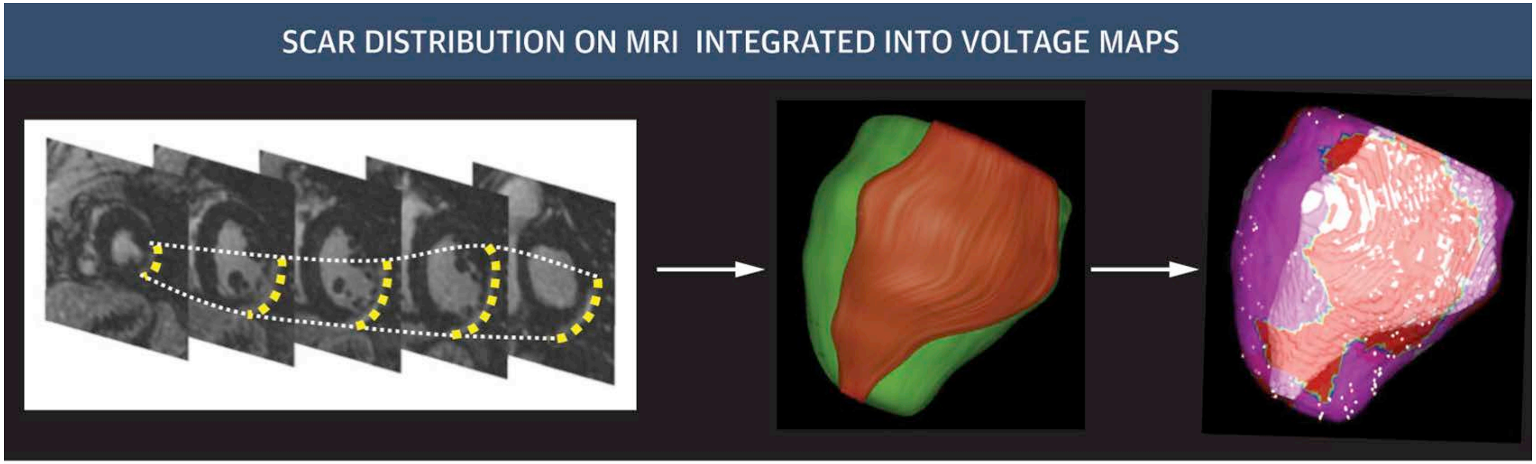
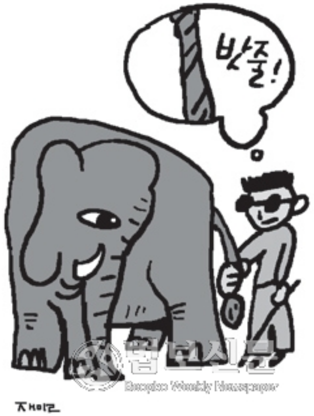
Image Integration to Facilitate VT Ablation


Konkuk University Medical Center
Department of Radiology
Sung Min Ko

Disclosure

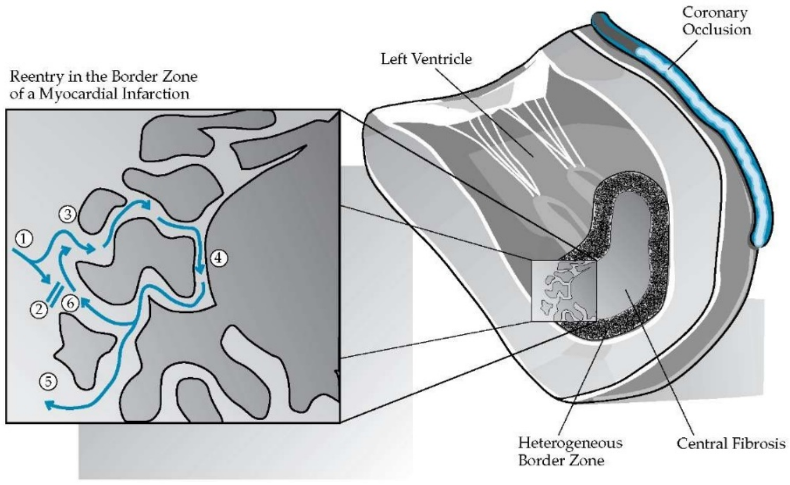


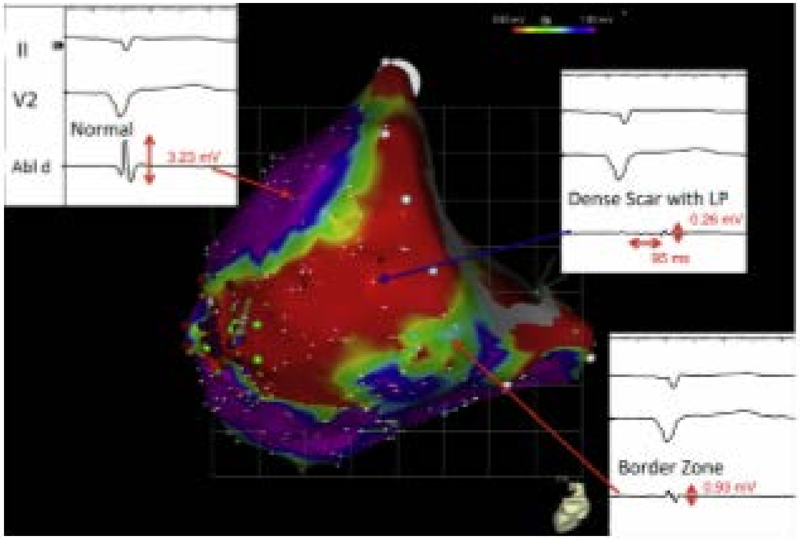
- **No clinical experience**
- **Journal Review**



Introduction

- **Electroanatomical voltage mapping (EVAM)**
  - Commonly used for mapping VT substrate to guide RFCA
  - Created by combining cardiac surface electrical activation with the spatial location of the catheter tip
  - Identify myocardial scar areas (low voltage area)

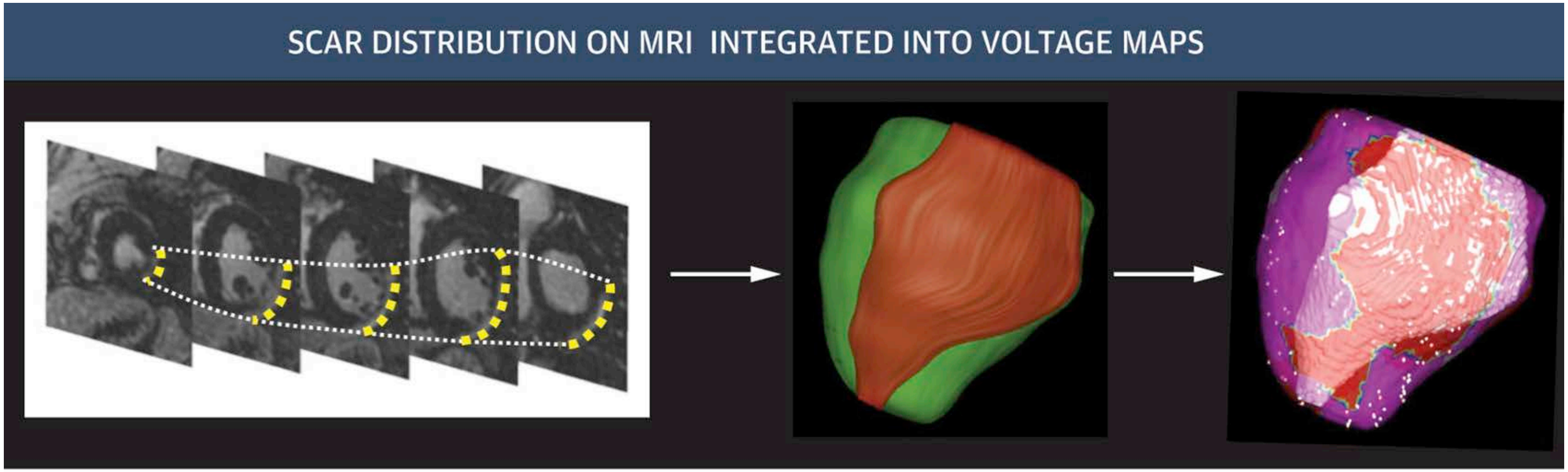




- **Limitation of EVAM**
  - Difficulty in detecting intramural and nontransmural scars
  - Suboptimal catheter contact
    → false low measurements of normal amplitude
  - Incomplete sampling
  - Significant radiation exposure for both patients and operator during RFCA
  - Very time-consuming!

Aims of Image Integration

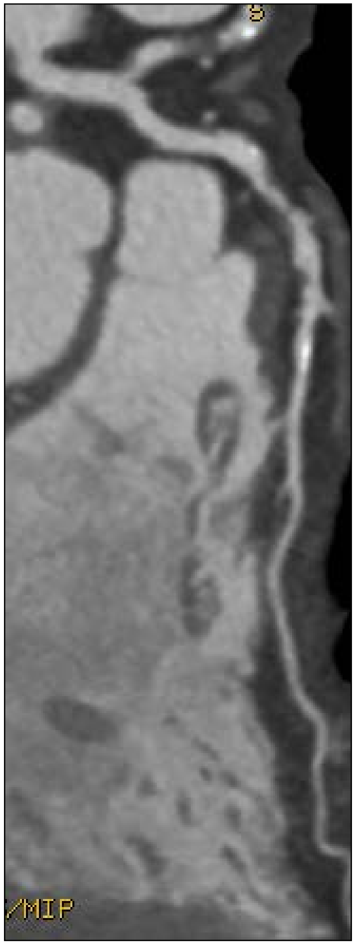
- Minimize the radiation exposure to patient and health care providers
- Enhance procedural outcomes
- Shorten procedure times
- Minimize the potential for procedure-related complications

