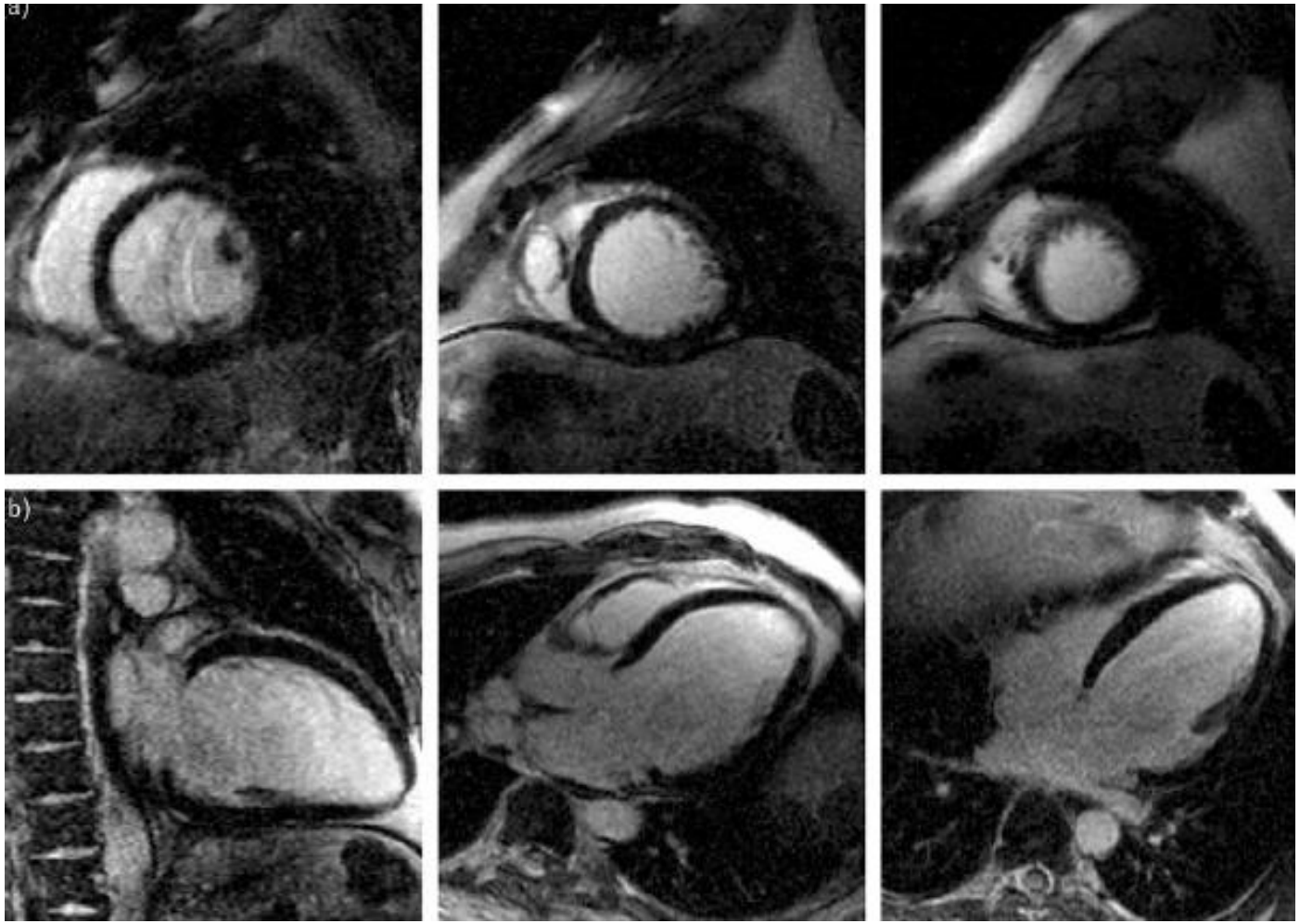
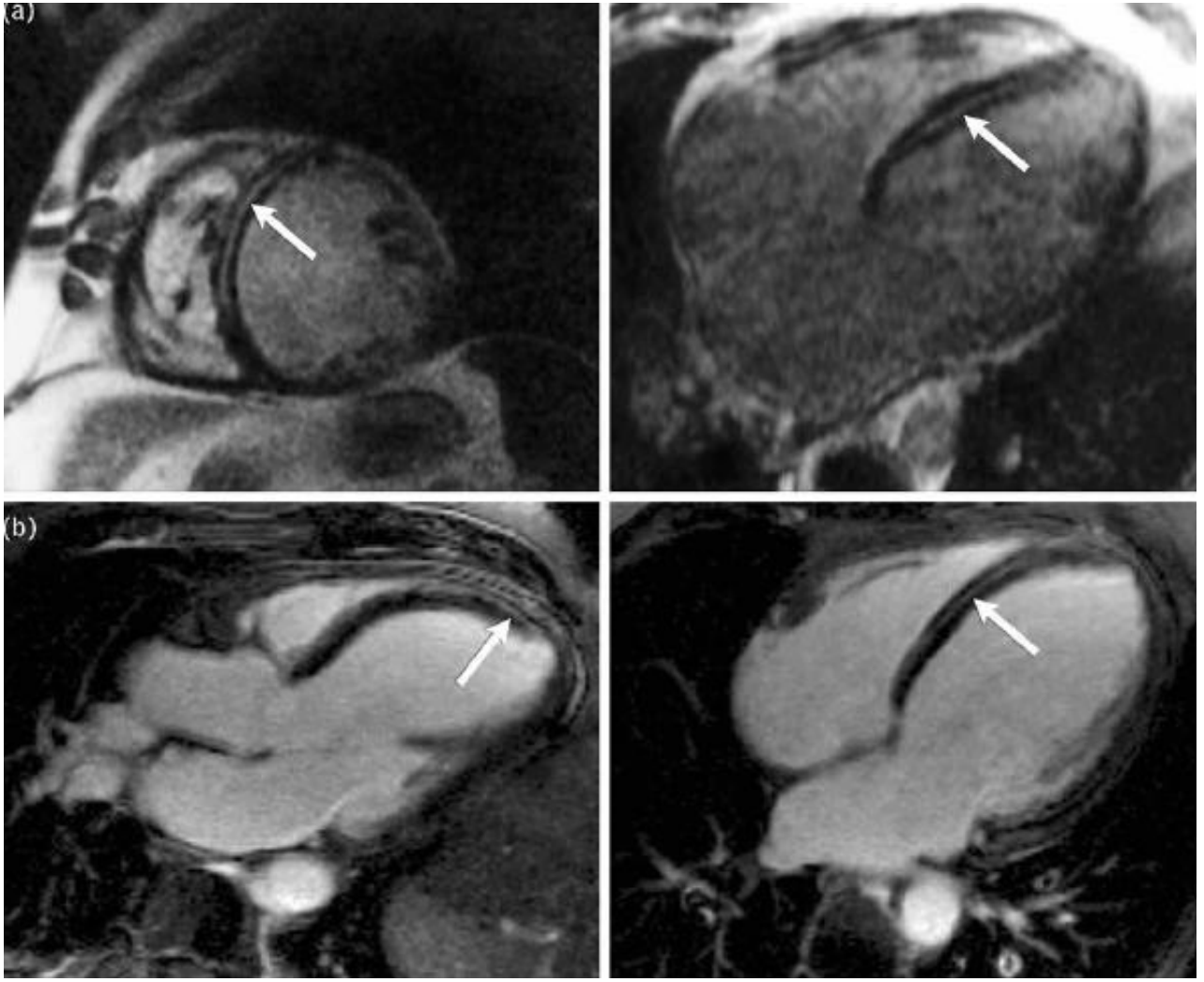
Received 23 June 2006 Accepted 9 August 2006



Ischemic cardiomyopathies secondary to symptomatic or silent MI show subendocardial or transmural LE extension.

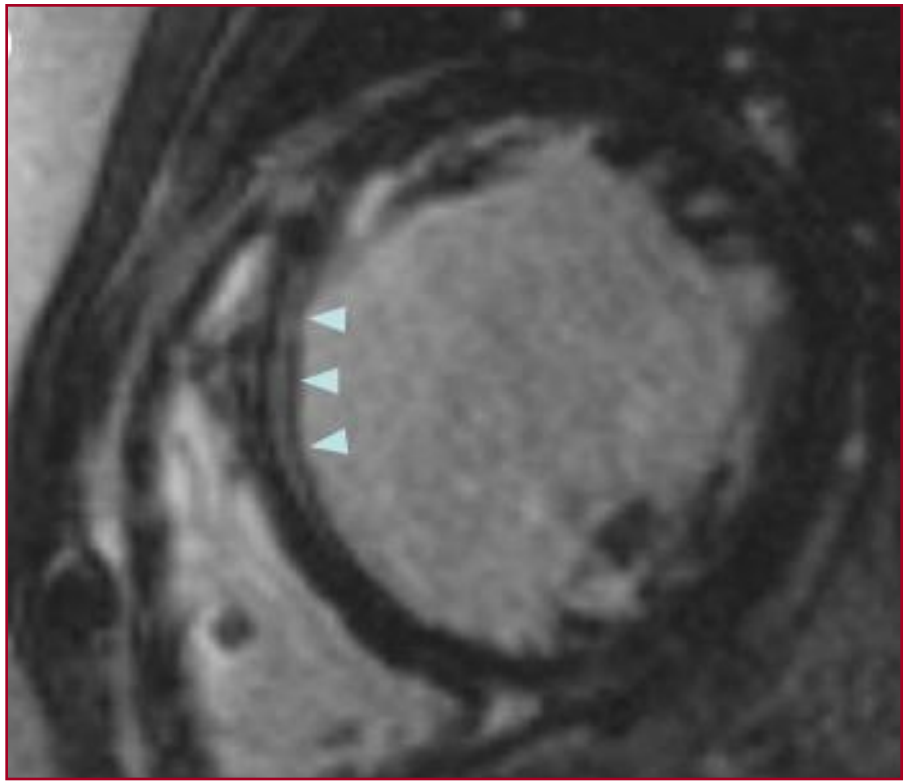


Primary dilated cardiomyopathies are characterized by absence or atypical patterns of LE, reflecting various grade of myocardial fibrosis



Primary dilated cardiomyopathies are characterized by absence or **atypical** patterns of LE, reflecting various grade of myocardial fibrosis

Typical pattern for idiopathic DCM : a mid ventricular rim of hyperenhancement



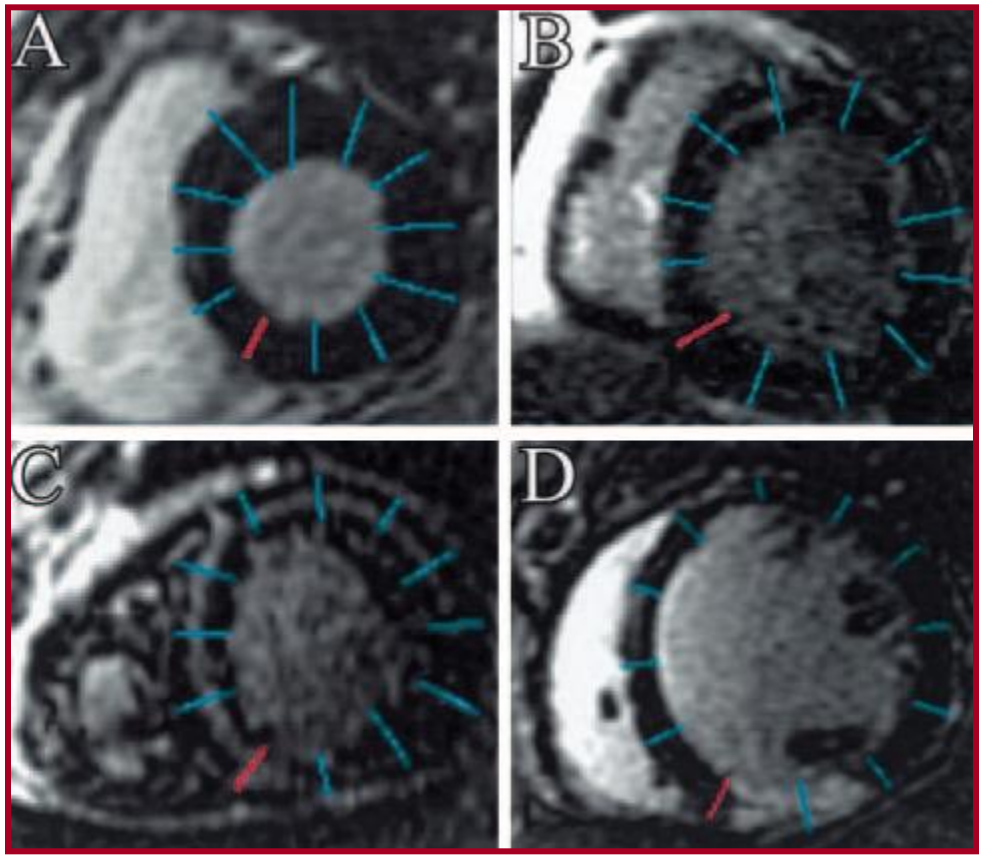
- The presence hyperenhancement has been shown to be an independent predictor of all cause mortality and the onset of potentially life threatening ventricular arrhythmias

Heart ONLINE

The use of cardiac magnetic resonance imaging to determine the aetiology of left ventricular disease and cardiomyopathy

Magnetic Resonance Assessment of the Substrate for Inducible Ventricular Tachycardia in Nonischemic Cardiomyopathy

Scar distribution and high risk of arrhythmia



Scar distribution may identify a subset of patients with mild to moderate left ventricular dysfunction and high risk of arrhythmia
not currently identified for ICD implantation

Circulation. 2005;112:2821-2825

Late Gadolinium Enhancement by Cardiovascular Magnetic Resonance Heralds an Adverse Prognosis in Nonischemic Cardiomyopathy

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Baltimore, Maryland

Objectives We examined whether the presence and extent of late gadolinium enhancement (LGE) by cardiovascular magnetic resonance (CMR) predict adverse outcomes in nonischemic cardiomyopathy (NICM) patients.

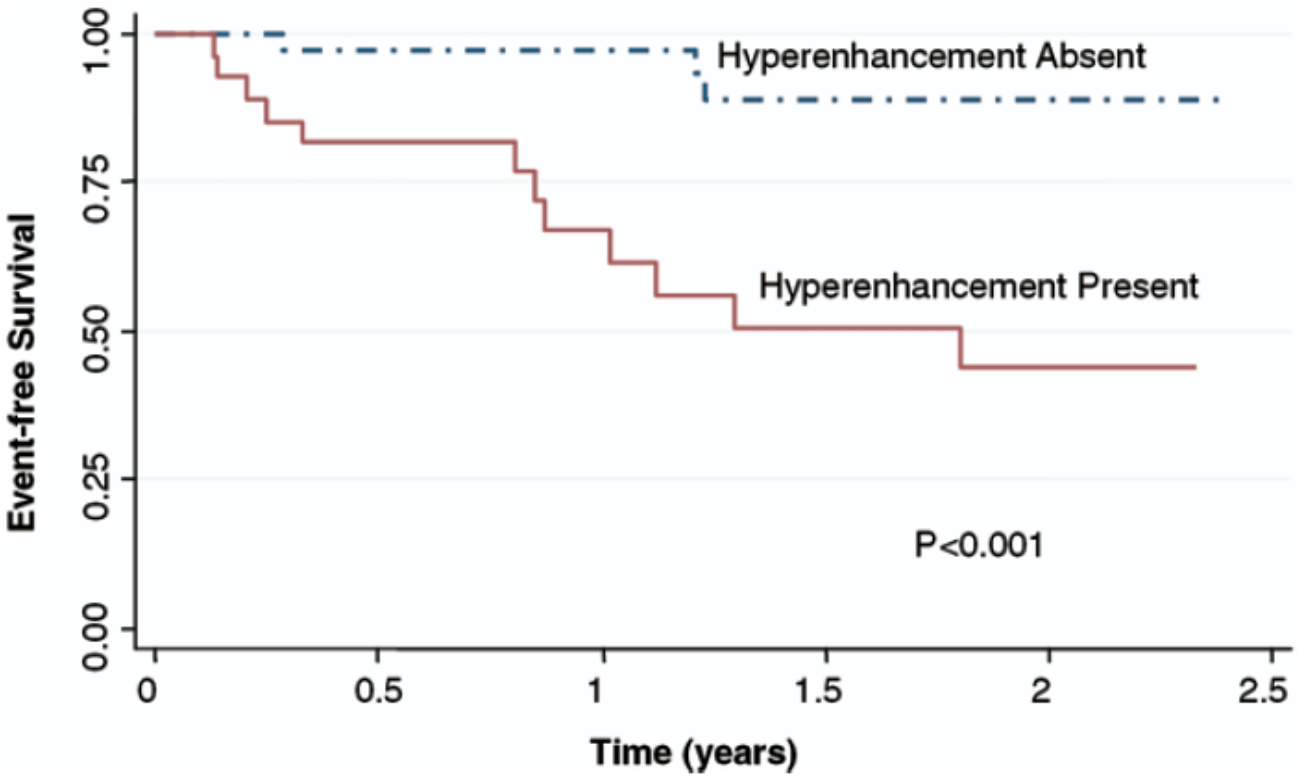
Background Morbidity and mortality is high in NICM patients. However, the clinical course of an individual patient is unpredictable and current risk stratification approaches are limited. Cardiovascular magnetic resonance detects myocardial fibrosis, which appears as LGE after contrast administration and may convey prognostic importance.

Methods In a prospective cohort study, 65 NICM patients with left ventricular (LV) ejection fraction ≤35% underwent CMR before placement of an implantable cardioverter-defibrillator (ICD) for primary prevention of sudden cardiac death. The CMR images were analyzed for the presence and extent of LGE and for LV function, volumes, and mass. Patients were followed for an index composite end point of 3 cardiac events: hospitalization for heart failure, appropriate ICD firing, and cardiac death.

Results A total of 42% (n = 27) of patients had CMR LGE, averaging 10 ± 13% of LV mass. During a 17-month median follow-up, 44% (n = 12) of patients with LGE had an index composite outcome event versus only 8% (n = 3) of those without LGE ($p < 0.001$ for Kaplan-Meier survival curves). After adjustment for LV volume index and functional class, patients with LGE had an 8-fold higher risk of experiencing the primary outcome (hazard ratio 8.2, 95% confidence interval 2.2 to 30.9; p = 0.002).

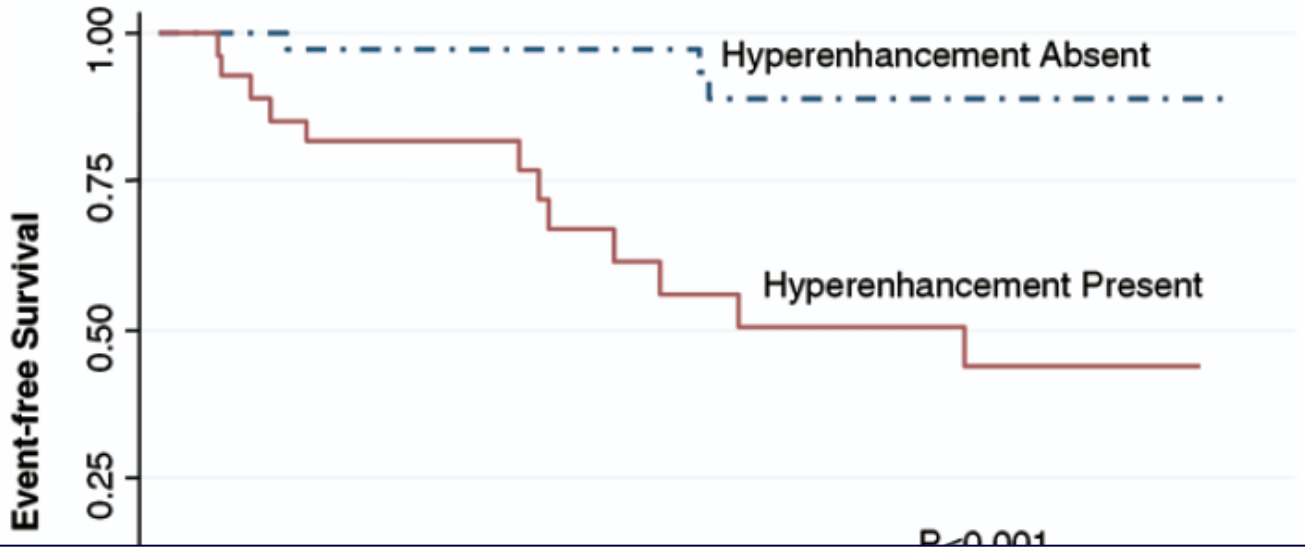
Conclusions A CMR LGE in NICM patients strongly predicts adverse cardiac outcomes. The CMR LGE may represent the end-organ consequences of sustained adrenergic activation and adverse LV remodeling, and its identification may significantly improve risk stratification strategies in this high risk population. (Imaging Techniques for Identifying Factors of Sudden Cardiac Death Risk; NCT00181233) (J Am Coll Cardiol 2008;51:2414–21) © 2008 by the American College of Cardiology Foundation

CMR and Prognosis in Nonischemic Cardiomyopathy



Kaplan-Meier Event-Free Survival Curve for the Occurrence of an Index Composite Event

CMR and Prognosis in Nonischemic Cardiomyopathy



After adjustment for LV volume index and functional class, patients with LGE had an 8-fold higher risk of experiencing cardiac death (sudden and nonsudden), ICD firing, and HF.

Kaplan-Meier Event-Free Survival Curve for the Occurrence of an Index Composite Event

Delayed-Enhanced Magnetic Resonance Imaging in Nonischemic Cardiomyopathy

Utility for Identifying the Ventricular Arrhythmia Substrate

Frank M. Bogun, MD, Benoit Desjardins, MD, PHD, Eric Good, DO, Sanjaya Gupta, MD, Thomas Crawford, MD, Hakan Oral, MD, Matthew Ebinger, DO, Frank Pelosi, MD, Aman Chugh, MD, Krit Jongnarangsin, MD, Fred Morady, MD

Ann Arbor, Michigan

Objectives The purpose of this study was to assess the value of delayed-enhanced magnetic resonance imaging (DE-MRI) to guide ablation of ventricular arrhythmias in patients with nonischemic cardiomyopathy (NIC).

Background In patients with NIC, ventricular arrhythmias often are associated with scar tissue. DE-MRI can be used to precisely define scar tissue.

Methods DE-MRI was performed in 29 consecutive patients (mean age 50 ± 15 years) with NIC (mean ejection fraction 37 ± 9%) referred for catheter ablation of ventricular tachycardia (VT) or premature ventricular complexes (PVCs). Scar was extracted from DE-MRIs and was then integrated into the electroanatomic map. Mapping data were correlated with respect to the localization of scar tissue.

Results Scar was identified by DE-MRI in 14 of 29 patients. Nine of these patients had VT and 5 had PVCs. In 5 of the patients there was predominantly endocardial scar, and mapping and ablation of arrhythmias was effectively performed from the endocardium in all 5 patients. In 2 patients scar was either intramural or epicardial with extension to the endocardium. In both patients with partial endocardial scar extension, the ablation was effective in eliminating some but not all arrhythmias. In 2 patients most of the scar tissue was confined to the epicardium; mapping identified and eliminated an epicardial origin in both patients. No effect on arrhythmias could be achieved in the other 5 patients with predominantly intramural scar.

Conclusions DE-MRI in patients without prior infarctions can help to identify the arrhythmogenic substrate; furthermore, it helps to plan an appropriate mapping and ablation strategy. (J Am Coll Cardiol 2009;53:1138–45)

Delayed-Enhanced Magnetic Resonance Imaging in Nonischemic Cardiomyopathy

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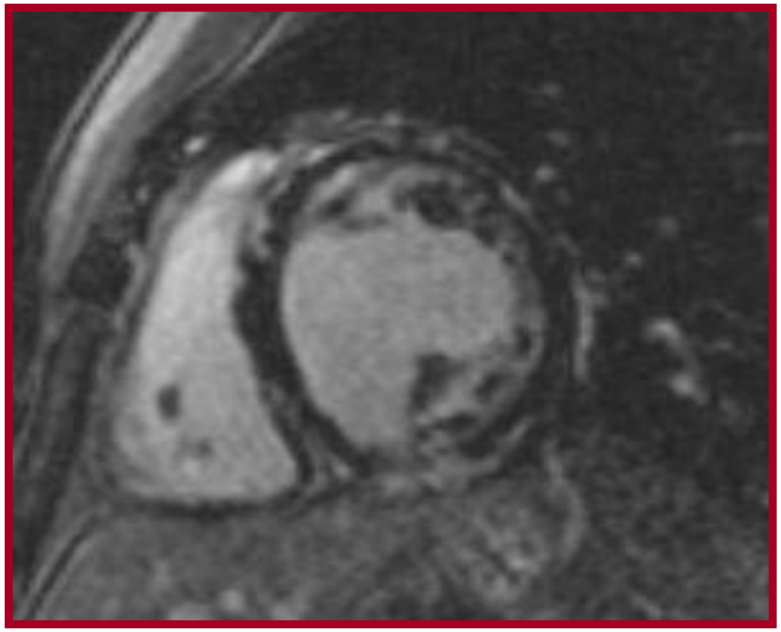
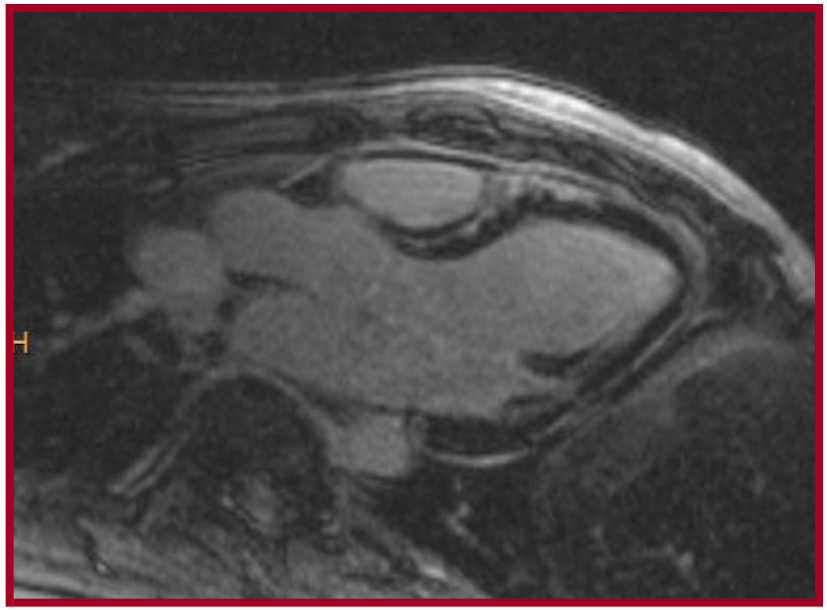
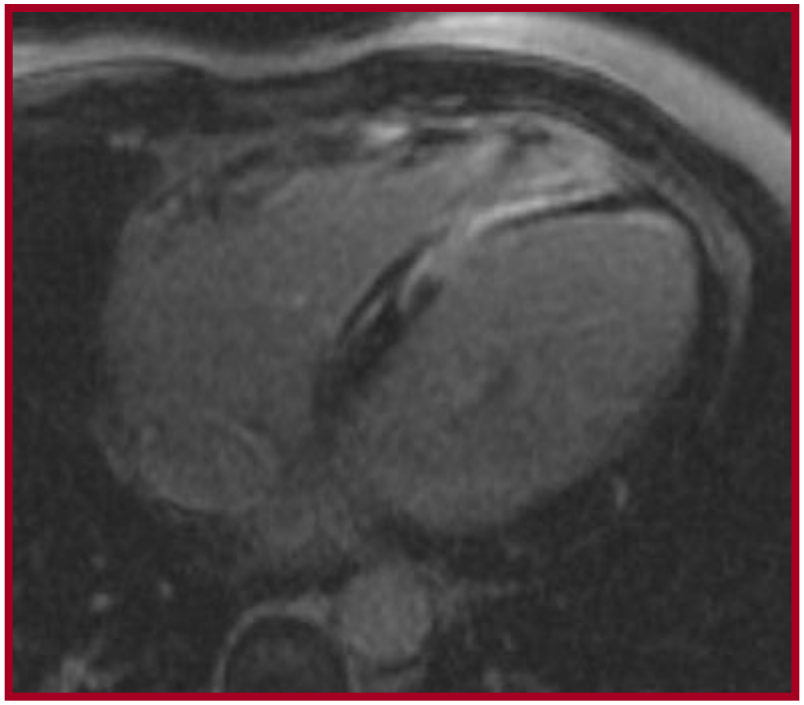
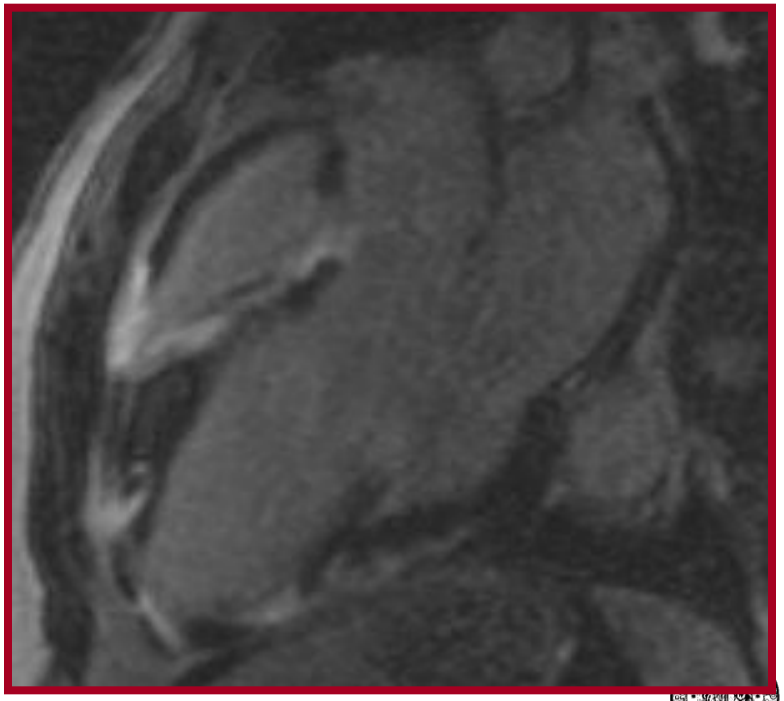
There may be a threshold of scar volume above which re-entrant VT is likely to occur









Delayed Enhancement Magnetic Resonance Imaging Predicts Response to Cardiac Resynchronization Therapy in Patients With Intraventricular Dyssynchrony

James A. White, MD,* Raymond Yee, MD,* Xiaping Yuan, PHD,† Andrew Krahn, MD,* Allan Skanes, MD,* Michele Parker, MS,‡ George Klein, MD,* Maria Drangova, PHD†§

London, Ontario, Canada; and Durham, North Carolina

OBJECTIVES We evaluated the ability of delayed enhancement magnetic resonance imaging (DE-MRI) to predict clinical response to cardiac resynchronization therapy (CRT).

BACKGROUND Cardiac resynchronization therapy reduces morbidity and mortality in selected heart failure patients. However, up to 30% of patients do not have a response. We hypothesized that scar burden on DE-MRI predicts response to CRT.

METHODS The DE-MRI was performed on 28 heart failure patients undergoing CRT. Patients with QRS ≥120 ms, left ventricular ejection fraction ≤35%, New York Heart Association functional class II to IV, and dyssynchrony ≥60 ms were studied. Baseline and 3-month clinical follow-up, wall motion, 6-min walk, and quality of life assessment were performed. The DE-MRI was performed 10 min after 0.20 mmol/kg intravenous gadolinium. Scar measured by planimetry was correlated with response criteria.

RESULTS Twenty-three patients completed the protocol (mean age 64.9 ± 11.7 years), with 12 (52%) having a history of myocardial infarction. Thirteen (57%) patients met response criteria. Percent total scar was significantly higher in the nonresponse versus response group (median and interquartile range of 24.7% [18.1 to 48.7] vs. 1.0% [0.0 to 8.7], $p = 0.0022$) and predicted nonresponse by receiver-operating characteristic analysis (area = 0.94). At a cutoff value of 15%, percent total scar provided a sensitivity and specificity of 85% and 90%, respectively, for clinical response to CRT. Similarly, septal scar ≤40% provided a 100% sensitivity and specificity for response. Regression analysis showed linear correlations between percent total scar and change in each of the individual response criteria.

