Ventricular Tachycardia

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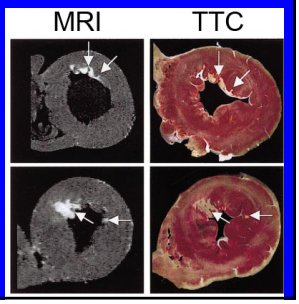
Presenter Disclosure Information

- There are no financial relationships relevant to this presentation.
- Off label use: MRI of patients with implanted devices; Gadolinium for cardiac studies

Delayed Enhancement MRI

- Detailed imaging of scar and viable myocardium
- Extensively validated
- High spatial resolution



Lima, J.A., et al. Circulation, 1995. **92**(5): p. 1117-25.
Kim, R.J., et al. NEJM, 2000. **343**(20): p. 1445-53.
Kim RJ, et al: *Circulation* 1999;100;1992-2002
Ashikaga et al. Circ Res, 2007. **101**: p. 939-47

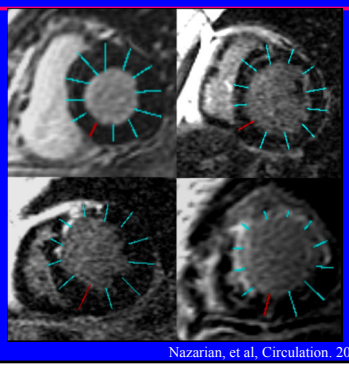
Non-Ischemic Cardiomypathy

Scar can be present and may be the substrate for VT

Scar Patterns: Different Degrees of Transmurality

No Scar

1-25%



26-75%

76-100%

Nazarian, et al, Circulation. 2005;112:2821-2825

Scar Pattern predicts VT Inducibility

- 7 different morphologies of sustained monomorphic ventricular tachycardia were inducible in 5 patients
- Median cycle length of 300 ms (interquartile range 240-345 ms)

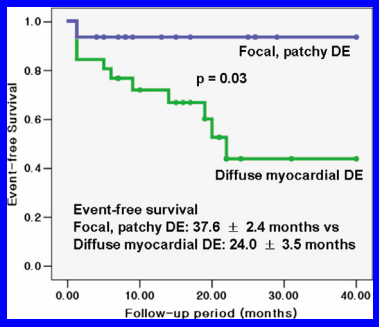
TABLE 2. MRI Parameters and Comparison After Stratification by Inducibility at Electrophysiological Study*

		Electrophysiological Study		
	All Patients (n=26)	Inducible (n=5)	Noninducible (n=21)	*P*
Left ventricular ejection fraction, %	27 (17–43)	16 (13–29)	29 (19–44)	0.18
Left ventricular end-diastolic volume, mL	201 (129–273)	159 (154–273)	205 (129–259)	0.72
Left ventricular mass, g	153 (113–192)	184 (160–197)	144 (113–189)	0.38
Patients with scar, n (%)	17 (65)	5 (100)	12 (57)	0.13
Scar volume, %	4.6 (0.8–7.2)	6.0 (5.7–7.2)	1.5 (0.7–6.3)	0.09
Predominant scar distribution involving 26%–75% of wall thickness, n (%)	6 (23)	5 (100)	1 (5)	<0.001

*Data are expressed as median (interquartile range) or absolute numbers (column percentage).

Nazarian, et al, Circulation. 2005;112:2821-2825

Scar Pattern Predicts Event-Free Survival



- 79 patients
- No ICDs
- EF 25-28%

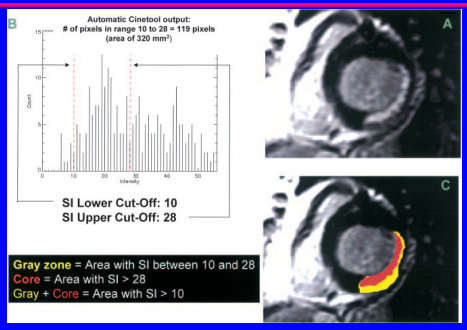
Cho, et al: *Circ J*. 2010; **74:** 476 – 483

Ischemic Cardiomyopathy

Hyperenhancement may not have uniform intensity

Gray Zone:

Intermediate level of hyperenhancement



Schmidt et al, Circulation. 2007;115:2006-2014

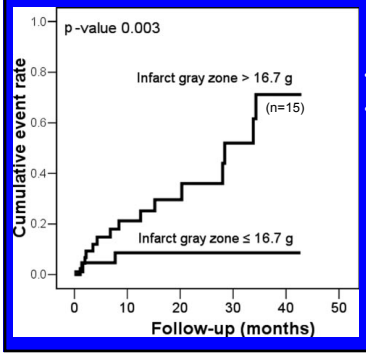
Extent of Gray Zone Predicts Inducibility

Schmidt et al, Circulation. 2007;115:2006-2014

TABLE 2. MRI Indices According to Inducibility Status at Electrophysiology Study

Variable	Noninducible (n=27)	Inducible (n=20)	*P*
MRI LVEF	0.30±0.10	0.29±0.07	0.79
LV end-diastolic volume, mL	220±70	228±57	0.68
LV end-systolic volume, mL	156±61	162±44	0.71
LV end-diastolic mass, g	146±46	132±30	0.23
Infarct location, n (%)			0.23
Anterior±other territory	15 (56)	15 (75)	
Inferior and/or lateral only	12 (44)	5 (25)	
Transmural infarct extent: % of sectors grouped by quartiles of transmurality			
No infarct	51±15	45±9	0.11
1% to 25% infarct transmurality	8±4	7±2	0.61
26% to 50% infarct transmurality	8±3	8±5	0.88
51% to 75% infarct transmurality	11±5	12±5	0.39
76% to 100% infarct transmurality	23±14	28±11	0.17
Extent of hyperenhancement, g			
Total (core+gray)	34±17	40±11	0.17
Infarct core	21±10	21±5	0.95
Gray zone	13±9	19±8	0.015

Extent of Gray Zone Predicts ICD Firings



- 91 patients with MI
- 18 patients with ICD firing

Roes S, Bax J et al: *Circ Cardio Imaging*. 2009;2:183-190.

Extent of Gray Zone Predicts ICD Firings

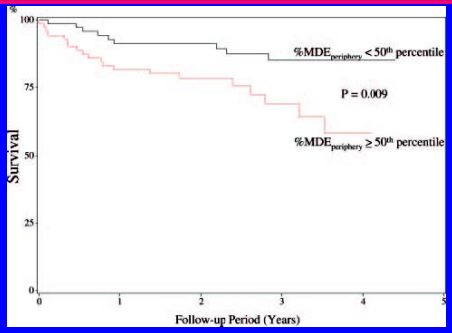
Table 2. Baseline MRI Variables

Variable	Total Population (n=91)	No Appropriate ICD Therapy (n=73)	Appropriate ICD Therapy (n=18)	*P* Value
LVEF, %	28±9	29±9	25±7	0.06
LV EDV, mL	333±112	331±117	339±95	0.8
LV ESV, mL	245±107	241±110	259±94	0.5
LV mass, g	148±40	148±41	149±38	0.9
Total infarct (infarct core+gray zone), g	46±25	43±23	58±29	0.02
Infarct core, g	26±17	25±16	30±17	0.2
Infarct gray zone, g	20±13	18±11	28±16	0.002

Data are expressed as mean±SD. LV indicates left ventricular; LV EDV, LV end-diastolic volume; LV ESV, LV end-systolic volume; LVEF, LV ejection fraction.

Roes S, Bax J et al: *Circ Cardio Imaging*. 2009;2:183-190.