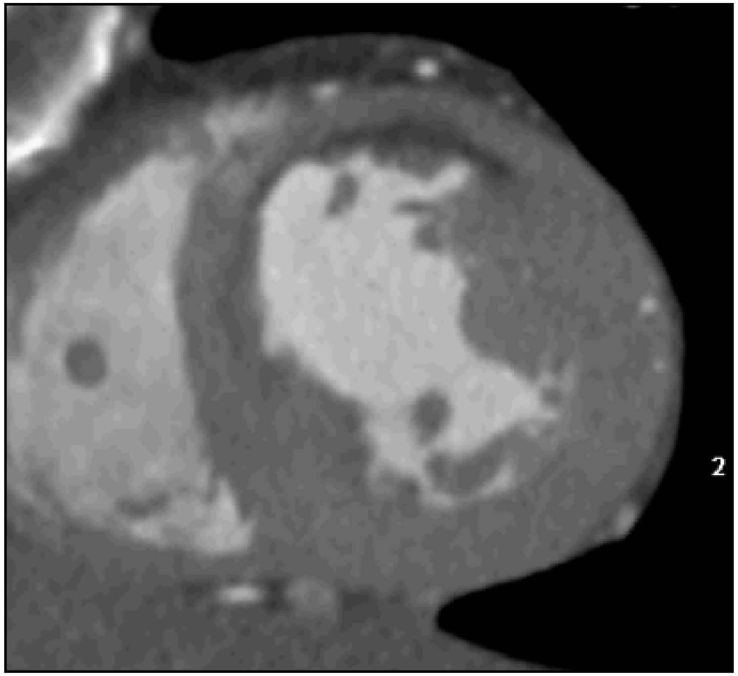


Cardiac CT

Old MI

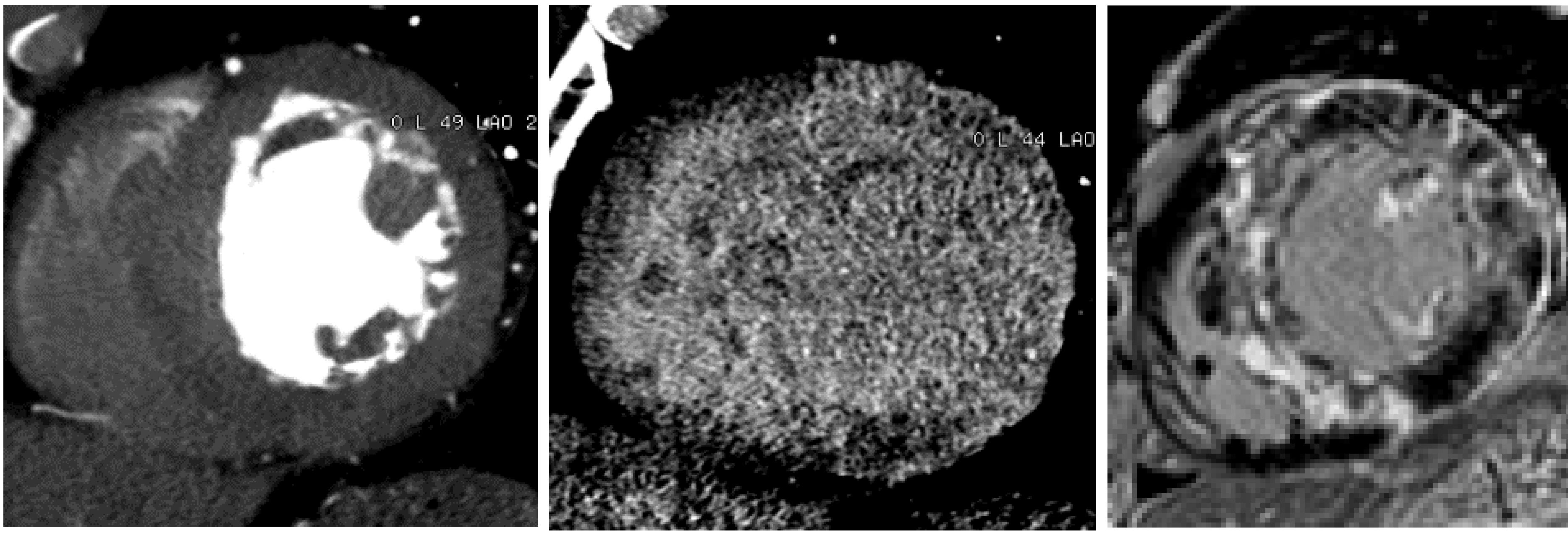
51M, old MI, chest pain



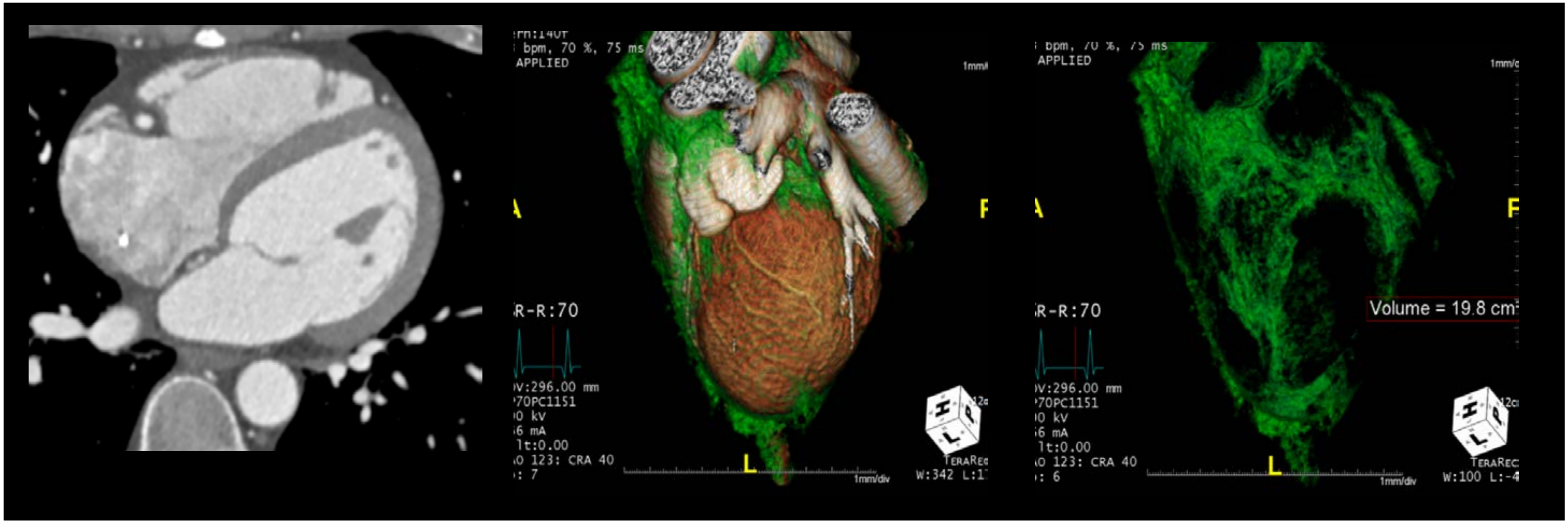


Cardiac CT for delayed contrast enhancement

Cardiac Sarcoidosis



Assessment of epicardial fat and coronary artery



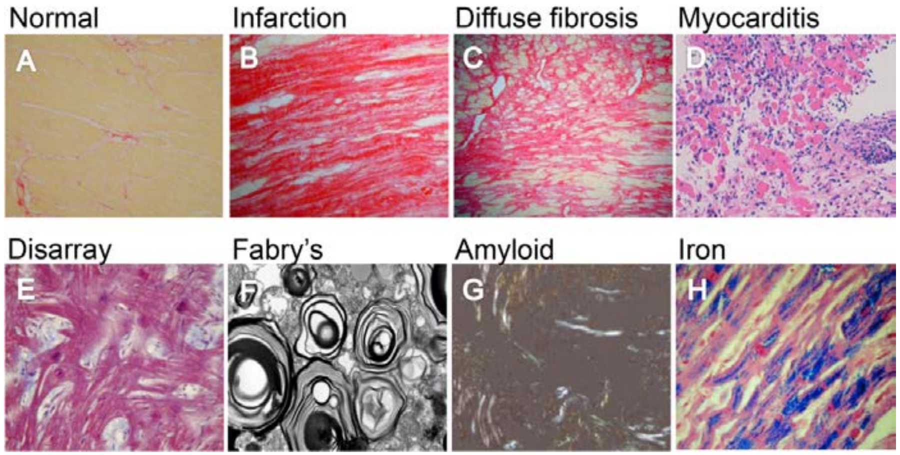
Late gadolinium enhancement cardiac magnetic resonance (LGE-CMR)

- The standard reference for myocardial scar depiction

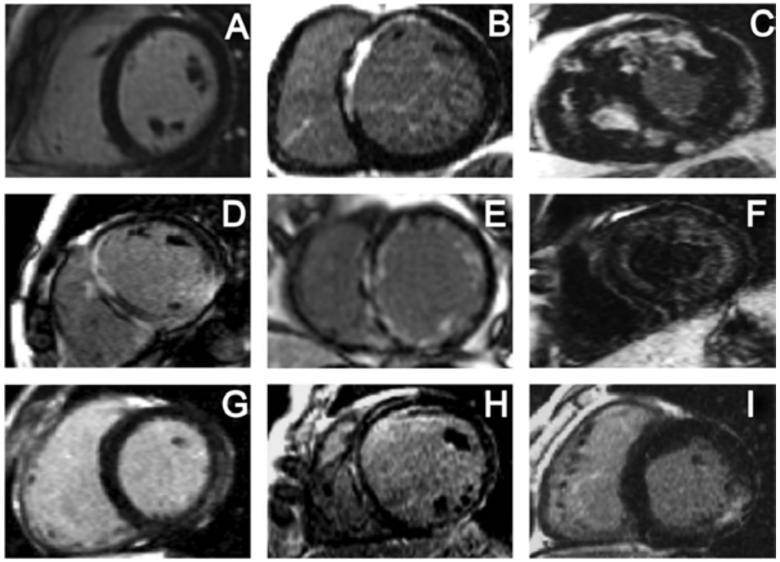
Circulation 1999;100:1992 -2002

- Tissue characterization

→ Optimization for ablation procedure



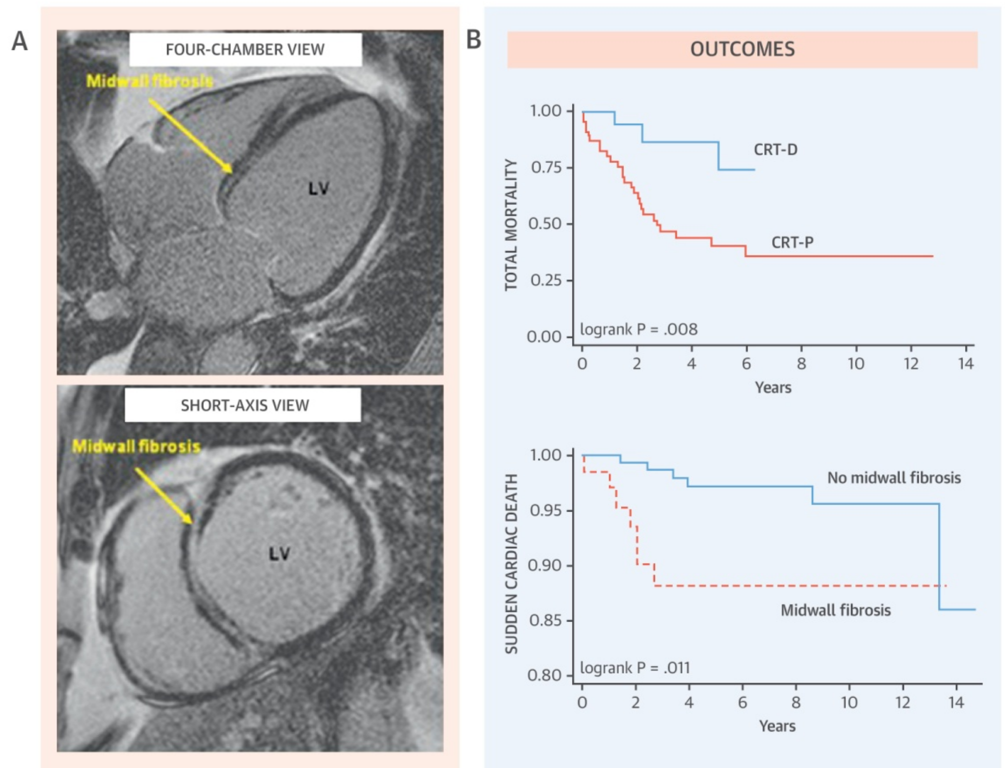
Captur G, et al. Heart 2016;0:1–7



Outcomes of Cardiac Resynchronization Therapy With or Without Defibrillation in Patients With Nonischemic Cardiomyopathy

- NICM who were +MWF (n = 68) or −MWF (n = 184) who underwent CMR prior to CRT device implantation.
- In patients with NICM, CRT-D was superior to CRT-P in +MWF but not −MWF.
- These findings have implications for the *choice of device therapy in patients with NICM.*

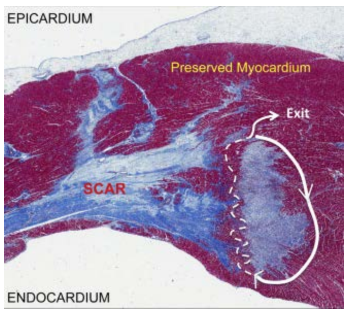
CENTRAL ILLUSTRATION: Cardiac Resynchronization Therapy in Non-ischemic Cardiomyopathy With or Without Left Ventricular Midwall Fibrosis

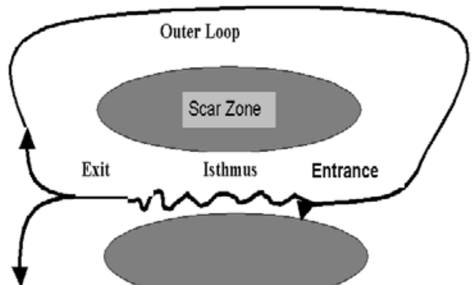


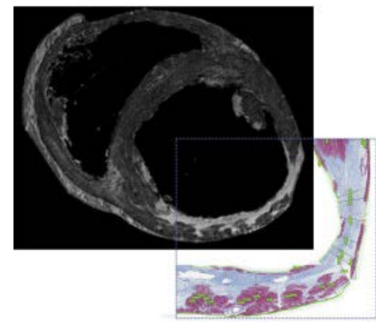
Leyva, F. et al. J Am Coll Cardiol. 2017;70(10):1216-27.

Late gadolinium enhancement cardiac magnetic resonance (LGE-CMR)

- Detection and Characterization of arrhythmogenic substrate







- Critical isthmus sites: ablation
- Scar transmurality- associated with slow conduction
- Signal intensity- identifying conducting channel and delineating core scar and border zone.

@ 2 methods to differentiating areas of infarct core & gray zone (heterogeneous tissue)

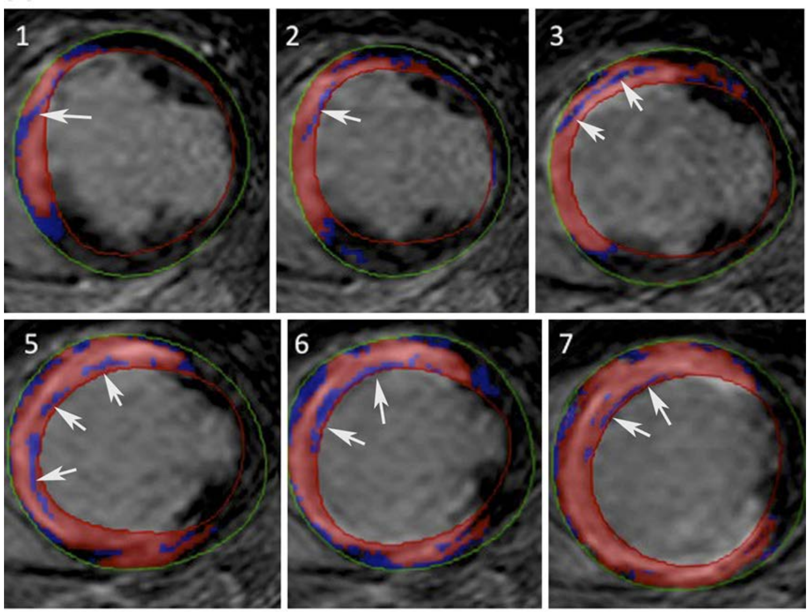
- Signal intensity of 3 SD and SI between 2 SD and 3 SD

- >50% of maximal SI and between 35-50% maximal SI

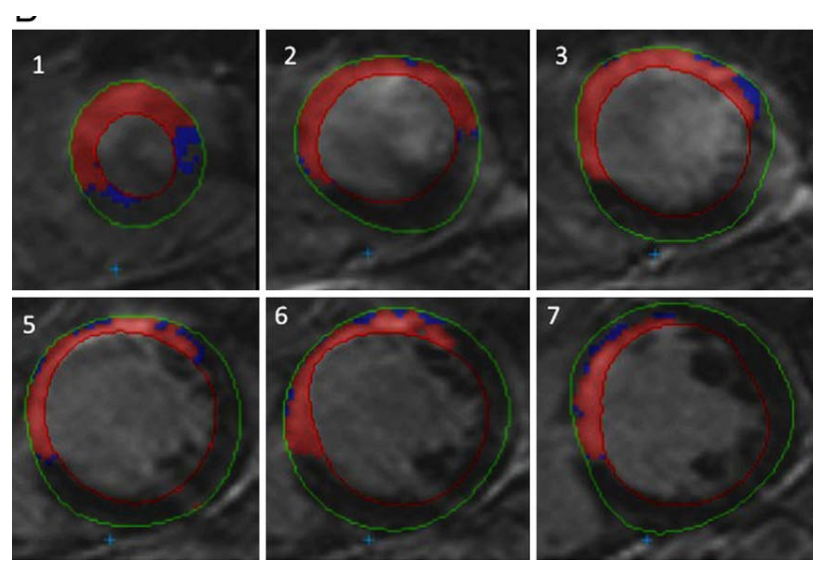
VT-related conduction channel using LGE-CMR in CMI

JACC 2011; 57:184-94

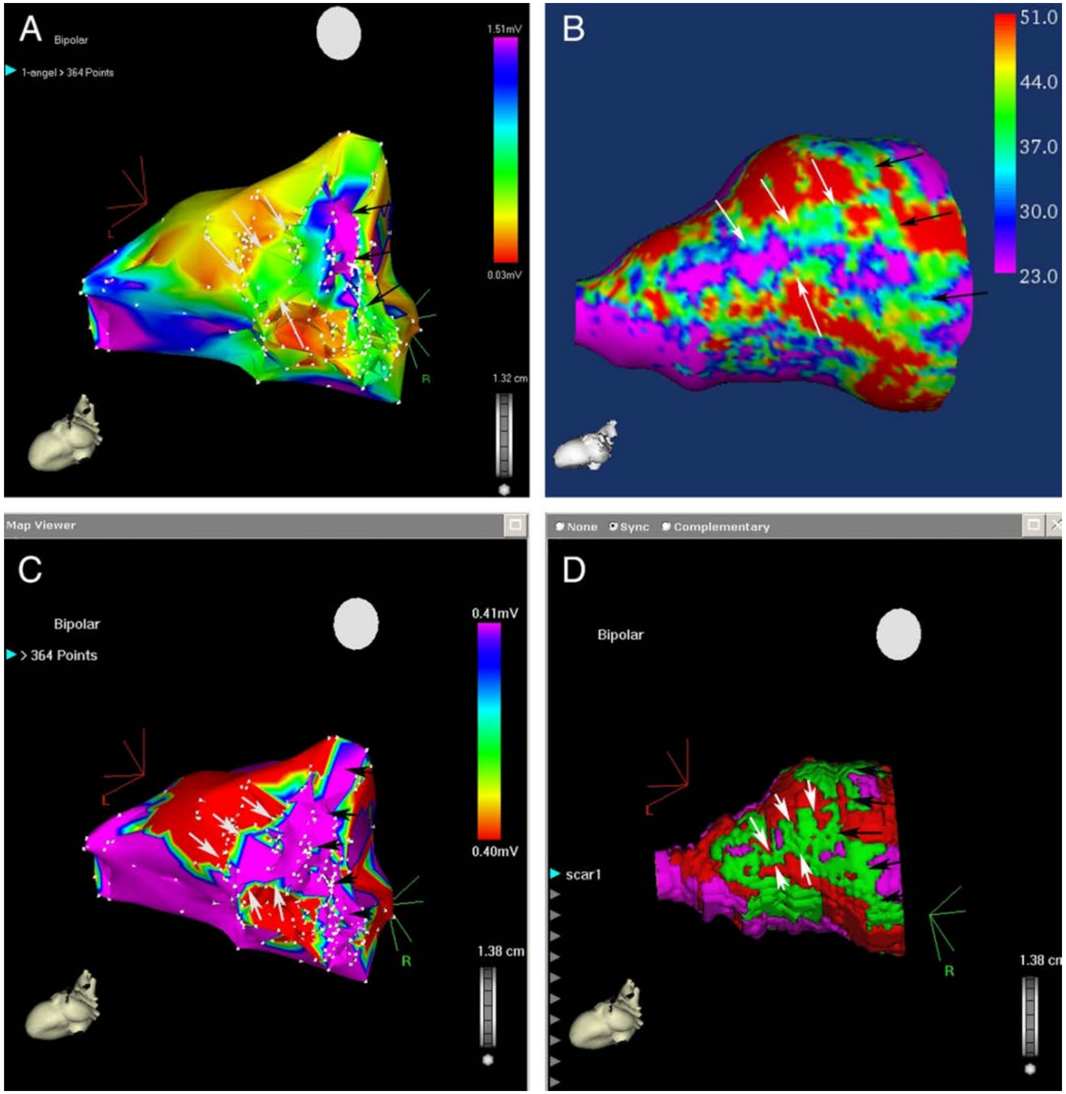
- 18 patients with SMVT and 18 control
- Scar (core area); SI >3 SD higher than remote normal myocardium
- Gray zone; areas of lower SI between 2 SD and 3 SD
- Heterogeneous tissue channel – corridor of HT in consecutives slices surrounded by scar and connected to normal myocardium by at least 1 side.



