Catheter ablation of ventricular tachycardia in patients with structural heart disease

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Scar-related VT. 
Which is the arrhythmogenic substrate? 
The source-sink mismatch

- Isthmus boundary segments with large transitions in infarct border zone thickness have large source-sink mismatch, and functional block forms there during VT.
- Impaired connexin 43 gap junction.
- Interstitial fibrosis results in displacement of myocytes from each other.
- Post-infarct structural remodeling also involves deposition of adipose tissue in the infarcted bed
- Dissociation of muscle fibers.

Unidirectional block and Slow conduction

Circulation 1997;95:988e996. Cardiovasc Res 1999;42:284e297.

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Scar related VT. Which is the arrhythmogenic substrate?

- The heterogeneous process of myocyte resorption and collagen deposition results in islands of surviving myocardial cells within healed infarct scars.

- These preserved myocardial bundles (channels) exist as a “labyrinth” in three dimensions, involving the endocardium, mid-myocardium, and epicardium.

Circulation 1997;95:988e996, Cardiovasc Res 1999;42:284e297.
Cardiac imaging in patients with ventricular tachycardia

**CMR**: CMR-based characterization of scar distribution and extent of scar transmurality provide important information to distinguish between ischemic cardiomyopathies and nonischemic cardiomyopathies. Further, the ability to detect subtle structural abnormalities, myocardial scar patterns, and myocardial inflammation allows differentiation between specific nonischemic etiologies such as myocarditis, sarcoid, and amyloid cardiomyopathies.

**MDCT**: Compared with CMR, a major advantage of MDCT is a significantly higher spatial resolution. Specifically, the spatial resolution of LGE CMR images is usually limited to 1.5 to 2 mm in plane, with ≤6- to 8-mm slice thickness.

**Nuclear Imaging and FDG-PET**
CMR imaging for defining VT substrate, determining optimal access for VT ablation and estimating lesion formation.
MDCT imaging in patients with ventricular tachycardia: define the thickness, the fat and the coronary arteries
EP tools for VT mapping

Tools for VT mapping

- Activation mapping during VT
- Entrainment mapping

80% of VTs are unmappable

Tools for VT mapping

- Voltage mapping in SR (identification of scars and conducting channels)
- Mapping of abnormal ventricular activity in SR (fragmented or late isolated potentials)

Substrate mapping

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Bipolar voltage mapping: looking for the cut-off values

- Bello et al. first showed that CT and PET correlated well with bipolar voltage zones ≤1 mV.
- Codreanu et al. using MRI have found that a bipolar signal amplitude ≤1.54 mV and a unipolar amplitude ≤ 6.52 mV showed the optimal receiver operating characteristic curves for defined image-based scar.
- With high-density mapping, the mean bipolar LV electrogram amplitude in normal ventricles was 4.8 ± 3.1 mV, with 95% of normal LV recordings having a bipolar voltage ≥1.55 mV.
- Based on these data, 1.5 mV has become the established cutoff for the bipolar signal for identifying a normal substrate using three-dimensional anatomic display.
- Typically, scar detection has been defined as bipolar voltages <1.5 mV, with lower voltages (variously defined as 0.1–0.5 mV) indicative of more dense scar.
- **A bipolar signal amplitude between 0.5 and 1.5 mV correlates well with the border zone.**
Was ist die optimale Ablationstrategie
The role of electrode size and interelectrode spacing
New 3-D mapping systems...
Endocardial unipolar voltage mapping: the 8.3 mV cut-off value for the LV

Circ Arrhythm Electrophysiol. 2011;4:49-55
Endocardial unipolar voltage mapping: the 5.5 mV cut-off value for the RV

Heart Rhythm. 2011;8:76-83.
Endocardial unipolar voltage mapping: the 4 mV cut-off value for the RVOT

Right Ventricular Outflow Tract Electroanatomical Abnormalities Predict Ventricular Fibrillation Inducibility in Brugada Syndrome