CONCLUSIONS The DE-MRI accurately predicted clinical response to CRT. This technique offers unique information in the assessment of patients referred for CRT. (J Am Coll Cardiol 2006;48: 1953–60) © 2006 by the American College of Cardiology Foundation

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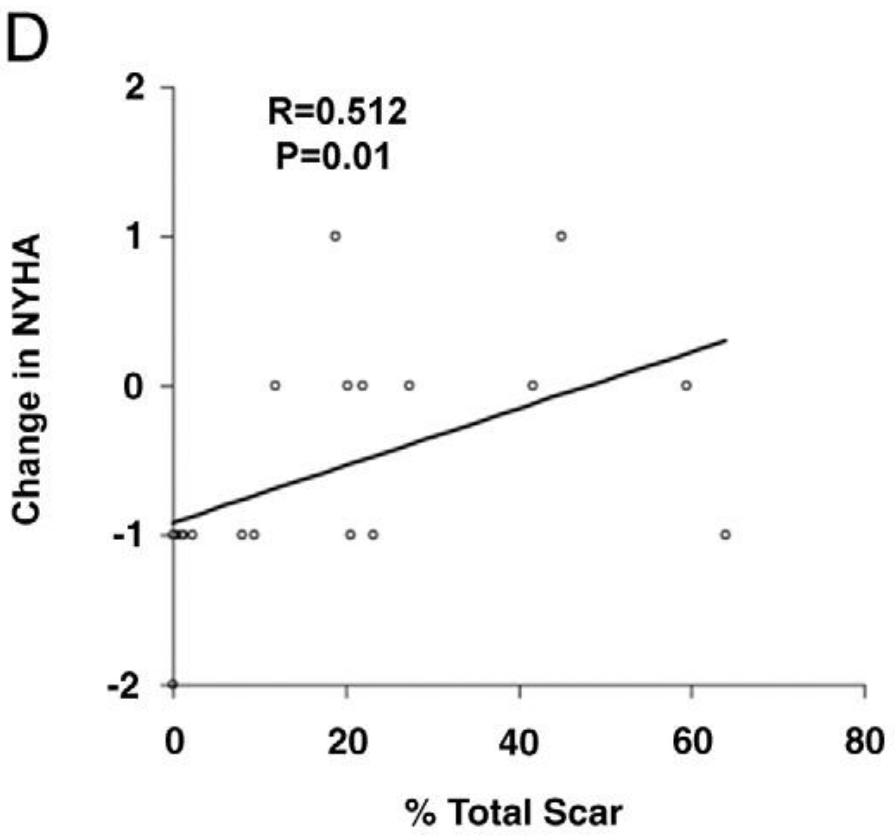
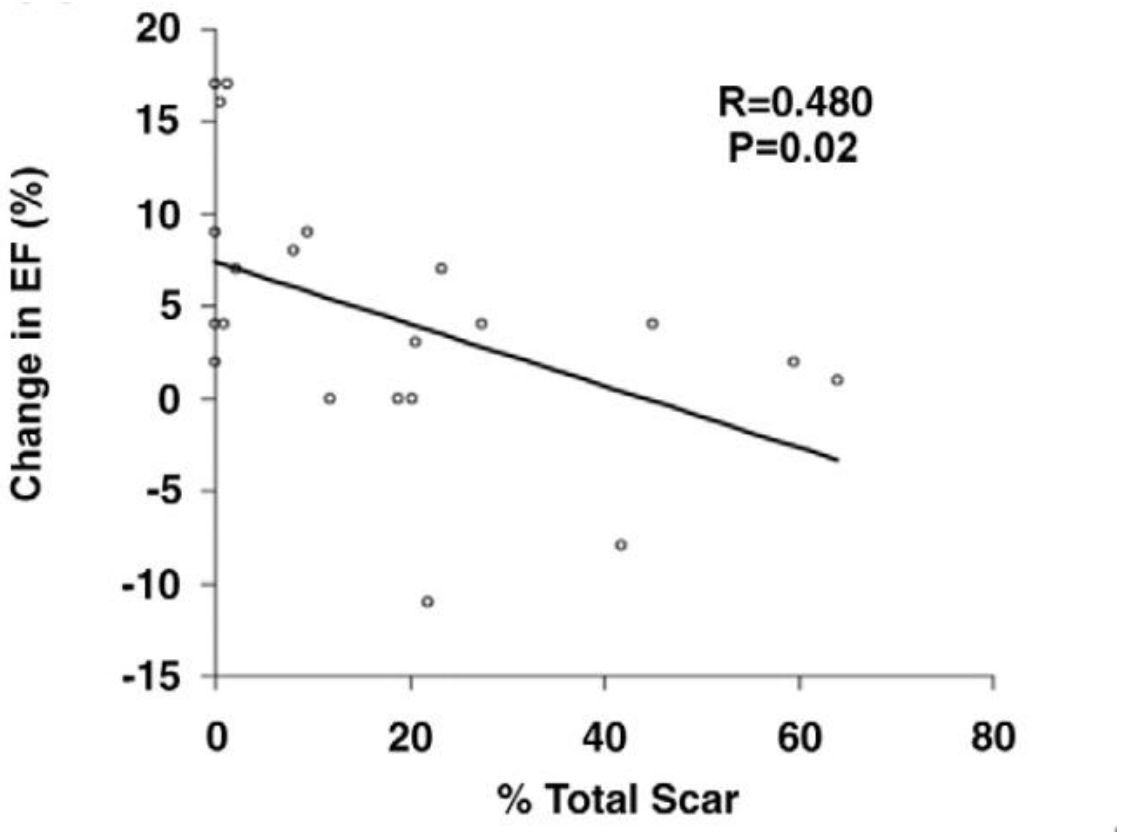


Linear regression plots showing the relationship between total percent scar and change in NYHA functional class at follow-up.

The DE-MRI accurately predicted clinical response to CRT.



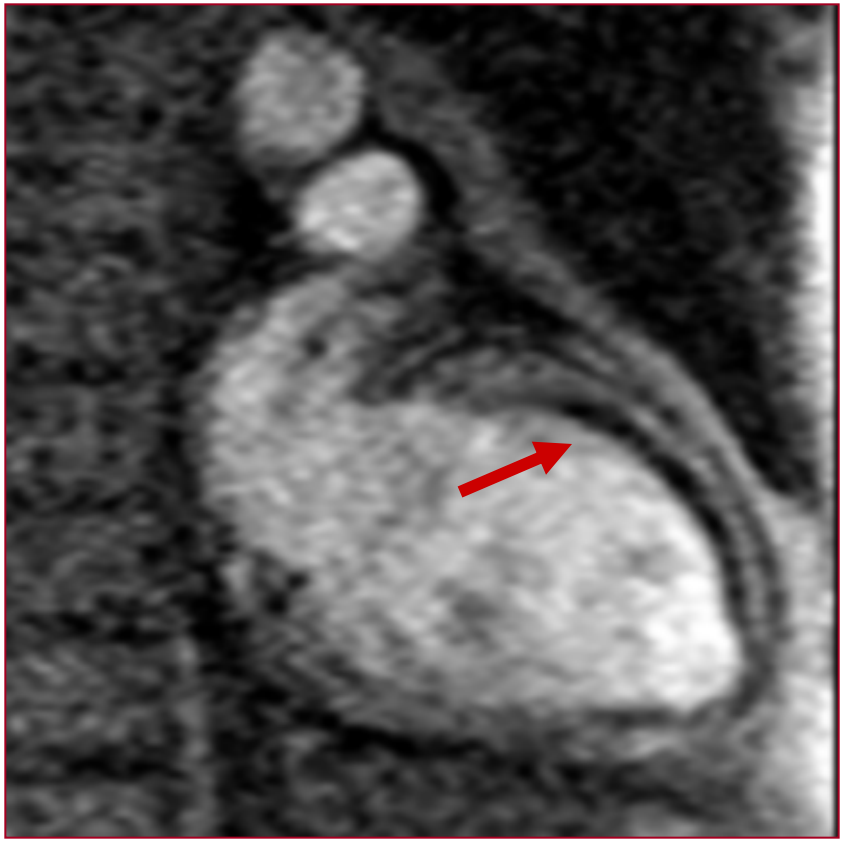
Linear regression plots showing the relationship between total percent scar and change in left ventricular ejection fraction

Avviciniamoci a TC e RM….

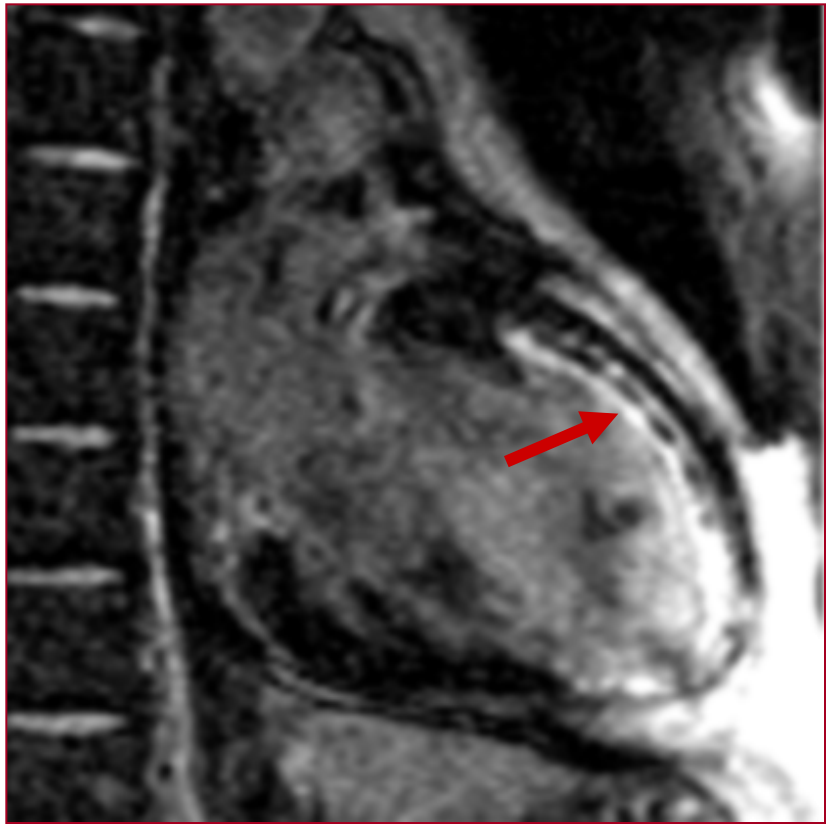
Cosa scegliere per caratterizzare il tessuto:

- Ischemic and Primary Dilated Cardiomyopathy
- Acute Myocardial Infarction

FIRST-PASS

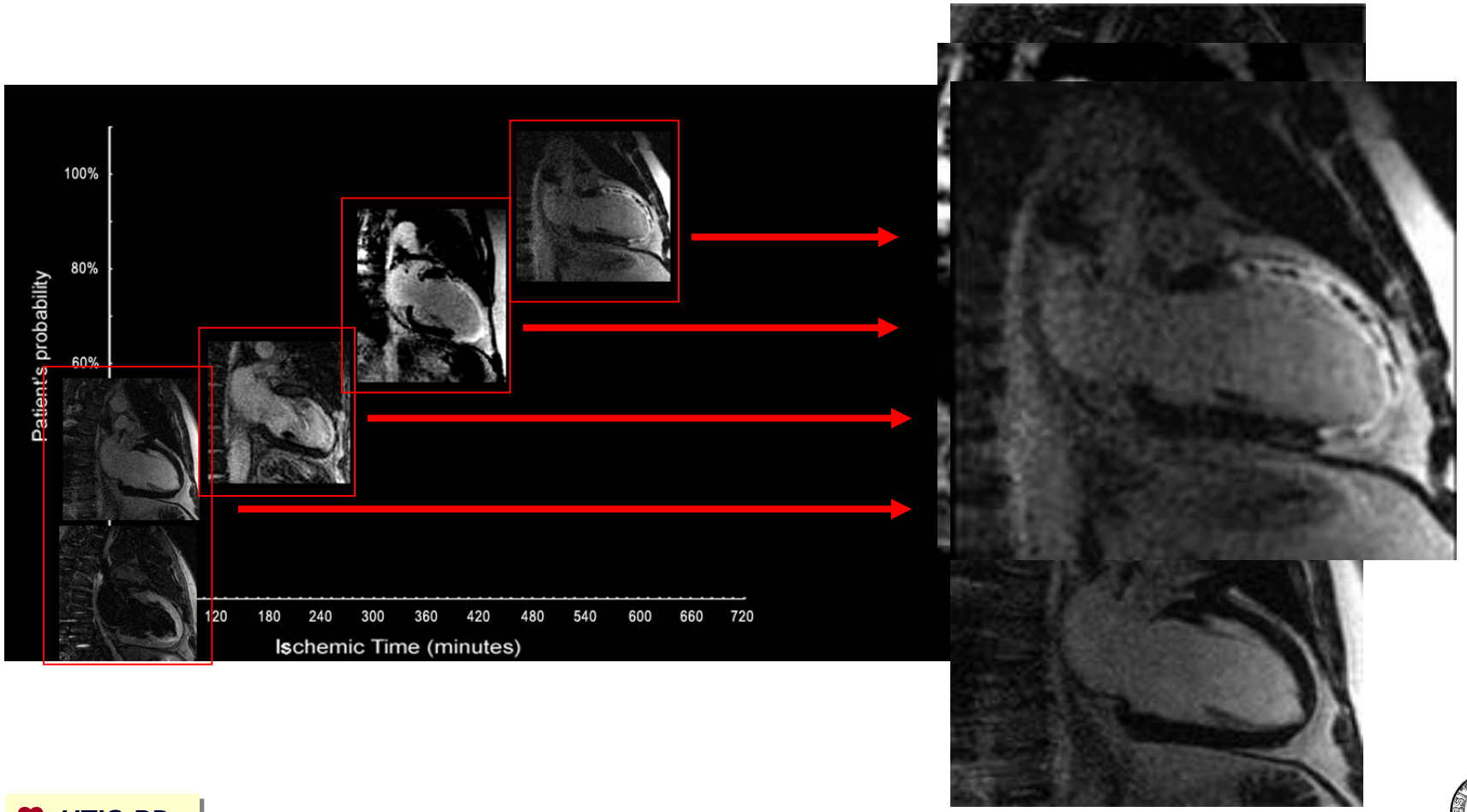


LATE-ENHANCEMENT



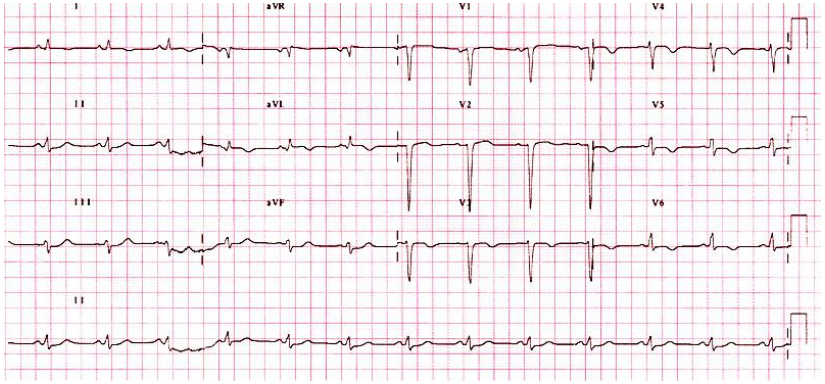
Length of ischemia is a major determinant of Microvascular Obstruction assessed by MRI after PTCA

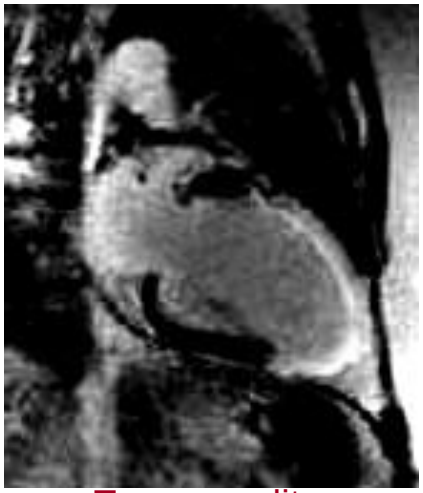
G.Tarantini MD et al. JACC 2005



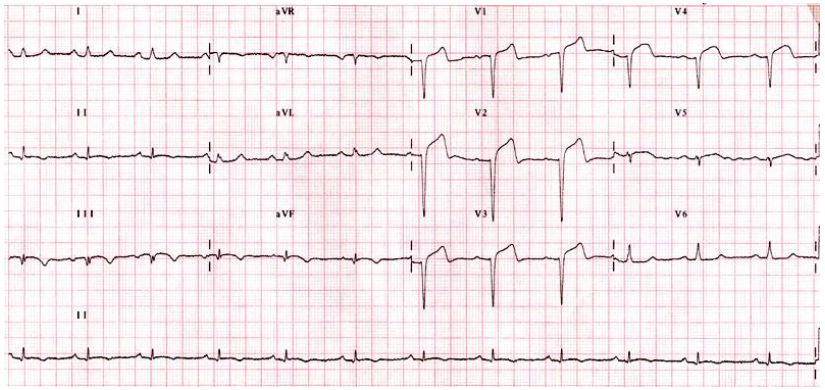
Pre-discharge persistency of ST elevation after AMI treated with PTCA predicts Microvascular Obstruction

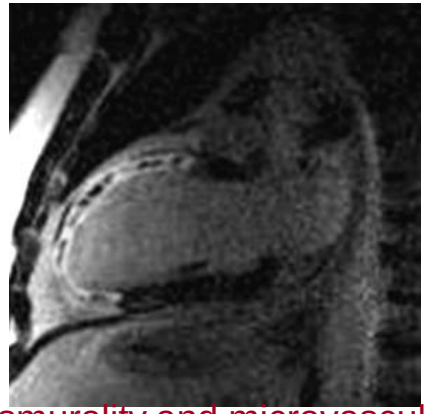
L. Cacciavillani MD et al. AHA 04 *(Circulation, Abs)*



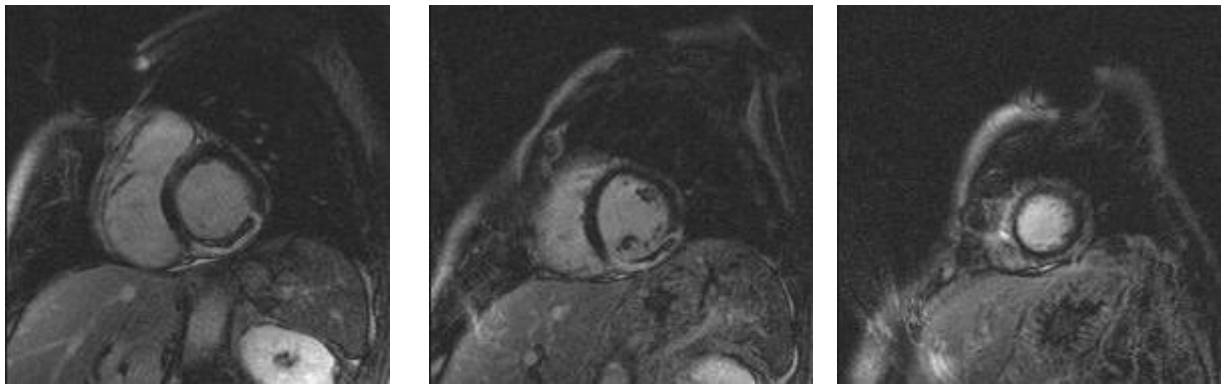


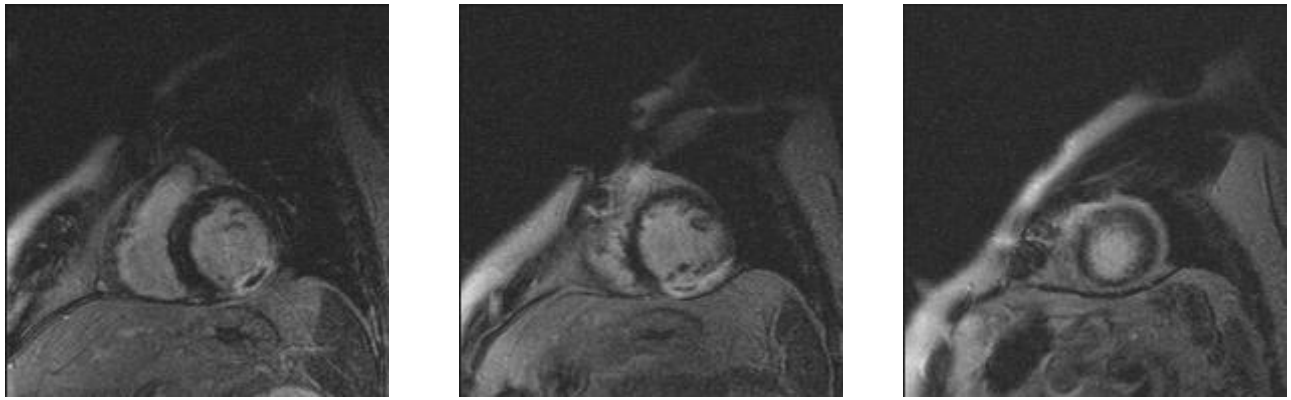
Transmurality

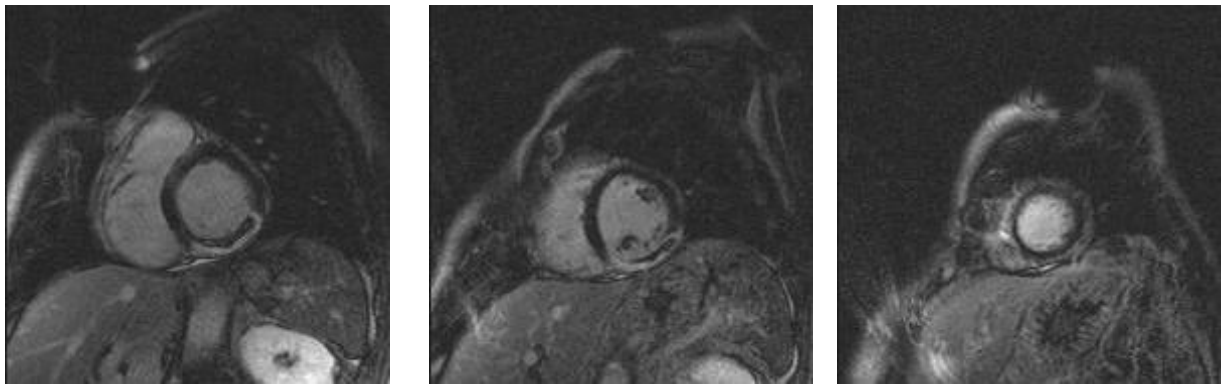


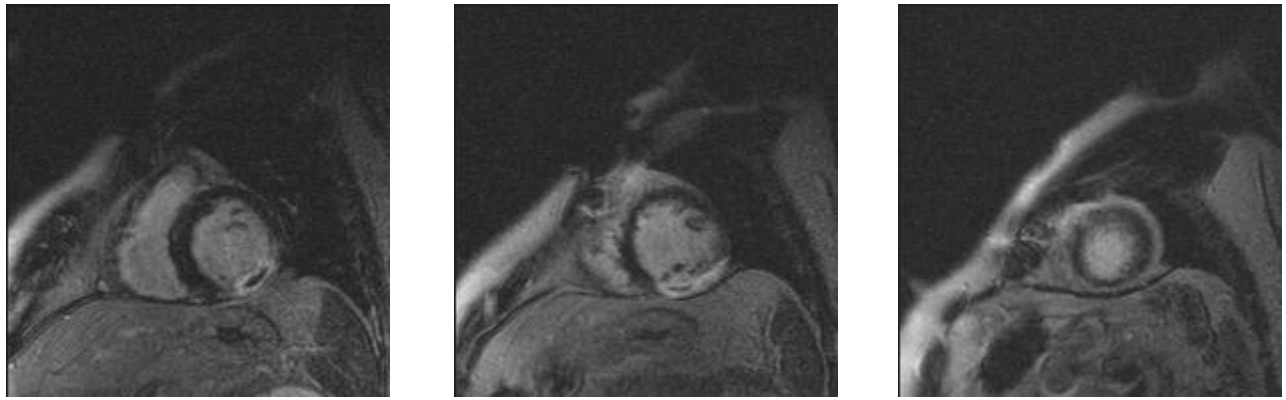


Transmurality and microvascular obstruction



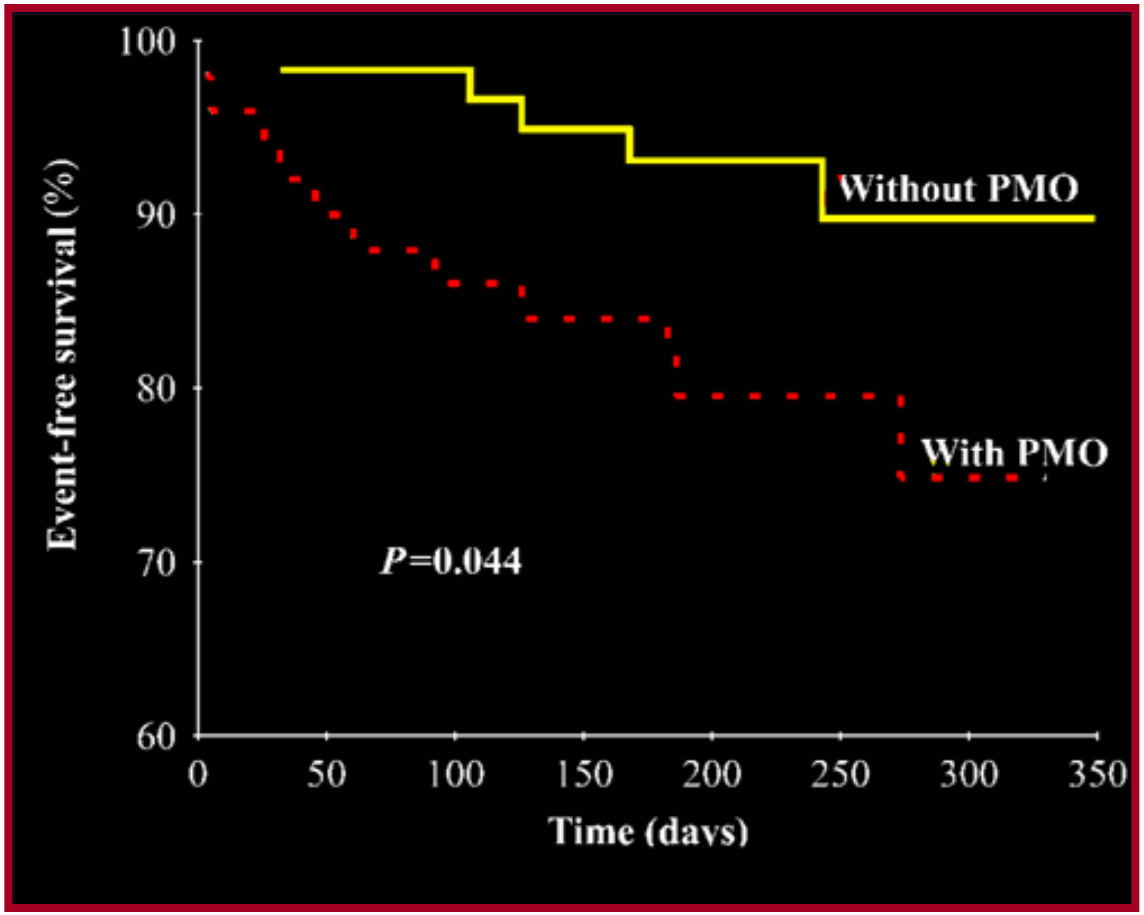


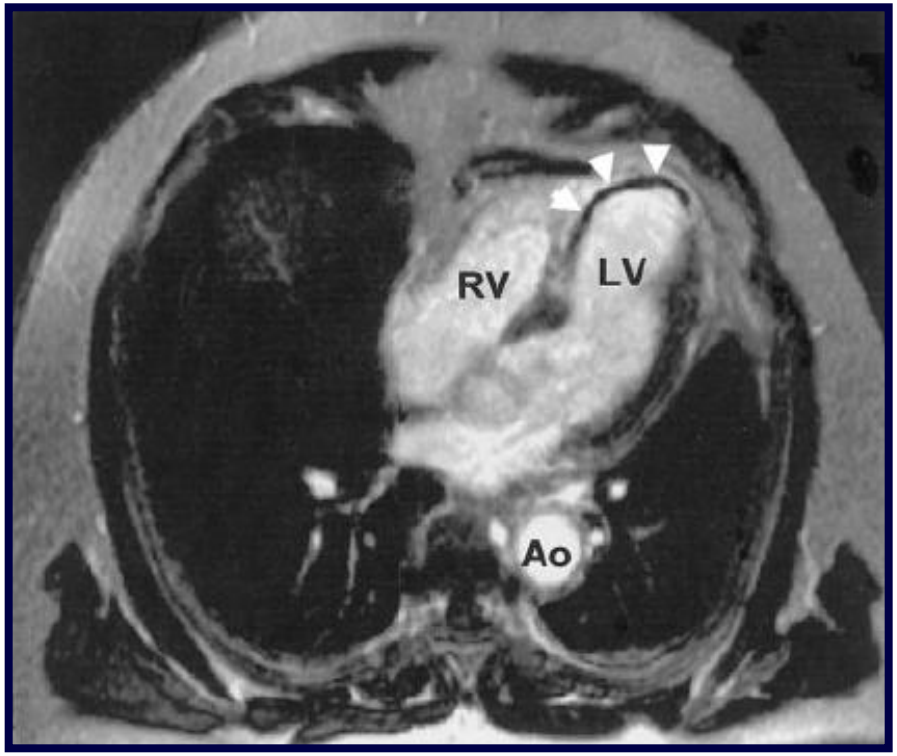


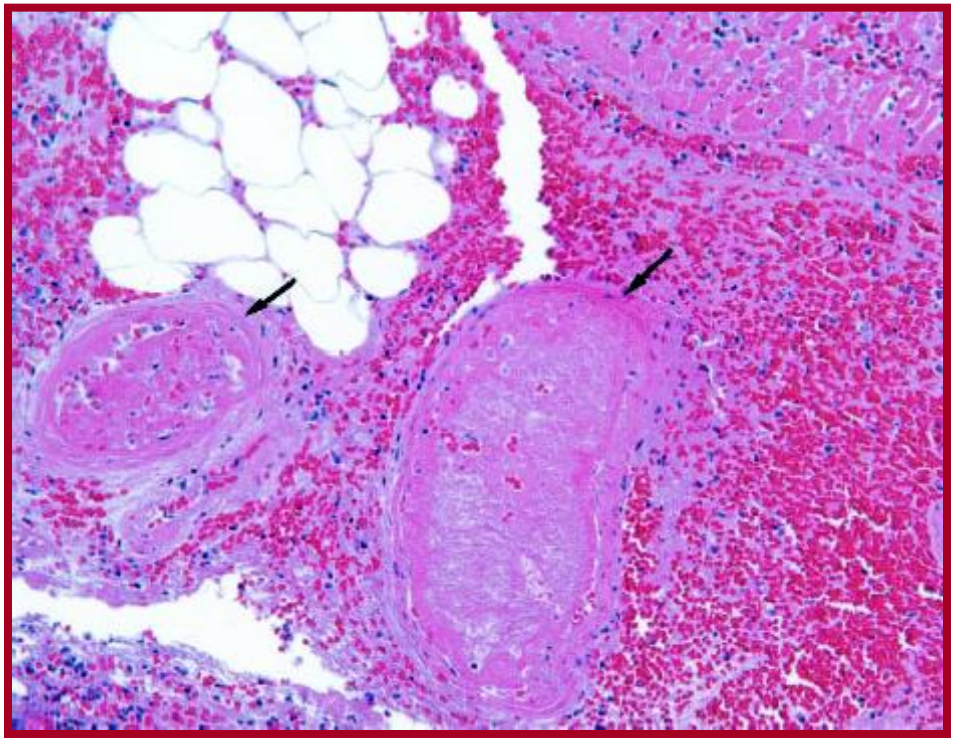


Microvascular Obstruction and his prognostic significance as assessed by MRI

Vinzenz Hombach , European Heart Journal (2005) 26, 549–557



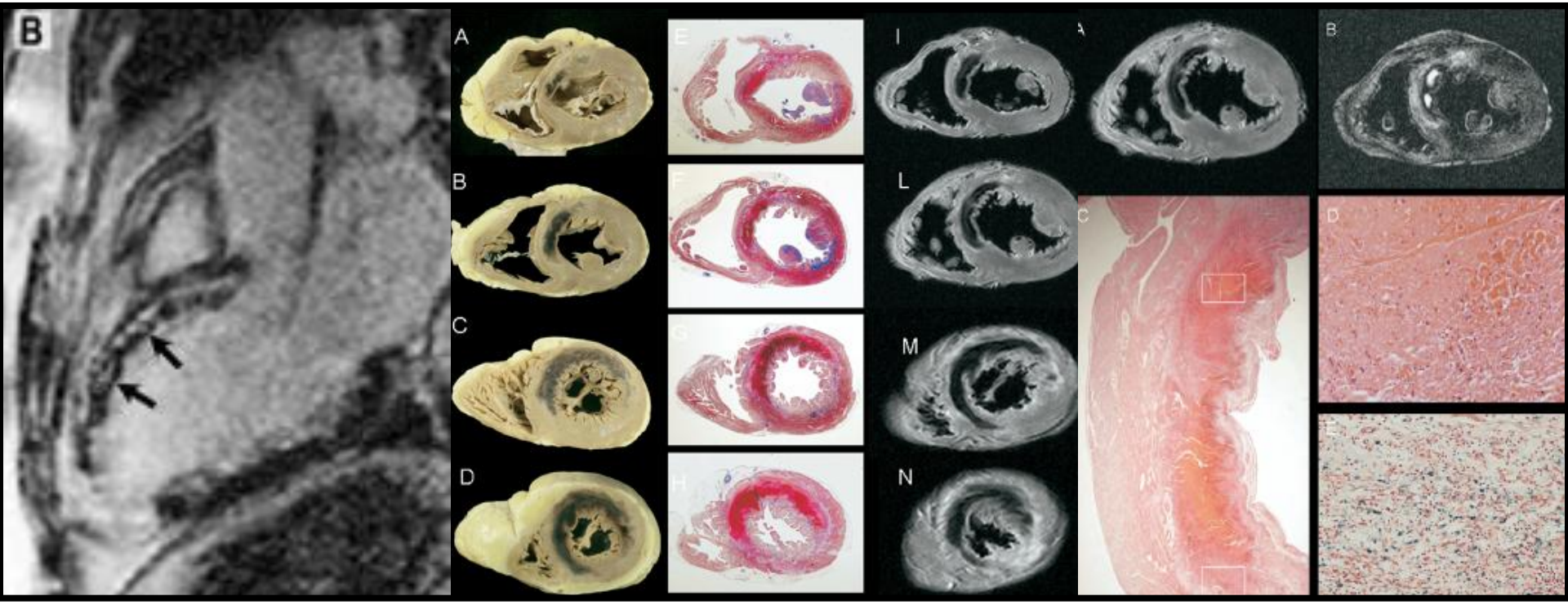




This microscopic examination confirms microvascular obstruction as predicted by CMRI scan.