Sustained monomorphic VT

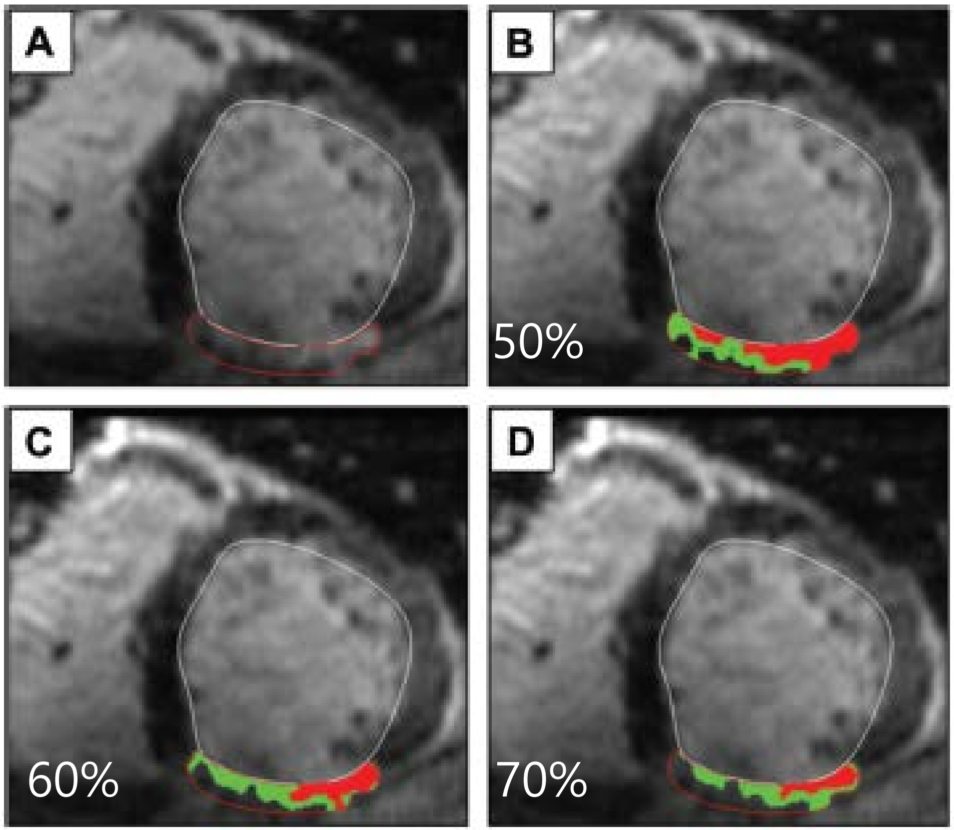


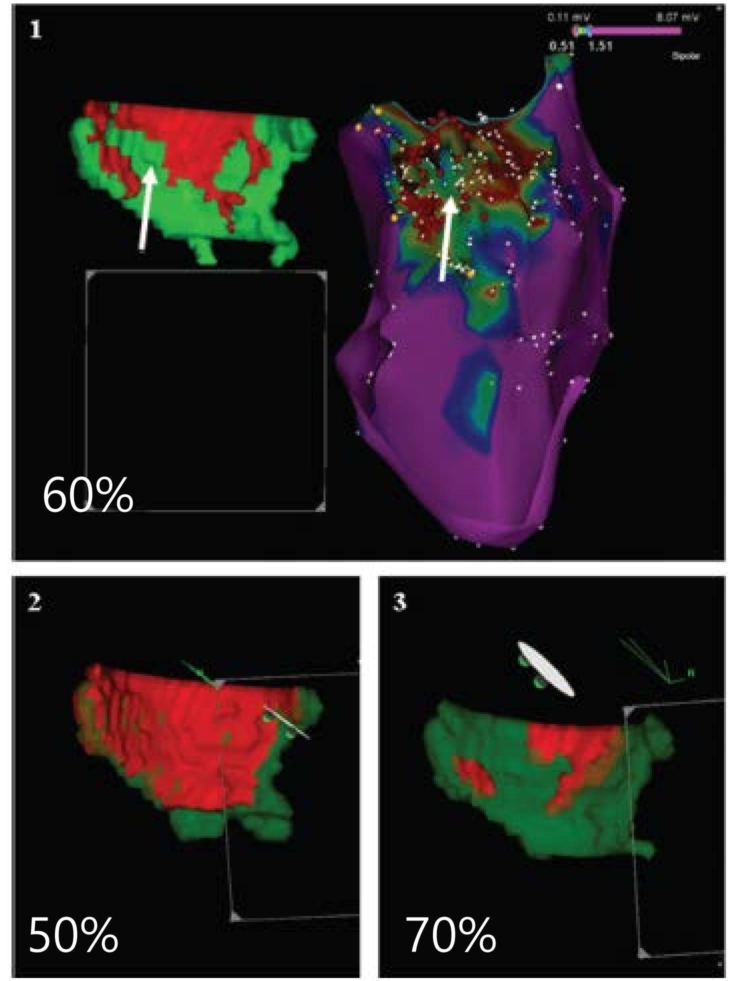
Control



- Channels of HT are more commonly identified in SMVT than in control patients
- The CC detected by endocardial voltage mapping can be identified by 3D SI mapping.

Integration of 3D-EAMs and CMR Scar Characterization Into the Navigation System to Guide VT Ablation





Andreu D, Circ Arrhythm Electrophysiol. 2011;4:674-683

Table 3. Comparison Between Electrogram Location and Bipolar Voltage, Using the Cutoff Value of 60% of Maximum Signal Intensity and Considering Only the Subendocardial Half-Wall Thickness

Location on CE-CMR–Derived Structures	Electrogram Voltage		
	CORE $<$0.5 mV	BZ $>$0.5, $\leq$1.5 mV	Healthy $>$1.5 mV
CORE	662 (85.1%)	239 (21.7%)	42 (3.0%)
BZ	103 (13.2%)	730 (66.2%)	119 (8.7%)
Healthy tissue	13 (1.7%)	134 (12.1%)	1214 (88.3%)
Total	778 (100%)	1103 (100%)	1375 (100%)

CE-CMR indicates contrast-enhanced cardiac magnetic resonance; CORE, core of the scar; and BZ, border zone of the scar. Healthy indicates normal myocardium.

Cohen κ coefficient=0.70.

- The best match was obtained when a cutoff value of 60% of the maximum pixel signal intensity was used, both for core *(r^2 =0.827; P<0.001) and BZ (r^2=0.511; P<0.020), identifying 69% of* conducting channels observed in the EAM.

- Scar characterization by means of high resolution CE-CMR resembles that of EAM and can be integrated into to the CARTO system to guide VT ablation.

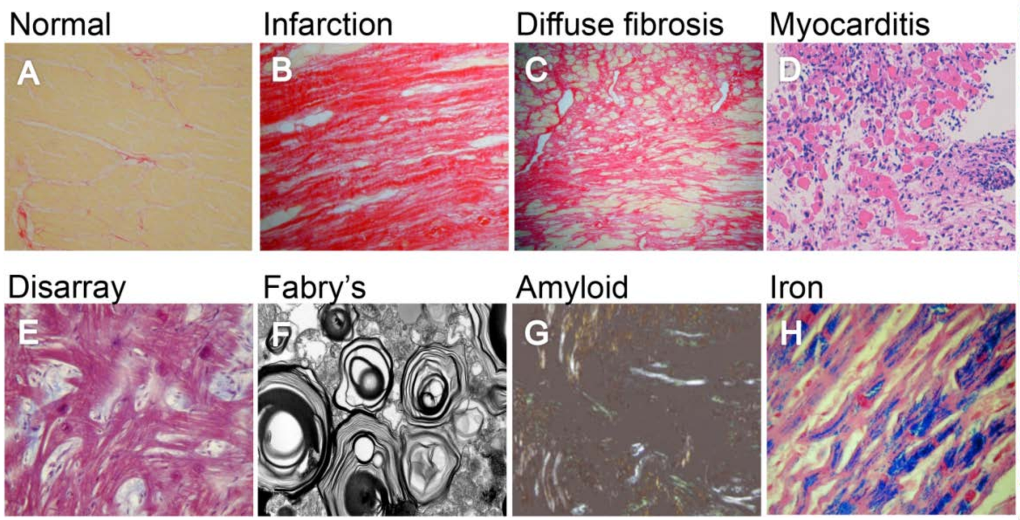
Late gadolinium enhancement cardiac magnetic resonance (LGE-CMR)

- **Limitation of LGE-CMR**

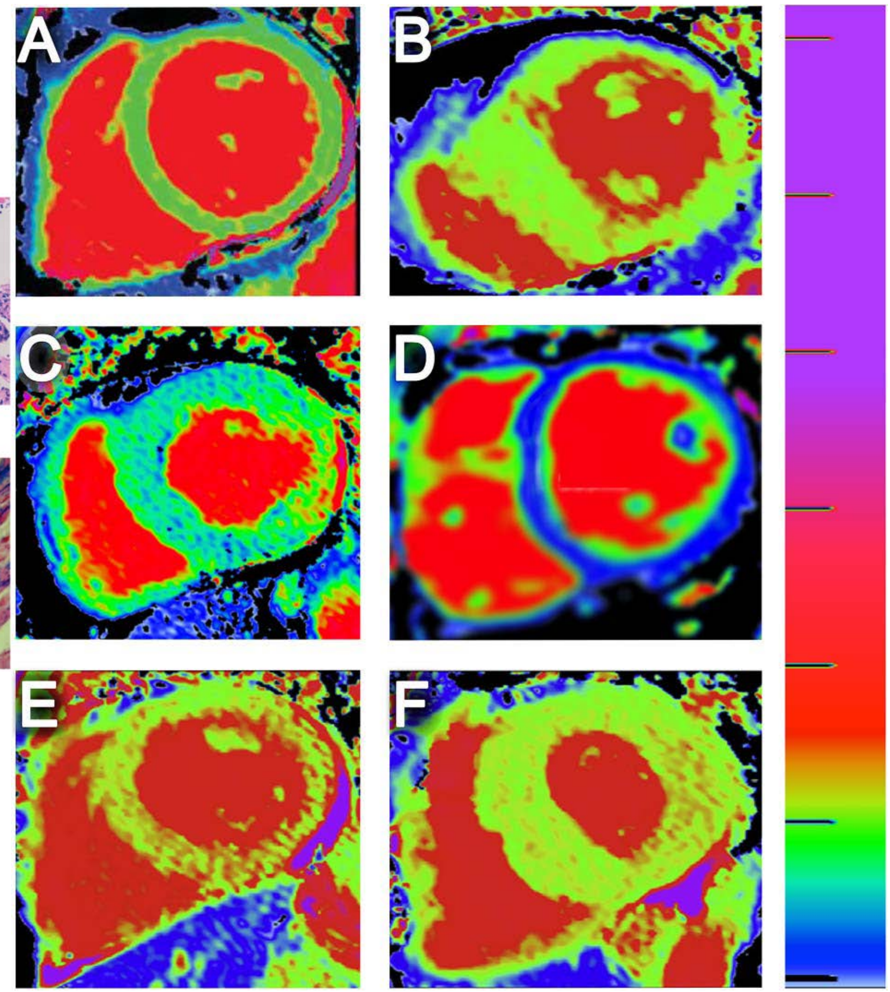
  - Contraindication for implanted pacemakers or cardiac defibrillators
  - Nephrogenic systemic fibrosis in patients with advanced RF
  - Lower spatial resolution (1.5× 1.5 × 6 mm)
  - Focal delayed enhancement