Extent of Gray Zone Predicts Survival



- 144 patients with CAD
- No ICD's
- Mean EF 42-45%

Yan A, Stevenson W, et al: *Circulation*. 2006;114:32-39

Extent of Gray Zone Predicts Survival

TABLE 2. Univariable and Multivariable Associations With All-Cause Mortality

	Univariable Analysis		Multivariable Analysis 1		Multivariable Analysis 2	
Variable	Unadjusted HR (95% CI)	P	Adjusted HR (95% CI)	P	Adjusted HR (95% CI)	P
Age*	1.37 (0.96-1.97)	0.09	…	…	1.45 (0.98-2.14)	0.06
Diabetes	2.21 (1.05-4.66)	0.04	…	…	…	…
Previous percutaneous coronary intervention	0.37 (0.16-0.88)	0.02	…	…	…	…
Previous coronary bypass surgery	2.39 (1.08-5.30)	0.03	…	…	…	…
QRS duration >120 ms	2.29 (0.98-5.38)	0.06	…	…	…	…
Left bundle-branch block	3.21 (1.22-8.44)	0.02	…	…	…	…
Corrected QT >440 ms	2.37 (1.14-4.93)	0.02	…	…	…	…
LV end-diastolic volume index†	1.13 (1.04-1.22)	0.004	…	…	…	…
LV end-systolic volume index†	1.13 (1.05-1.23)	0.002	1.16 (1.07-1.26)	<0.001	…	…
LVEF‡	1.36 (1.08-1.72)	0.01	…	…	1.52 (1.19-1.94)	<0.001
%MDE periphery§	1.31 (1.06-1.63)	0.01	1.45 (1.15-1.84)	0.002	1.42 (1.11-1.81)	0.005
MDE periphery, g	1.06 (1.00-1.11)	0.035	…	…	…	…

For model 1, predictors on univariable analysis ($P<0.10$) were evaluated in this multivariable model by forward stepwise selection ($P<0.10$ for entry and $P>0.05$ for removal) criteria. For model 2, age, LVEF, and %MDE periphery were all entered into this multivariable model.
*HR per decade increase.
†HR per 10-mL/m² increase.
‡HR per 10% decrease.
§HR per 10% increase.

Yan A, Stevenson W, et al: *Circulation*. 2006;114:32-39

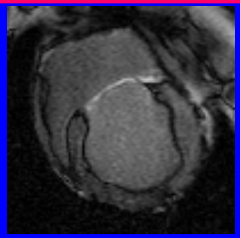
Extent of Scar can Predict Mortality

- 349 patients (76% men) with EF of 24%.
- 56 events (51 deaths and 5 CTx)
- Mean scar percentage higher in patiets with events: (39 ± 22 vs. 30 ± 20, p = 0.003)
- Transmurality score higher in patients with events (9.7 ± 5 vs. 7.8 ± 5, p = 0.004).
- Effect of Gray Zone ???

Kwon et at: JACC: Cardiovascular Imaging 2009; 2(1); 34-44.

What is the Gray Zone?

10 Week Swine Infarct Model:
Inducibility Correlates with Gray Zone

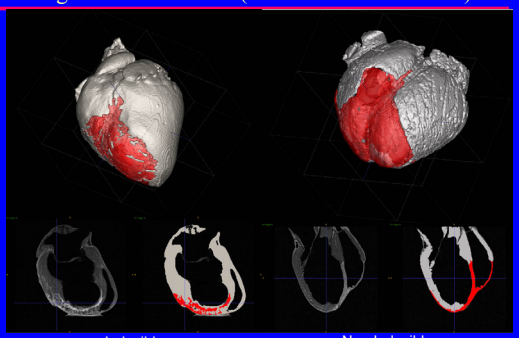


- Inducible VTs in 8 of 17 pigs
- Gray Zone: 21 ± 8 % infarct

- Non- Inducible in 9 of 17 pigs
- Gray Zone: 12 ± 3 % infarct

p < 0.009

Gray Zone = Tissue Heterogeneity
High Resolution MRI (0.4x0.4x0.4 mm voxels)



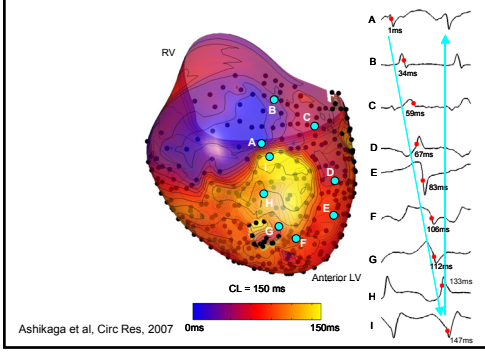
Inducible Non Inducible

What do the images tell us about the mechanisms of VT?