Severe Microvascular Damage & Hypoenhanced Core

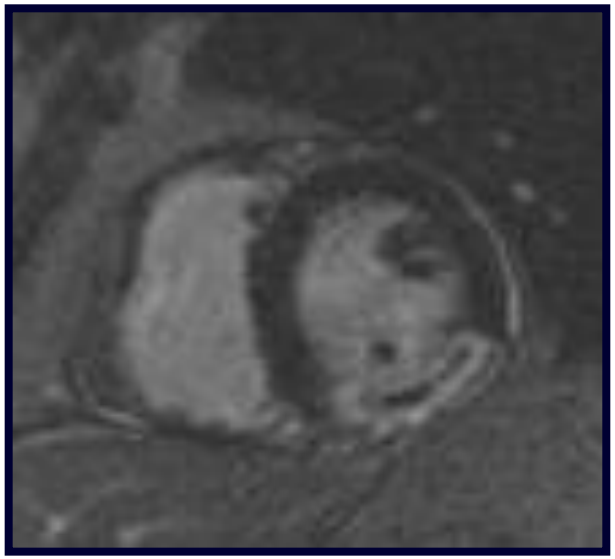
Basso C et al. Am J Cardiol 2007;100:1322–1327



T1 IR DE *in vivo* **Hystology** **T2 *ex vivo***

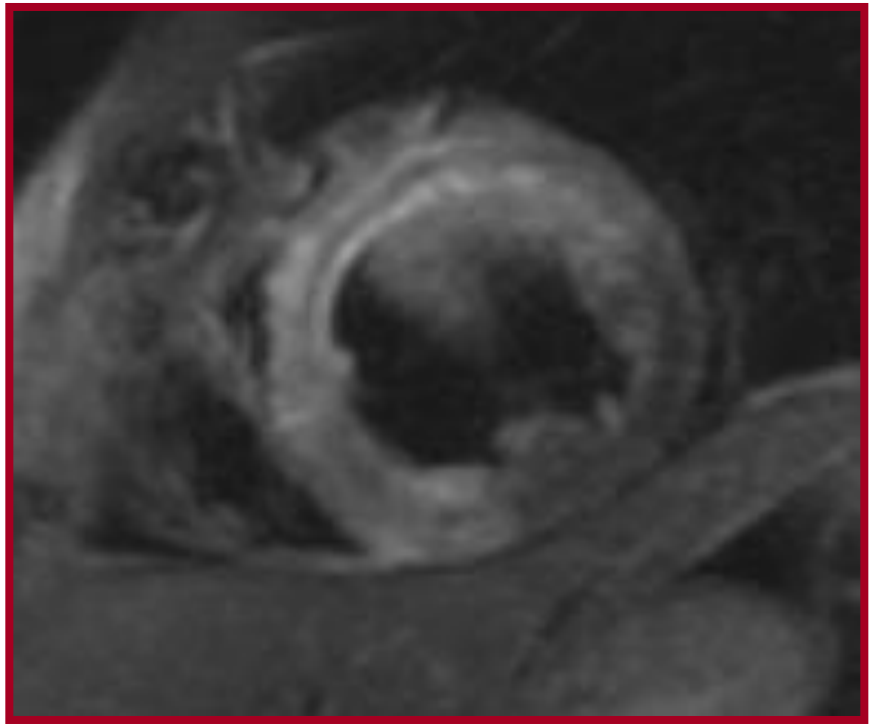
Morphological validation of reperfused haemorrhagic myocardial infarction: comparison between T2 and T1-late enhancement sequences

Hypointense core on T1 IR sequence



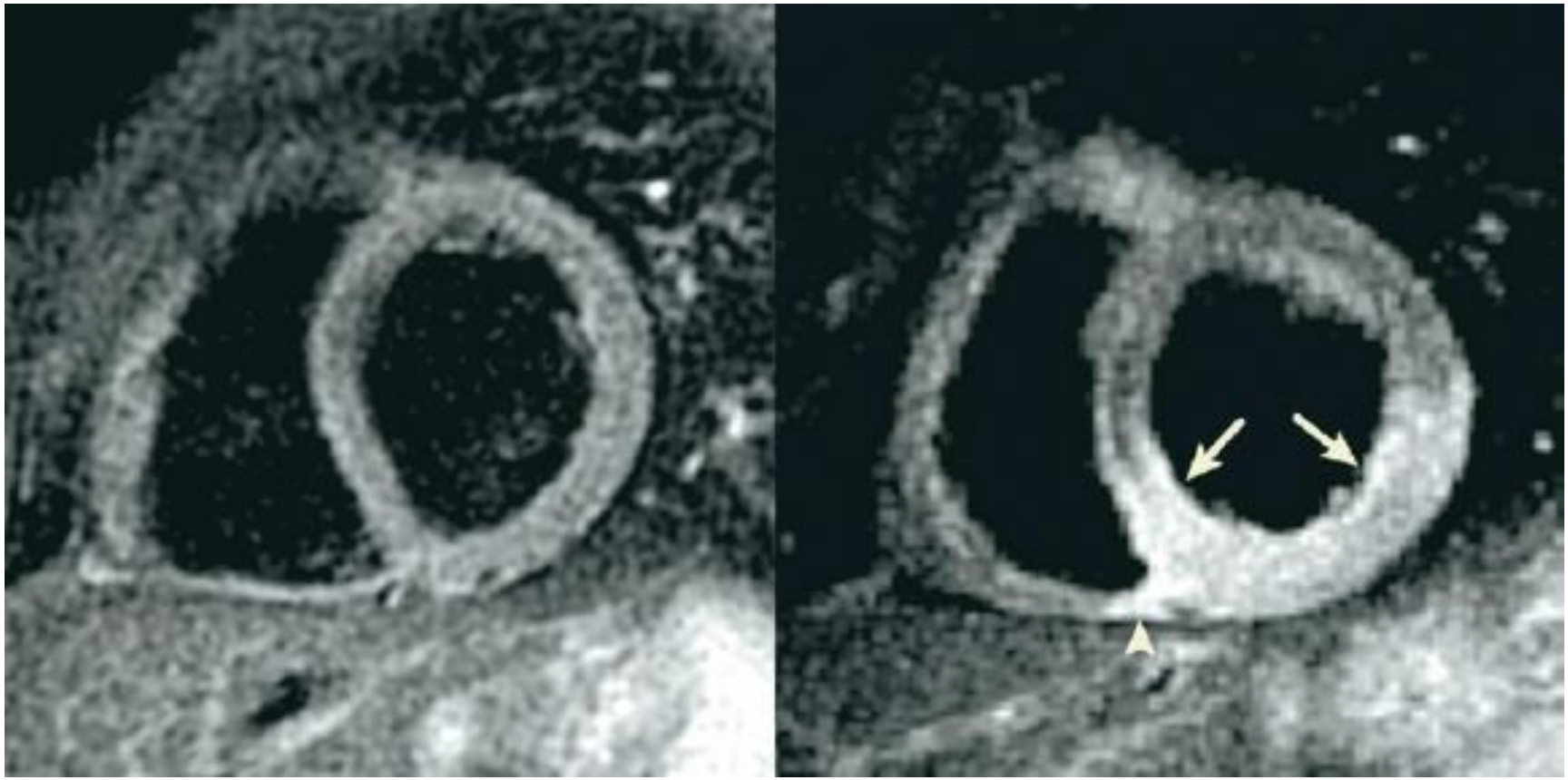
“Severe microvascular damage”: areas of late hypoenhancement surrounded by hyperenhanced tissue after gadolinium injection

Hypointense stria on T2-weighted image



“Hemorrhagic AMI”: hypointense zones due to paramagnetic susceptibility effect of deoxyhemoglobin on T2-weighted images

T2-Weighted CMR Images



The Salvaged Area at Risk in Reperfused Acute Myocardial Infarction as Visualized by Cardiovascular Magnetic Resonance

Matthias G. Friedrich, MD,* Hassan Abdel-Aty, MD,*† Andrew Taylor, MD,‡
Jeanette Schulz-Menger, MD,† Daniel Messroghli, MD,† Rainer Dietz, MD†

Calgary, Alberta, Canada; Berlin, Germany; and Melbourne, Australia

Objectives We aimed to characterize the tissue changes within the perfusion bed of infarct-related vessels in patients with acutely reperfused myocardial infarction (MI) using cardiovascular magnetic resonance (CMR).

Background Even in successful early revascularization, intermittent coronary artery occlusion affects the entire perfusion bed, also referred to as the area at risk. The extent of the salvaged area at risk contains prognostic information and may serve as a therapeutic target. Cardiovascular magnetic resonance can visualize the area at risk; yet, clinical data have been lacking.

Methods We studied 92 patients with acute MI and successful reperfusion 3 ± 3 days after the event and 18 healthy control subjects. Breath-hold T2-weighted and contrast-enhanced ("late enhancement") CMR were used to visualize the reversible and the irreversible myocardial injury, respectively.

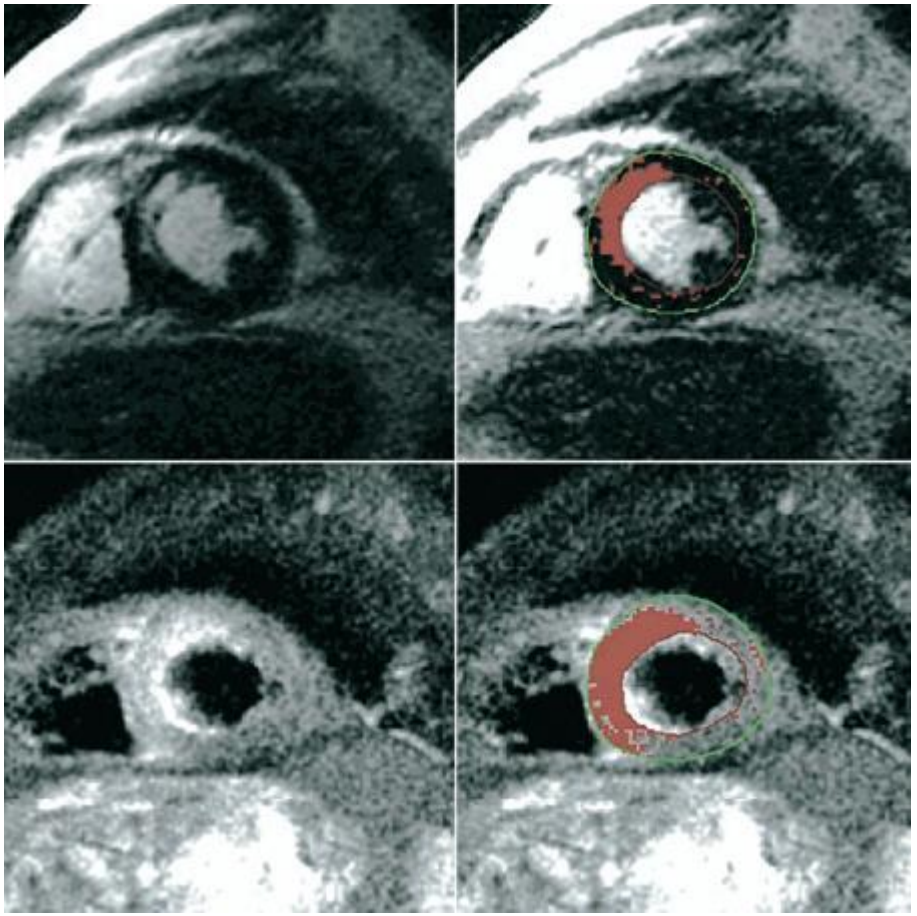
Results All reperfused infarcts consistently revealed a pattern with both reversibly and irreversibly injured tissue. In contrast to the infarcted area, reversible damage was always transmural, exceeding the infarct in its maximal extent by 16 ± 11% (absolute difference of the area of maximal infarct expansion 38 ± 15% vs. 22 ± 10%; $p < 0.0001$). None of the controls had significant T2 signal intensity abnormalities.

Conclusions In patients with reperfused MI, CMR visualizes both reversible and irreversible injury. This allows for quantifying the extent of the salvaged area after revascularization as an important parameter for clinical decision-making and research. (J Am Coll Cardiol 2008;51:1581–7)

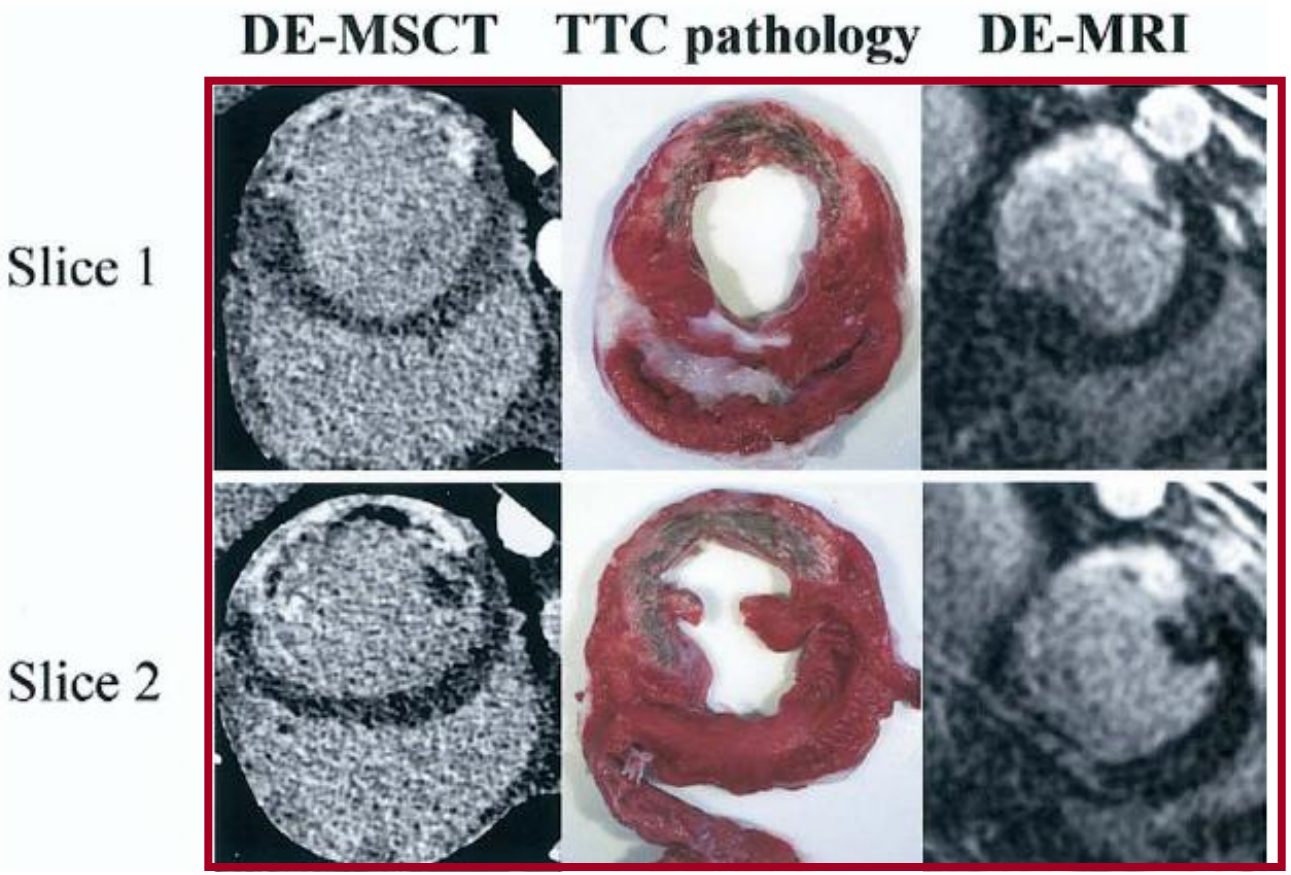
The Salvaged Area at Risk

J Am Coll Cardiol 2008;51:1581–7

In patients with reperfused MI, CMR visualizes both reversible and irreversible injury with very high sensitivity and specificity. This allows for quantifying the extent of the salvaged area after revascularization.

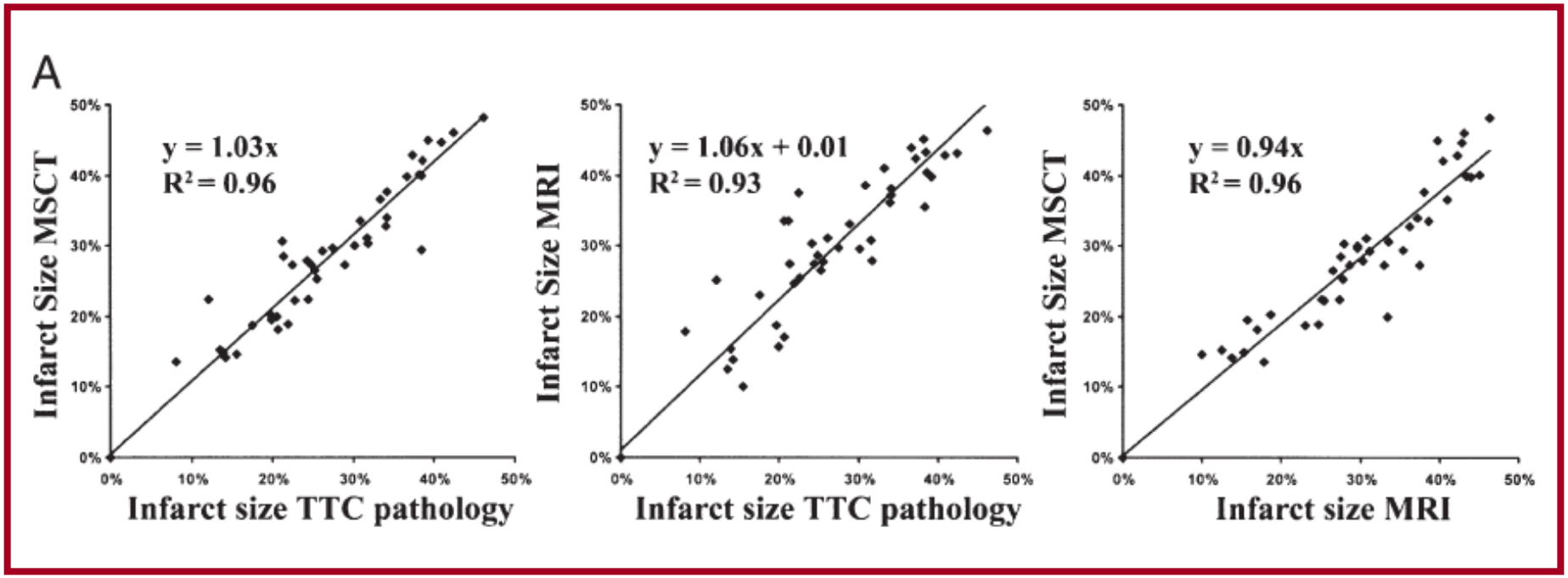


Multislice Computed Tomography and Magnetic Resonance Imaging for the Assessment of Reperfused Acute Myocardial Infarction



J Am Coll Cardiol 2006;48:144–52

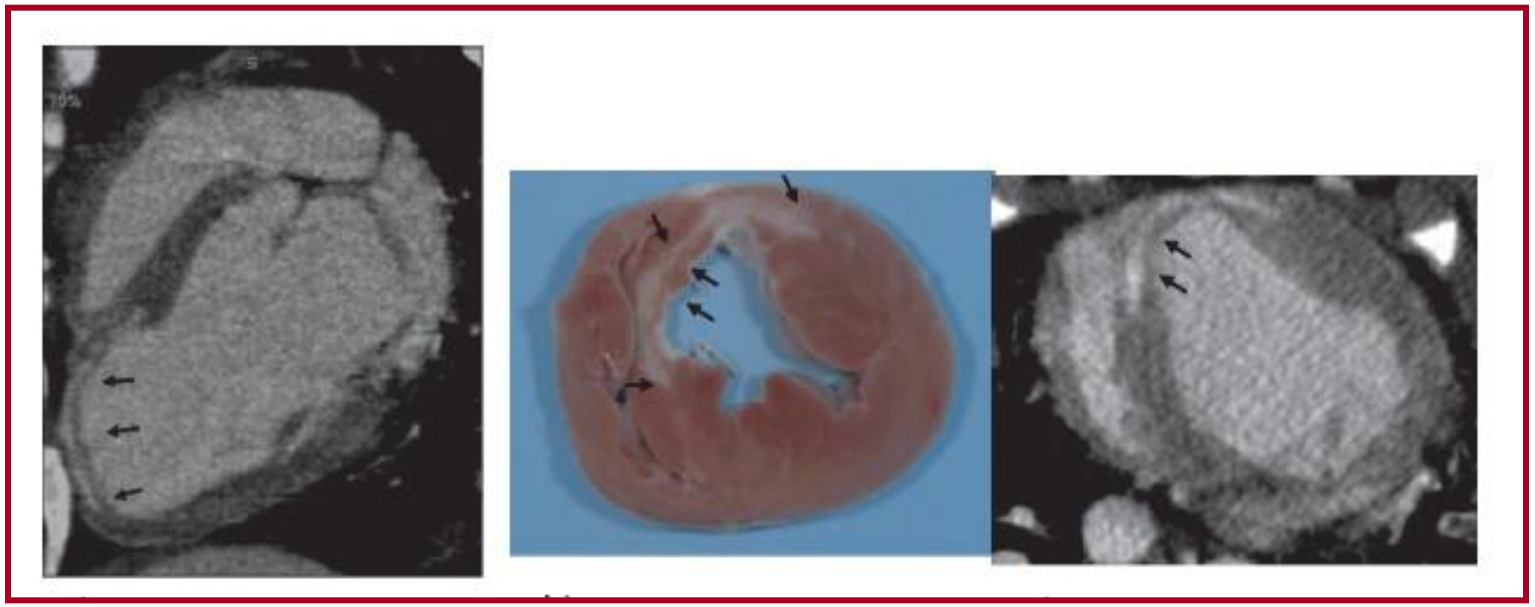
Multislice Computed Tomography and Magnetic Resonance Imaging for the Assessment of Reperfused Acute Myocardial Infarction



J Am Coll Cardiol 2006;48:144–52

Contrast-Enhanced Multidetector Computed Tomography Viability Imaging After Myocardial Infarction

Characterization of Myocyte Death, Microvascular Obstruction, and Chronic Scar



Circulation. 2006;113:394-404

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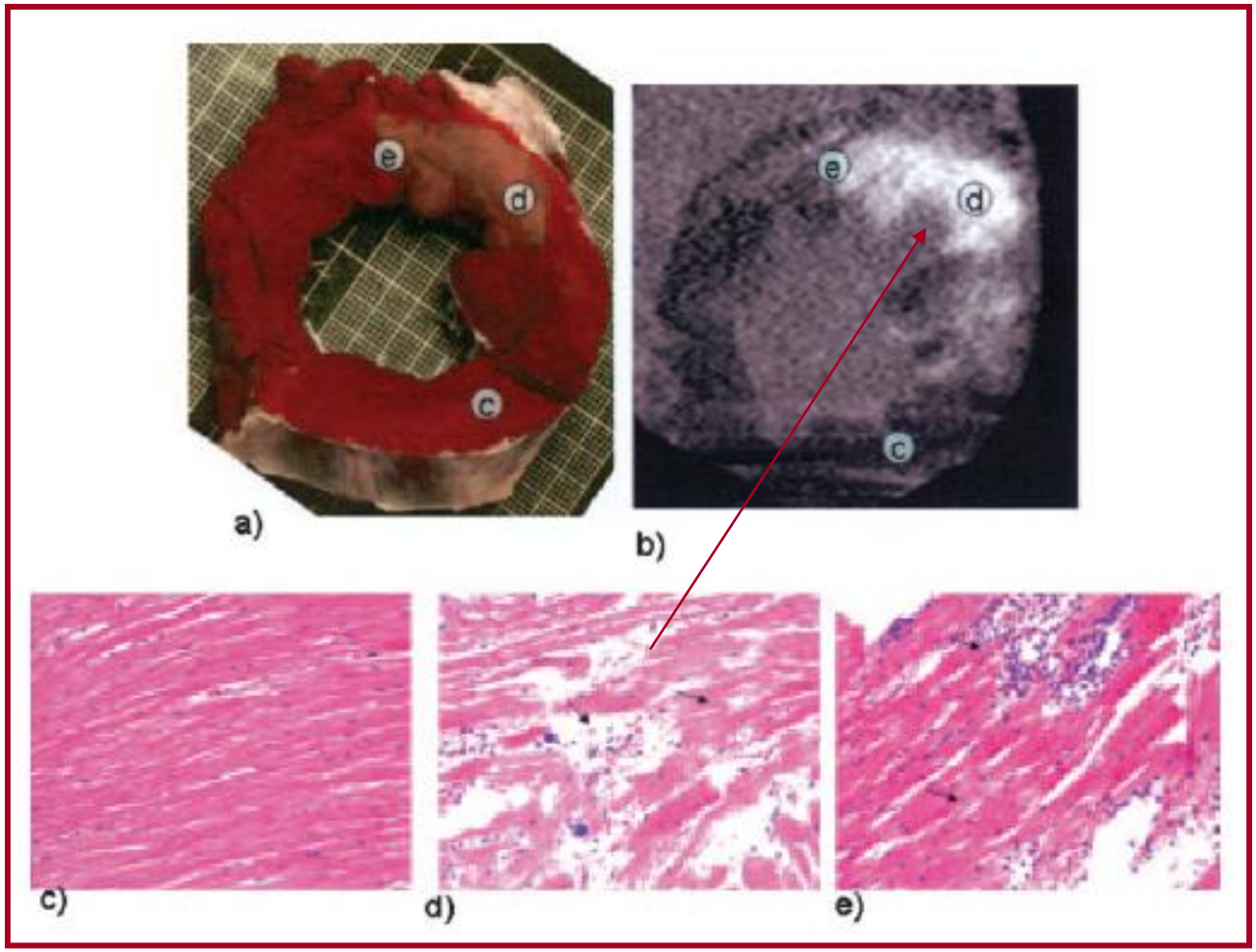


UTIC-PD

Circulation. 2006;113:394-404

Characterization of Peri-Infarct Zone Heterogeneity by Contrast-Enhanced Multidetector Computed Tomography

A Comparison With Magnetic Resonance Imaging

Karl H. Schuleri, MD,* Marco Centola, MD,* Richard T. George, MD,* Luciano C. Amado, MD,* Kristine S. Evers, AA,* Kakuya Kitagawa, MD, PHD,* Andrea L. Vavere, MS,* Robert Evers, BSRT,* Joshua M. Hare, MD,‡ Christopher Cox, PHD,§ Elliot R. McVeigh, PHD,† João A. C. Lima, MD,* Albert C. Lardo, PHD*†‡

Baltimore, Maryland; and Miami, Florida

Objectives This study examined whether multidetector computed tomography (MDCT) improves the ability to define peri-infarct zone (PIZ) heterogeneity relative to magnetic resonance imaging (MRI).

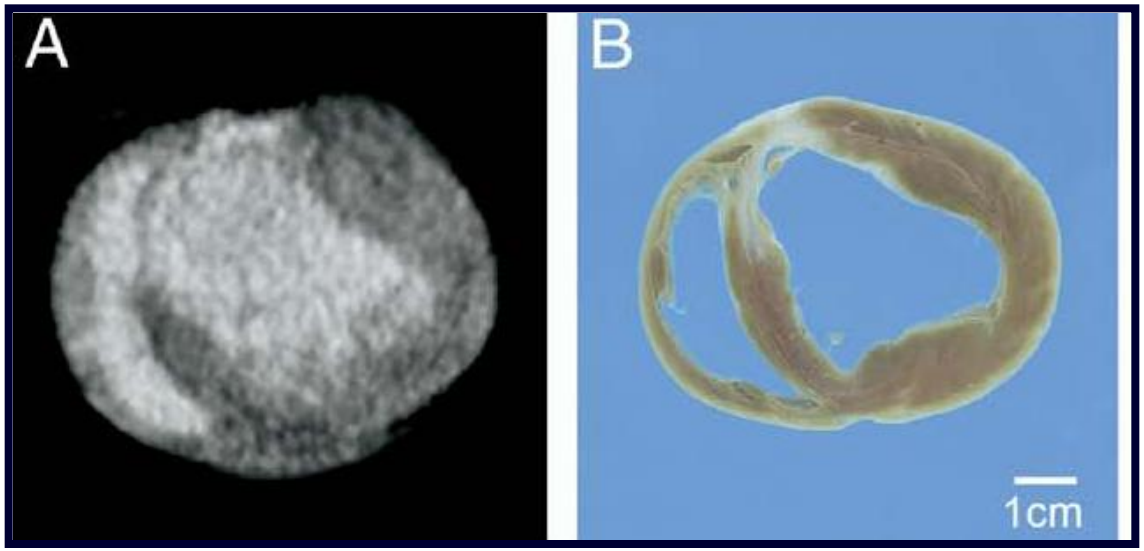
Background The PIZ as characterized by delayed contrast-enhancement (DE)-MRI identifies patients susceptible to ventricular arrhythmias and predicts outcome after myocardial infarction (MI).

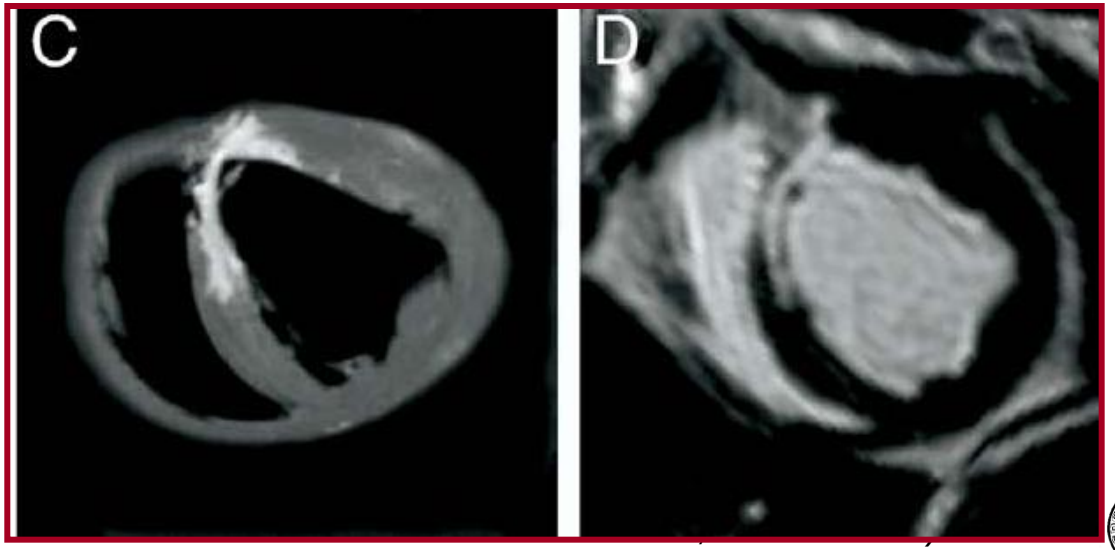
Methods Fifteen mini-pigs underwent coronary artery occlusion followed by reperfusion. Both MDCT and MRI were performed on the same day approximately 6 months after MI induction, followed by animal euthanization and ex vivo MRI ($n = 5$). Signal density threshold algorithms were applied to MRI and MDCT datasets reconstructed at various slice thicknesses (1 to 8 mm) to define the PIZ and to quantify partial volume effects.

Results The DE-MDCT reconstructed at 8-mm slice thickness showed excellent correlation of infarct size with post-mortem pathology ($r^2 = 0.97$; $p < 0.0001$) and MRI ($r^2 = 0.92$; $p < 0.0001$). The DE-MDCT and -MRI were able to detect a PIZ in all animals, which correlates to a mixture of viable and nonviable myocytes at the PIZ by histology. The ex vivo DE-MRI PIZ volume decreased with slice thickness from 0.9 ± 0.2 ml at 8 mm to 0.2 ± 0.1 ml at 1 mm ($p = 0.01$). The PIZ volume/mass by DE-MDCT increased with decreasing slice thickness because of declining partial volume averaging in the PIZ, but was susceptible to increased image noise.

Conclusions A DE-MDCT provides a more detailed assessment of the PIZ in chronic MI and is less susceptible to partial volume effects than MRI. This increased resolution best reflects the extent of tissue mixture by histopathology and has the potential to further enhance the ability to define the substrate of malignant arrhythmia in ischemic heart disease noninvasively. (J Am Coll Cardiol 2009;53:1699–707)

Comparison of Infarct Morphology by MDCT With Post-Mortem Pathology and MRI





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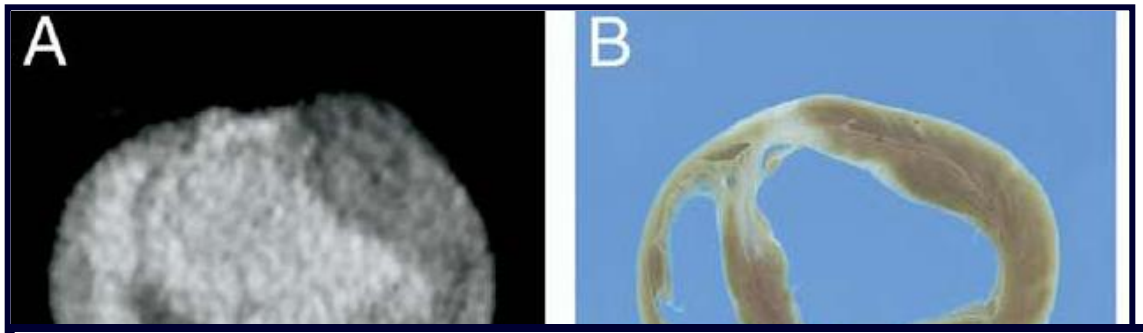
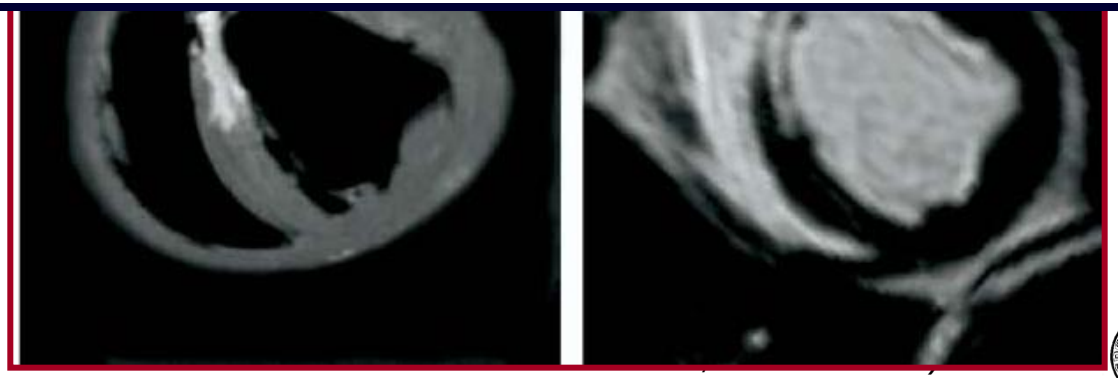


- A DE-MDCT provides a more detailed assessment of the PIZ in chronic MI than MRI.
- This increased resolution best reflects the extent of tissue mixture by histopathology and has the potential to further enhance the ability to define the substrate of malignant arrhythmia in ischemic heart disease noninvasively



Avviciniamoci a TC e RM….