Tissue characterization using mapping

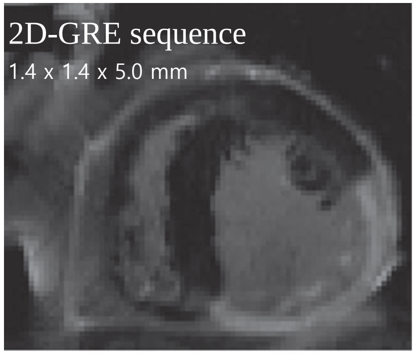
Captur G, et al. Heart 2016;0:1–7

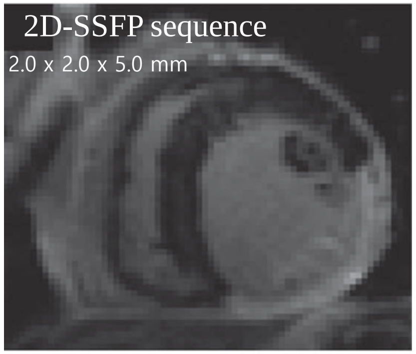


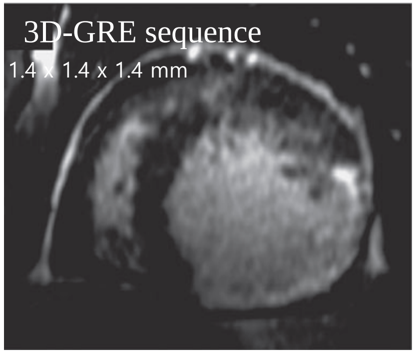
T1 mapping



3D LGE-CMR sequences improve conducting channel delineation prior to VT ablation







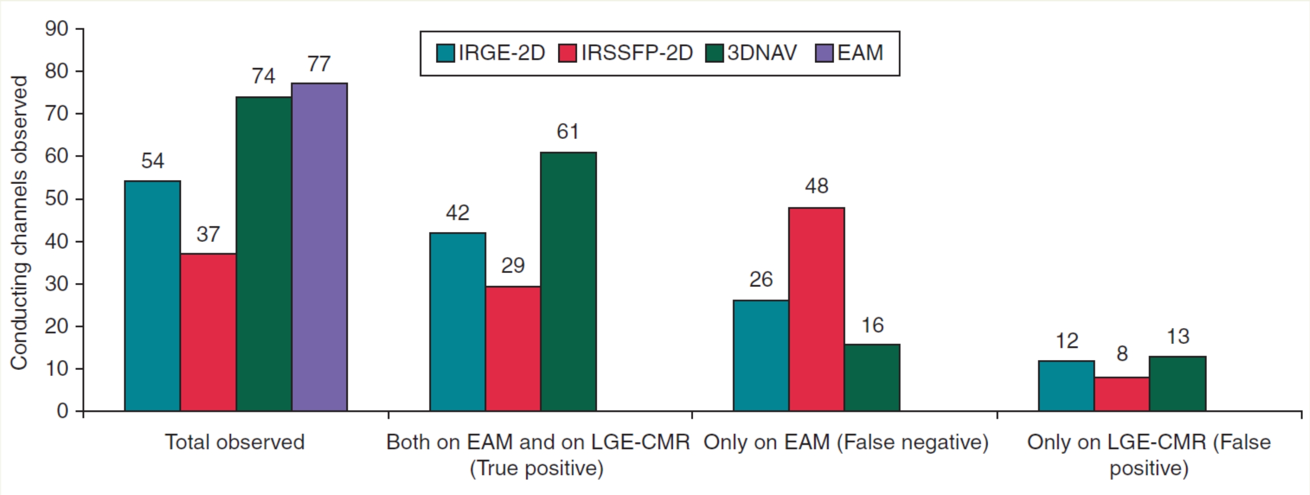
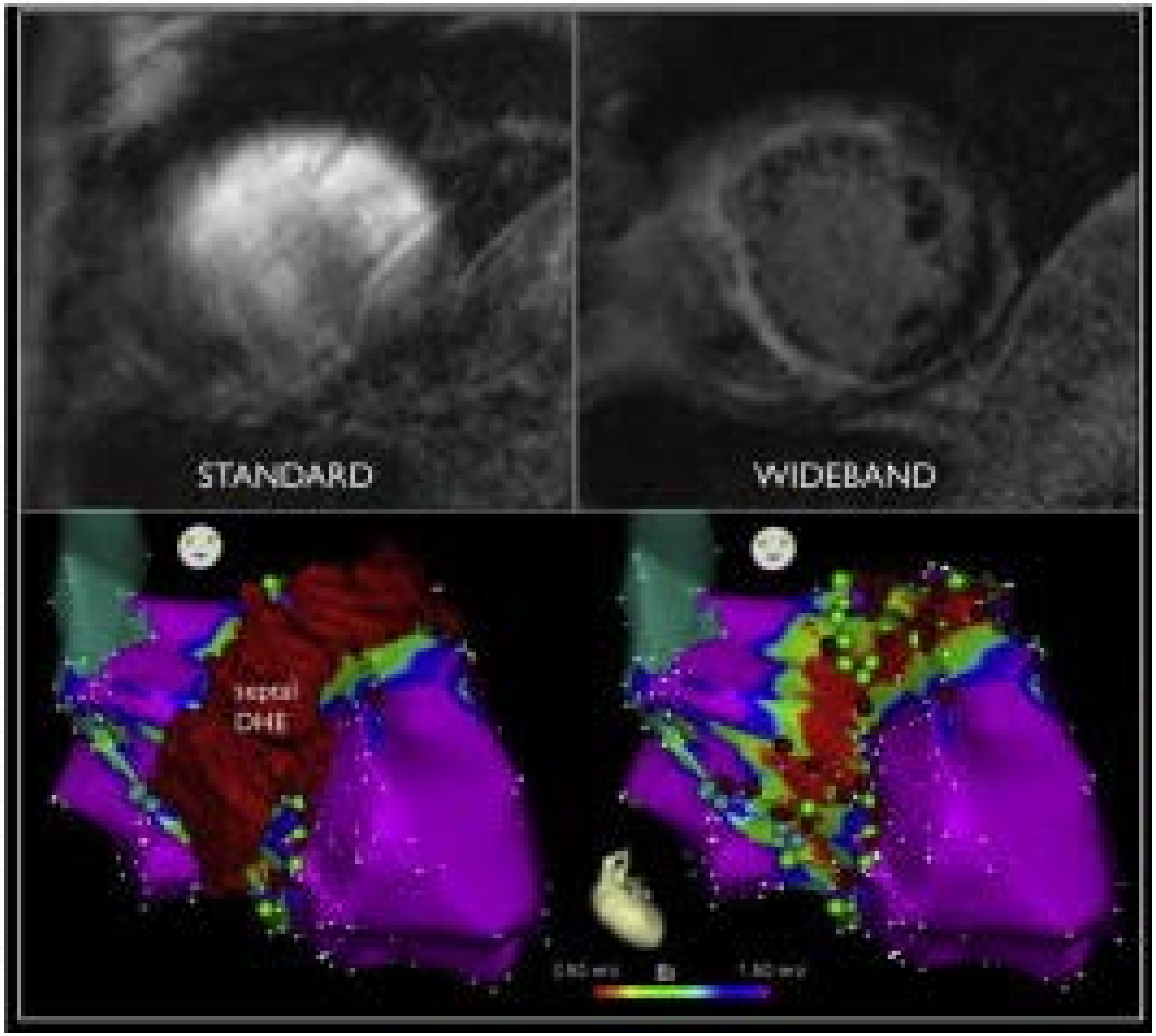


Figure 3 Matching between the CCs observed in the substrate EAM and the CCs identified in the 3D left ventricle reconstructions using different CMR sequences.

Europace 2015;17, 938–45

MR image before and after application of the WIDEBAND method of device artifact attenuation



Stevens SM, et al. Heart Rhythm 2013

Benefit of imaging depending on type of ablation procedure

- **Ablation of post MI VT**

  - CMR for scar location

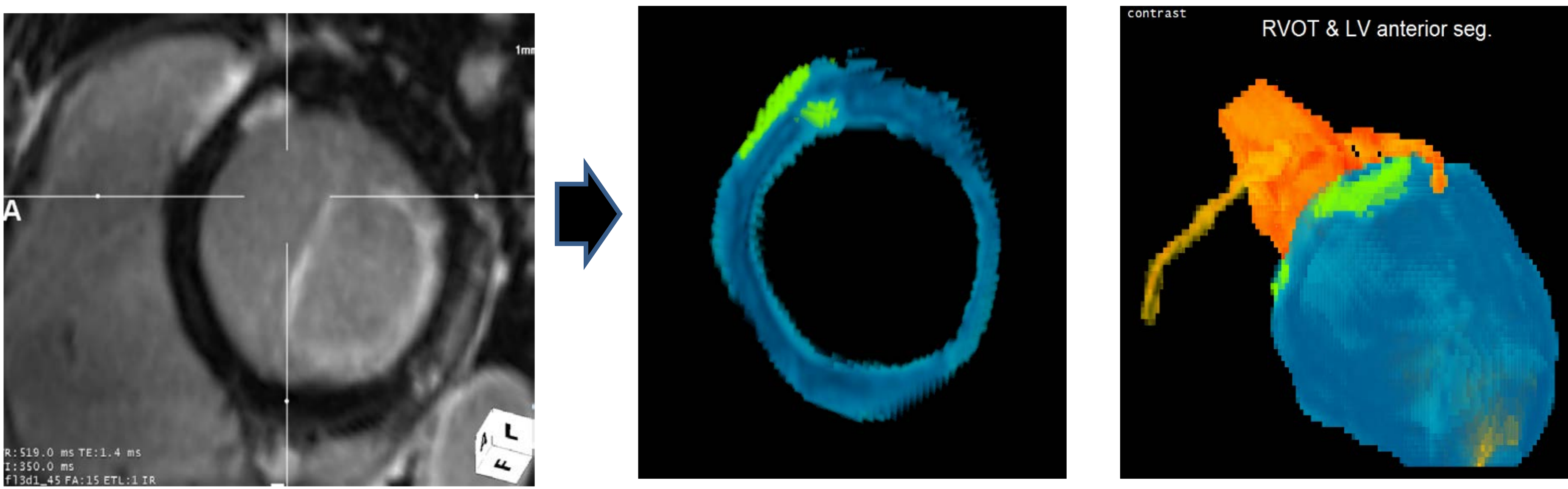
- **Ablation of VT in NICM**

  - Endocardial ablation; CMR for scar location

  - Epicardial ablation; Cardiac CT for coronary and phrenic nerve location

3D Reconstruction of LGE-MRI

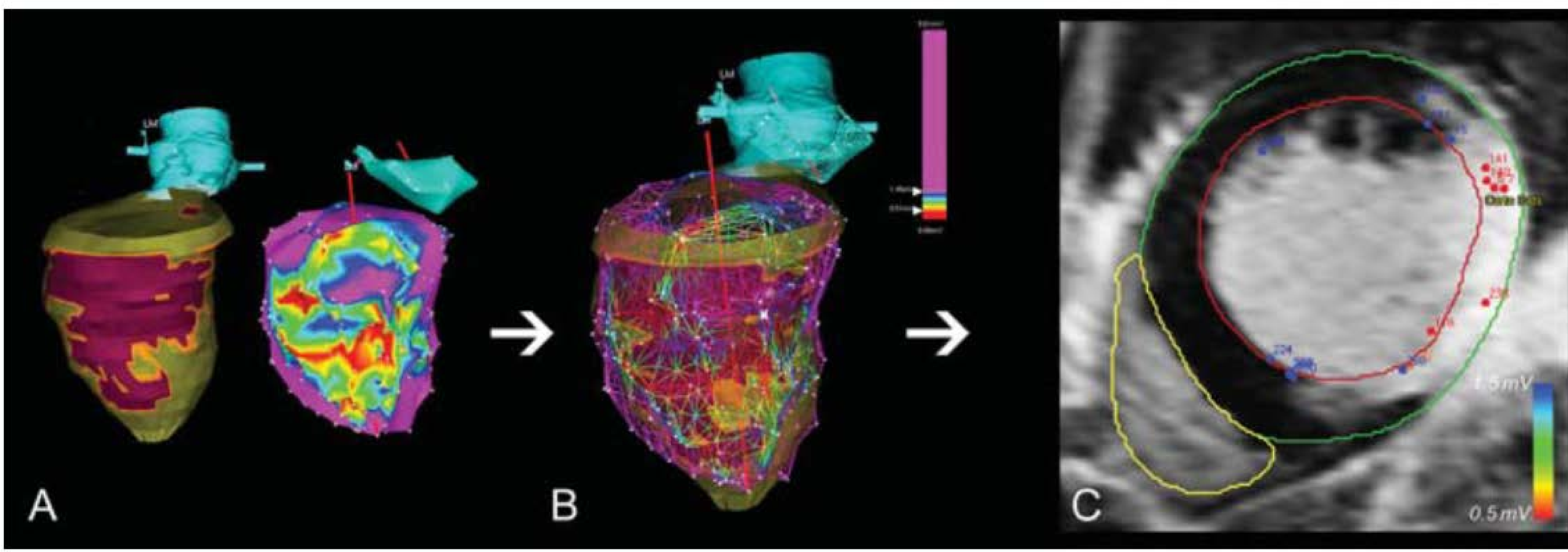
- 3D color coding image, focusing on the target lesion



VT-related conduction channel using LGE-CMR in CMI

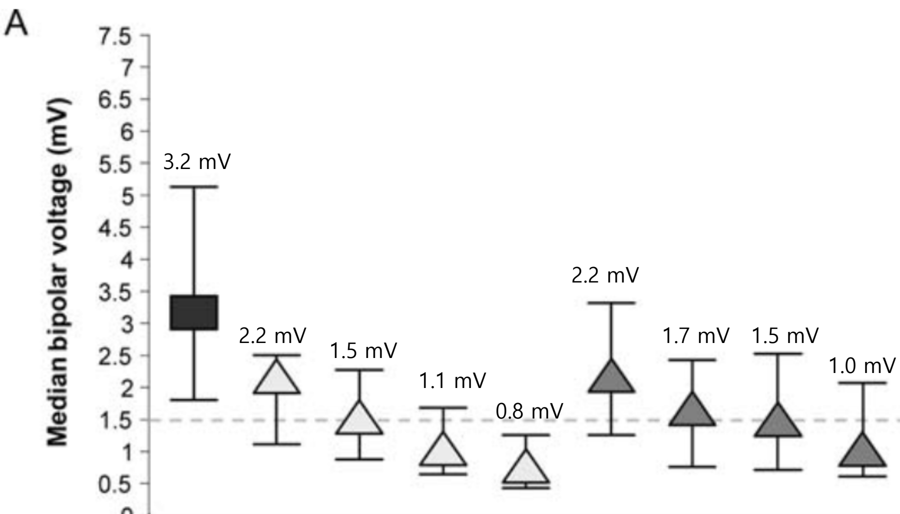
- 15 patients after MI
- Merging of LGE-MRI meshes with EVAM (CartoMERGE software)
- Voltage amplitudes of each mapping points

  vs. LGE characteristics (transmurality and signal intensity)

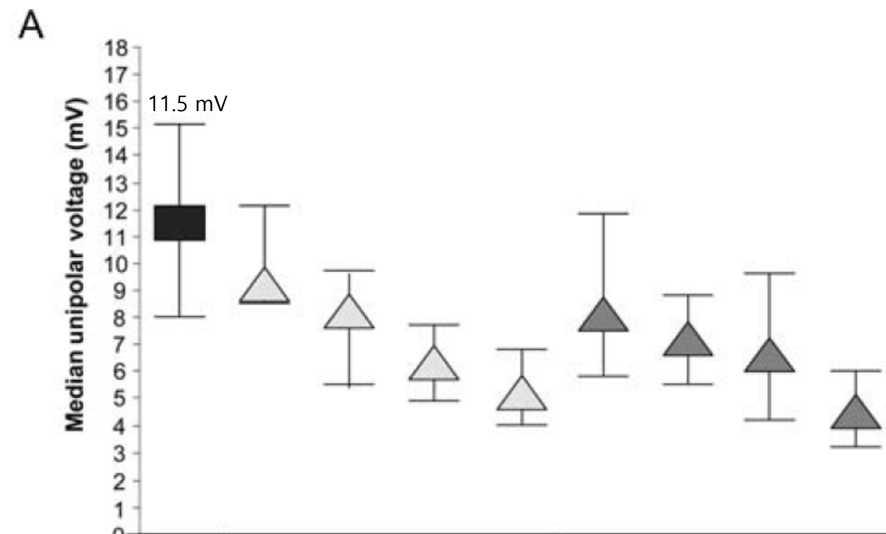


Wijnmaalen AP et al. Eur Heart J. 2011; 32:104-114.