Electroanatomic Correlations

Epicardial Electrograms during VT

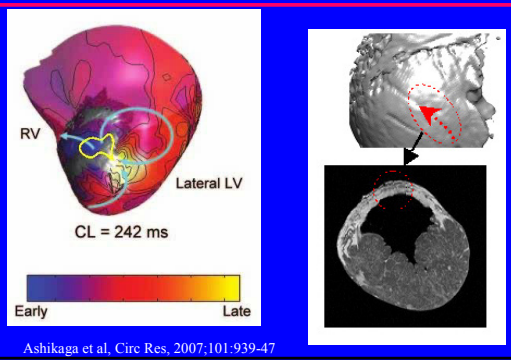
Recordings from Multielectrode Epicardial Sock



Ashikaga et al, Circ Res, 2007

Epicardial Reentry Registered with Scar:

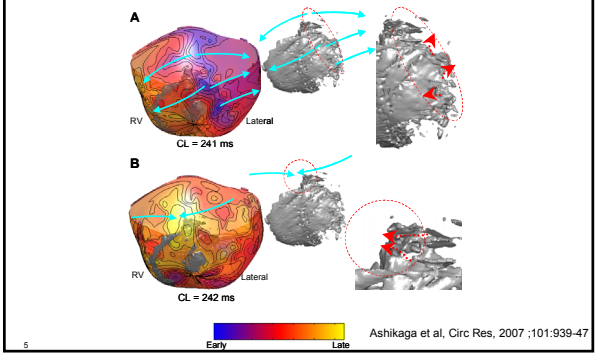
Reentry Through Viable Tissue in Scar



Ashikaga et al, Circ Res, 2007;101:939-47

Epicardial Centrifugal Pattern VT

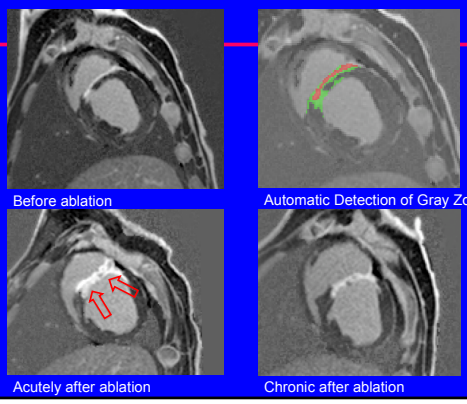
Reentry Through and Around Scar



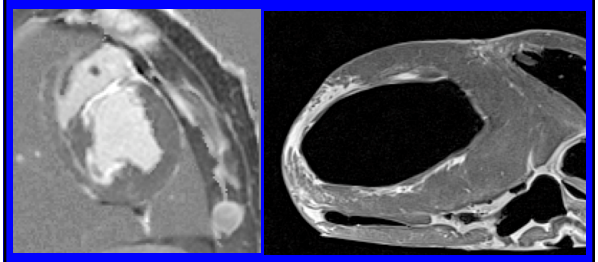
Ashikaga et al, Circ Res, 2007 ;101:939-47

Is the Gray (Heterogeneous) Zone identified on MRI the critical pathway for VT generation?

Ablation in Gray Zone Can Eliminate VTs Chronically



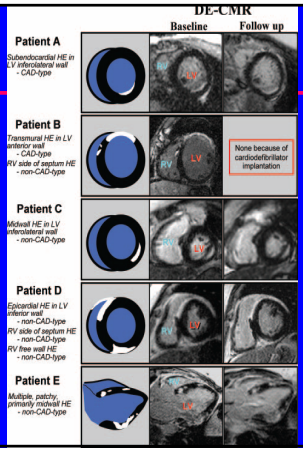
Incomplete ablation of the Gray Zone: Inducible VT



Standard resolution MRI

High resolution MRI

Sarcoidosis

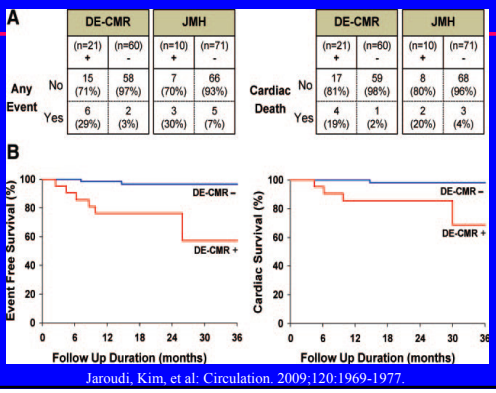


Sarcoidosis

DE-MRI

Jaroudi, Kim, et al: Circulation. 2009;120:1969-1977.