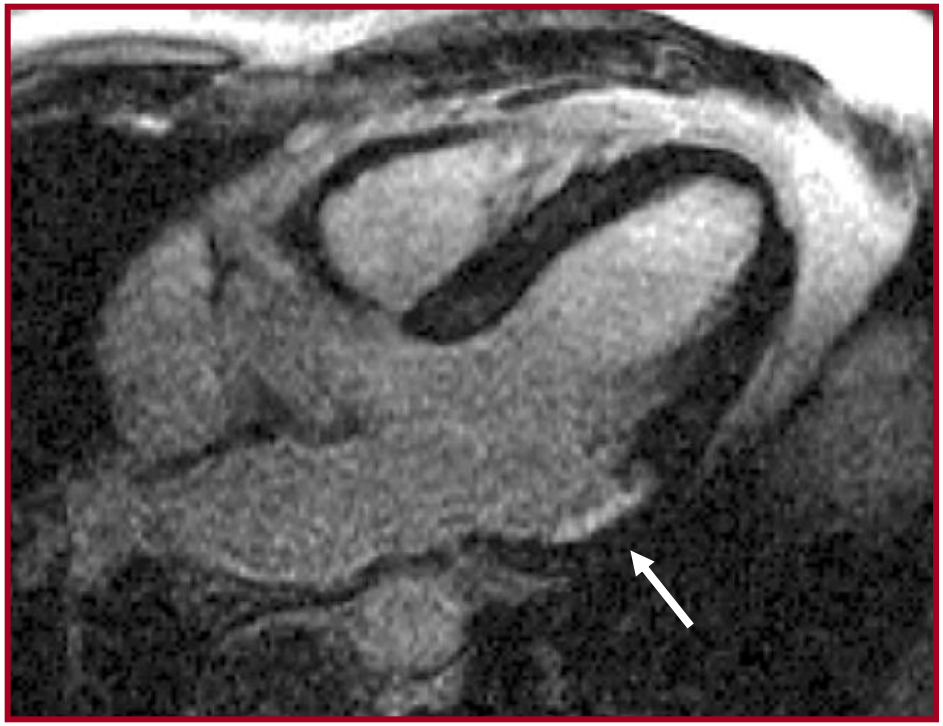
Cosa scegliere per caratterizzare il tessuto:

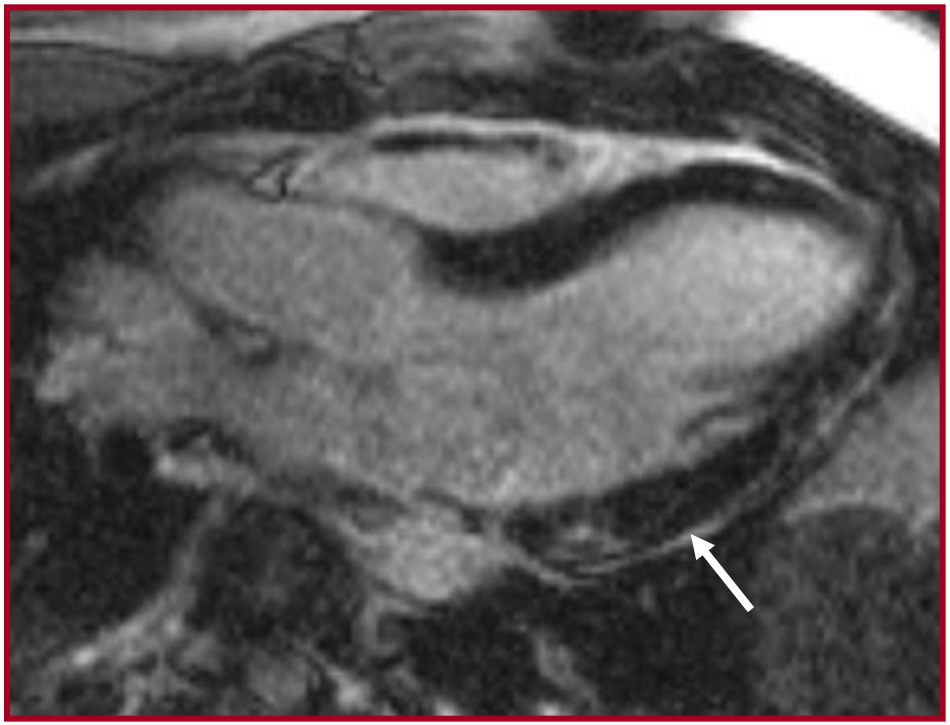
- Ischemic and Primary Dilated Cardiomyopathy
- Acute Myocardial Infarction
- Myocarditis

JACC White Paper

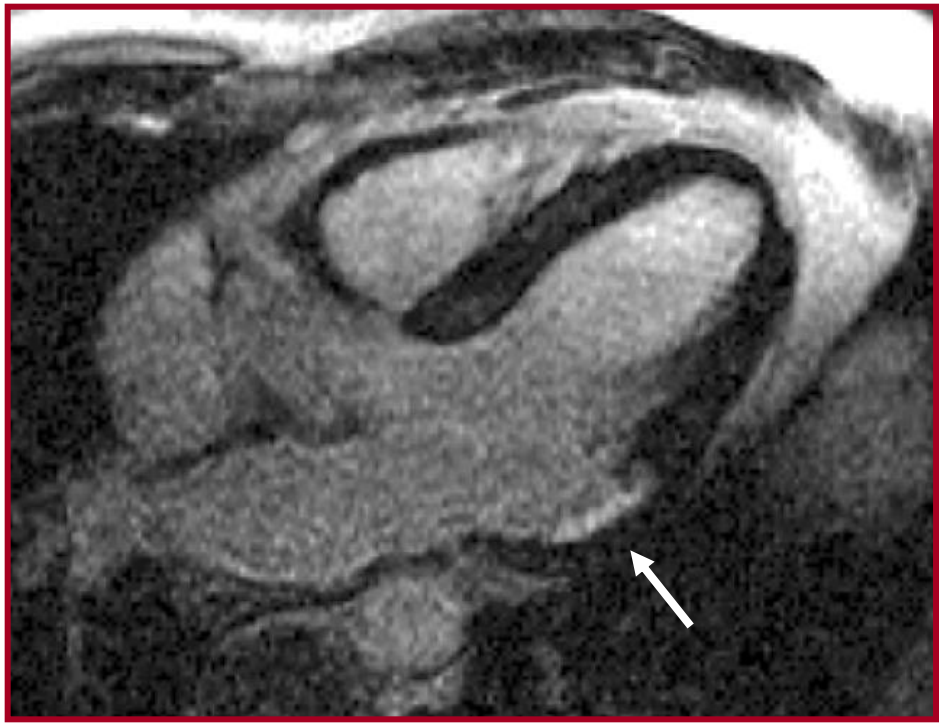
Cardiovascular Magnetic Resonance in Myocarditis: A JACC White Paper

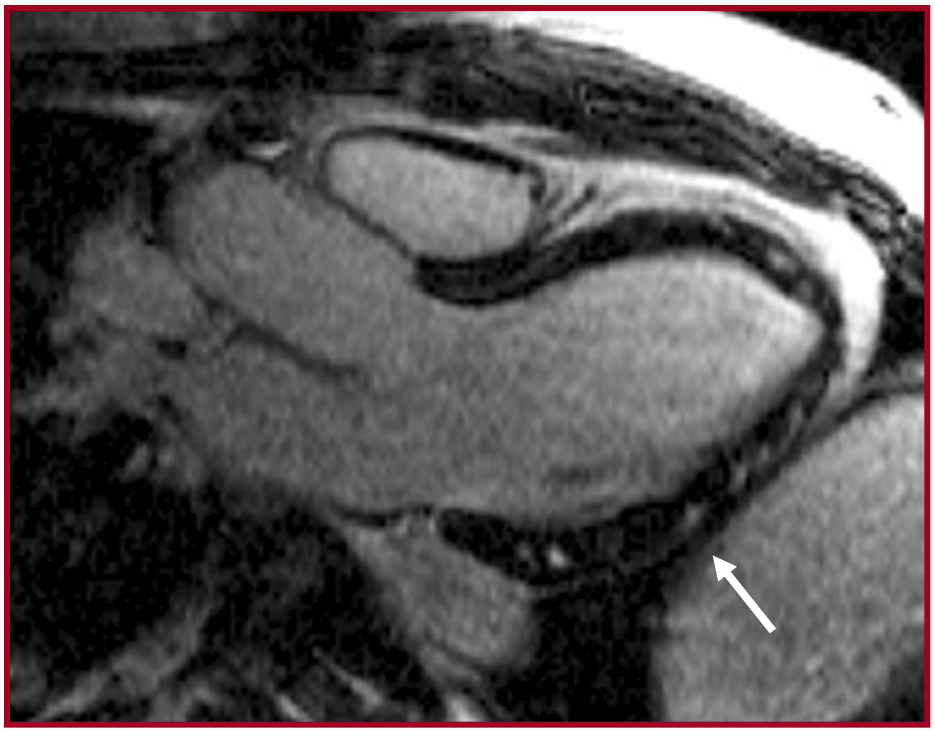
Matthias G. Friedrich, MD,* Udo Sechtem, MD,‡ Jeanette Schulz-Menger, MD,§ Godtfred Holmvang, MD,‖ Pauline Alakija, MD,† Leslie T. Cooper, MD,¶ James A. White, MD,# Hassan Abdel-Aty, MD,§ Matthias Gutberlet, MD,** Sanjay Prasad, MD,†† Anthony Aletras, PHD,‡‡ Jean-Pierre Laissy, MD,§§ Ian Paterson, MD,‖‖ Neil G. Filipchuk, MD,* Andreas Kumar, MD,* Matthias Pauschinger, MD,¶¶ Peter Liu, MD,## for the *International Consensus Group on Cardiovascular Magnetic Resonance in Myocarditis*





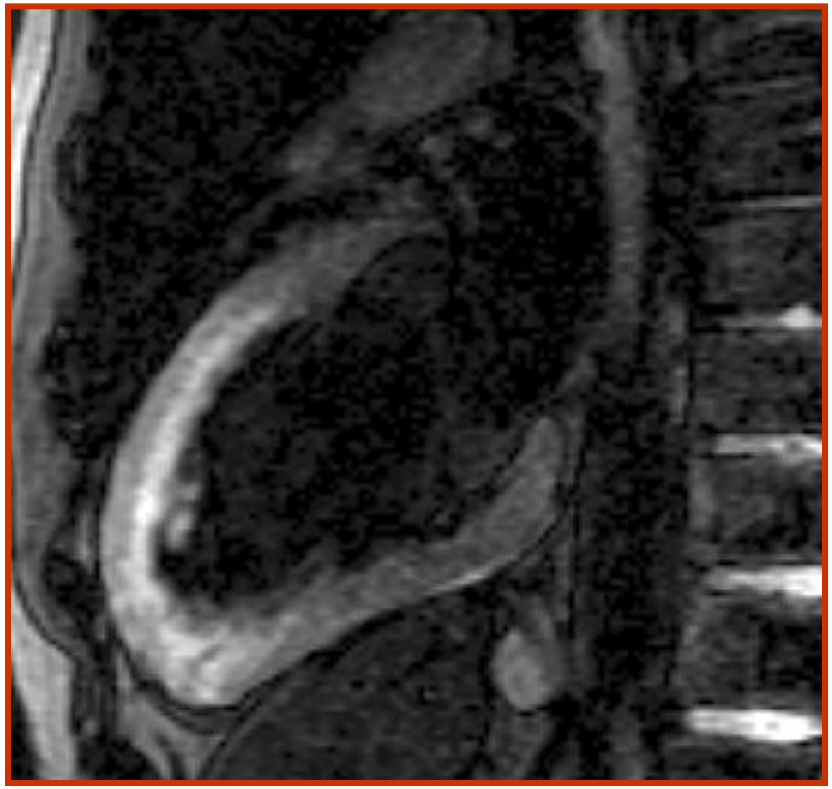
The late enhancement patterns allow for the discrimination of ischemic versus nonischemic injuries

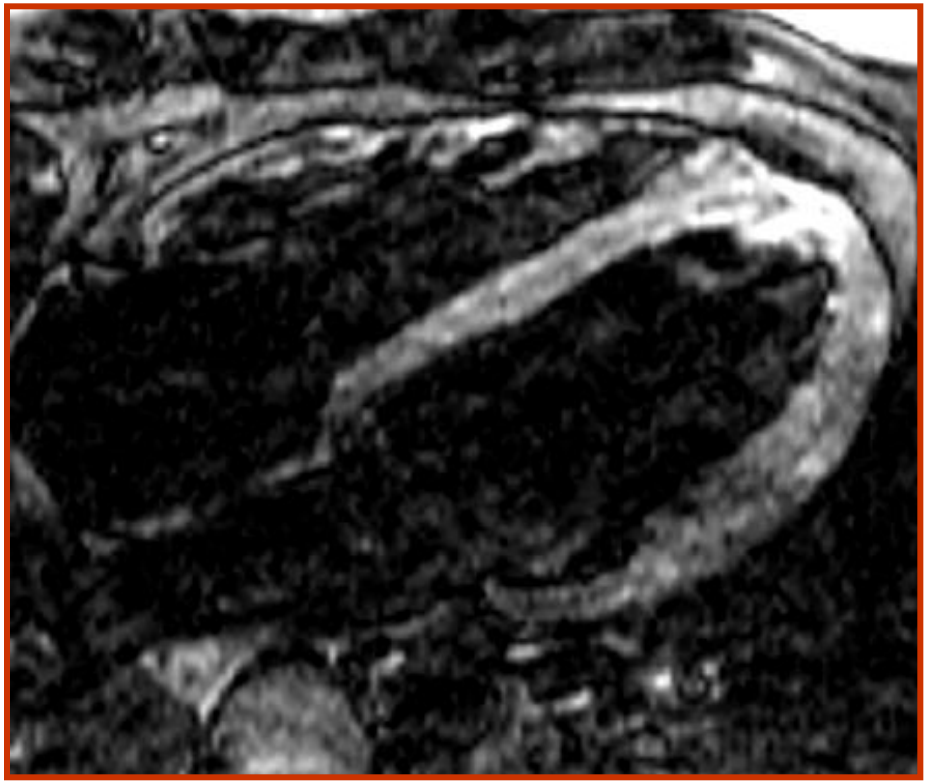




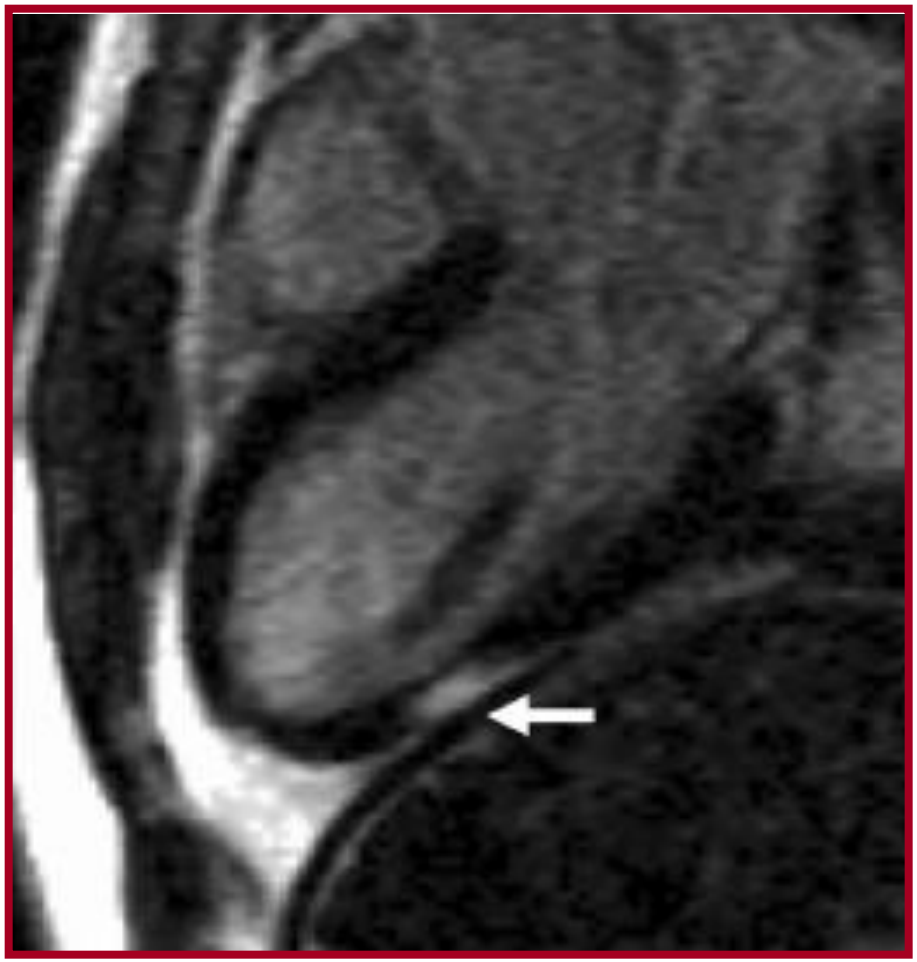
The late enhancement patterns allow for the discrimination of ischemic versus nonischemic injuries

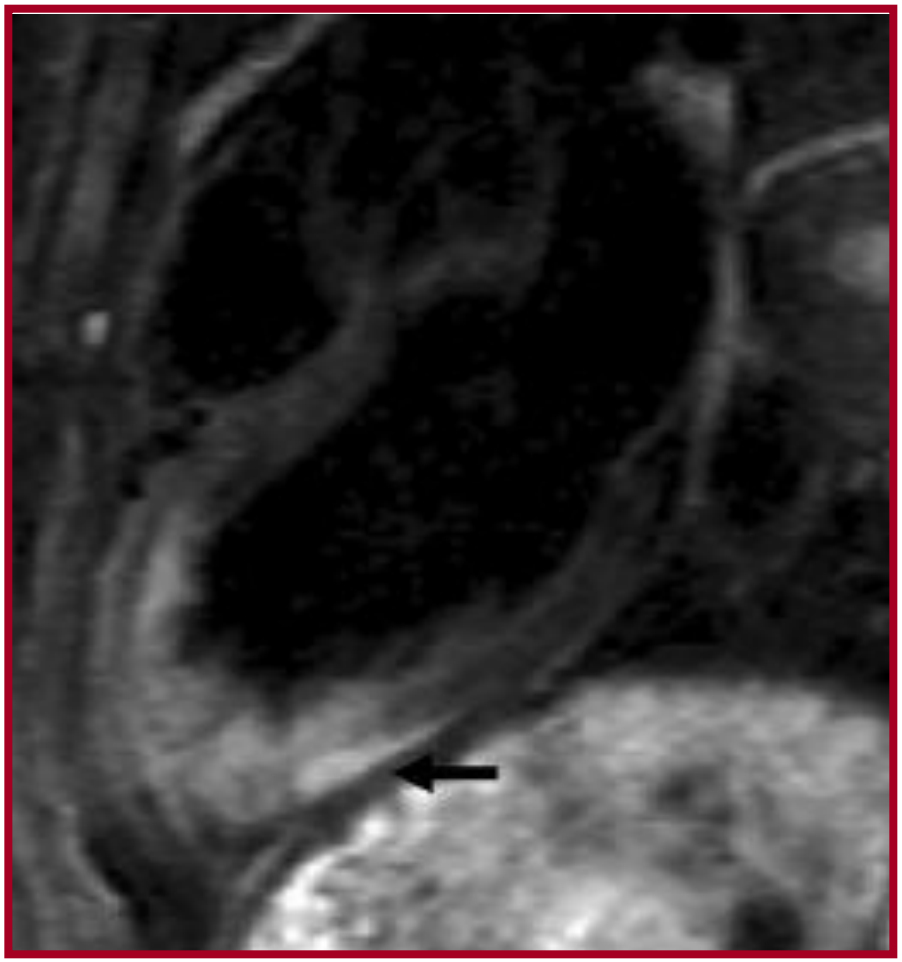
CMR can be used for detection of inflammation, using images for visualizing edema



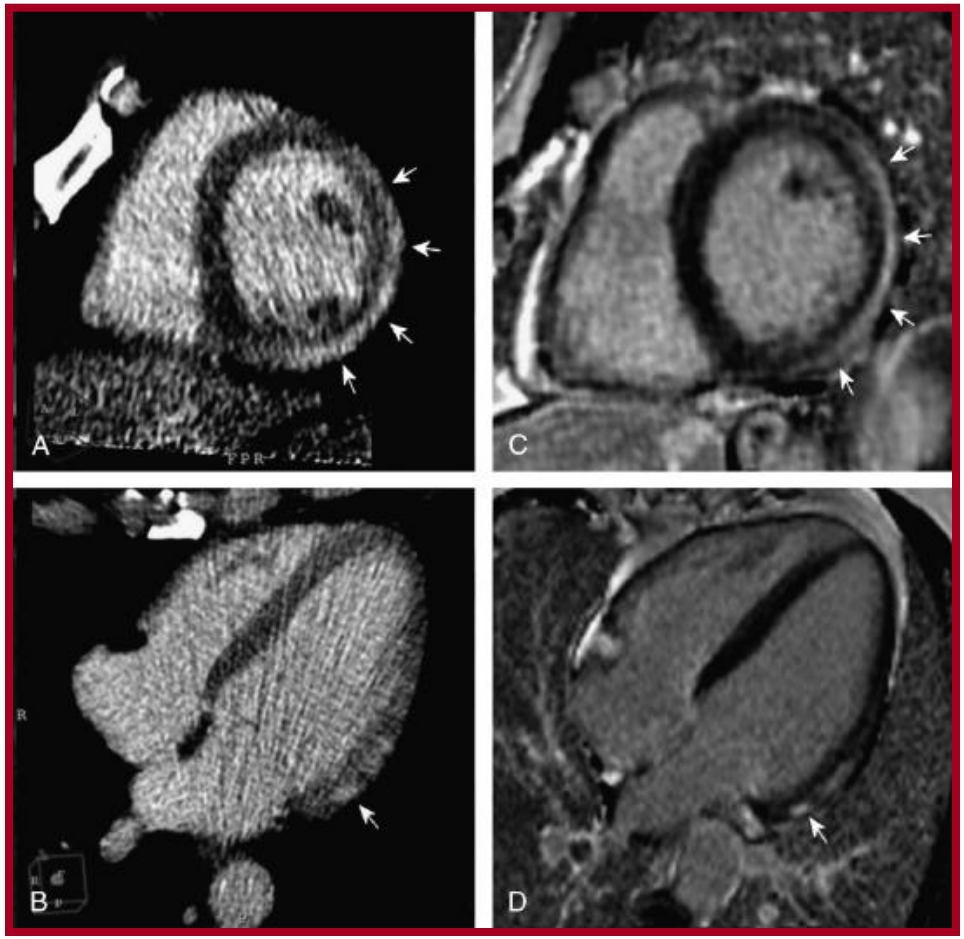


EVIDENCE OF ACUTE INFLAMMATION AND PRESENCE OF EPICARDIAL LGE ABNORMALITIES





Acute Chest Pain With Normal Coronary Angiogram: Role of Contrast-Enhanced Multidetector Computed Tomography in the Differential Diagnosis Between Myocarditis and Myocardial Infarction



J Comput Assist Tomogr 2008;32:228-232

Acute Chest Pain With Normal Coronary Angiogram: Role of Contrast-Enhanced Multidetector Computed Tomography in the Differential Diagnosis Between Myocarditis and Myocardial Infarction

MRI because of its lack of irradiation, should be the tool of reference to assess differential diagnosis between MI and myocarditis.

CT has several advantages.

- CT examination is shorter than MRI (a few minutes compared with approximately 40 minutes for a whole MRI examination).
- It is widely known that patient monitoring is easier during CT examination than MRI.
- CT scanner with intravenous contrast injection is often performed to find another cause of chest pain such as aortic dissection or pulmonary embolism. After exclusion of those diagnoses and as patient is still in the CT scanner, adding a single acquisition without reinjection may help to identify or eliminate MI and myocarditis

J Comput Assist Tomogr 2008;32:228-232

Avviciniamoci a TC e RM….

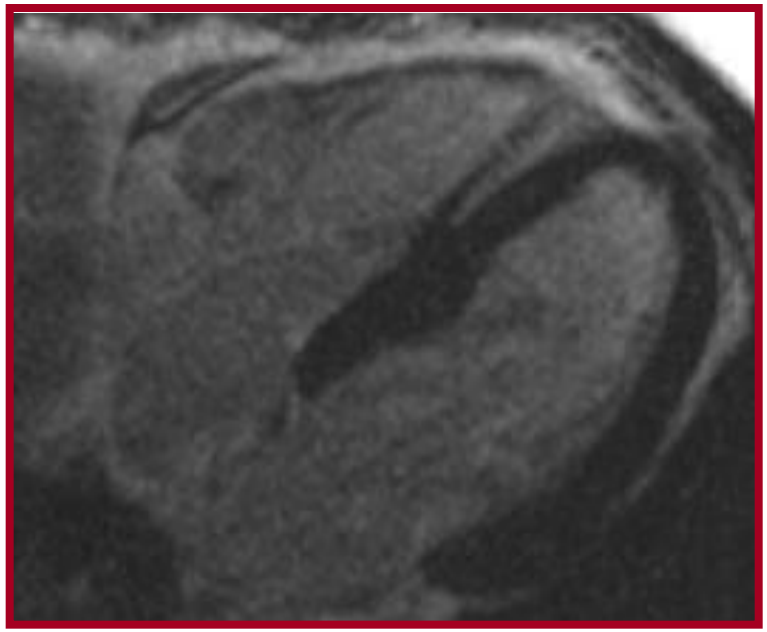
Cosa scegliere per caratterizzare il tessuto:

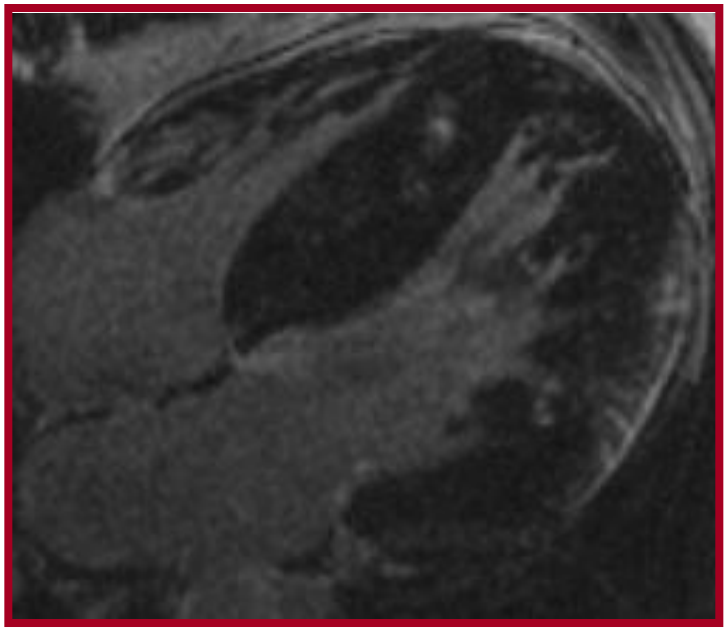
- Ischemic and Primary Dilated Cardiomyopathy
- Acute Myocardial Infarction
- Myocarditis
- Hypertrophic Cardiomyopathy

CMR to determine the aetiology of left ventricular disease and cardiomyopathies: key points

In Hypertrophic Cardiomyopathy CMR can:

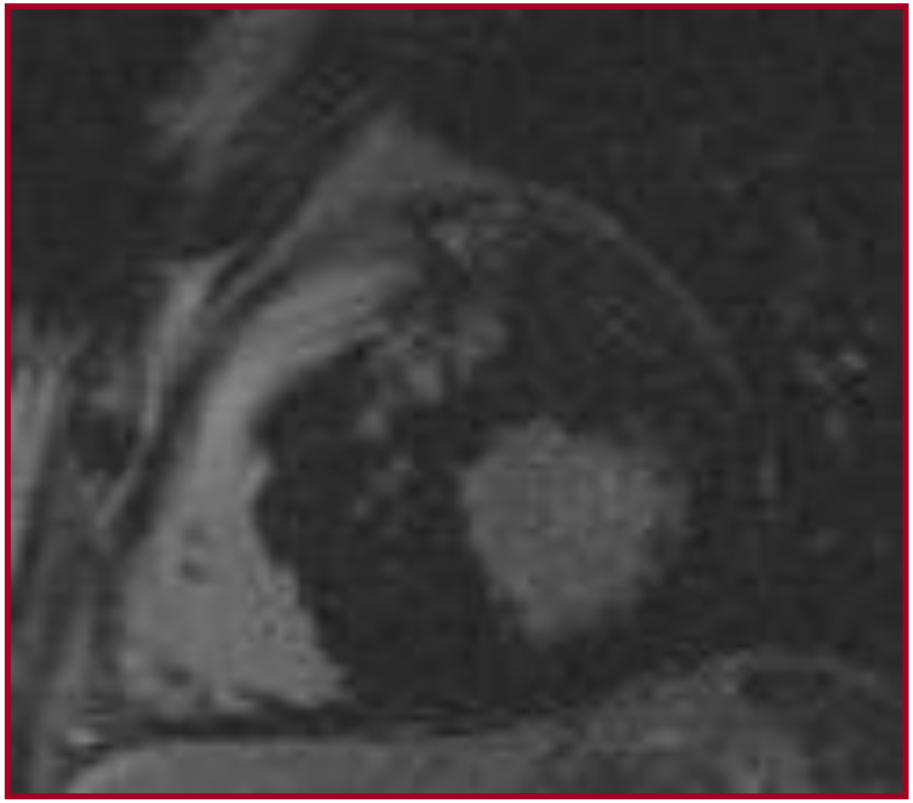
- differentiate physiological from pathological hypertrophy

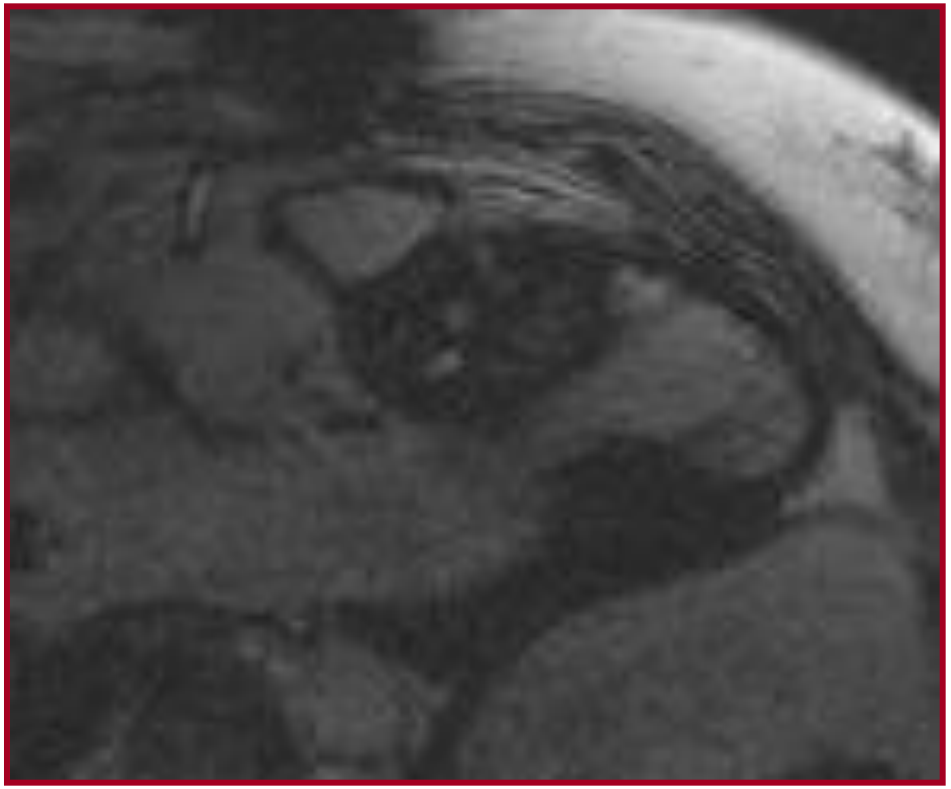




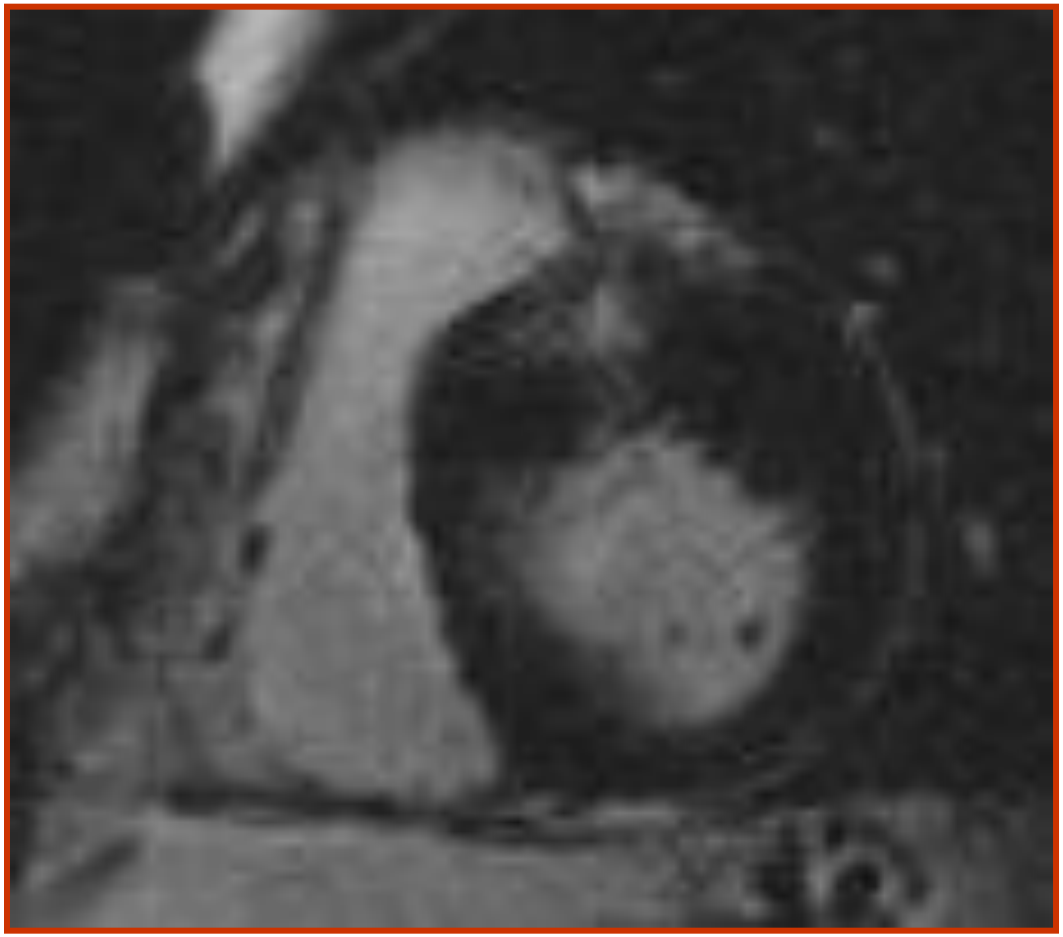
Heart 2008;94:510–518.