Median bipolar and unipolar voltages of points located at short axis LGE-CMR segments coded for transmurality and SI of scar



Mapping points	n = 1533	n = 19	n = 178	n = 205	n = 479	n = 94	n = 126	n = 62	n = 180
Intensity Location Transmurality	No	Core Endo 25%	Core Endo 50%	Core Endo 75%	Core 100%	Gray Endo 25%	Gray Endo 50%	Gray Endo 75%	Gray 100%
No		0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Core Endo 25%	0.01		0.04	<0.01	<0.01	0.7	0.08	0.07	0.02
Core Endo 50%	<0.01	0.04		<0.01	<0.01	<0.01	0.8	0.8	0.02
Core Endo 75%	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	0.01	0.6
Core 100%	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	<0.01
Gray Endo 25%	<0.01	0.7	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01
Gray Endo 50%	<0.01	0.08	0.8	<0.01	<0.01	<0.01		0.7	<0.01
Gray Endo 75%	<0.01	0.07	0.8	0.01	<0.01	<0.01	0.7		0.07
Gray 100%	<0.01	0.02	0.02	0.6	<0.01	<0.01	<0.01	0.07	

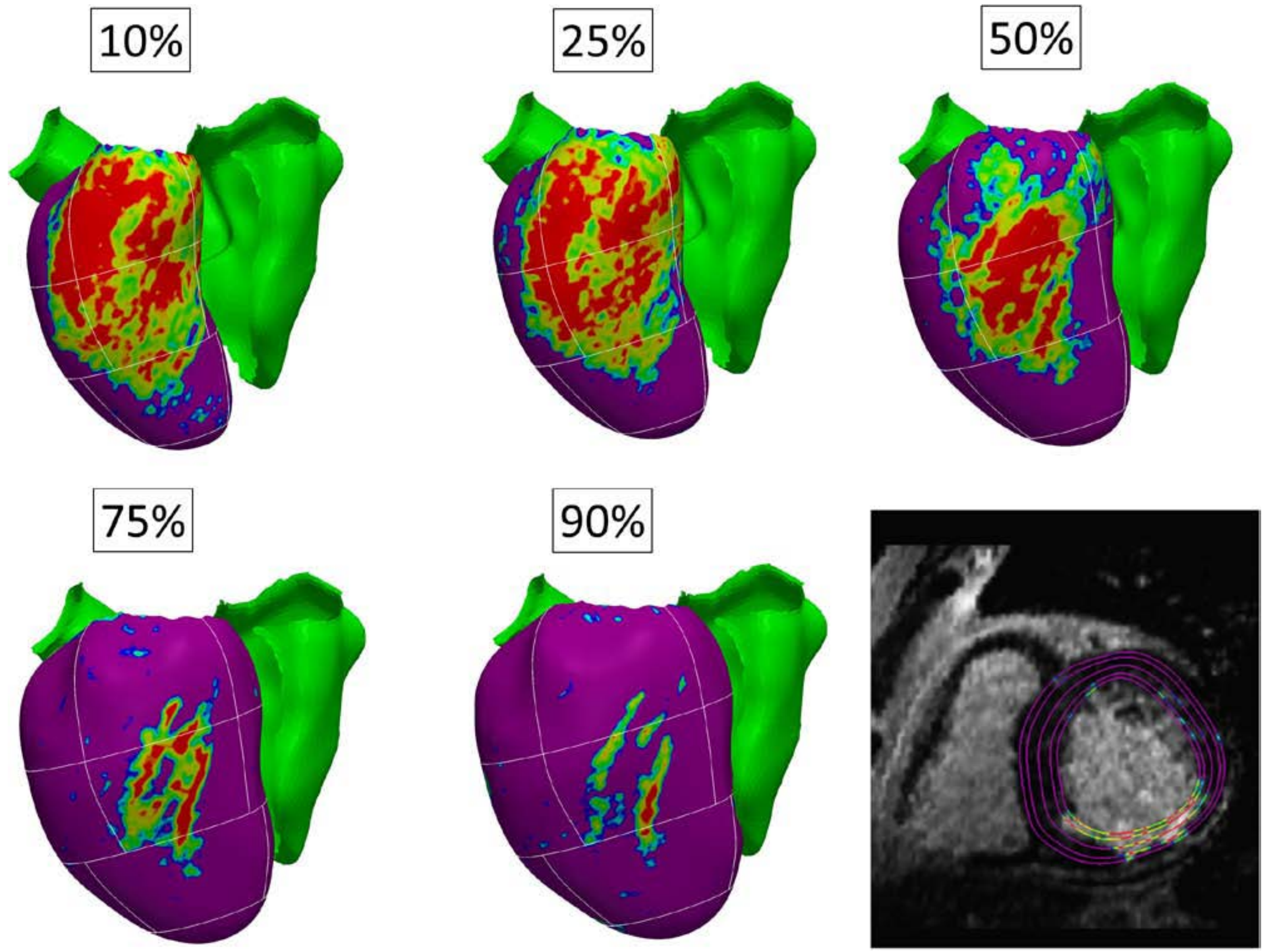


Mapping points	n = 1533	n = 19	n = 178	n = 205	n = 479	n = 94	n = 126	n = 62	n = 180
Intensity Location Transmurality	No	Core Endo 25%	Core Endo 50%	Core Endo 75%	Core 100%	Gray Endo 25%	Gray Endo 50%	Gray Endo 75%	Gray 100%
No		0.3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Core Endo 25%	0.3		0.01	<0,01	<0.01	0.07	<0.01	<0.01	<0,01
Core Endo 50%	<0.01	0.01		<0.01	<0.01	0.3	0.09	0.01	<0.01
Core Endo 75%	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	1.0	<0.01
Core 100%	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	<0.01
Gray Endo 25%	<0.01	0.07	0.3	<0.01	<0.01		0.04	<0.01	<0.01
Gray Endo 50%	<0.01	<0.01	0.09	<0.01	<0.01	0.04		0.06	<0.01
Gray Endo 75%	<0.01	<0.01	0.01	1.0	<0.01	<0.01	0.06		<0.01
Gray 100%	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	

- Real-time integration including scar transmurality and heterogeneity and EAVM data during catheter ablation of post-MI VTs is feasible and accurate (mean position error of < 4 mm).
- Endocardial bipolar and unipolar electrogram amplitudes decrease with increasing scar transmurality and are also influenced by scar heterogeneity as quantified by SI.
- The currently used bipolar electrogram cut-off value of 1.5 mV can not fully delineate non-transmural scar, small subepicardial scar, and infarct gray-zones as identified by LGE-MRI.

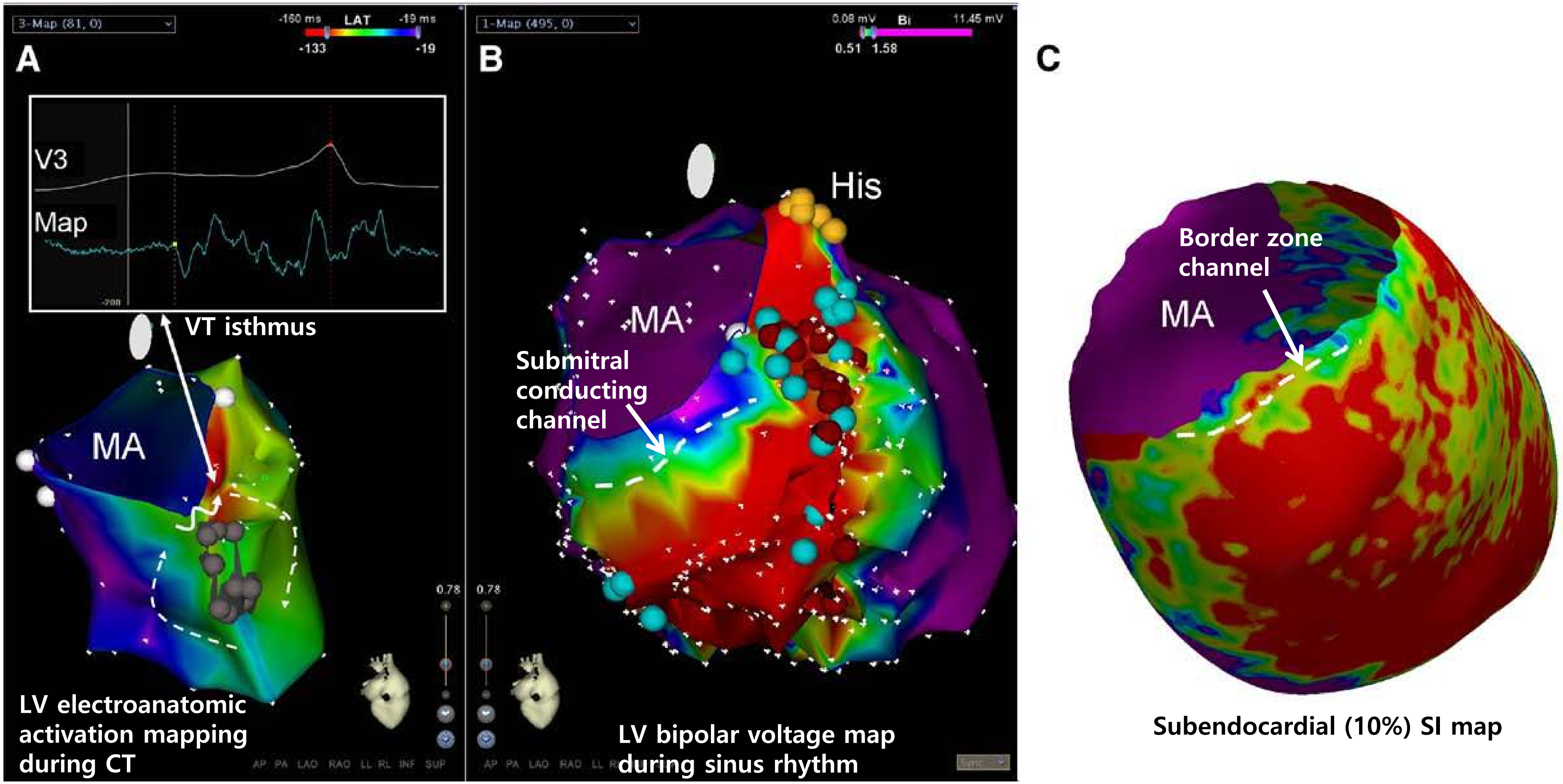
3D Architecture of Scar and Conducting Channels Based on High Resolution ce-CMR

21 patients with healed MI and VT



Circ Arrhythm Electrophysiol. 2013;6:528-537

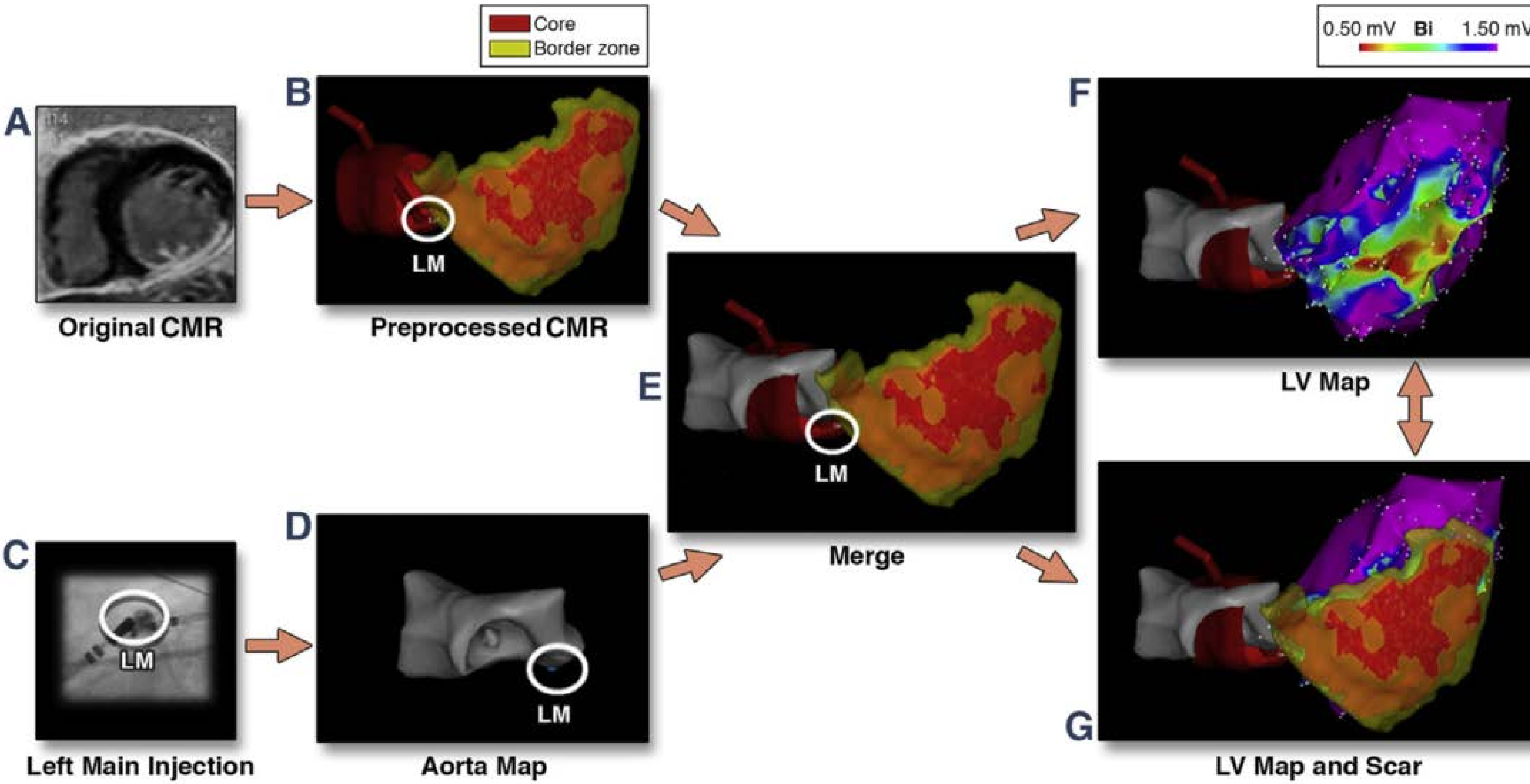
An example of a submitral border zone channel related to VT



- Scar area decreased progressively from endocardium to epicardium (scar area/LV area: 34.0±17.4% at endocardium, 24.1±14.7% at 25%, 16.3±12.1% at 50%, 13.1±10.4 at 75%, 12.1±9.3% at epicardium; $P<0.01$).
- Forty-five BZ channels (2.1±1.0 per patient, 23.7±12.0 mm length, mean minimum width 2.5±1.5 mm) were identified, 85% between the endocardium and 50% shell and 76% present in ≥1 layer.
- The ce-CMR–defined BZ channels identified 74% of the critical isthmus of clinical VTs and 50% of all the conducting channels identified in electroanatomic maps.