Konstantinos P. Letsas, Michael Efremidis, Dimitrios Asvestas, Konstantinos Vlachos, Stamatis Georgopoulos, Gary Tse, Tong Liu, George Bazoukis, Antonios Sideris, Adrian Baranchuk, Joachim R. Ehrlich and Pedro Brugada

Circulation: Arrhythmia and Electrophysiology. 2018;11:e005928, originally published February 8, 2018
ARVC case:
Bipolar and unipolar voltage mapping
LAVAs: sensitive but not specific...
DEEP-guided VT ablation
Pace-mapping for the identification of “channels”: pace latency >40ms
Late isolated potentials in SR with near-field capture during pacing (long S-QRS)
Identical pace-mapping (12/12) with near-field capture and S-QRS >40 ms (latency)
Progressive delay and elimination of late potential: an effective end-point for substrate ablation?
Patients that should be considered for epicardial mapping include those with:

- a failed prior ablation;
- VT unrelated to coronary artery disease;
- a CMR suggesting mid-myocardial or epicardial scar; and
- an ECG suggestive of an epicardial exit.
Case presentation:
a 63 yo patient with DCM and VT storm
Endocardial approach: small areas of low bipolar signals and large areas of low unipolar signals
Epicardial mapping and ablation

- Dilated cardiomyopathy (Epi>Endo)
- Arrhythmogenic cardiomyopathy (Epi>Endo)
- Chagas disease (Epi>Endo)
- Myocarditis (Epi)
- Hypertrophic cardiomyopathy (Mid-myo and Epi)
- Sarcoidosis (Mid-myo and Epi)
- Brugada syndrome (Epi)
- Ischaemic cardiomyopathy (Endo>Epi)
Epicardial mapping and ablation
Patients were treated either by confining the RF lesions to the endocardial surface with limited substrate ablation (Group 1) or underwent endocardial and epicardial ablation of abnormal potentials within the scar (homogenization of the scar, Group 2).

During a mean follow-up of 25±10 months, the VTs recurrence rate was 47% (23 of 49 patients) in Group 1 and 19% (8 of 43 patients) in Group 2.

Ablation using endo-epicardial homogenization of the scar significantly increase freedom from VTs in ischemic cardiomyopathy patients.
End-points of scar related-VT ablation

- Non-inducibility is not a sufficient end-point for VT ablation. In a recent meta-analysis, no significant association was found between the rates of VT non-inducibility and recurrence at follow-up.

- Substrate modification (endo-epi):
  - Elimination or modification (entrance block, further delay) of late or fractionated potentials within the scar;
  - Scar dechanneling: ablation of potential channels of conduction; (data from voltage mapping and pace mapping);
  - Scar homogenization;
  - Core isolation: encirclement of the scar;
  - Failure to capture with high output pacing allows the assessment of lesion completeness.

- Substrate modification should aim to transform a patchy scar to a dense scar.
Subjects with ischemic cardiomyopathy and hemodynamically tolerated VT were randomized to clinical ablation versus substrate-based ablation that targeted all “abnormal” electrograms in the scar.

Primary endpoint was recurrence of VT.

At 12-month follow-up, 15.5% and 48.3% patients had VT recurrence in substrate-based and clinical VT ablation groups, respectively.

12% of patients with substrate ablation and 32% with clinical ablation required rehospitalization.

Overall 12-month mortality was 11.9%; 8.6% in substrate ablation and 15.0% in clinical ablation groups, respectively.

J Am Coll Cardiol 2015;66:2872–82
VT ablation trials

The VTACH study

- The VTACH (Ventricular Tachycardia Ablation in Coronary Heart Disease) study randomized patients with prior MI, LVEF <50%, and hemodynamically stable VT to ICD implantation or ICD implantation and ablation.
- Amiodarone was used in 35% of patients in each group at the time of randomization.
- At 2 years, the primary endpoint of time to first recurrence of VT or VF was significantly longer with the ablation group versus control group (median 18.6 months vs. 5.9 months).
- The freedom from VT/VF was 47% in the ablation group and 29% in the control group (p: 0.045).
  (Lancet 2010;375: 31-40.)