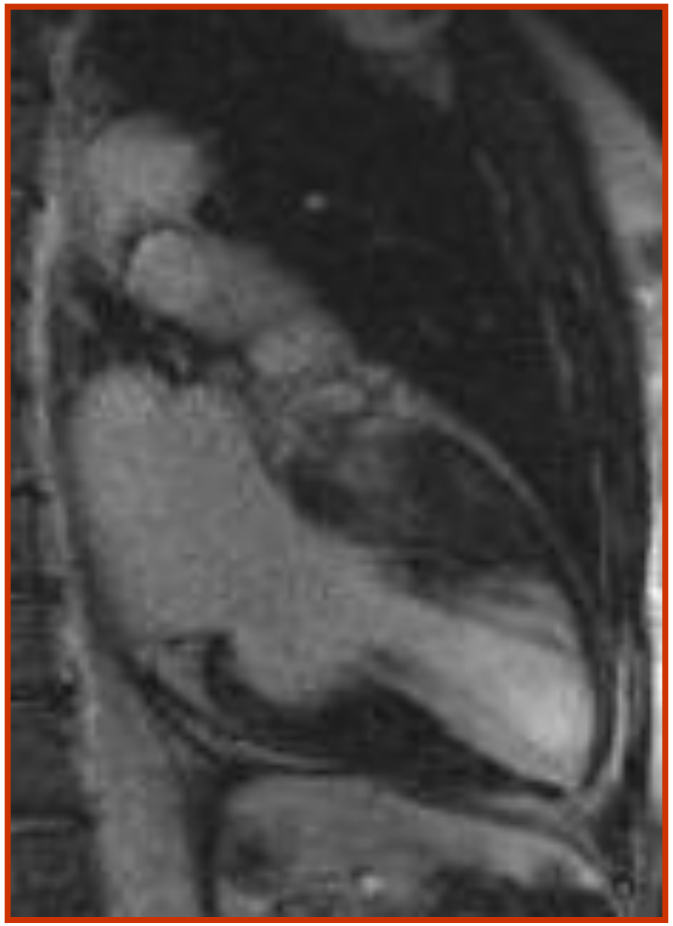
Hypertrophic Cardiomyopathy





Hypertrophic Cardiomyopathy





CMR to determine the aetiology of left ventricular disease and cardiomyopathies: key points

the prognostic value of the presence and extent of hyperenhancement in HCM patients is still unknown and the results of ongoing studies are awaited.

Heart ONLINE

The use of cardiac magnetic resonance imaging to determine the aetiology of left ventricular disease and cardiomyopathy

Avviciniamoci a TC e RM….

Cosa scegliere per caratterizzare il tessuto:

- Ischemic and Primary Dilated Cardiomyopathy
- Acute Myocardial Infarction
- Myocarditis
- Hypertrophic Cardiomyopathy
- Arrhythmogenic Right Ventricular Cardiomyopathy

Magnetic Resonance Imaging of Arrhythmogenic Right Ventricular Dysplasia

Sensitivity, Specificity, and Observer Variability of Fat Detection Versus Functional Analysis of the Right Ventricle

Harikrishna Tandri, MD,* Ernesto Castillo, MD,† Victor A. Ferrari, MD,‡ Khurram Nasir, MD,* Darshan Dalal, MD,* Chandra Bomma, MD,* Hugh Calkins, MD,* David A. Bluemke, MD, PHD†

Baltimore, Maryland; and Philadelphia, Pennsylvania

OBJECTIVES The purpose of this study was to determine interobserver agreement for interpretation of magnetic resonance imaging (MRI) examinations of arrhythmogenic right ventricular dysplasia (ARVD) and to determine sensitivity and specificity of fat detection versus functional parameters measured by MRI.

BACKGROUND The interobserver variability of MRI and the relative importance of different MRI parameters (fat detection, regional and global right ventricular [RV] function) for ARVD diagnosis is unknown.

METHODS Two experienced observers blinded to the clinical history independently analyzed MRI datasets obtained from 40 patients evaluated for ARVD. Twenty normal subjects underwent MRI and served as control subjects. The MRI scans were performed according to a standard protocol on a 1.5-T scanner. The observers reported on fat infiltration, global and regional RV function, myocardial thinning, and chamber dilatation qualitatively. The RV volumes were measured on the cine sequences.

RESULTS Interobserver kappa scores for fat infiltration, global and regional RV function, wall thinning, and RV outflow dilatation were 0.74, 0.94, 0.89, 0.93, and 0.93, respectively. Correlation coefficients between observers for RV end-diastolic volume, end-systolic volume, and ejection fraction were 0.93, 0.94, and 0.95, respectively ($p < 0.001$). Fifteen patients were diagnosed with ARVD using Task Force criteria. Sensitivity of fat infiltration, RV enlargement, and regional RV dysfunction for diagnosing ARVD was 84%, 68%, and 78%, and specificity was 79%, 96%, and 94%, respectively.

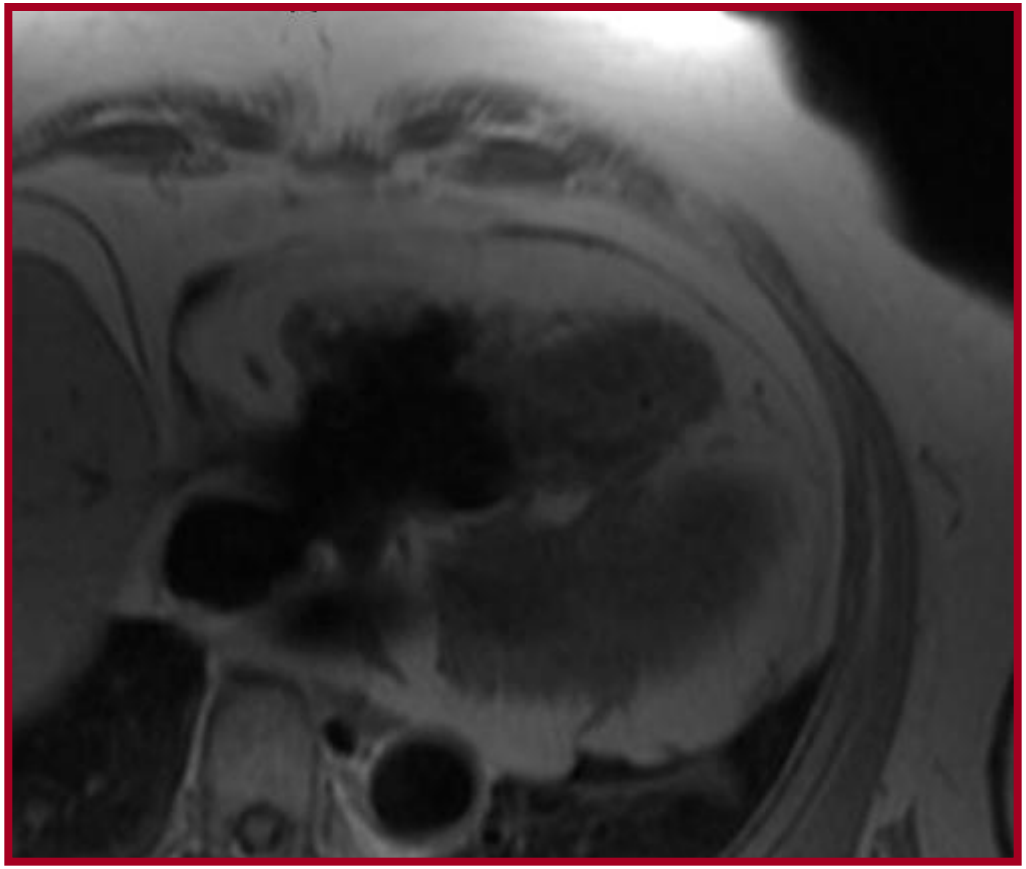
CONCLUSIONS Qualitative assessment of RV structure and function is highly reproducible for experienced observers. Among the qualitative parameters, fat infiltration is less reproducible and lacks specificity compared with RV kinetic abnormalities. (J Am Coll Cardiol 2006;48:2277–84)

Incidence and Interobserver Agreement for the Qualitative MR Variables

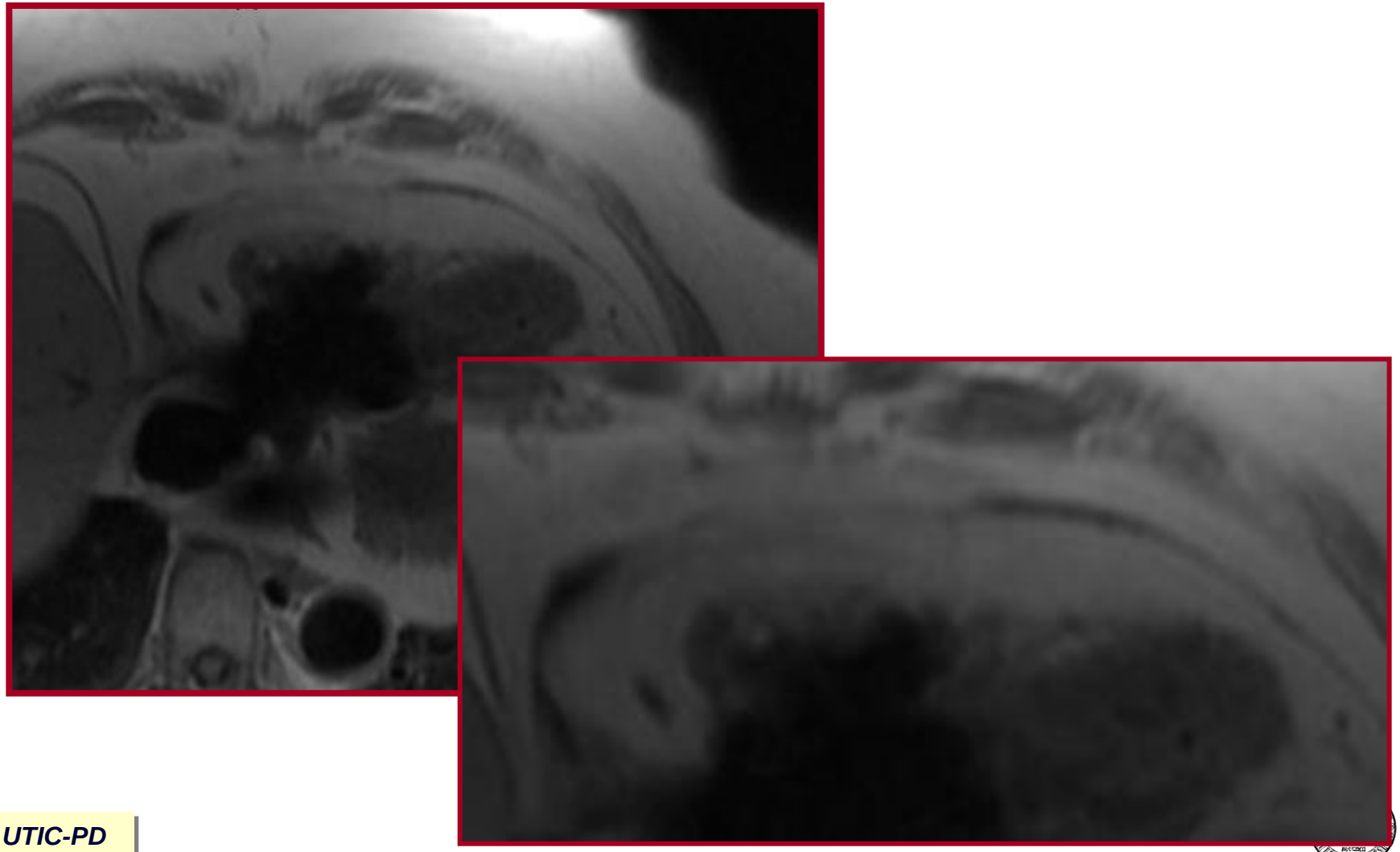
Variable	ARVD	IVT	Controls	% Agreement
Intramyocardial fat	84%	34%	4%	88%
Wall thinning	6%	0%	0%	100%
RV dilation	68%	4%	0%	95%
Regional function	78%	0%	4%	97%
RV outflow tract enlargement	66%	0%	4%	93%

Identification of fat within the myocardium by MRI may not be specific and is in fact the least reproducible MRI parameter

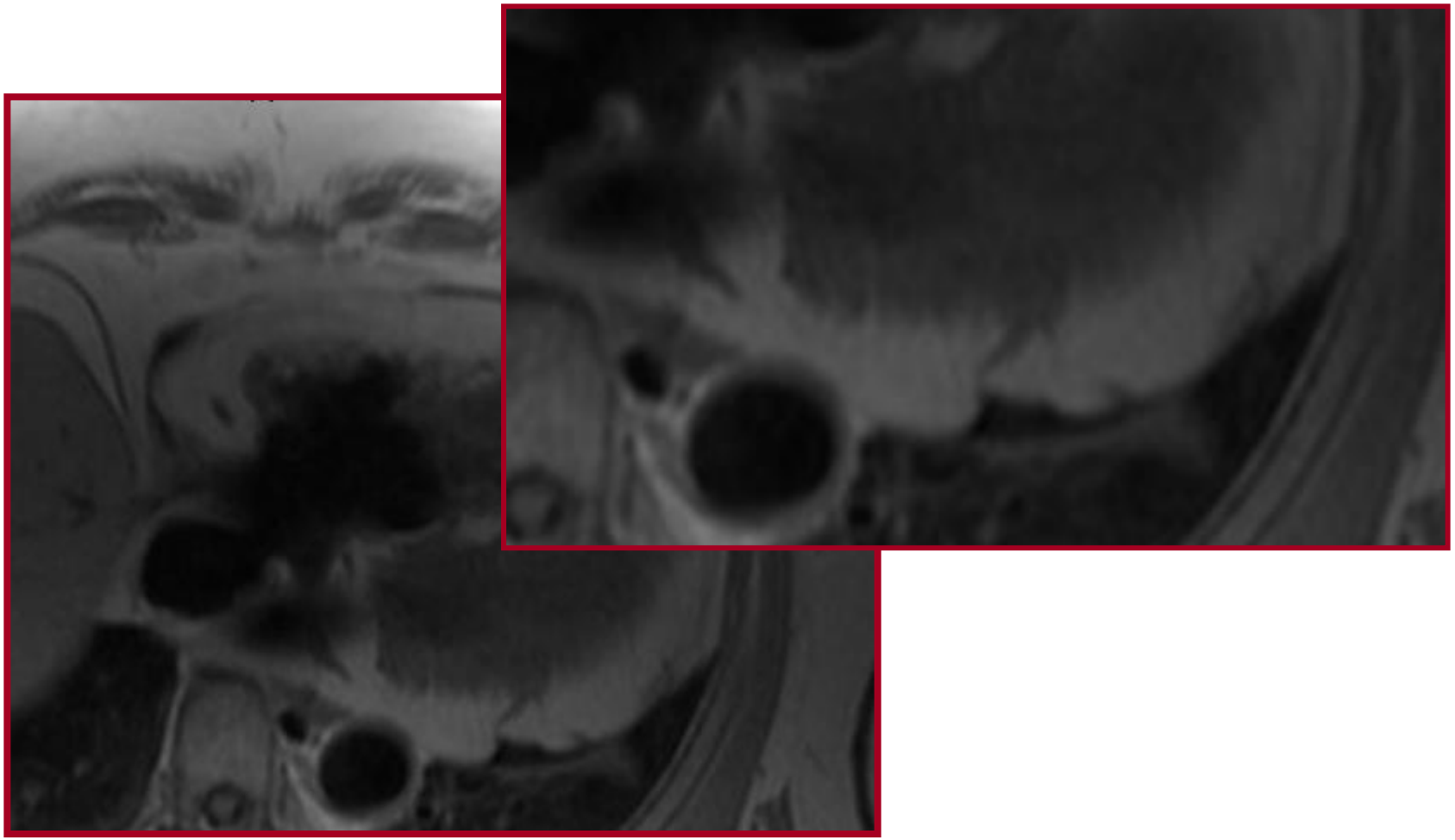
Identification of Intramyocardial Fat by MRI

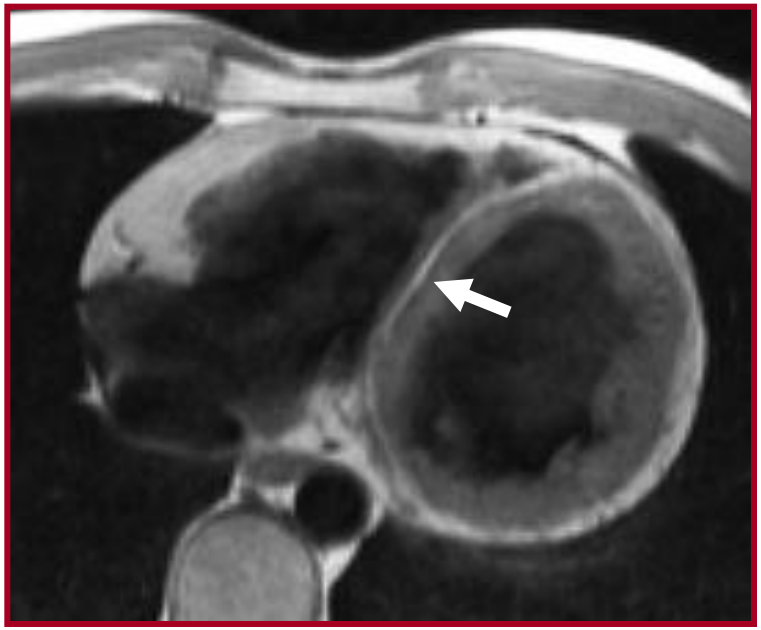


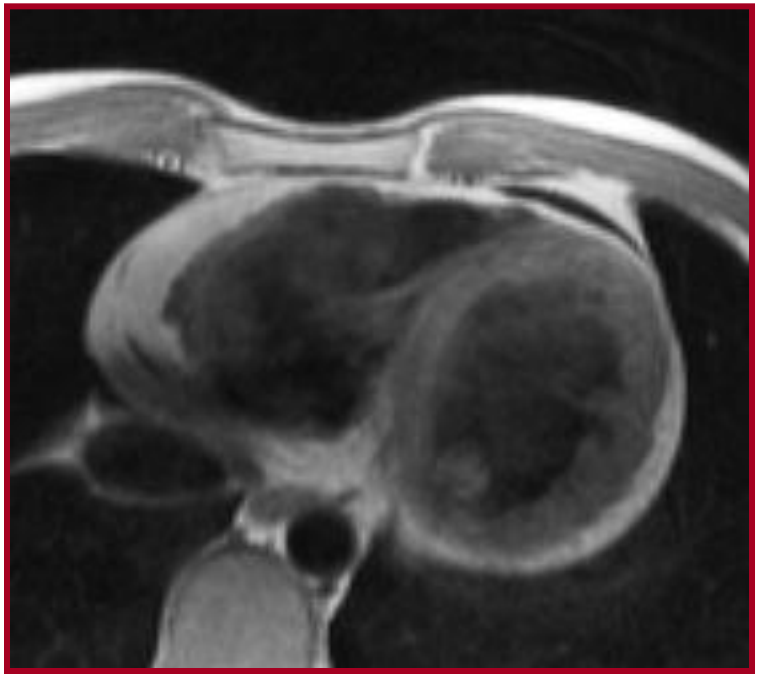
Identification of Intramyocardial Fat by MRI

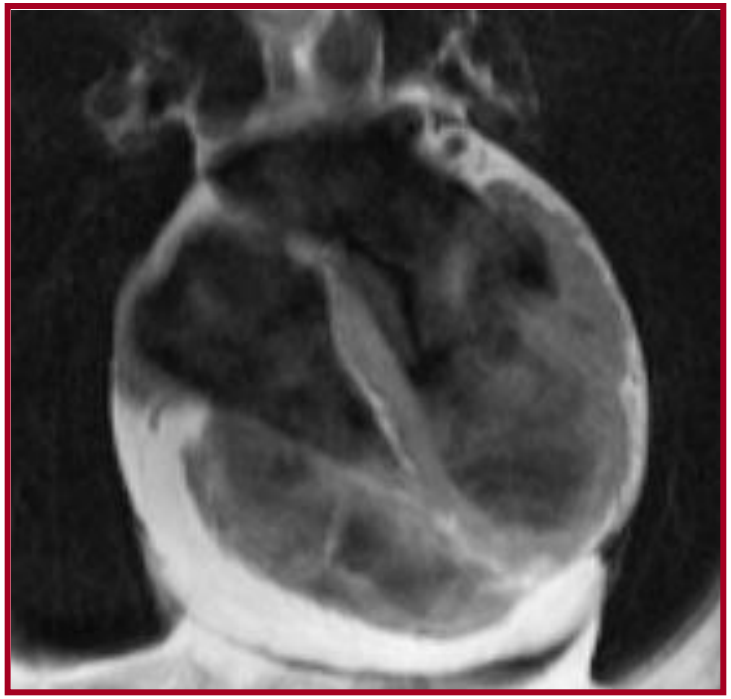


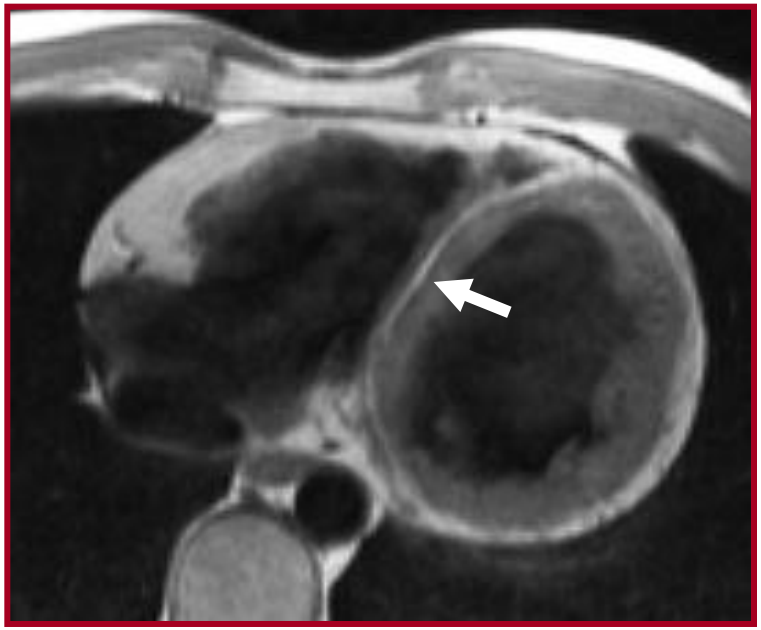
Identification of Intramyocardial Fat by MRI

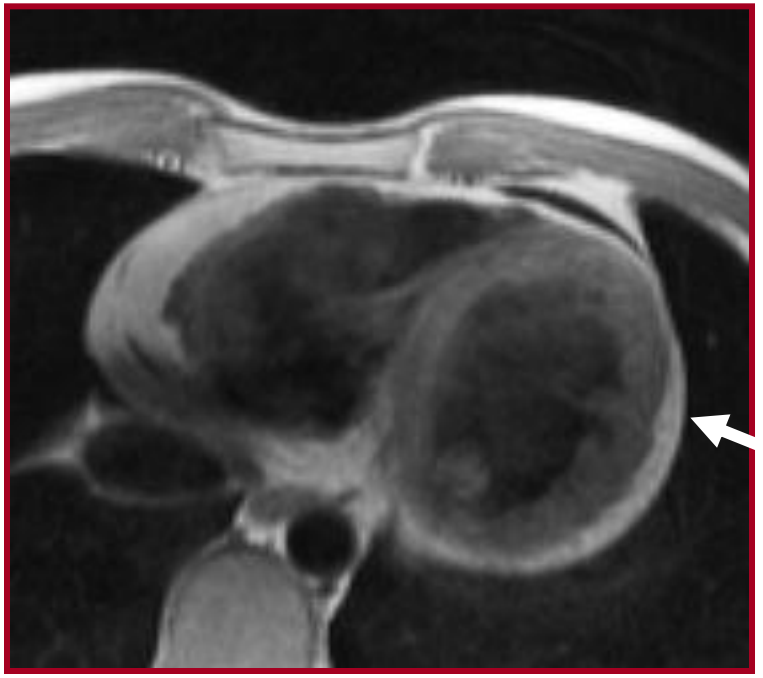


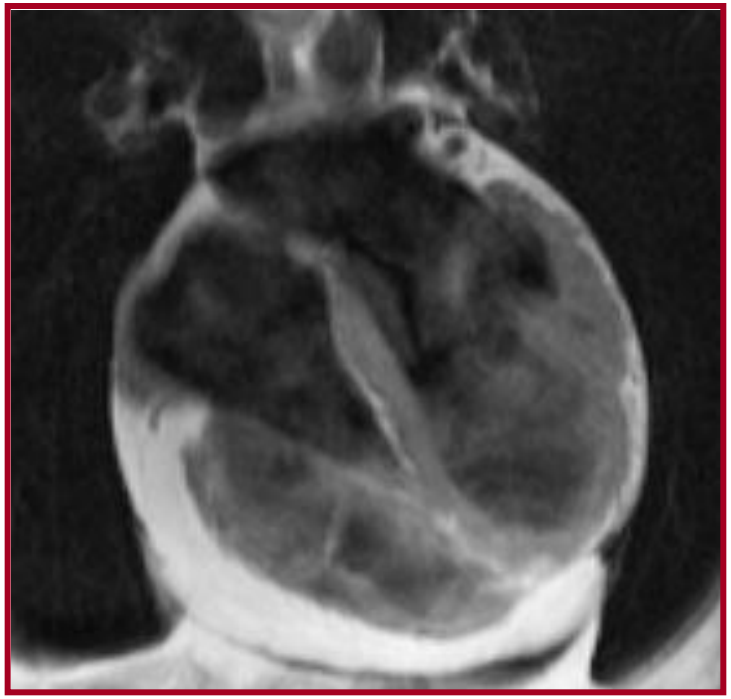


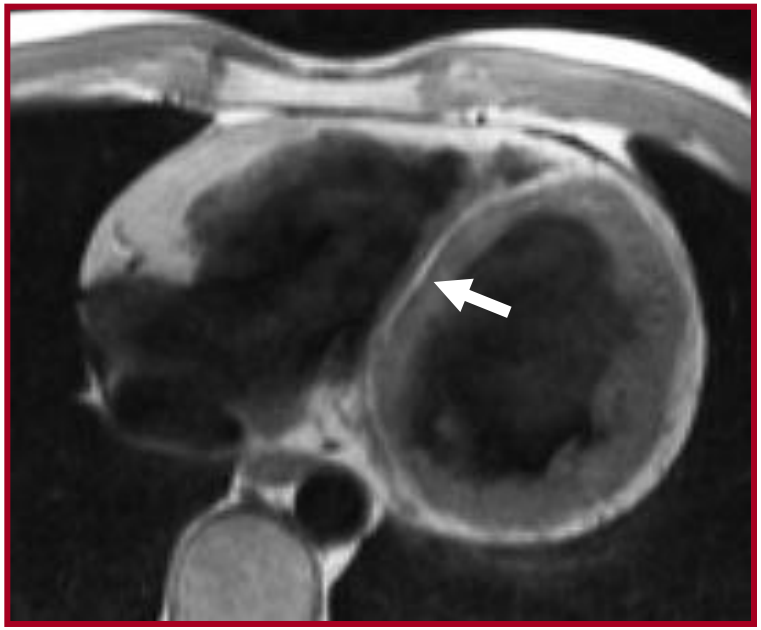


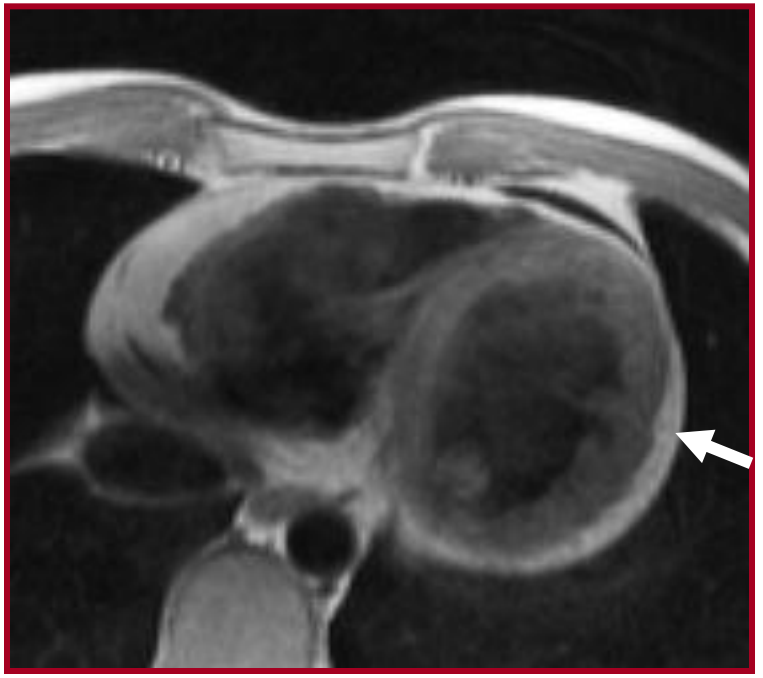


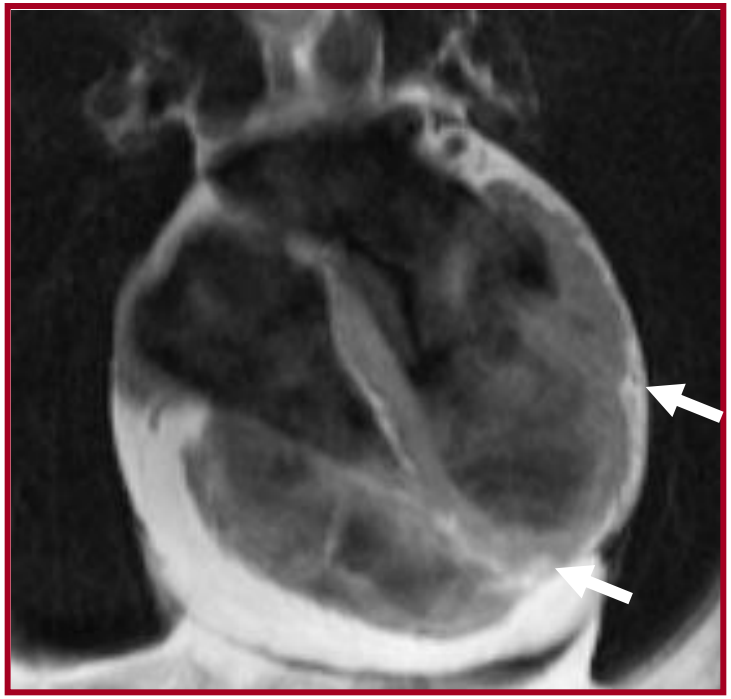












Noninvasive Detection of Myocardial Fibrosis in Arrhythmogenic Right Ventricular Cardiomyopathy Using Delayed-Enhancement Magnetic Resonance Imaging

Harikrishna Tandri, MD,* Manoj Saranathan, PHD,† E. Rene Rodriguez, MD,* Claudia Martinez, MD,* Chandra Bomma, MD,* Khurram Nasir, MBBS,* Boas Rosen, MD,* João A. C. Lima, MD,* Hugh Calkins, MD,* David A. Bluemke, MD, PHD*†

Baltimore, Maryland

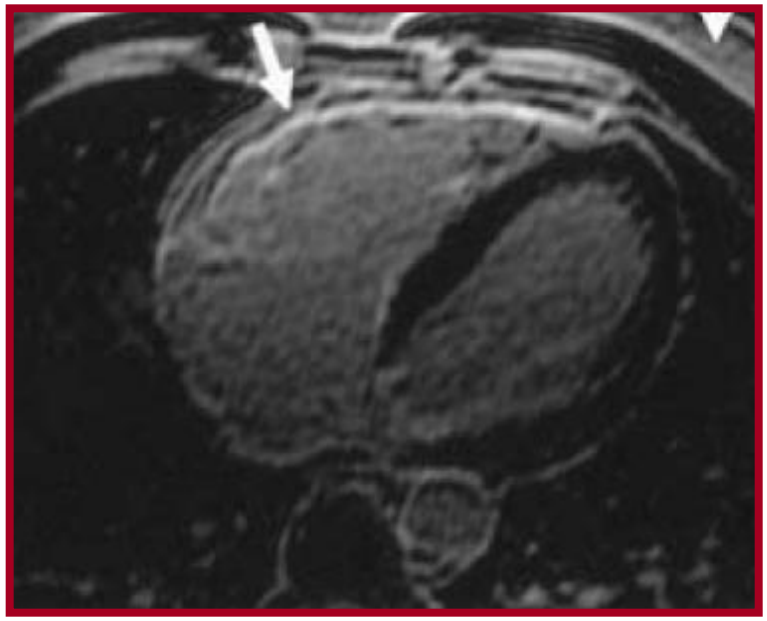
OBJECTIVES We evaluated the role of myocardial delayed-enhancement (MDE) magnetic resonance imaging (MRI) for noninvasive detection of fibrosis in Arrhythmogenic right ventricular dysplasia/cardiomyopathy (ARVD/C).

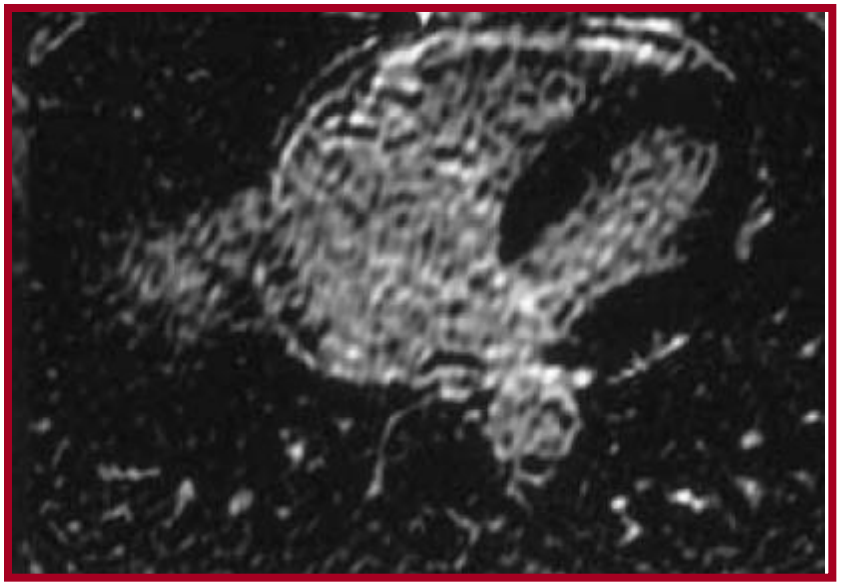
BACKGROUND Arrhythmogenic right ventricular dysplasia/cardiomyopathy is characterized by fibro-fatty replacement of the right ventricle (RV) leading to arrhythmias and RV failure. Endomyocardial biopsy can demonstrate fibro-fatty replacement of the RV myocardium; however, the test is invasive and carries a risk of perforation.