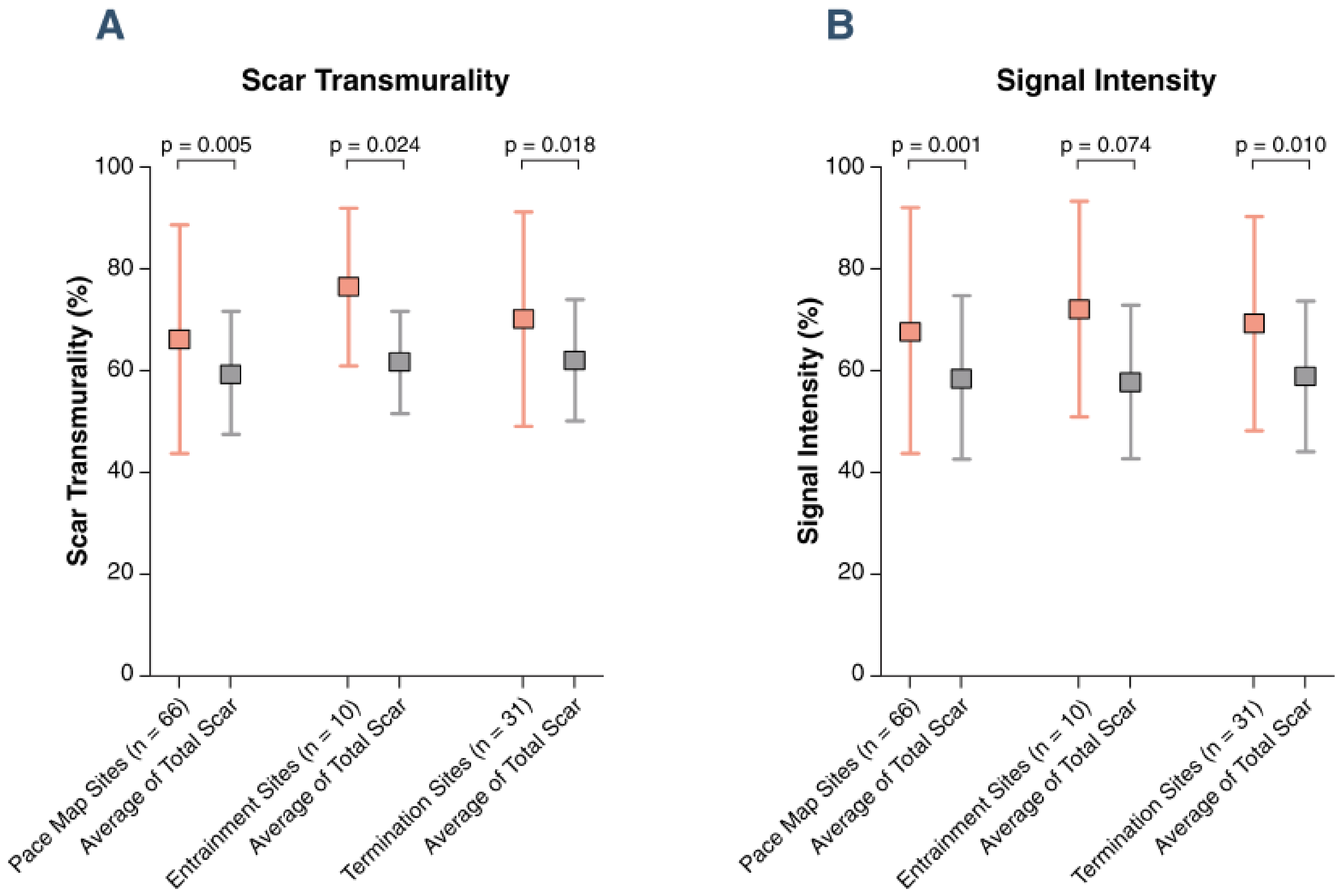
LGE-CMR based identification of critical isthmus sites of ischemic and nonischemic VT

44 patients (23 ischemic and 21 nonischemic, LVEF 44±12%)



Piers SR et al. JACC Cardiovasc Imaging 2014; 7:774-84.

Scar transmurality and SI at Critical Isthmus Sites

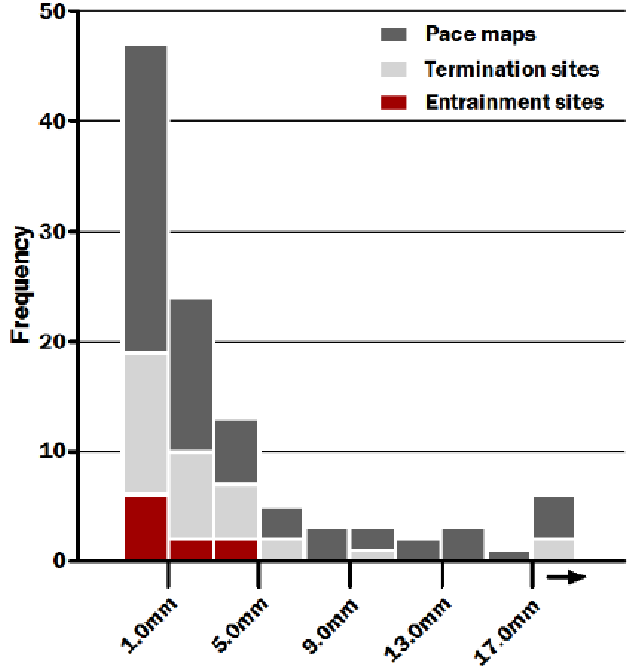


- The critical isthmus sites had high scar transmurality and SI compared with the average of the entire scar.

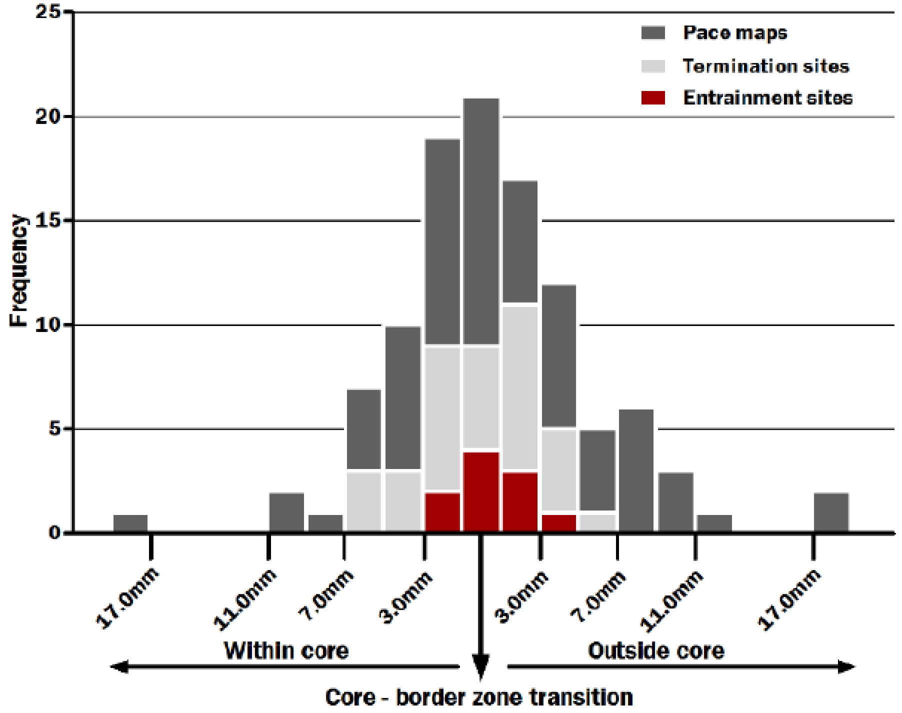
Distance From Critical Isthmus Sites to >75% Transmural Scar and the Core-BZ Transition

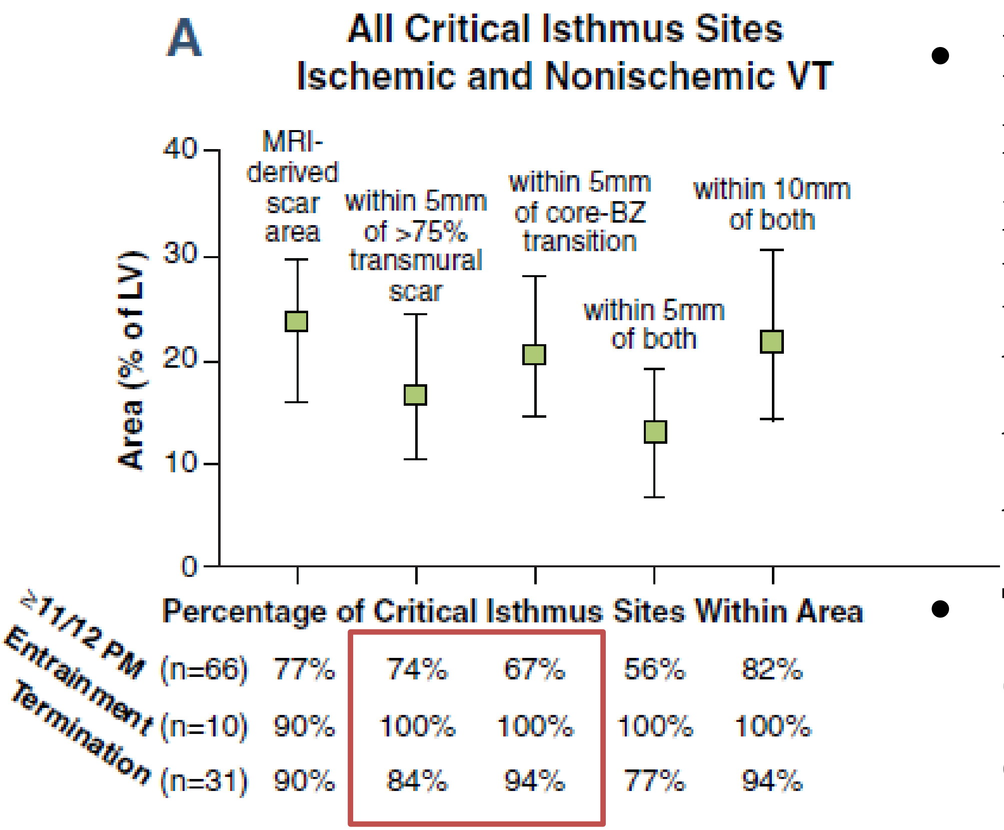
Core: SI ≥50% of SI_{max}, BZ: SI 35-50% of SI_{max}

Distance to >75% transmural scar



Distance to core-borderzone transition





- Both in ischemic and nonischemic VT, critical isthmus sites are typically located in close proximity to the CMR-derived core-BZ transition and to >75% transmural scar.
- These findings suggest that CMR-derived scar characteristics may guide to critical isthmus sites during VT ablation

Cardiac CT for VT

- **Cardiac CT**

  - Coronary anatomy, epicardial fat

  - Hypo-attenuation (10 HU↓) in ARVC patients

  - Radiation dose

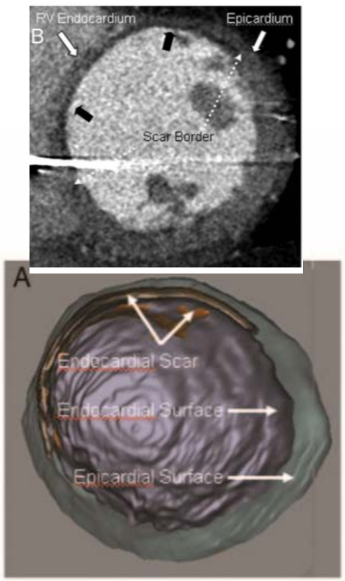
- **Scar detection**

  - Wall thinning: (WT < 5 mm)

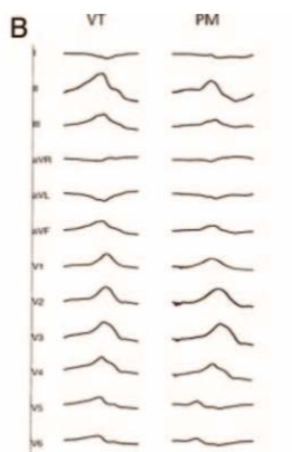
  - Delayed enhancement

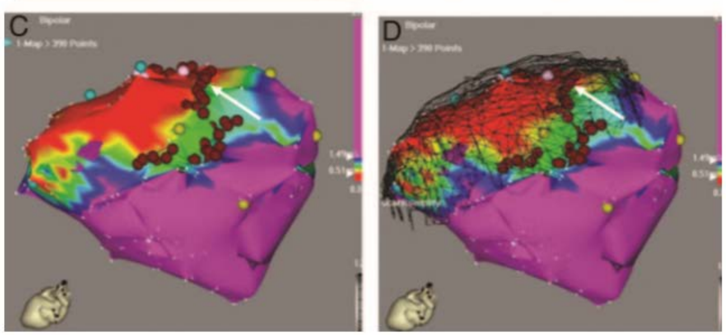
Anatomic, dynamic, and perfusion characteristics of abnormal myocardium to guide VT ablation