The SMASH-VT study

- The SMASH-VT (Substrate Mapping and Ablation in Sinus Rhythm to Halt Ventricular Tachycardia) study randomized patients with prior MI presenting with spontaneous VT/VF to ICD implantation alone or in combination with catheter ablation.
- Patients taking class I or III antiarrhythmic drugs were excluded.
- Catheter ablation resulted in a 65% reduction in the rate of appropriate ICD therapy.
  (N Engl J Med 2007;357: 2657-65.)

The VANISH trial

- The VANISH (Ventricular Tachycardia Ablation versus Escalated Antiarrhythmic Drug Therapy in Ischemic Heart Disease) trial evaluated the relative roles of catheter ablation versus escalating antiarrhythmic drug therapy in post-MI ICD patients with recurrent VT despite receiving class I or III drugs, a typically encountered clinical situation.
- The composite primary endpoint of death, VT storm, or appropriate ICD shock was reduced by 28% with ablation (HR: 0.72; 95% CI: 0.53 to 0.98; p 1/4 0.04).
  (N Engl J Med 2016;375:111-21.)

The SMS study

- In the SMS (Substrate Modification Study), catheter ablation failed to decrease the primary endpoint of time to first VT/VF recurrence in post-MI patients with LVEF <40% and hemodynamically unstable VT.
- Ablation did result in a >50% reduction in total ICD interventions. Antiarrhythmic drug (class I or III) use was approximately 30% in both groups at time of enrollment.
  (Circ Arrhythm Electrophysiol 2017;10:e004422.)
VT ablation ...

Noninvasive Cardiac Radiation for Ablation of Ventricular Tachycardia

Phillip S. Cuculich, M.D., Matthew R. Schill, M.D., Rojano Kashani, Ph.D., Sasa Mutic, Ph.D., Adam Lang, M.D., Daniel Cooper, M.D., Mitchell Faddis, M.D., Ph.D., Marye Gleva, M.D., Amit Noheria, M.B., B.S., Timothy W. Smith, M.D., D.Phil., Dennis Hallahan, M.D., Yoram Rudy, Ph.D., and Clifford G. Robinson, M.D.

THANK YOU VERY MUCH FOR YOUR ATTENTION

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The presence of late potentials was identified in the majority of patients (79%).

By adjusting voltage cutoffs, 37 putative channels were identified in 21 of 24 patients (88%).

The presence of late potentials within a voltage channel was seen in 11 (46%) of 24 patients and 17 (46%) of 37 channels.

A VT isthmus site was contained within a channel in 11 (30%) of 37 channels and in 11 (46%) of 24 patients.

The use of these channels alone in identifying the clinical isthmus has low specificity, and therefore their ability to accurately guide ablation is poor.
Non-inducibility is not a sufficient end-point for VT ablation.

The abnormal potentials (late, fragmented) do not bear the same clinical utility.

Non-selective ablation of all abnormal potential particularly at the border zone may be associated with collateral damage due to expansion of necrotic zone.
Six eligible studies (enrolling 403 patients, with 1 randomized study) comparing the two strategies.

At a median follow-up of 18 months, the relative risk (RR) of VT recurrence was not significantly different with substrate-based vs. activation/entrainment guided VT ablation (0.72, 95% confidence interval [CI] 0.44-1.18), P=0.2).

Acute success (RR 1.02, 95% CI 0.95-1.1, P=0.6), complications (RR 0.8, 95% CI 0.35-1.82, P=0.5) cardiovascular mortality and total mortality did not differ significantly (RR 0.83, 95% CI 0.38-1.79, P=0.6 and RR 0.76, 95% CI 0.36-1.59, P=0.5, respectively).

Kumar et al. JCE 2016
Techniques to identify local abnormal ventricular activities

- Pacing from the right ventricle, particularly with a shortly coupled S2, may create some delay between the far-field and the poorly coupled near-field potential.