METHODS Thirty consecutive patients were prospectively evaluated for ARVD/C. Magnetic resonance imaging was performed on a 1.5-T scanner. Ten minutes after intravenous administration of 0.2 mmol/kg of gadodiamide, MDE-MRI was obtained. Diagnosis of ARVD/C was based upon the Task Force criteria and did not include MRI findings.

RESULTS Twelve (40%) of 30 patients met the Task Force criteria for ARVD/C. Eight (67%) of the 12 ARVD/C patients demonstrated increased signal on MDE-MRI in the RV compared with none (0%) of the 18 patients without ARVD/C ($p < 0.001$). Endomyocardial biopsy was performed in 9 of the 12 ARVD/C patients. Of the nine patients, four had fibro-fatty changes consistent with the diagnosis of ARVD/C. Each of these patients had increased RV signal on MDE-MRI. None of the patients without ARVD/C had any abnormalities either on histopathology or on MDE-MRI. Electrophysiologic testing revealed inducible sustained ventricular tachycardia (VT) in six of the eight ARVD/C patients with delayed enhancement, compared with none of the ARVD/C patients without delayed enhancement ($p = 0.01$).

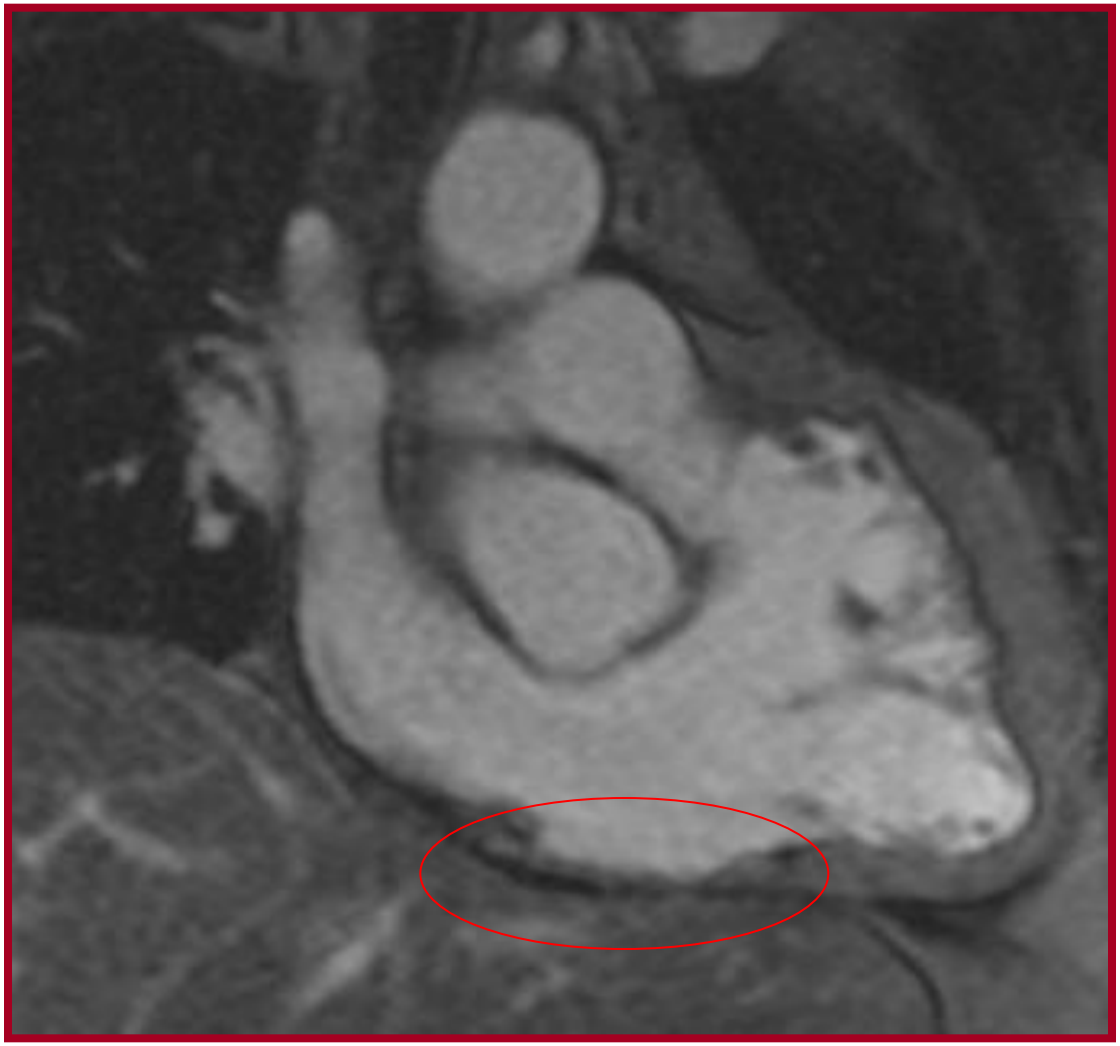
CONCLUSIONS Noninvasive detection of RV myocardial fibro-fatty changes in ARVD/C is possible by MDE-MRI. Magnetic resonance imaging findings had an excellent correlation with histopathology and predicted inducible VT on programmed electrical stimulation, suggesting a possible role in evaluation and diagnosis of patients with suspected ARVD/C. (J Am Coll Cardiol 2005;45:98–103)

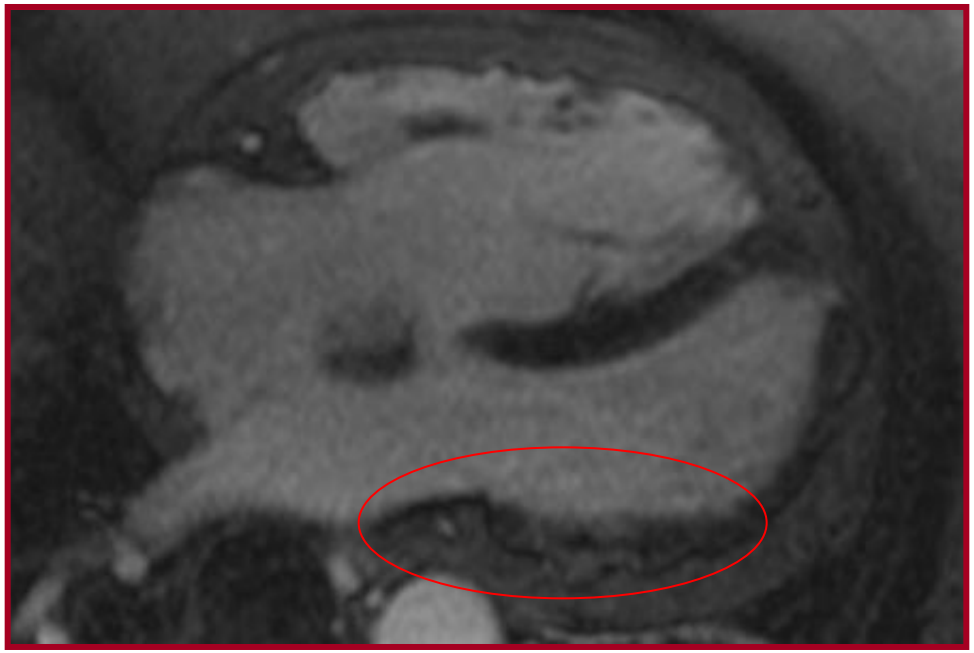


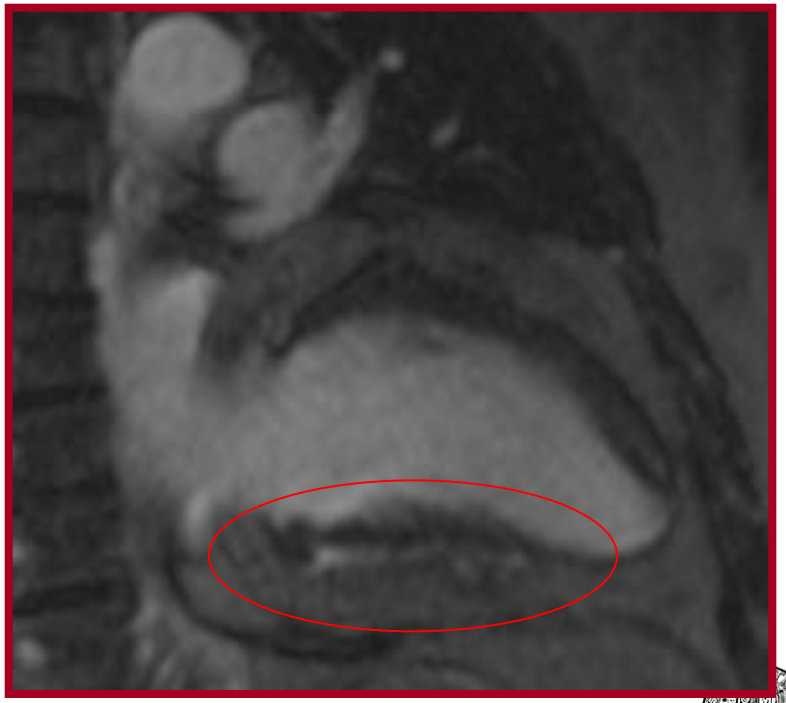


J Am Coll Cardiol 2005;45:98 –103

Noninvasive Imaging of Fibrosis in ARVD

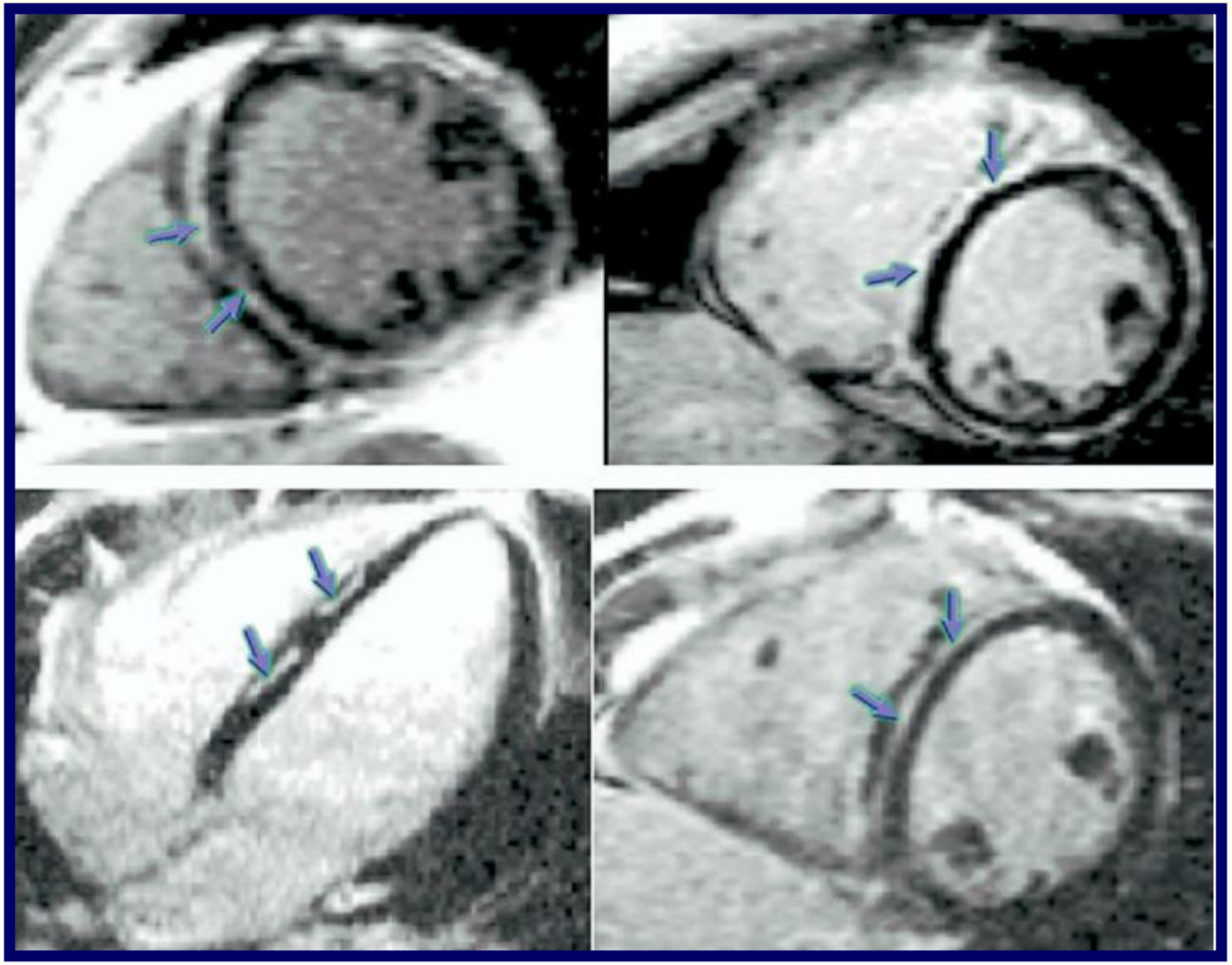






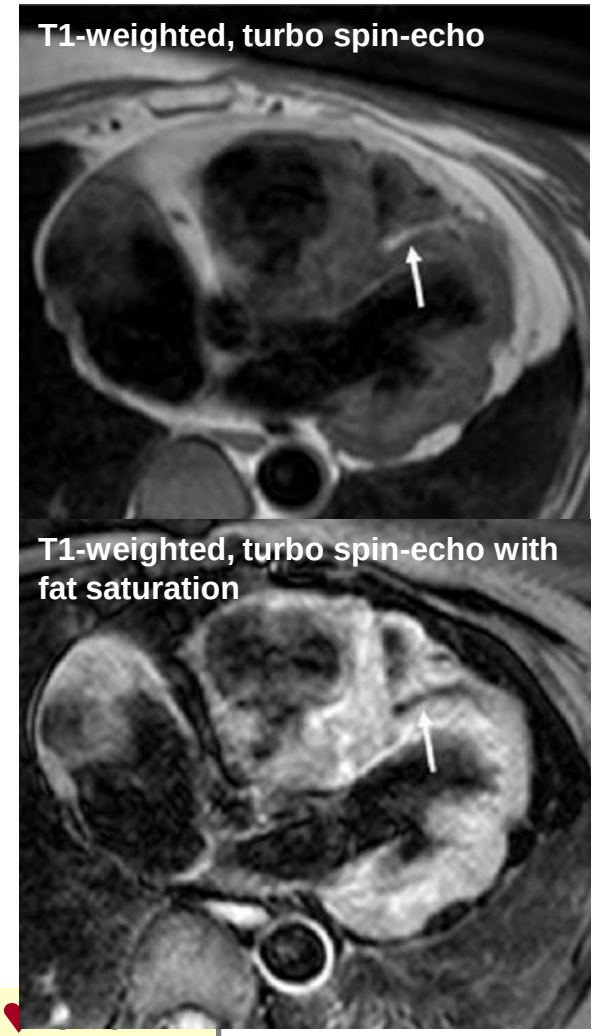
Left-Dominant Arrhythmogenic Cardiomyopathy

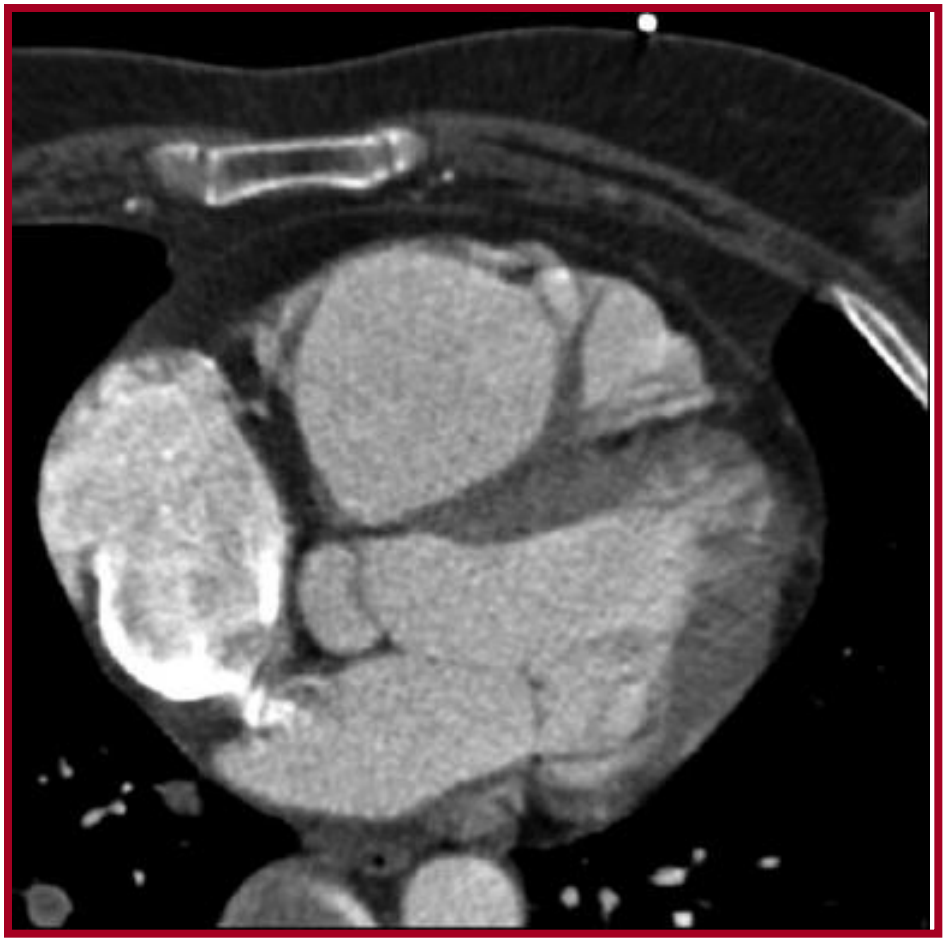
An Under-Recognized Clinical Entity



J Am Coll Cardiol 2008;52:2175–87

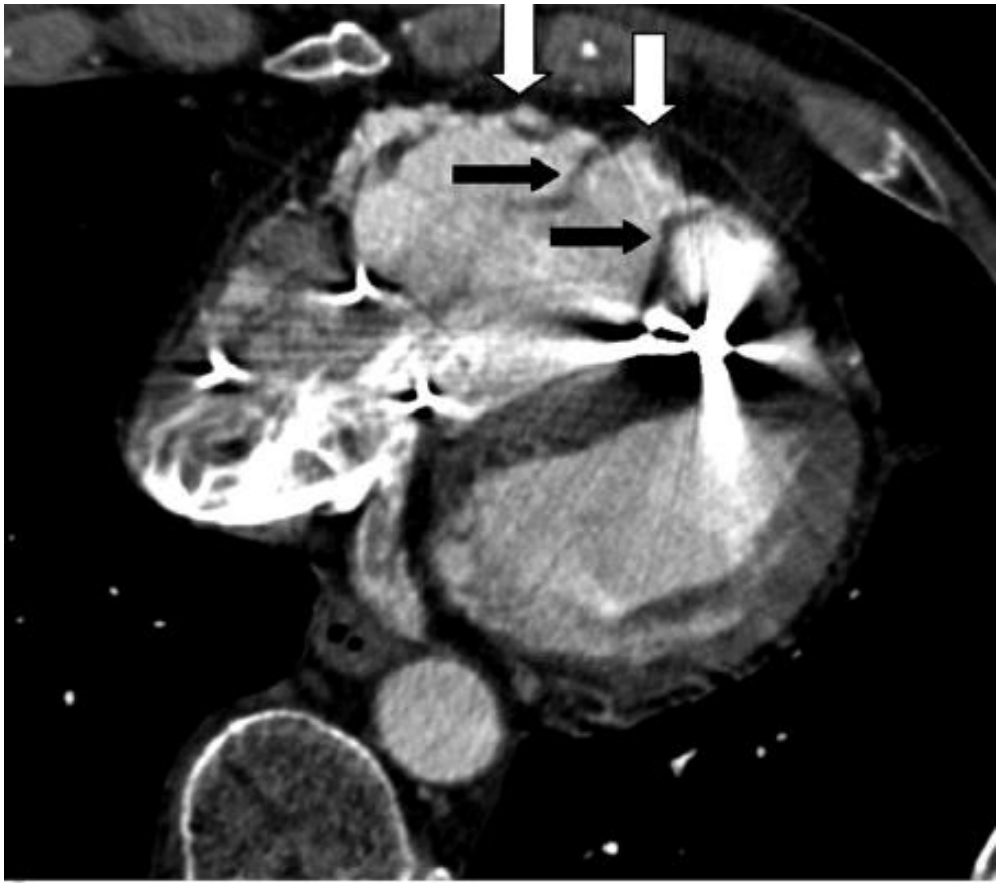
Magnetic Resonance Imaging and Computed Tomography Findings in Arrhythmogenic Right Ventricular Cardiomyopathy





Circulation 2006;113;e673-e675

Evolving Role of Multidetector Computed Tomography in Evaluation of Arrhythmogenic Right Ventricular Dysplasia/Cardiomyopathy



Am J Cardiol 2007;100:99 –105

Avviciniamoci a TC e RM….

Cosa scegliere per caratterizzare il tessuto:

- Ischemic and Primary Dilated Cardiomyopathy
- Acute Myocardial Infarction
- Myocarditis
- Hypertrophic Cardiomyopathy
- Arrhythmogenic Right Ventricular Cardiomyopathy
- Intracardiac Thrombi

Clinical, imaging, and pathological characteristics of left ventricular thrombus: A comparison of contrast-enhanced magnetic resonance imaging, transthoracic echocardiography, and transesophageal echocardiography with surgical or pathological validation

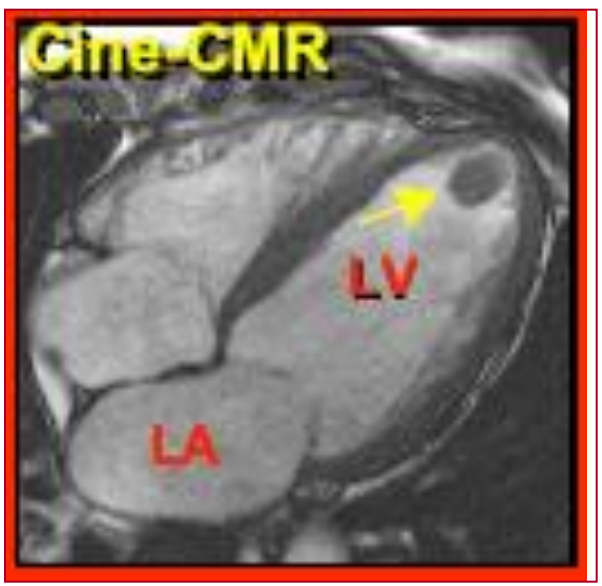
Am Heart J 2006;152:75-84.

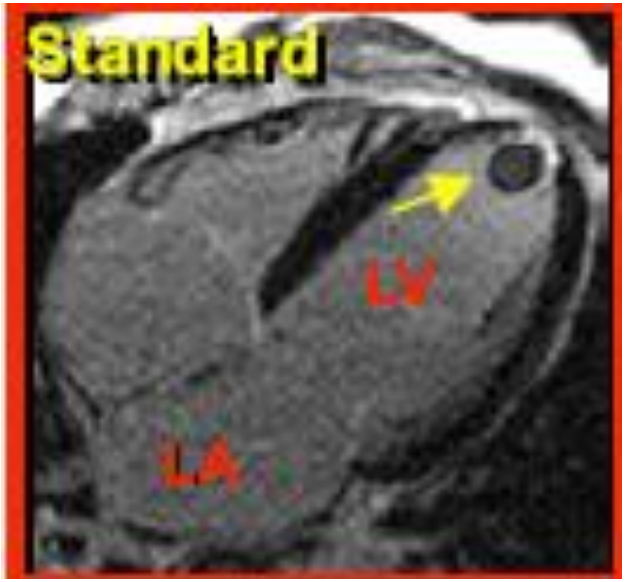
Sensitivity and specificity for subgroup with all 3 imaging modalities

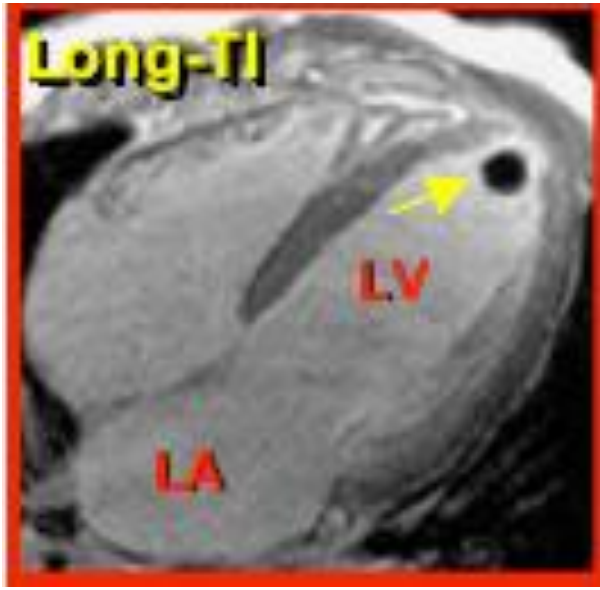
	Total (n)	MRI	TTE	TEE
Sensitivity	48	88% (79%-97%)	23% (11%-35%)	40% (26%-54%)
Specificity	112	99% (97%-100%)	96% (92%-99.6%)	96% (92%-99.6%)

Detection of Left Ventricular Thrombus by Delayed-Enhancement Cardiovascular Magnetic Resonance

Prevalence and Markers in Patients With Systolic Dysfunction







J Am Coll Cardiol 2008;52:148–57

Visualization of Ventricular Thrombi With Contrast-Enhanced Magnetic Resonance Imaging in Patients With Ischemic Heart Disease

Nico R. Mollet, MD; Steven Dymarkowski, MD; Wim Volders, MD; Jurgen Wathiong, MD; Lieven Herbots, MD; Frank E. Rademakers, MD; Jan Bogaert, MD

Background—Ventricular thrombus formation is a frequent and potentially dangerous complication in patients with ischemic heart disease. Although transthoracic echocardiography (TTE) is generally used as diagnostic technique, we explored the role of contrast-enhanced (CE)-MRI to detect ventricular thrombi.

Methods and Results—In 57 patients with acute myocardial infarction, chronic myocardial infarction, or ischemic cardiomyopathy, MRI was performed to evaluate ventricular function (CINE-MRI) and to depict presence of myocardial necrosis and/or scarring and no-reflow areas (CE-MRI). All studies were analyzed for concomitant ventricular thrombi. CE-MRI depicted 12 mural thrombi (3.1 ± 2.9 cm^3), located in left ventricular (LV) apex or adherent to anteroseptum, presenting as black, well-defined structures surrounded by bright contrast-enhanced blood. Thrombus formation on CE-MRI was related to larger end-diastolic volumes; lower ejection fractions; the region of delayed enhancement and lowest wall motion score, especially in left anterior descending coronary artery territory; and LV aneurysm formation. On CINE-MRI, thrombi were found in 6 patients. Nonvisualized thrombi were usually small (mean size 1.2 ± 0.7 cm^3). TTE depicted thrombi in 5. Nonvisualized lesions were most frequently located in LV apex and had a larger size than nonvisualized lesions on CINE-MRI (3.0 ± 3.2 cm^3). In 3 patients with suspected apical thrombus on TTE, MRI was normal.

Conclusions—CE-MRI is not only an excellent technique to depict myocardial necrosis and scar tissue in patients with ischemic heart disease, but this study also suggests a better identification of LV thrombi than with presently used clinical imaging modalities, such as TTE. (***Circulation***. **2002;106:2873-2876.**)

Brief Rapid Communications

Visualization of Ventricular Thrombi With Contrast-Enhanced Magnetic Resonance Imaging in Patients With Ischemic Heart Disease

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Size of nonvisualized thrombi on CINE-MRI ranged from 0.5 to 2.5 cm3. Size of nonvisualized thrombi on TTE ranged from 0.8 to 8.0 cm3), and 6 of them were located in LV apex.

Avviciniamoci a TC e RM….

Cosa scegliere per caratterizzare il tessuto:

- Ischemic and Primary Dilated Cardiomyopathy
- Acute Myocardial Infarction
- Myocarditis
- Hypertrophic Cardiomyopathy
- Arrhythmogenic Right Ventricular Cardiomyopathy
- Intracardiac Thrombi
- Cardiac Masses

MR Imaging of Cardiac Masses

- Stati morphologic imaging
- Fast spin-echo T1- and T2-weighted imaging
- Fat suppression prepulses
- Dynamic assessment Dynamic assessment
- Myocardial tagging
- Administration of gadolinium
- Perfusion

These techniques demonstrate the superior tissue characterization of MR imaging comparedwith CT and echocardiography.
Specific tumoral characterization is possible only in cases of **myxoma**, **lipoma**, **fibroma**, **cysts**,and **hemangioma**

Magn Reson Imaging Clin N Am 16 (2008) 137–164

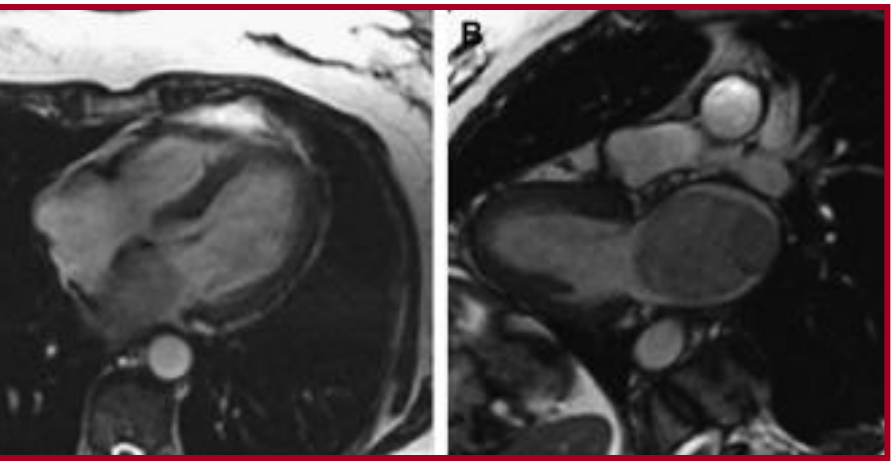
Table 1
Benign cardiac tumors

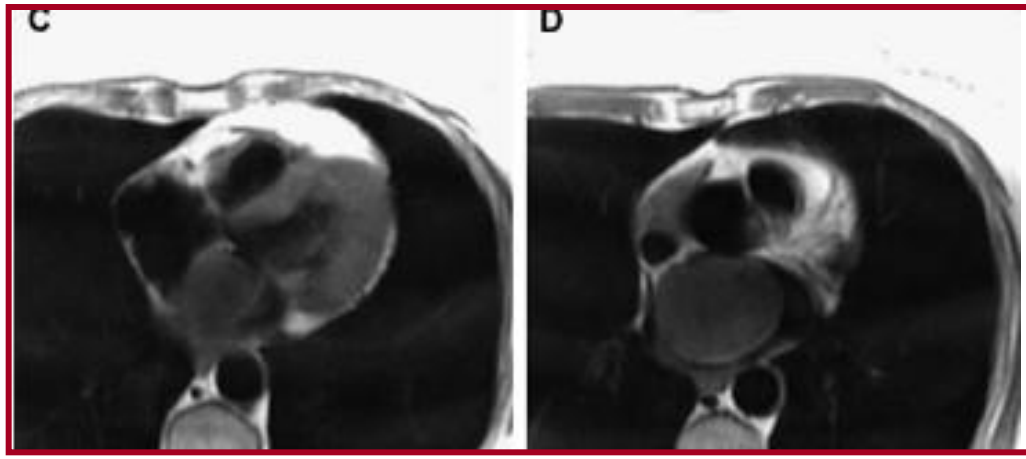
Type of Tumor	Site	Location	Population	T1-weighted	T2-weighted	Cine-MR Imaging	Postcontrast Enhancement	Special Diagnostic Features / Syndrome	Other Data
Myxoma	Intracavitary	Interatrial septum (left atrium, 80%; right atrium, 15%–20%)	Female: male ratio, 3:1 30–60 years	Isointense, heterogenous	Hyperintense, heterogenous	High signalintensity	Heterogenous enhancement	Carney complex, mobile left atrial tumor, commonly has a stalk, attachment to fossa ovalis	Areas of necrosis, calcification, and overlying thrombus may be present
Papillary fibroelastoma	Intracavitary	Cardiac valves (usually left-sided)	Middle-aged to elderly	Isointense	Isointense			Small (< 1 cm) frondlike sessile lesions attached to left-sided cardiac valves	Usually not well seen on MR imaging
Fibroma	Intramural	Ventricular septum, left ventricle free wall, right ventricle	Children, mean age 13 years	Isointense	Hypointense	Isointense	Enhancement	Gorlin syndrome, usually solitary intramural ventricular mass that distorts normal anatomy, commonly calcified	Lack of first-pass enhancement on perfusion imaging
Lipoma	Epicardial/ intramural/ endocardial	Variable	Adults	Hyperintense	Hyperintense	High signal intensity	None	Encapsulated homogenous masses that are commonly epicardial, suppression with fat saturation techniques	