Fusion of 3D LV anatomy and 3D hypoperfusion reconstruction



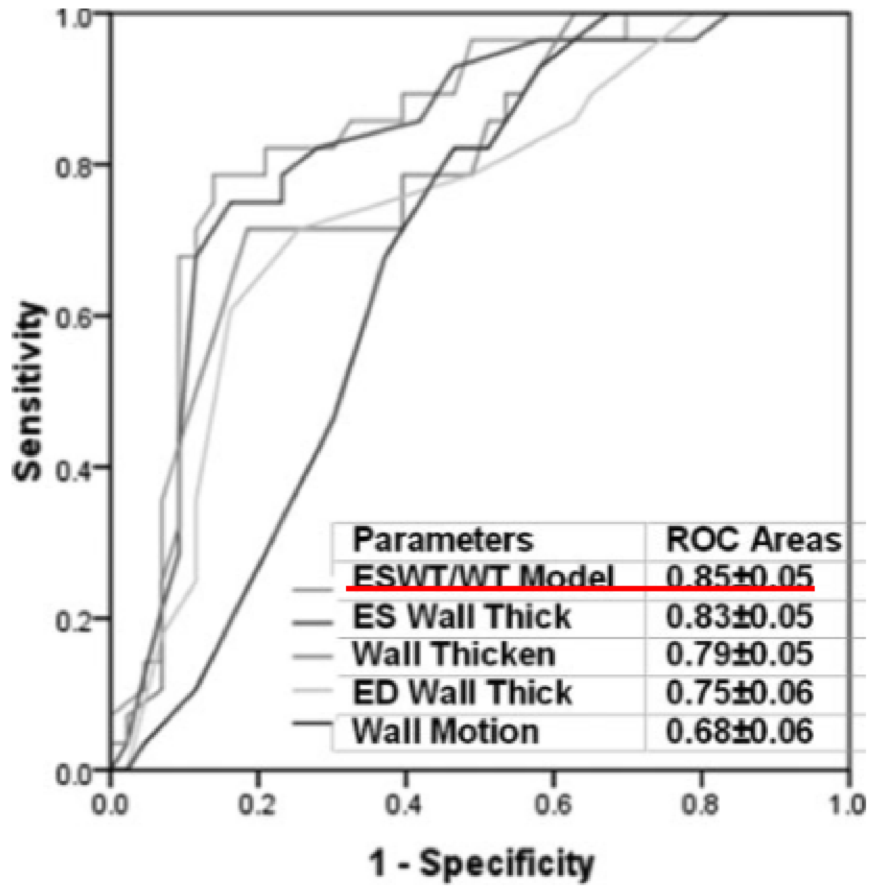
≥ 11/12 pace-mapping match





Voltage map

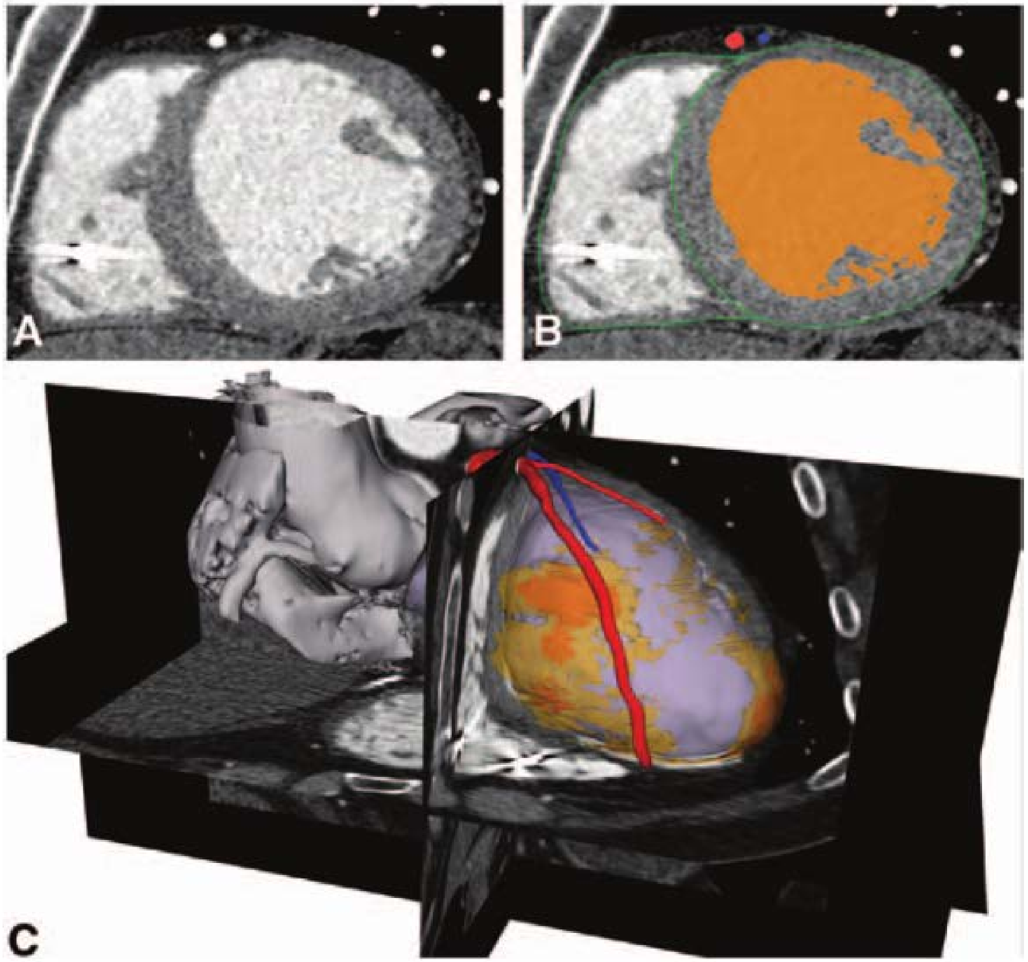
Abnormal voltage segment <1.5 mV



Tian J, et al. Cir Arrhythm Electrophysiol 2010;3:496-504

- Areas of CT hypoperfusion correlate best with areas of abnormal voltage (<1.5 mV) rather than scar alone (<0.5 mV).
- 3D CT-defined abnormal myocardium can be accurately extracted and embedded in clinical mapping systems displaying areas of abnormal anatomic, dynamic, and perfusion parameters for substrate-guided VT ablations.

Regional myocardial wall thinning correlates to arrhythmogenic substrates in post MI VT

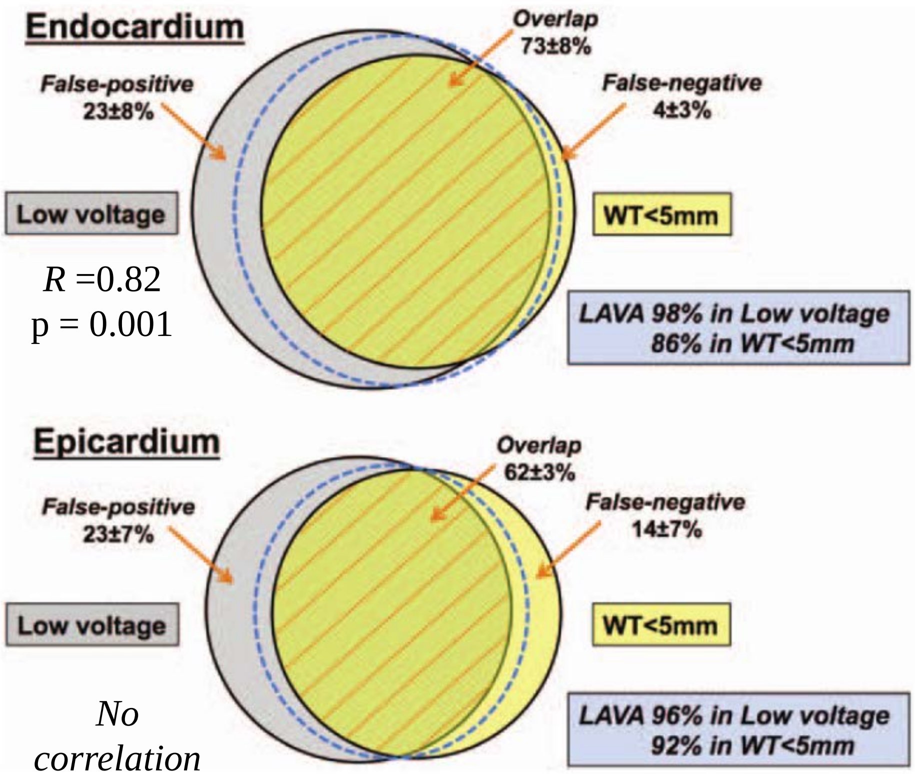


N=13

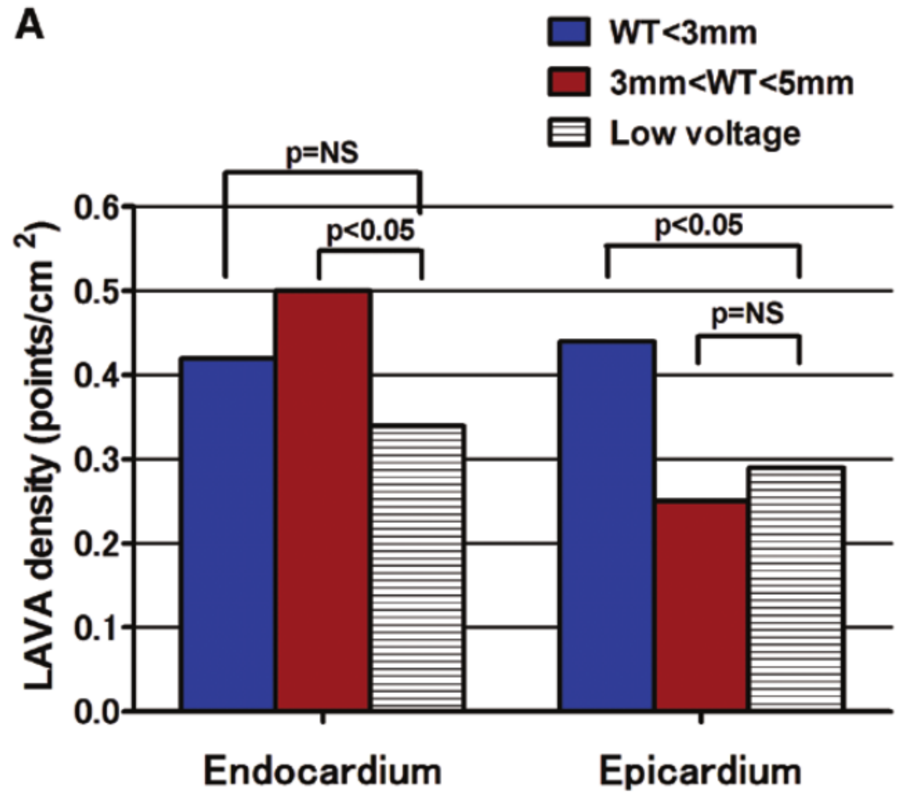
Orange , WT <3 mm
Yellow , WT <5 mm

Komatsu Y et al. Circ Arrhythm Electrophysiol. 2013; 6:342-50.

The regional wall thinning area vs low-voltage area



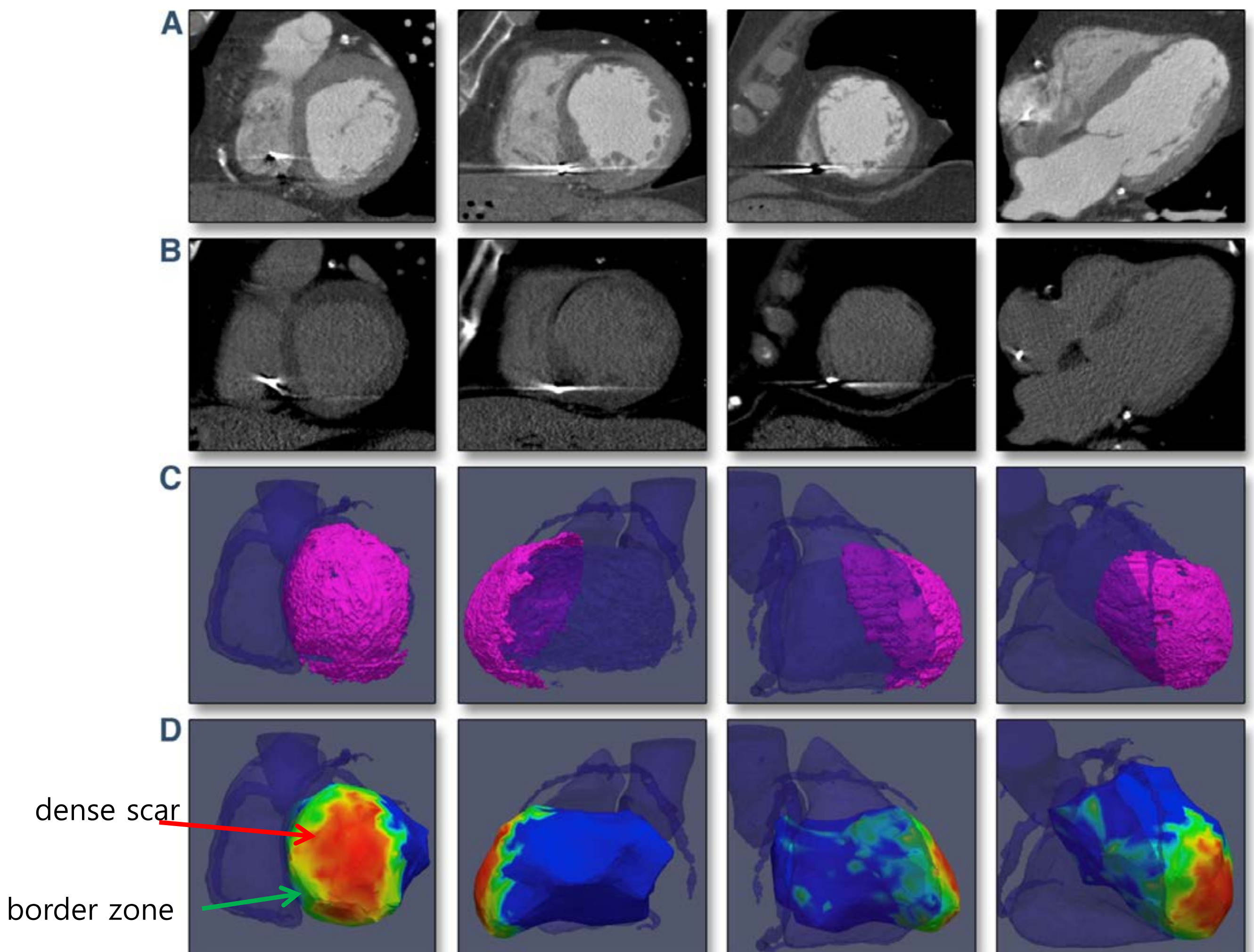
Distribution and characteristics of local abnormal ventricular activities



- Despite a good correlation between the area of regional WT <5 mm and endocardial voltage-defined scan, WT area is substantially smaller than the low-voltage area.
- 87% of LAVA are located within the WT <5 mm, and the remaining 13% are not farther than 23 mm from its border.
- The vast majority of very late LAVA are present within the thinnest region (93% in the WT <3 mm).
- **The integration of MDCT WT with 3D EAVMs can help focus mapping and ablation on the culprit regions.**