Outcomes

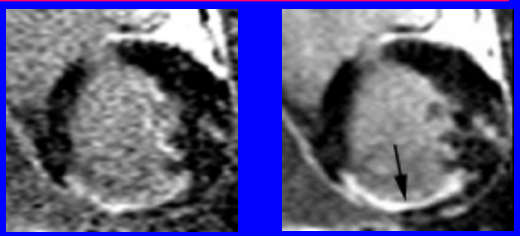


Jaroudi, Kim, et al: Circulation. 2009;120:1969-1977.

Limitations of MRI Scar Imaging

- Motion Effects
- Partial Volume Effects
- Artifacts from ICD
- Nephrogenic Systemic Fibrosis

Motion can Reduce Resolution



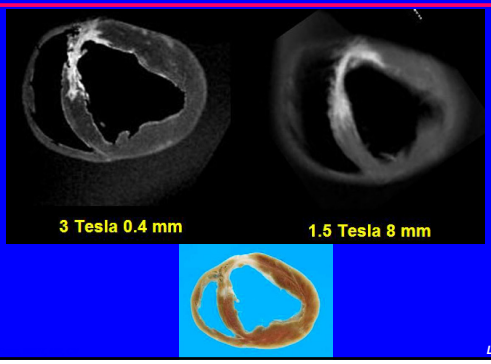
No Motion Correction

Motion Corrected

Kellman P, McVeigh ER, et al. 2002;47(2):372-383 . *Magn Reson Med.*

Partial Volume Effects can Reduce Resolution

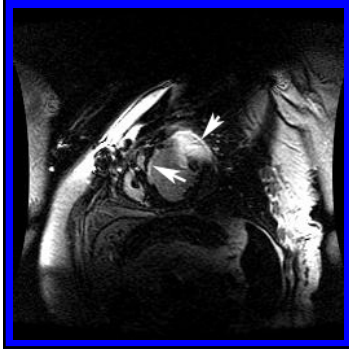
Intensity Averaging with thick slices



Lardo Lab

Artifacts from ICD

Can Mimic HyperEnhancement



Imaging safe with ICD

- 555 MRI examinations performed in 460 patients
- Special protocol used
- No adverse events
- No clinically significant changes in pacing parameters
- Adequate scar imaging in 60-80%

Fixes are being developed

Nephrogenic Systemic Fibrosis

- Scleroderma like syndrome
- Develops in patients with severe renal disease
  - Generally on dialysis
- Rare, not reversible
- First reported in 2000
- Linked to Gadolinium use in 2006
- Mechanism(s) unknown
- Does not occur in patients with GFR > 30 ml/mim

Summary

- Delayed enhancement MRI can accurately identify detailed anatomy of scar
- Multiple VT circuits can exist through and around areas of scar
- Scar transmurality distribution appears to be related to arrhythmogenic potential in Non-Ischemic Cardiomyopathy
- The critical zones for occurrence of VT in ICM are likely areas of tissue heterogeneity (gray zone) that can be imaged with MRI
- The extent of scar heterogeneity is related to the risk of sudden death in ischemic cardiomyopathy
- Delayed enhancement MRI may be very useful in diagnosing cardiac sarcoidosis
- Limitations include motion effects, partial volume effects, and the presence of an ICD

Clinical Implications

- Delayed enhancement MRI may help predict risk of arrhythmias, and probably sudden death
- Delayed enhancement MRI has added predictive power over that of EF alone in ICM
- Delayed enhancement MRI will likely lead to more accurate indications for ICD placement, and may help guide VT ablation
- Delayed enhancement MRI may be useful in guiding therapy of possible cardiac sarcoidosis

Investigators

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