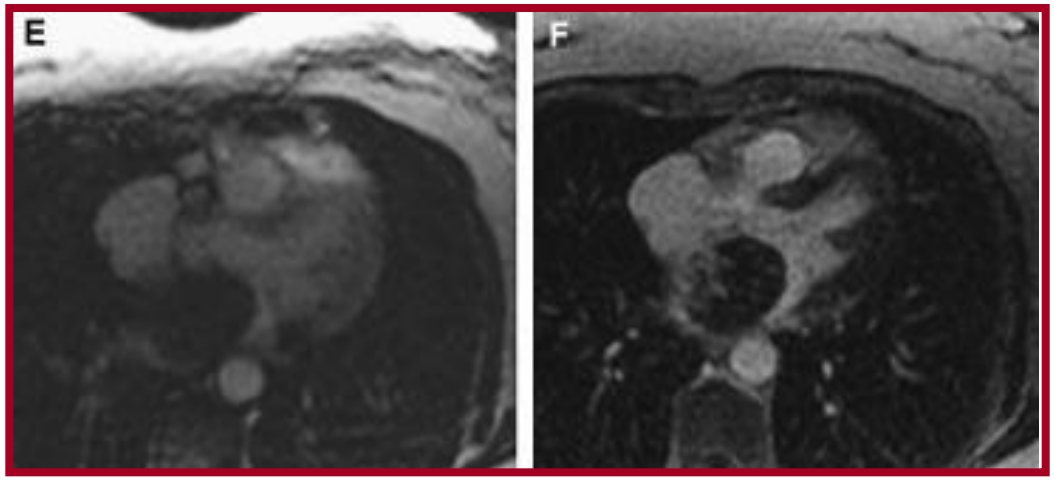
Mixoma

SSFP images

T1-weighted black-blood





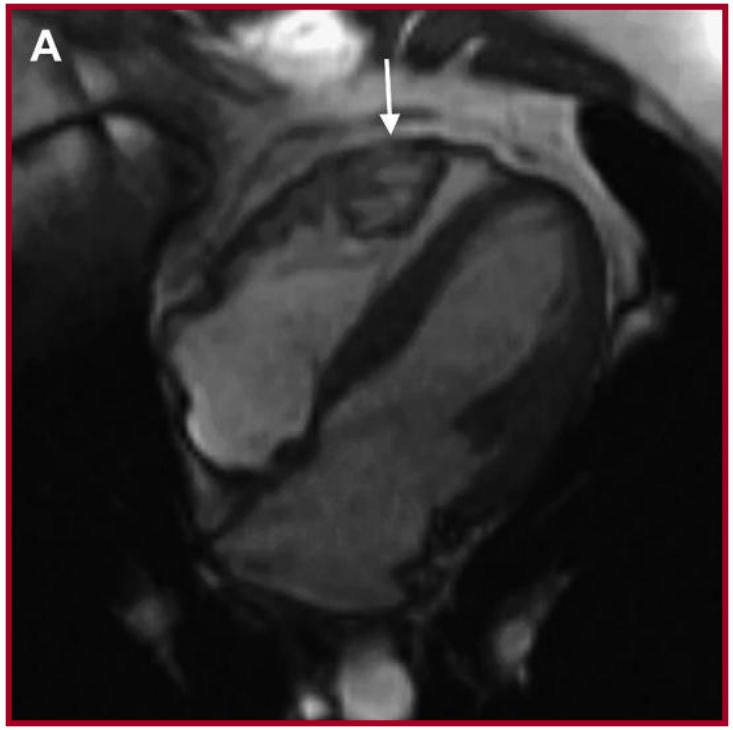


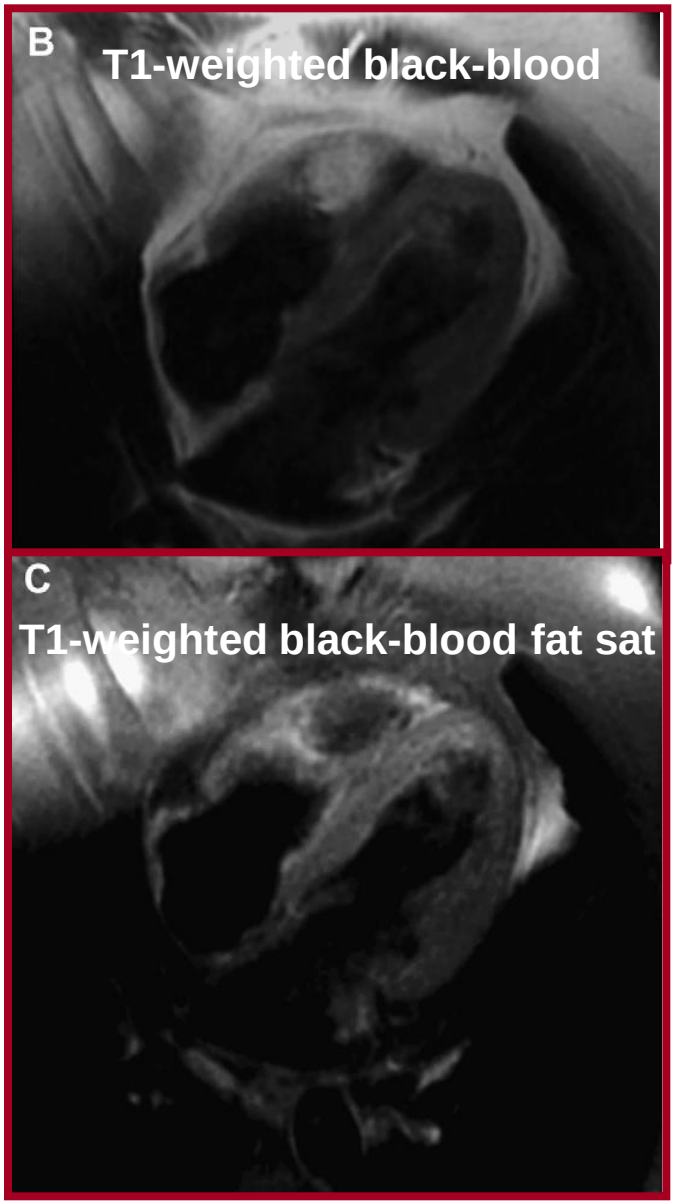
DE inversion-recovery

Magn Reson Imaging Clin N Am 16 (2008) 137–164

Lipoma

SSFP images





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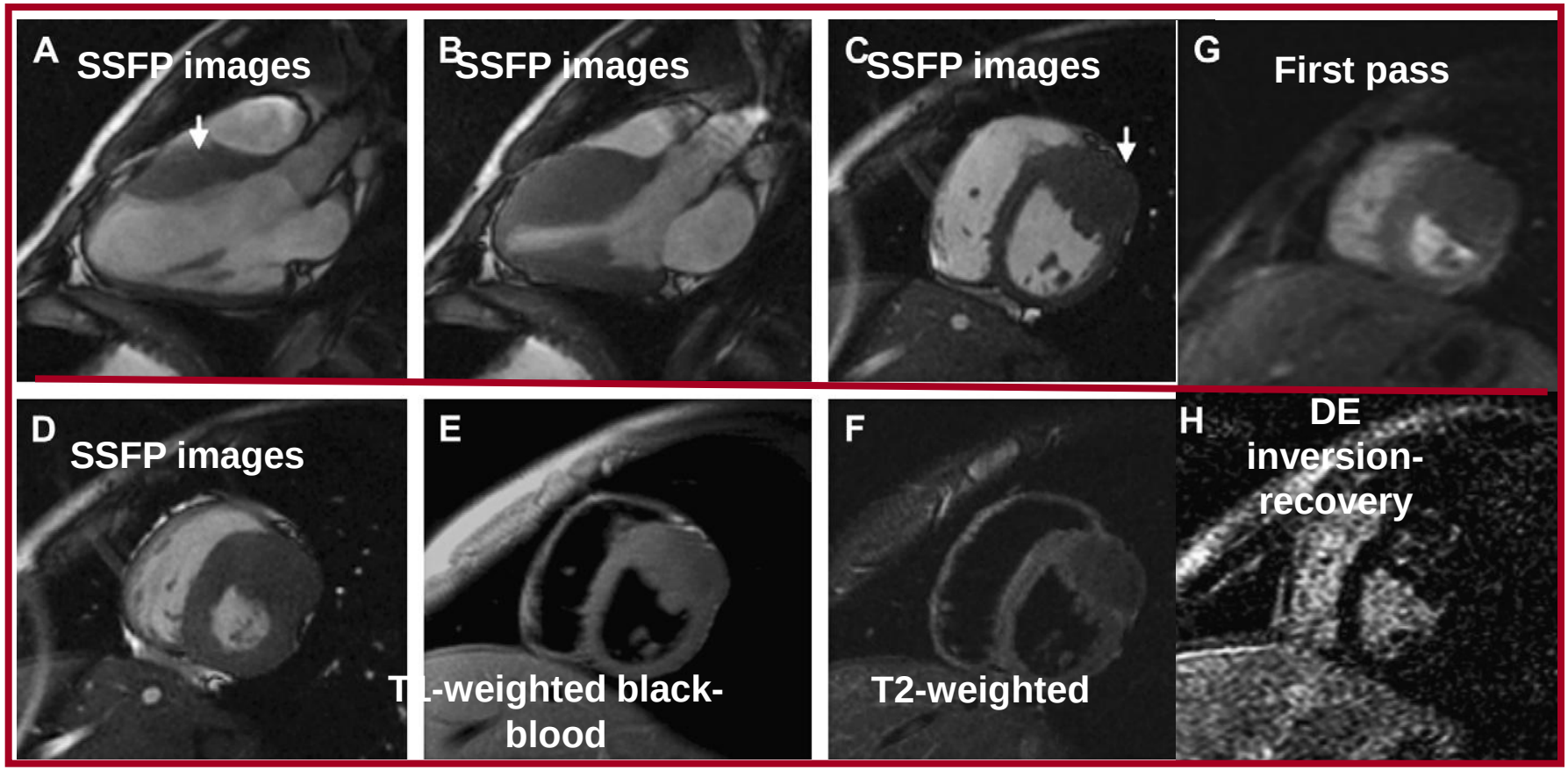
Fibroma



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Avviciniamoci a TC e RM….

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- Cardiac Masses

MRI for cardiac Tissue Characterization

- Ischemic and Primary Dilated Cardiomyopathy
- Acute Myocardial Infarction
- Myocarditis
- Hypertrophic Cardiomyopathy
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- Intracardiac Thrombi
- Cardiac Masses

Malignant Cardiac Tumors

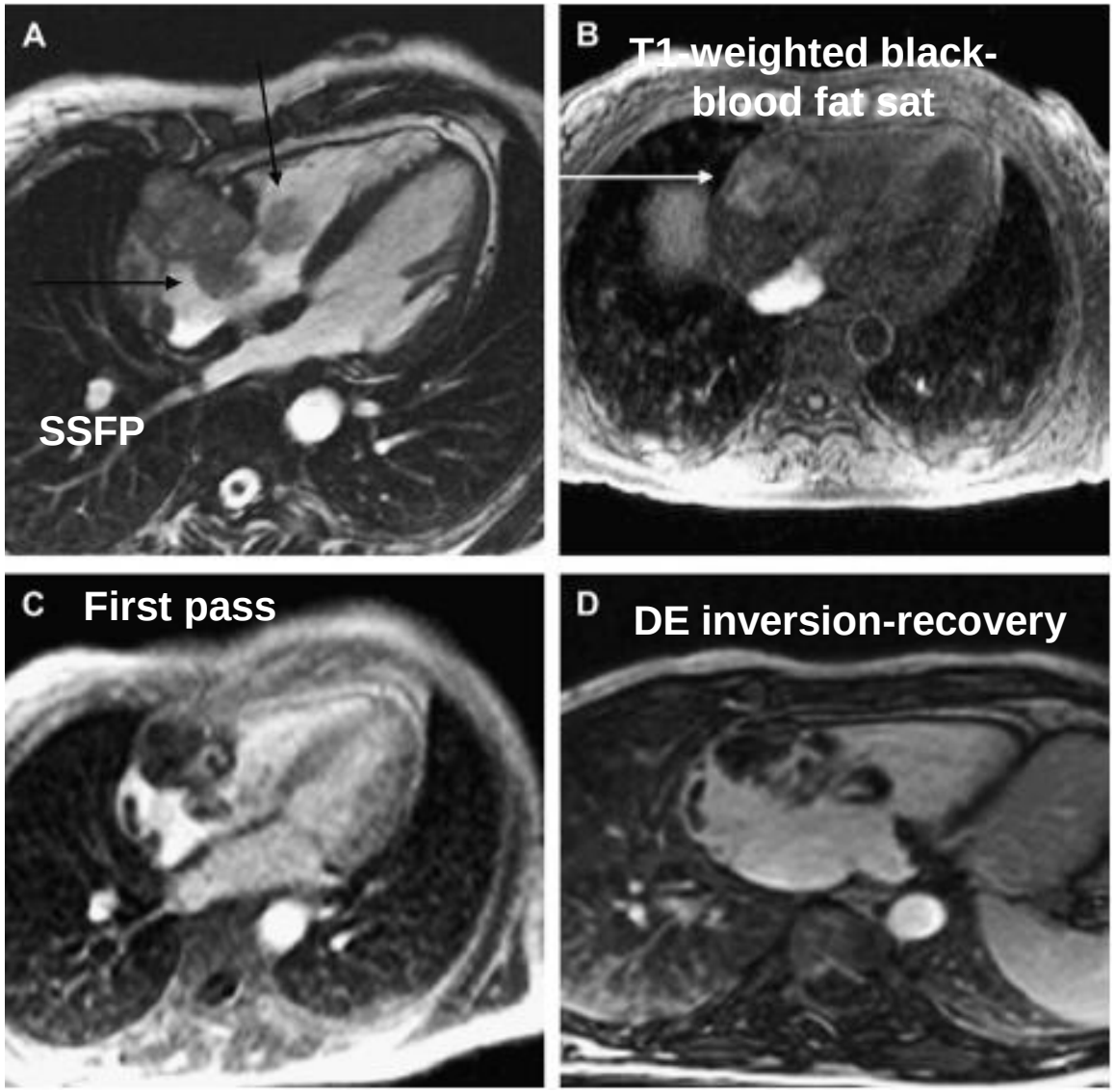
MR imaging usually cannot provide
a specific tissue diagnosis for the different malignancies
but can demonstrate aggressive features
that favor a malignant etiology: poor border definition,
heterogenous appearance with foci of necrosis
and hemorrhage, frequent involvement of the
right-sided cardiac chambers or involvement of
multiple chambers, extracardiac extension, and
coexistent pericardial effusions.

Magn Reson Imaging Clin N Am 16 (2008) 137–164

ANGIOSARCOMA

Magnetic Resonance Imaging of Pericardial Disease and Cardiac Masses

John D. Grizzard, MD[a,*], Gregory B. Ang, MD[b]



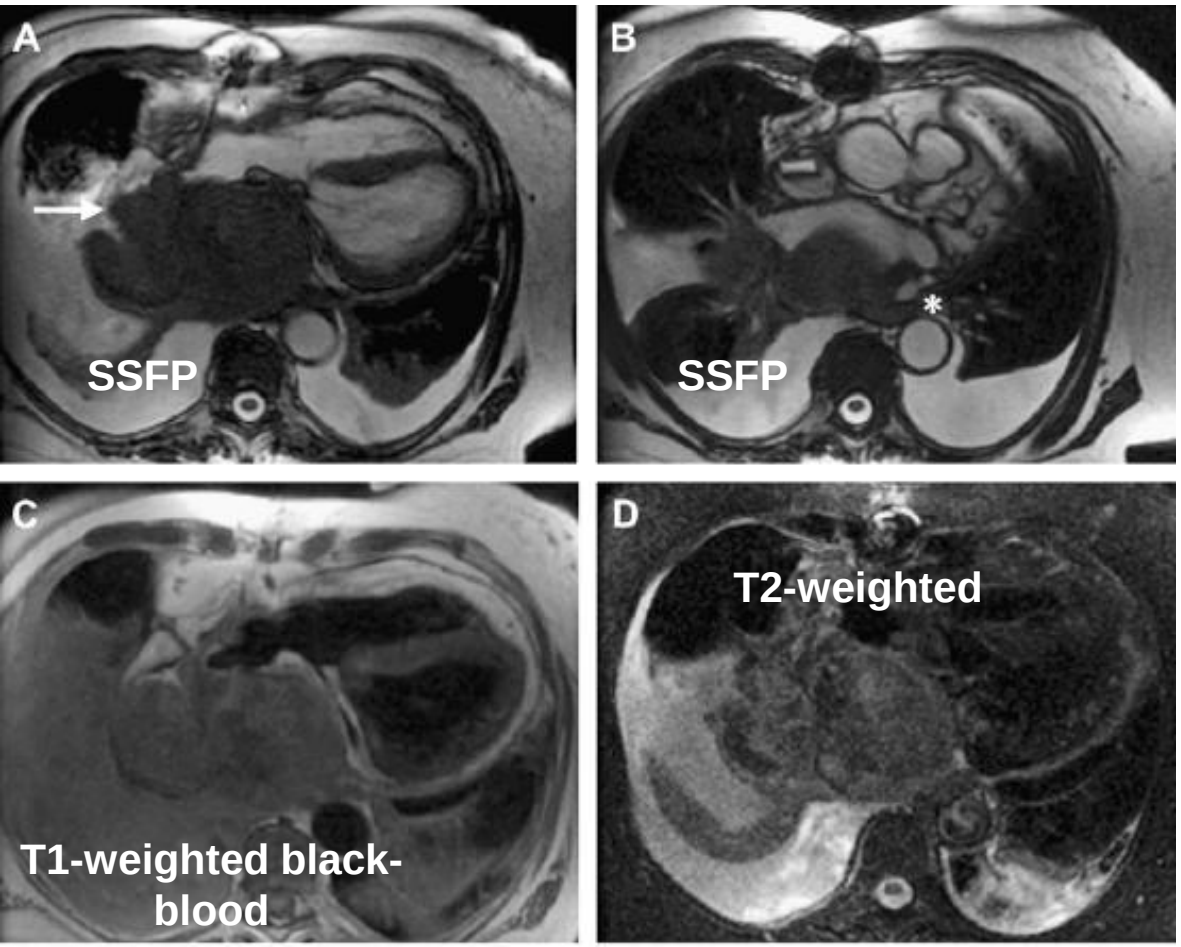
Cardiol Clin 25 (2007) 111–140

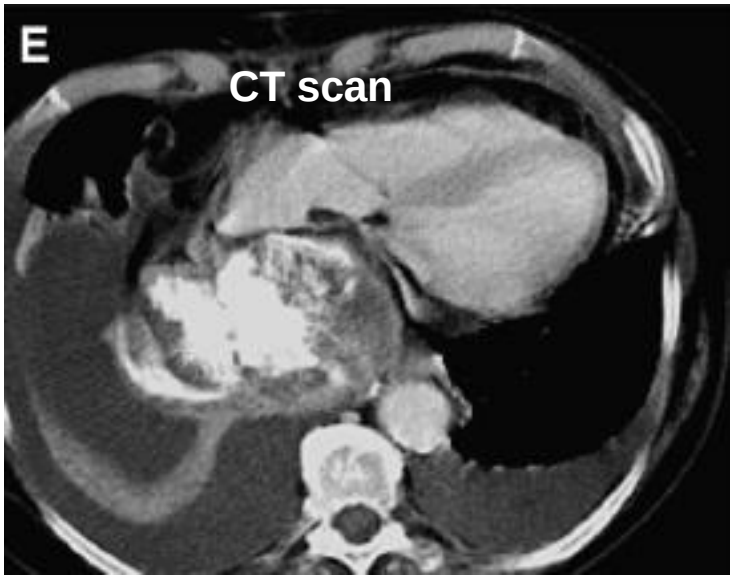
Table 2
Malignant cardiac tumors

Type of Tumor	Location	Population	T1-weighted	T2-weighted	Cine-MR Imaging	Postcontrast Enhancement	Special Diagnostic Features	Other Data
Angiosarcoma	Right atrium	Males, mean age 42 years	Isointense with hyperintense areas (hemorrhage), "cauliflower" appearance	Isointense	Heterogenous, partly hyperintense	Strong enhancement, "sunray" appearance	Bulky, irregular right atrial mass that frequently infiltrates the pericardium	Most common primary malignancy; hemorrhagic areas; cardiac tamponade
Undifferentiated sarcoma	Left atrium	Variable	Isointense	Isointense		Nonspecific	Variable morphology: infiltrative or masslike	Possible pericardial origin
Osteosarcoma	Left atrium	Variable	Heterogeneously isointense (no detailed reports)	Heterogeneously hyperintense	Heterogenous, mostly isointense	Nonspecific	Calcification	Often involves the mitral valve; pulmonary venous obstruction
Rhabdomyosarcoma	Variable	Children	Isointense	Isointense, heterogenous	Isointense	Enhancement with central nonenhancing areas (necrosis)	Central necrosis	May arise from valves; may involve pericardium
Malignant fibrous histiocytoma	Left atrium	Slight female predilection, mean age 47 years	Isointense	Hyperintense		Limited reports, heterogenous enhancement	Posterior wall of the left atrium in > 80% of cases	Pulmonary venous obstruction; left atrial obstruction; distinguish from myxoma

Leiomyosarcoma	Left atrium	Variable	Isointense	Hyperintense	Nonspecific	Posterior wall of the left atrium in > 80% of cases	Pulmonary venous obstruction; left atrial obstruction; distinguish from myxoma
Fibrosarcoma	Left atrium	Variable	Isointense, heterogenous	Hyperintense	Central nonenhancement	Large areas of necrosis	Most common sarcoma to involve ventricles; pericardial involvement frequent (possible pericardial origin)
Liposarcoma	Left atrium	Variable	Not reported	Not reported	Nonspecific	Foci of macroscopic fat sometimes evident	
Lymphoma	Right atrium and ventricle	Immunocompromised patients	Iso- or hypointense	Hyperintense	Homogenous or heterogenous enhancement		Less likely than sarcomas to demonstrate necrosis and extend into cardiac chambers

Osteosarcoma



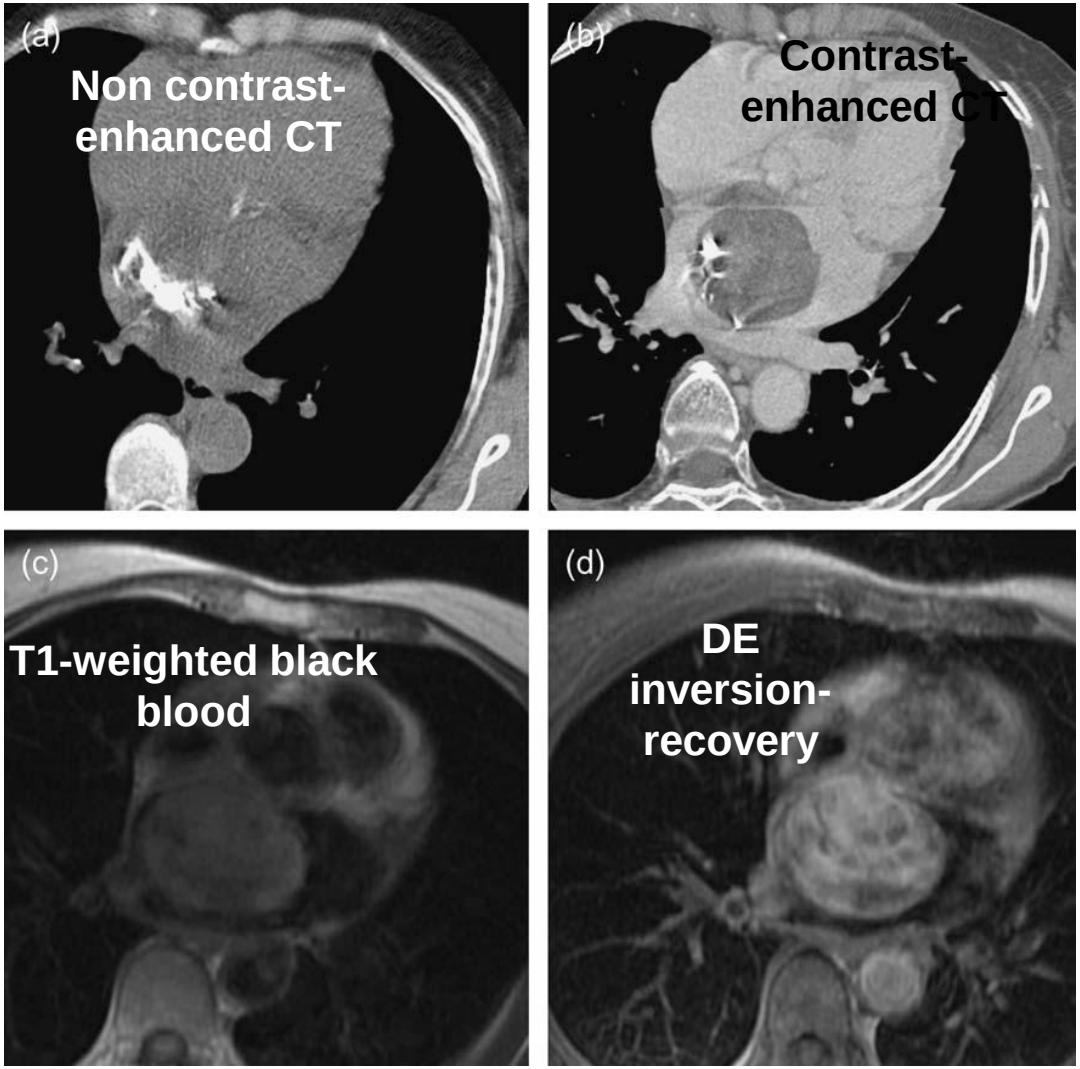


Magn Reson Imaging Clin N Am 16 (2008) 137–164

Benign cardiac tumours: Cardiac CT and MRI imaging appearances

Journal of Medical Imaging and Radiation Oncology (2009) 52, 550–558

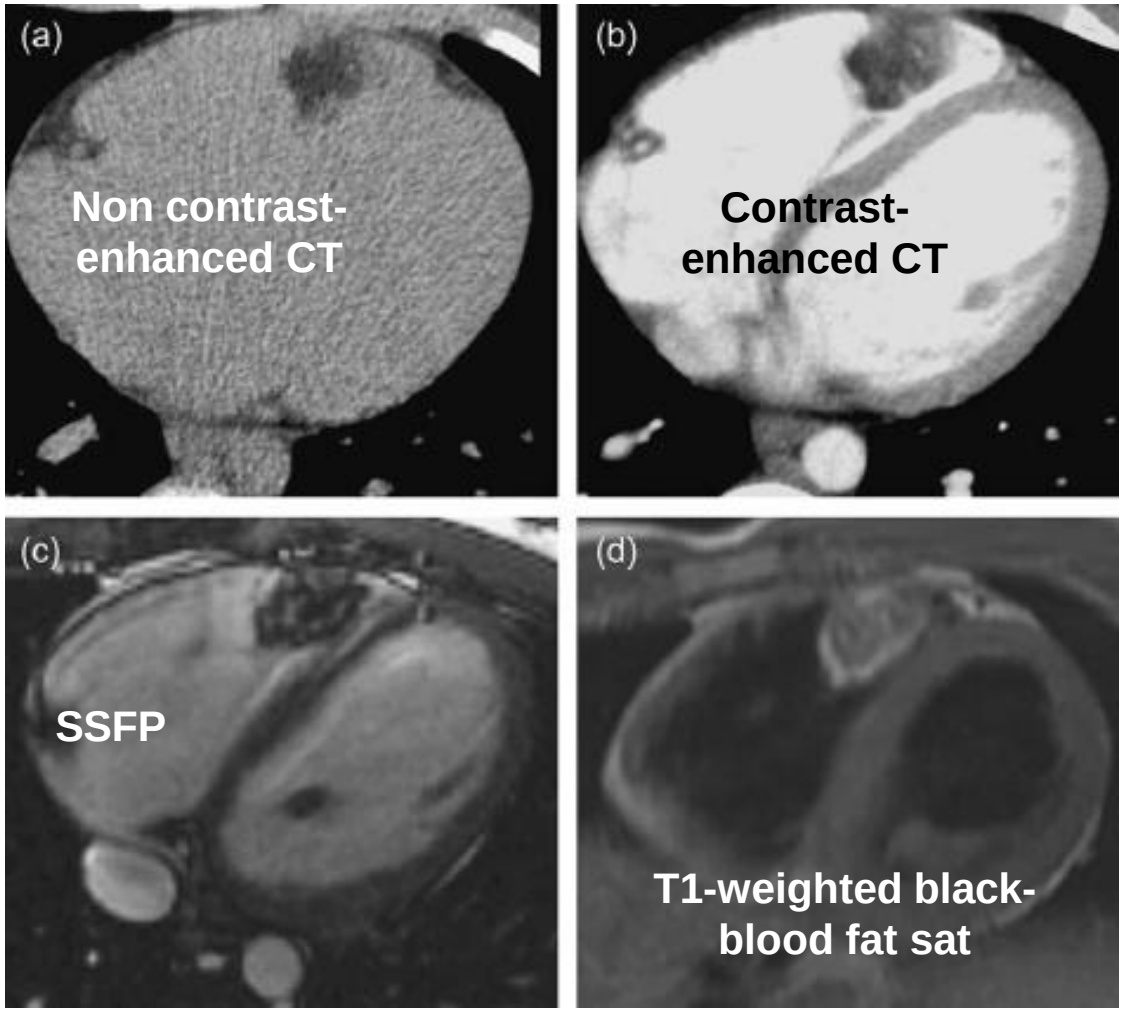
MIXOMA



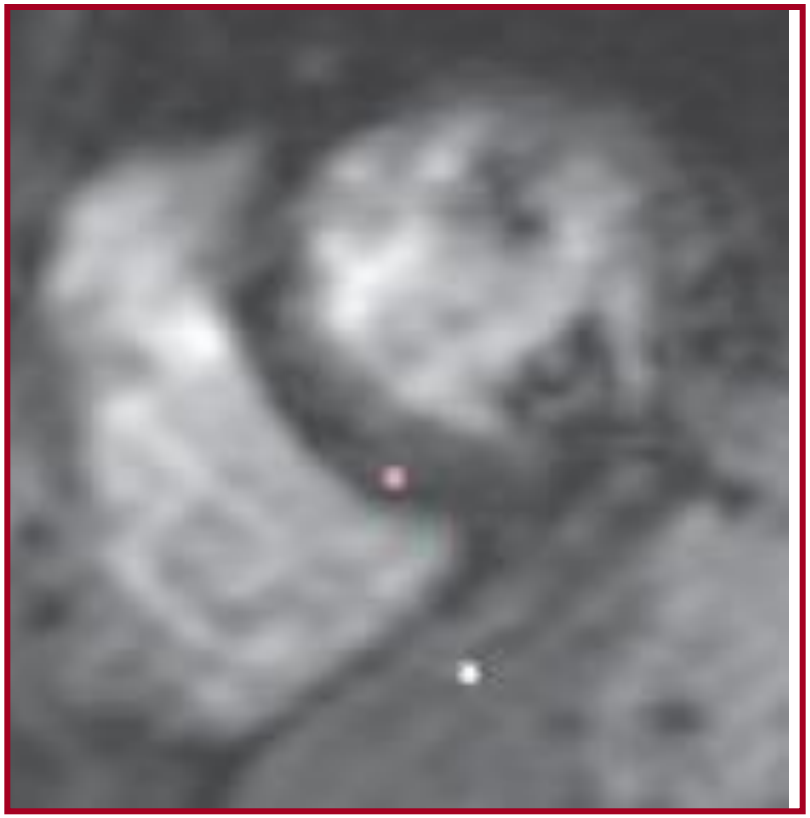
Benign cardiac tumours: Cardiac CT and MRI imaging appearances

Journal of Medical Imaging and Radiation Oncology (2009) 52, 550–558

LIPOMA



Emocromatosi



T2* weighted

- MRI consente la caratterizzazione tissutale miocardica identificando i DEPOSITI di ferro.
- I valori di ferritina ed il livello epatico di ferro non sono dei predittori validi di sovraccarico a livello cardiaco.
- L'accumulo di ferro è soprattutto epicardico, a patch a carico del ventricolo sinistro, quindi la biopsia ha una bassa sensibilità diagnostica.
- La tecnica GRE T2* consente una rapida e riproducibile valutazione dell'accumulo intracardiaco.

Heart 2008; 49:510-518

Cardiovascular Magnetic Resonance in Cardiac Amyloidosis

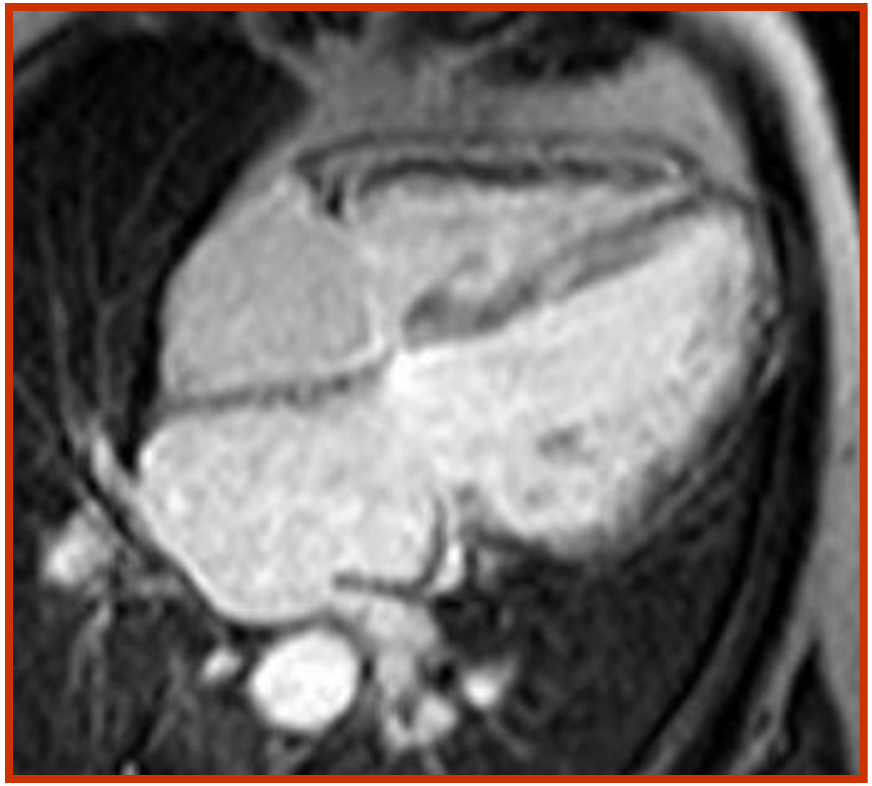
Alicia Maria Maceira, MD; Jayshree Joshi, BSc; Sanjay Kumar Prasad, MD, MRCP; James Charles Moon, MB, MRCP; Enrica Perugini, MD; Idris Harding, BSc; Mary Noelle Sheppard, MD, FRCPath; Philip Alexander Poole-Wilson, MD, FRCP; Philip Nigel Hawkins, PhD, FRCP; Dudley John Pennell, MD, FRCP

Background—Cardiac amyloidosis can be diagnostically challenging. Cardiovascular magnetic resonance (CMR) can assess abnormal myocardial interstitium.