Cardiac CT with DE in the characterization of VT structural substrate

CT vs. EAM Scar in a Patient With ICM

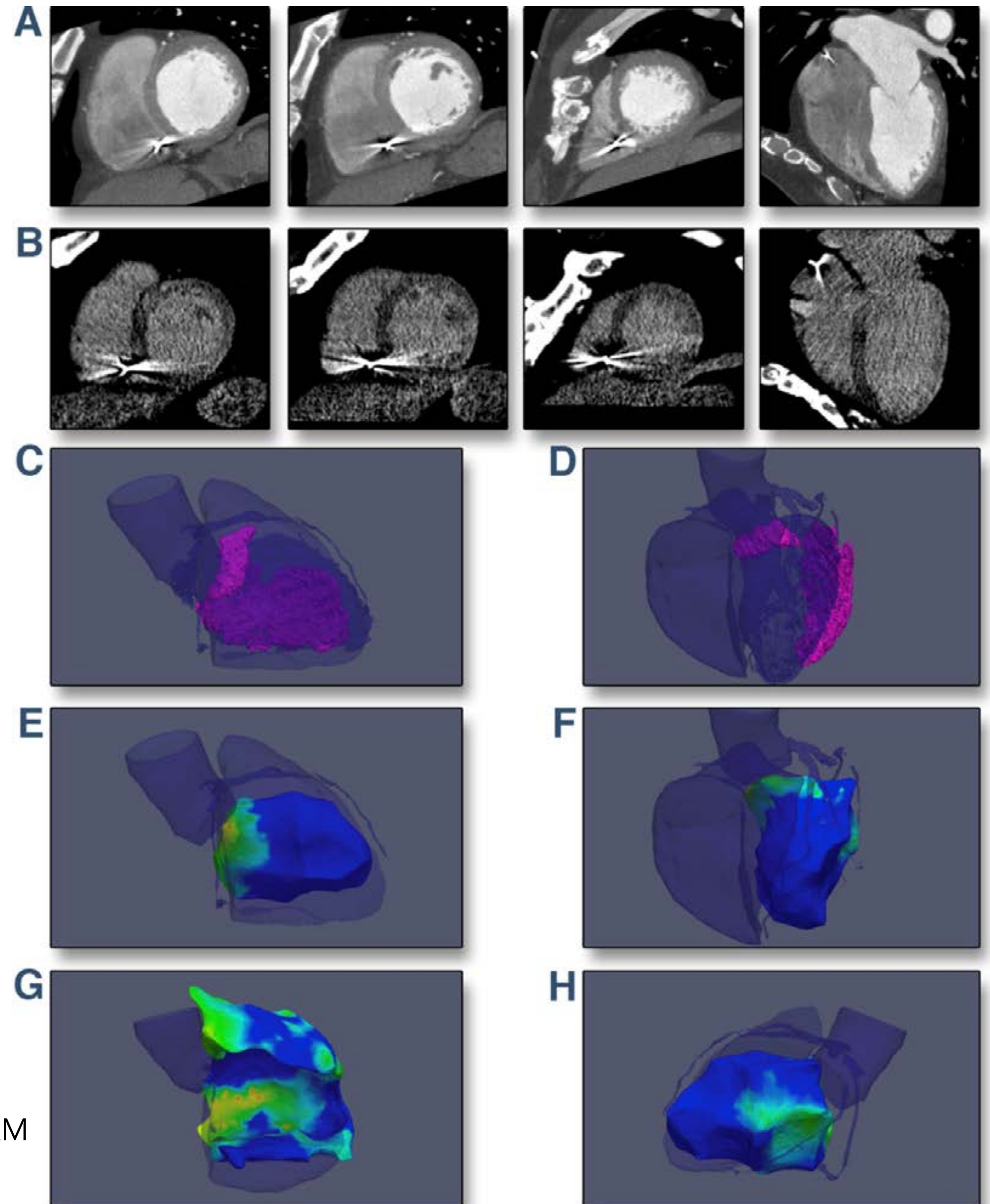


42 patients
(35 had ICD)

3D reconstruction of CT with scar segmentation

Bipolar endocardial EAM

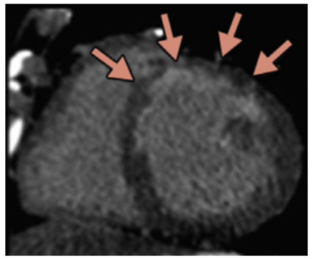
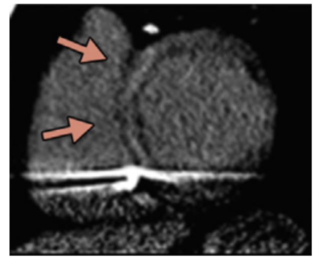
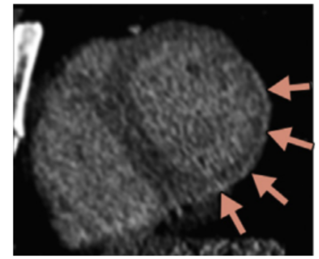
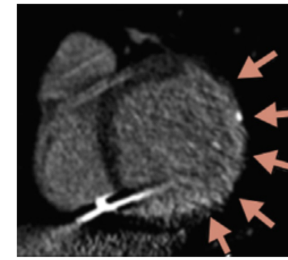
CT vs. EAM Scar in a Patient With NICM



Uniplar endocardial EAM

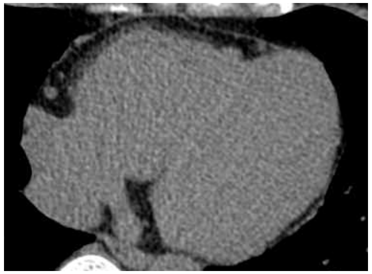
Unipolar epicardial EAM

TABLE 2 Segmental Comparison Between Scars at CT and Low Voltages at EAM

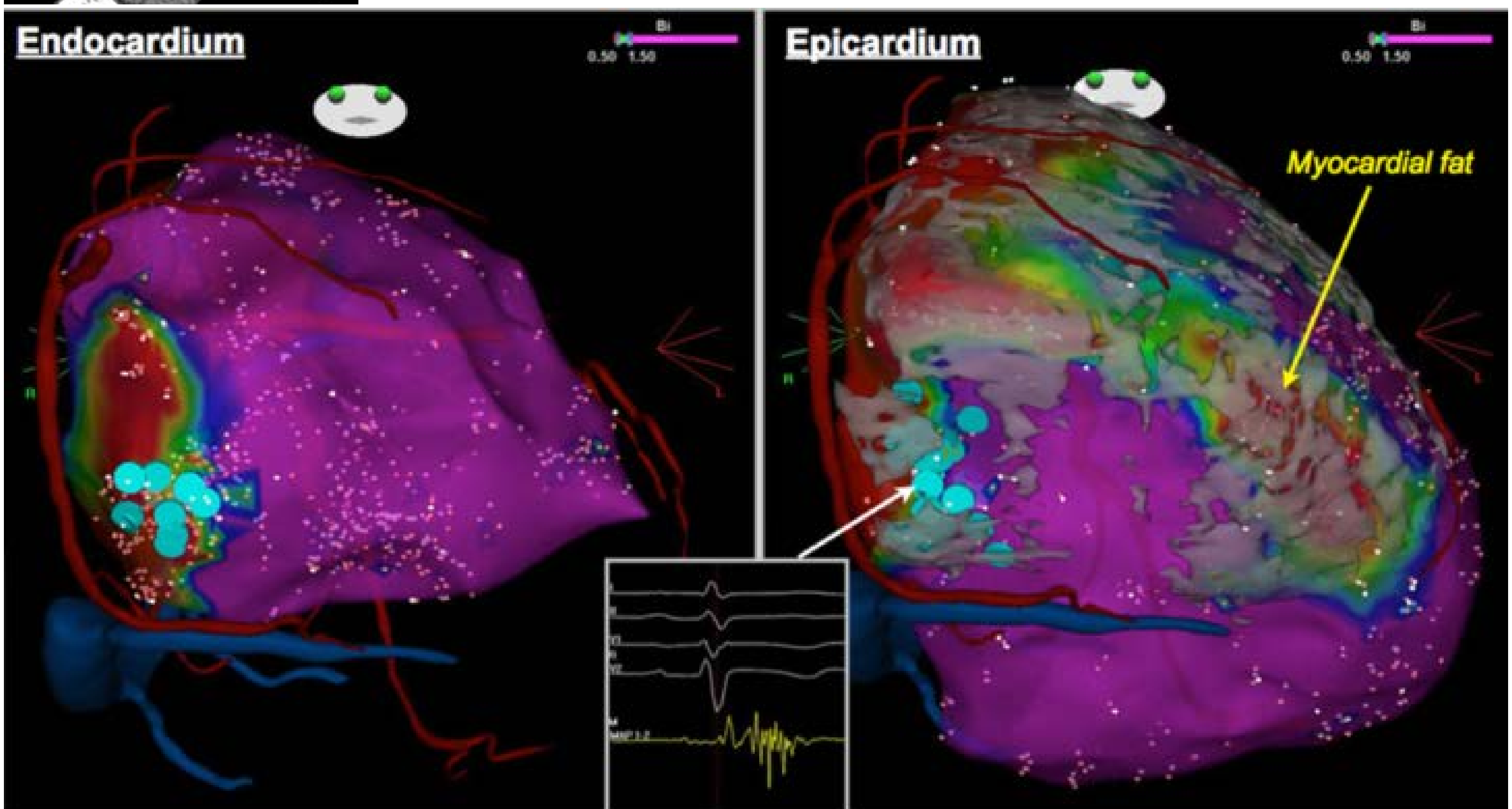
EAM Approach	EAM Voltages	Scars With Subendocardial Distribution at CT 	Scars With Mesocardial Distribution at CT 	Scars With Subepicardial Distribution at CT 	Scars With Transmural Distribution at CT 
Endo-EAM	BV <1.5 mV	(n = 527; scar = 109) Average K = 0.565	(n = 34; scar = 4) Average K = 0.764	(n = 391; scar = 68) Average K = 0.394	(n = 374; scar = 88) Average K = 0.598
	UV <8 mV	(n = 170; scar = 33) Average K = 0.411	(n = 17; scar = 4) Average K = 0.882	(n = 102; scar = 22) Average K = 0.437	(n = 119; scar =24) Average K = 0.434
Epi-EAM	BV <1.5 mV	(n = 204; scar = 26) Average K = 0.432	(n = 17, scar = 2) Average K = 0.765	(n = 221; scar = 39) Average K = 0.650	(n = 136; scar = 24) Average K = 0.828
	UV <8 mV	(n = 85; scar = 17) Average K = 0.772	n.a.	(n = 68; scar = 15) Average K = 0.912	(n = 68; scar = 15) Average K = 0.912

- Good overall concordance ($\kappa = 0.536$) between CT and EAM in the detection of scar
- Delayed enhancement and wall thinning – sensitivity 76%, specificity 86% and NPV 95% for identifying segments characterized by low voltages
- **CT with delayed-enhancement provides a 3D characterization of VT scar substrate together with a detailed anatomic model of the heart.**

Myocardial fat and VT substrate in ARVC



N= 16 ARVC

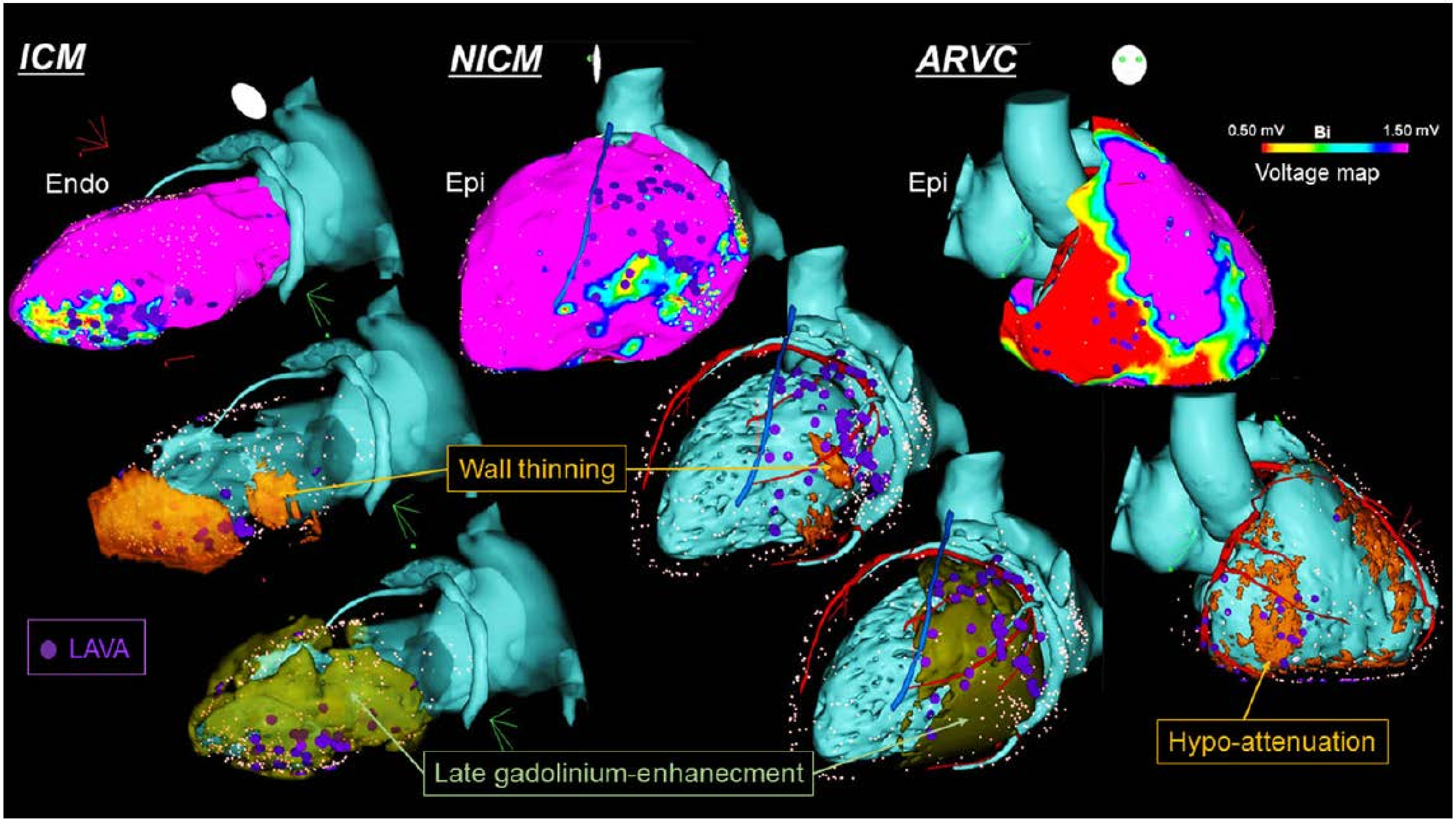


J Am Heart Assoc 2014;3(4): e000935

- A positive correlation between the extent of fat in RV free wall and the size of the low-voltage region on both endocardium (r=0.61, P=0.012) and epicardium (r=0.57, P=0.042).
- A high concordance between the location of RV fat and low voltage in the epicardium (k=0.69), but fair concordance in the endocardium (k=0.41) with fewer low-voltage regions compared to the RV fat at MDCT
- The vast majority of LAVA located around the border of the RV fat segmentation.

The integration of MDCT-imaged myocardial fat with 3D-EAM provides valuable information on the extent and localization of VT substrate and demonstrates ablation targets clustering in its border region.

Image Integration (CT, CMR, and EAM) to Guide Catheter Ablation in Scar-Related Ventricular Tachycardia



J Cardiovasc Electrophysiol 2016;27:699-708

Conclusion

- **Cardiac CT and CMR integration into 3D-EAM systems** continues to change the landscape of ablation procedures in electrophysiology by lowering the ionizing radiation and enhancing the safety of ablation procedures and improving outcomes by focusing on areas of interest by providing information about cardiac anatomy and adjacent structures as well as tissue integrity.

Njeim M, et al. JACC Cardiovascular imaging 2016;9:873-86


Thank you for attention!