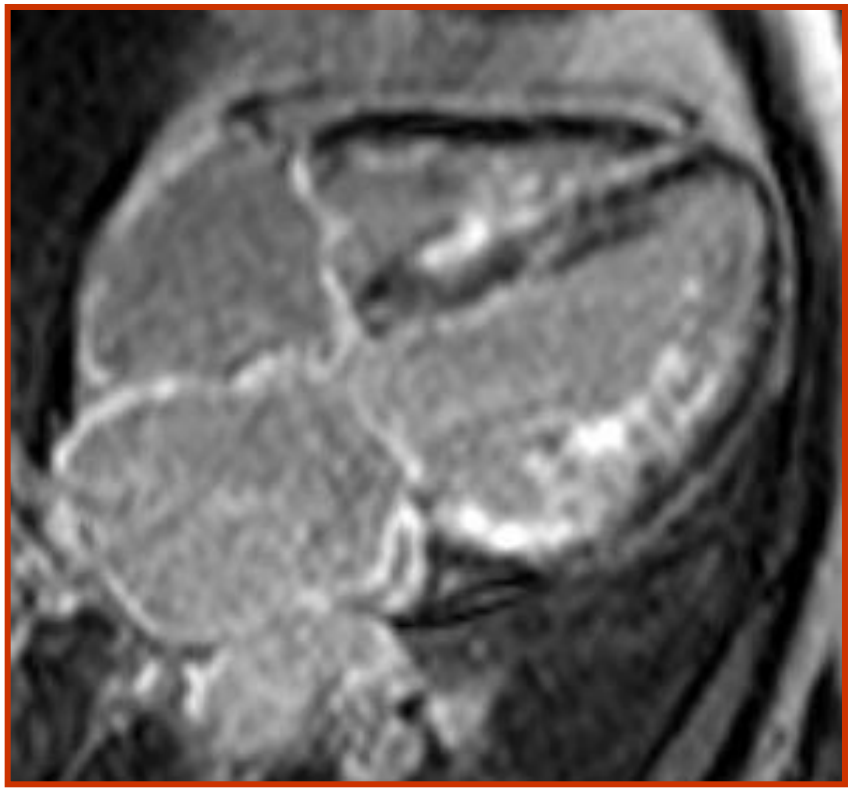
Methods and Results—Late gadolinium enhancement CMR was performed in 30 patients with cardiac amyloidosis. In 22 of these, myocardial gadolinium kinetics with T_1 mapping was compared with that in 16 hypertensive controls. One patient had CMR and autopsy only. Subendocardial T_1 in amyloid patients was shorter than in controls (at 4 minutes: 427±73 versus 579±75 ms; $P<0.01$), was shorter than subepicardium T_1 for the first 8 minutes ($P\leq0.01$), and was correlated with markers of increased myocardial amyloid load, as follows: left ventricular (LV) mass ($r=-0.51$, $P=0.013$); wall thickness ($r=-0.54$ to -0.63, $P<0.04$); interatrial septal thickness ($r=-0.52$, $P=0.001$); and diastolic function ($r=-0.42$, $P=0.025$). Global subendocardial late gadolinium enhancement was found in 20 amyloid patients (69%); these patients had greater LV mass (126±30 versus 93±25 g/m^2; $P=0.009$) than unenhanced patients. Histological quantification showed substantial interstitial expansion with amyloid (30.5%) but only minor fibrosis (1.3%). Amyloid was dominantly subendocardial (42%) compared with midwall (29%) and subepicardium (18%). There was 97% concordance in diagnosis of cardiac amyloid by combining the presence of late gadolinium enhancement and an optimized T_1 threshold (191 ms at 4 minutes) between myocardium and blood.

Conclusions—In cardiac amyloidosis, CMR shows a characteristic pattern of global subendocardial late enhancement coupled with abnormal myocardial and blood-pool gadolinium kinetics. The findings agree with the transmural histological distribution of amyloid protein and the cardiac amyloid load and may prove to have value in diagnosis and treatment follow-up. (***Circulation*. 2005;111:186-193.**)

Key Words: amyloid ■ gadolinium ■ magnetic resonance imaging ■ heart diseases ■ cardiomyopathy



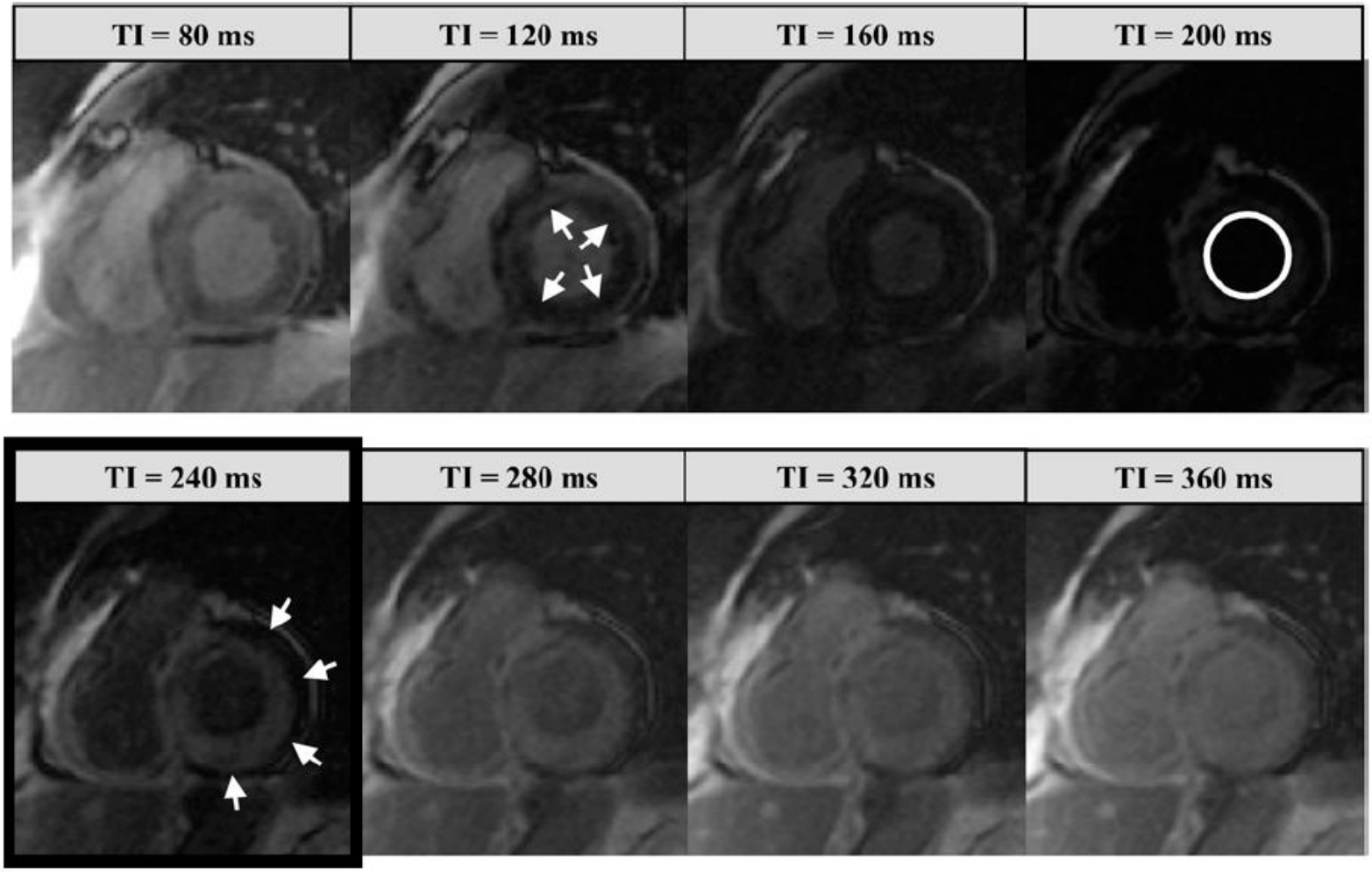
4 minuti



10 minuti

Cardiovascular Magnetic Resonance in Clinically Suspected Cardiac Amyloidosis

Noninvasive Imaging Compared to Endomyocardial Biopsy



J Am Coll Cardiol 2008;51:1022–30

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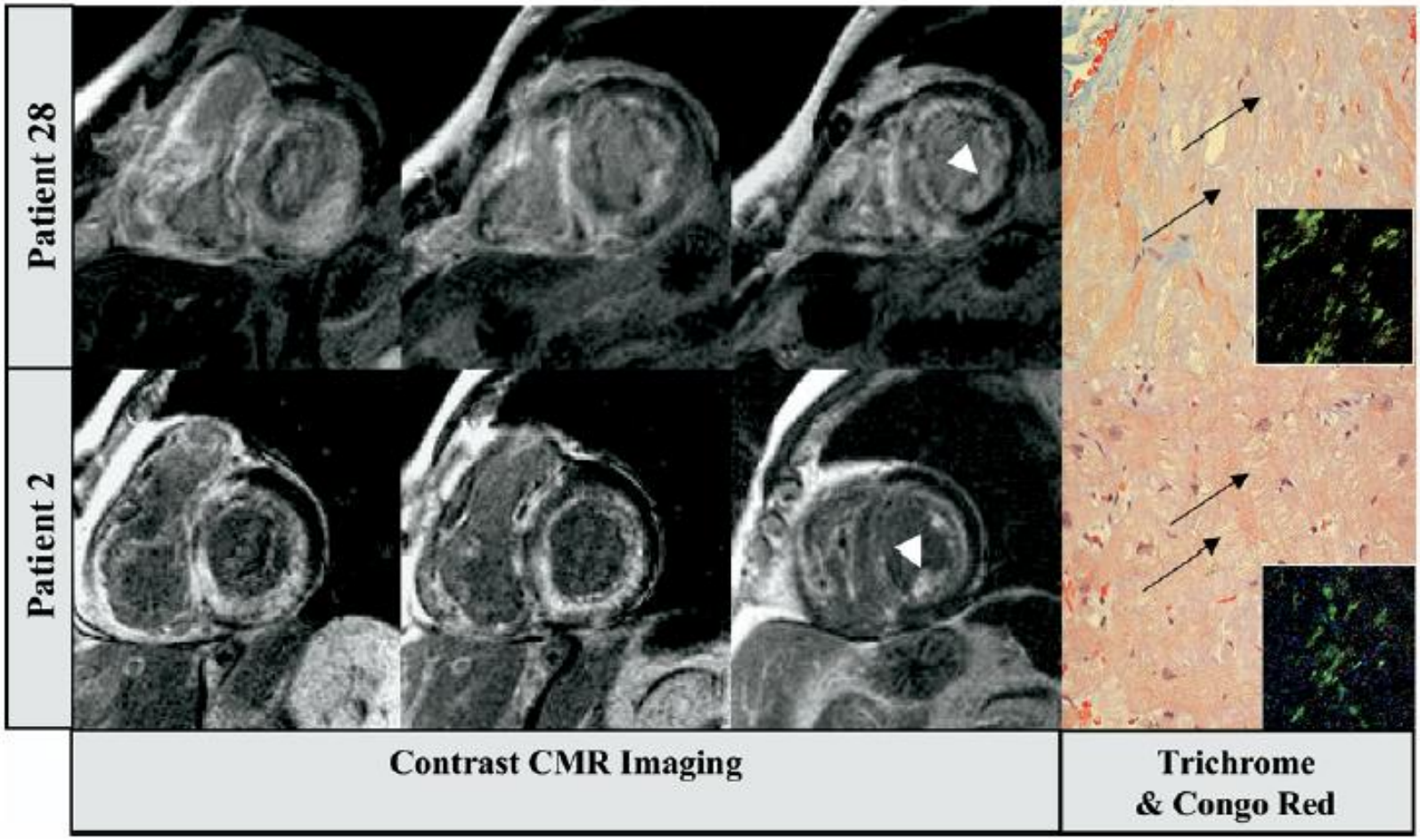

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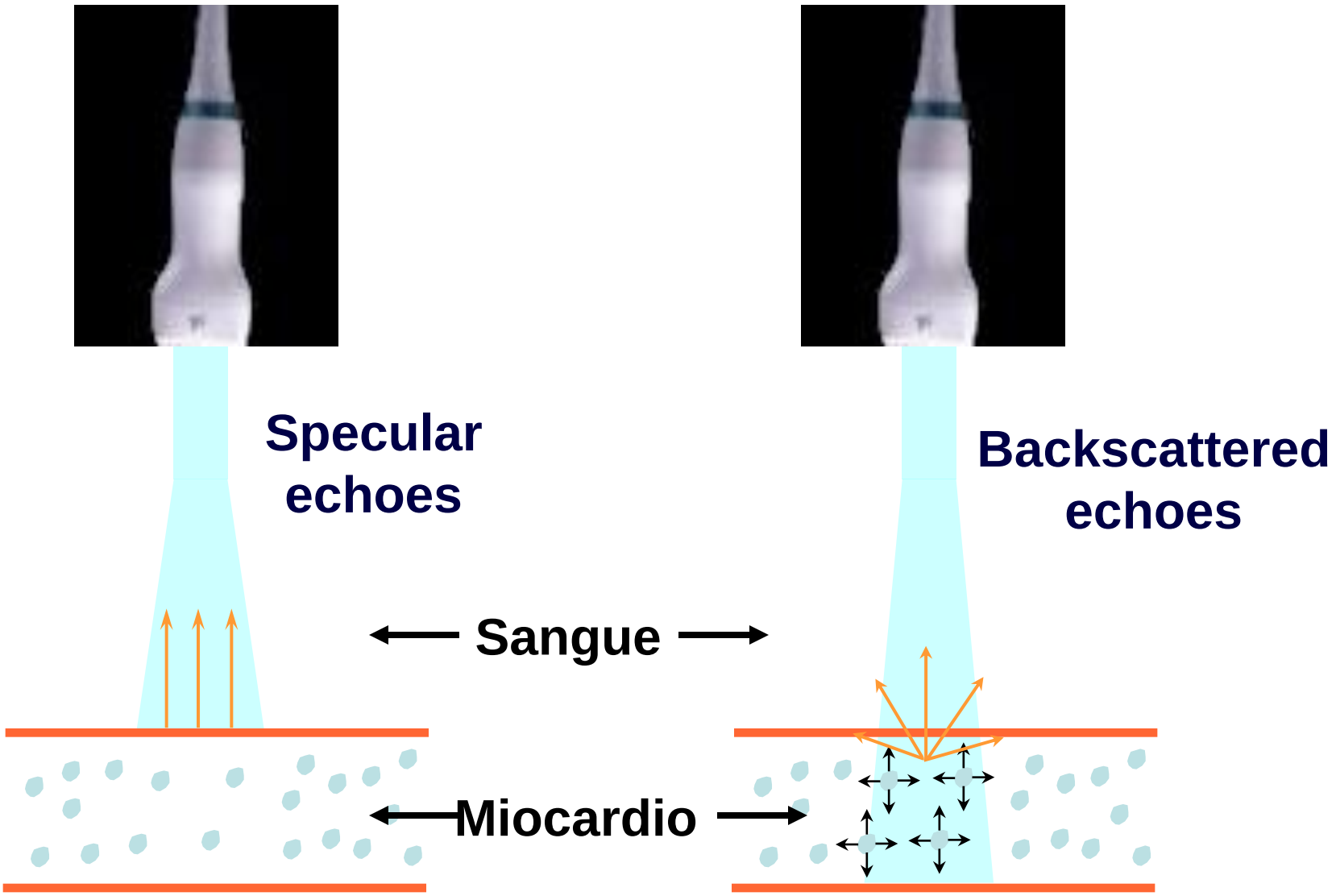
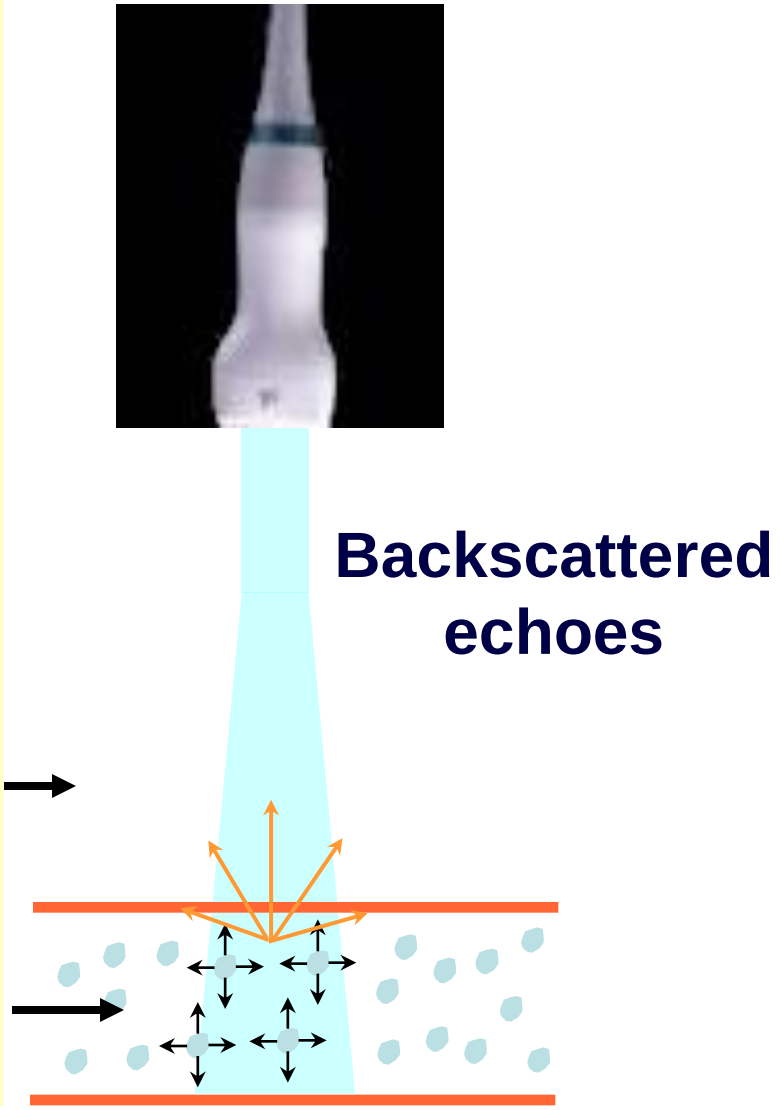

Specular
echoes
Backscattered
echoes
Sangue
Miocardio

La lunghezza d'onda del fascio ultrasonoro incidente è molto maggiore dei confini tra i diversi elementi della struttura tissutale, così che gli ultrasuoni vengono dispersi (backscatter)
secondo un fenomeno multidirezionale.

La quantità di questa energia ultrasonora retrodispersa dipende dalla non omogeneità all'interno del tessuto e dalla frequenza degli ultrasuoni.

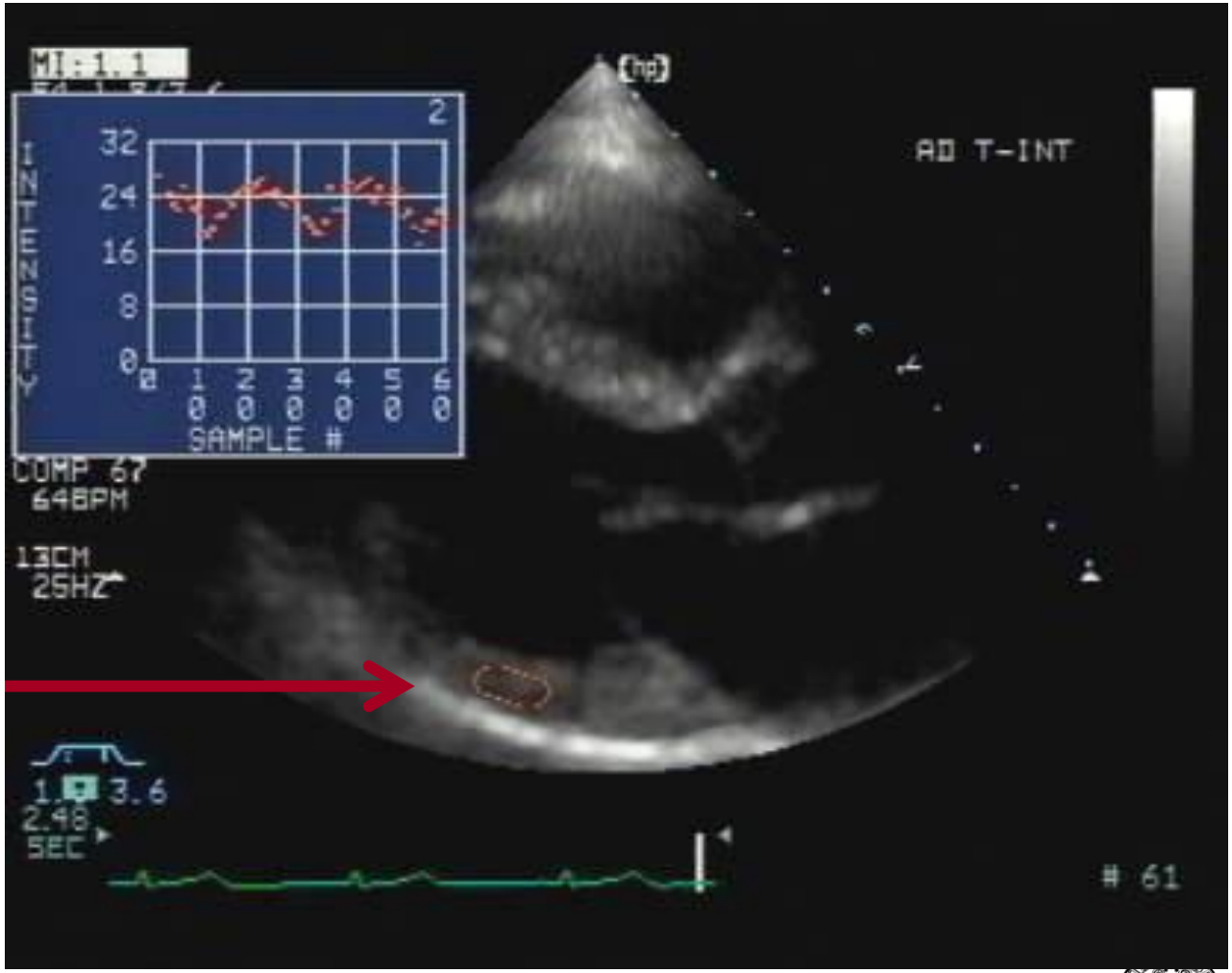
E' possibil misurare lo spettro completo della frequenza ultrasonora del segnale retrodisperso (backscattered) la frequenza media di questo chiamata integrated backscatter.



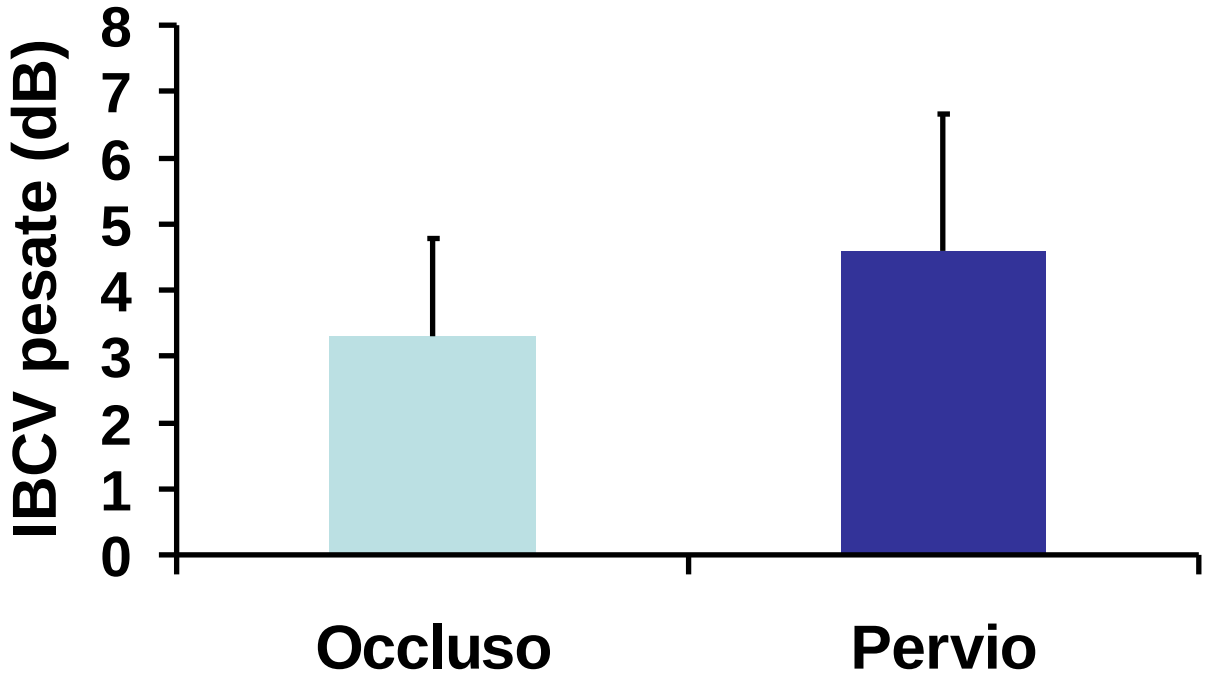
Metodo
analisi delle immagini

Variazione Ciclica del BSC Miocardico

Posizionamento della regione d'interesse



Determination of successful reperfusion after trombolysis for AMI, using tissue characterization

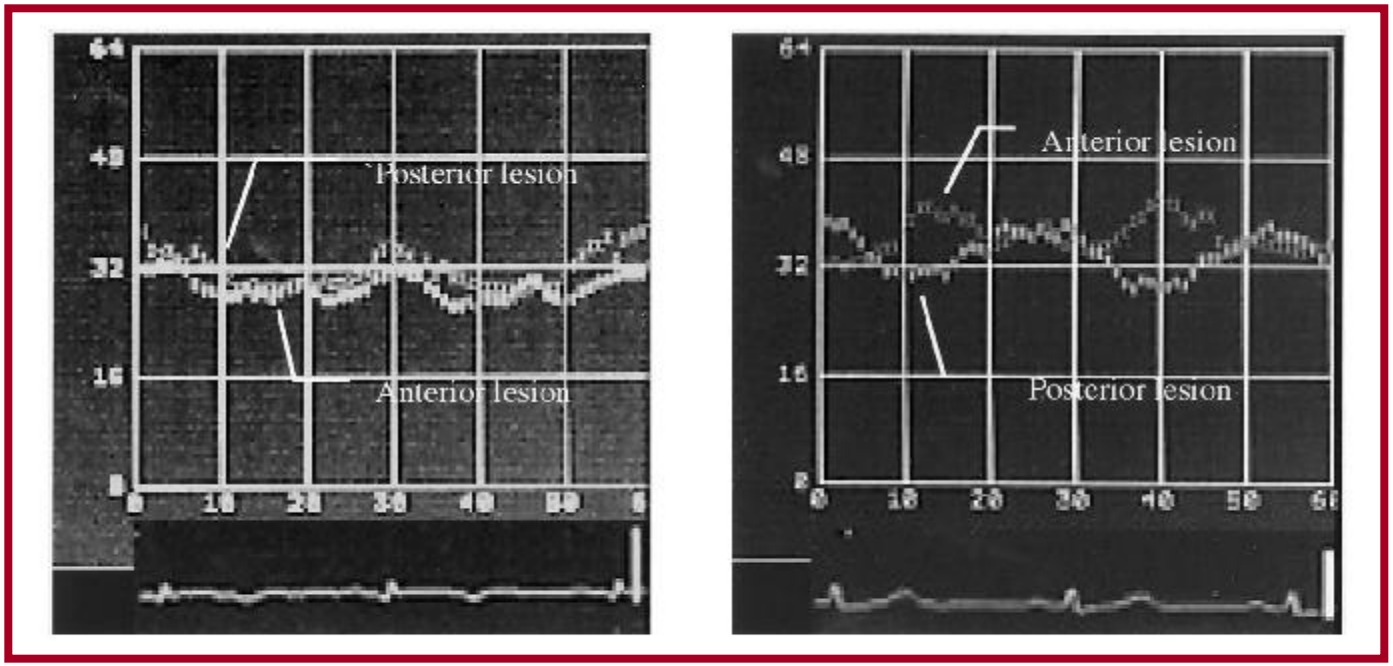


IBcv (delta 15% vs remoto) →Sensibilità 92%
Specificità 75% per la pervietà post-trombolisi

Circulation 2002; 105:157-161

Detection of TIMI-3 Flow Before Mechanical Reperfusion With Ultrasonic Tissue Characterization in Patients With Anterior Wall Acute Myocardial Infarction

Katsuomi Iwakura, MD; Hiroshi Ito, MD; Shigeo Kawano, MD; Atsushi Okamura, MD; Katsuaki Asano, MD; Tadashi Kuroda, MD; Koji Tanaka, MD; Tohru Masuyama, MD; Masatsugu Hori, MD; Kenshi Fujii, MD



w/ TIMI flow grade 3

w/ TIMI flow grade 0

Circulation 2003;107:3159-3164

Detection of TIMI-3 Flow Before Mechanical Reperfusion With Ultrasonic Tissue Characterization in Patients With Anterior Wall Acute Myocardial Infarction

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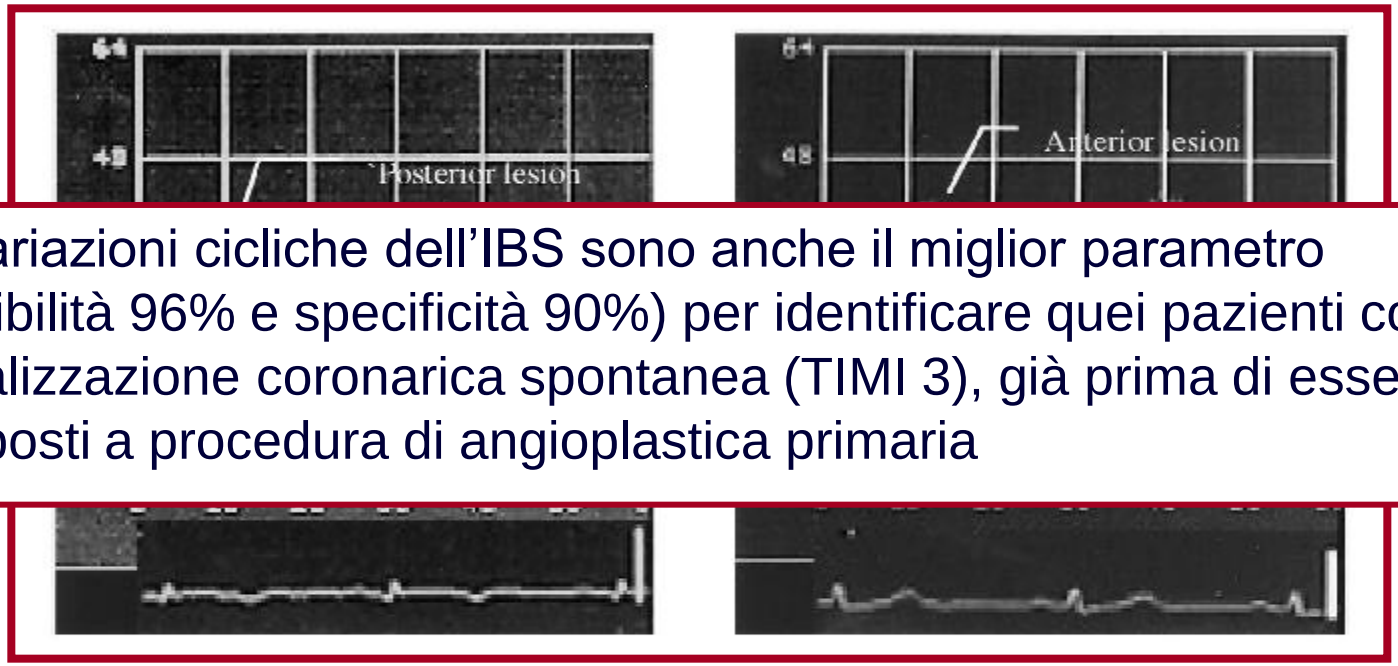

•Le variazioni cicliche dell'IBS sono anche il miglior parametro (sensibilità 96% e specificità 90%) per identificare quei pazienti con ricanalizzazione coronarica spontanea (TIMI 3), già prima di essere sottoposti a procedura di angioplastica primaria

w/ TIMI flow grade 3 w/ TIMI flow grade 0

Circulation 2003;107:3159-3164

Effects of Acute Myocardial Ischemia on Intramyocardial Contraction Heterogeneity

A Study Performed with Ultrasound Integrated Backscatter During Transesophageal Atrial Pacing

Paolo Colonna, MD; Roberta Montisci, MD; Leonarda Galiuto, MD;
Luigi Meloni, MD; Sabino Iliceto, MD

Background—Subendocardial thickening is greater than subepicardial thickening and acute myocardial ischemia mainly impairs the former. Integrated backscatter cyclic variations (IBScv) reflect regional myocardial contractility and are blunted during myocardial ischemia. We hypothesized that stress-induced myocardial ischemia mainly affects subendocardial IBScv.

Methods and Results—Multiplane transesophageal echocardiography and simultaneous atrial pacing were performed in 12 patients without coronary artery disease (CAD) and in 25 with significant CAD. In a transgastric 2-chamber view, we calculated IBScv in subendocardium and subepicardium and a heterogeneity index, both at rest and at peak-pacing. In 27 myocardial segments of patients with normal coronary arteries, and in 16 myocardial segments supplied by coronary artery without significant stenosis in patients with CAD, there was a transmural gradient of IBScv at rest and the heterogeneity index did not change during all the protocol steps. In the 53 myocardial segments related to a significantly narrowed coronary artery, the transmural gradient of IBScv, present at rest, significantly decreased at peak-pacing because of subendocardial blunting, but promptly recovered 5 seconds after pacing interruption. Moreover, the myocardial thickening at rest and peak pacing correlated with the subendocardial IBScv behavior and not with the subepicardial one.

Conclusions—IBScv are greater in the subendocardium than in the subepicardium. Atrial pacing stress test does not affect IBScv in segments supplied by nonstenotic coronary arteries, whereas it affects segments supplied by diseased coronary arteries, blunting exclusively subendocardial IBScv. Heterogeneity of IBScv intramyocardial changes caused by stress-induced ischemia must be taken into account when using IBScv for investigating myocardial ischemia.
(***Circulation***. 1999;100:1770-1776.)

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- During a reduction of myocardial perfusion capable of inducing myocardial ischemia, the subendocardial layer undergoes contractility impairment even in the absence of functional impairment of the subepicardial layer

- Stress-induced myocardial ischemia mainly affect subendocardial Integrated Backscatter cyclic variations → subendocardial regional myocardial contractility

Circulation. 1999;100:1770-1776.

Possibilità di informazioni sui diversi strati transmurali