- Pacing from the catheter recording the potential of interest may be performed. The stimulus to QRS (S-QRS) delay will be prolonged when pacing a poorly coupled fiber especially when the pacing strength is reduced to threshold. As a consequence, the QRS morphology may also change, as the exit from the fibrotic region may be different.

- Abnormal potentials may be identified during local ectopics by the observation of sequential ventricular electrograms.
Core isolation
ARVC vs. Brugada syndrome: “diseases of conexome”
Epicardial substrate mapping in DCM: Bipolar voltage and LP mapping
Playing with the cut-off values
Diseases displaying epicardial circuits

- Dilated cardiomyopathy (Epi>Endo)
- Arrhythmogenic cardiomyopathy (Epi>Endo)
- Chagas disease (Epi>Endo)
- Myocarditis (Epi)
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Stepwise algorithm for identifying an epicardial origin from the basal superior and lateral LV in patients with non-ischemic cardiomyopathy.
Epicardial substrate mapping in DCM: Bipolar voltage and LP mapping
Stepwise algorithm for identifying an epicardial origin from the basal superior and lateral LV in patients with non-ischemic cardiomyopathy
Structural heart disease and VT ablation

- CAD
- DCM
- ARVC
- HCM
- BrS

scar-related VT/VF
Tools for VT mapping

- Voltage mapping in SR (identification of scars and conducting channels)
- Mapping of abnormal ventricular activity in SR (fragmented or late isolated potentials)
Epicardial substrate mapping in DCM: Bipolar voltage and LP mapping
Unipolar voltage mapping

- The normal signal amplitude was 8.27 mV for LV ENDO UNI electrograms.

- In all patients with ENDO UNI low voltage, the ENDO UNI low-voltage regions were directly opposite to an area of EPI BIP low voltage.

- Areas of unipolar voltage < 5.5 mV are associated with epicardial abnormalities in the RV.

Heart Rhythm. 2011;8:76-83.
Circ Arrhythm Electrophysiol. 2011;4:49-55
Fractionated potentials

- Fractionated electrograms: amplitude <0.5 mV, duration >133 ms, and amplitude/duration ratio <0.005.
- Fractionated signals reflect areas of slow conduction with “zig-zag” propagation (reflecting scar/fibrosis) and are thought to be highly specific for diseased tissue.

Circulation 1986;73:645–652, Circulation 1982;65:856–861
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Circ Arrhythm Electrophysiol 2017;10:e004422.
Voltage mapping: identification of conducting channels
Late potentials - Isolated potentials

- Late or isolated potentials during sinus rhythm (≥20-40 ms after the end of surface QRS) reflect local depolarization of surviving fiber bundles that are well insulated by dense scar.

- Pacing at these sites can capture the local potential and conduct slowly out of the scar, resulting in a long stimulus to QRS interval and, if sharing an exit of a targeted VT, a good or excellent pace map.

- In a previous report, all confirmed VT isthmuses displayed isolated potential in sinus rhythm, and ablation in these areas was associated with good outcomes.

- Abolition of late potentials is considered an effective endpoint of VT ablation.

- Although late potentials during sinus rhythm are very sensitive in identifying critical isthmuses of VT, they are not very specific (30% at bystander sites).

J Am Coll Cardiol 2003;41:81–92. J Am Coll Cardiol 2006;47:2013–2019. Circulation 1995;91: 2385–2391. J Cardiovasc Electrophysiol 2012;23:621-7.
A meticulous substrate mapping involves LP mapping
End-points of scar related-VT ablation

- Non-inducibility remains the classical end-point: abolishing the “clinical” VTs is the minimum end-point for VT ablation.
- Pacing should be performed within the scar.
- Non-inducibility is not a sufficient end-point for VT ablation.
- In a recent meta-analysis, no significant association was found between the rates of VT non-inducibility and recurrence at follow-up.
- It appears that VT inducibility is a probabilistic rather than deterministic phenomenon. Pace several times within the scar.
- The optimal time point to perform VT induction is yet unknown.
- NIPS a few days after the ablation procedure might provide additional prognostic information.

Santangeli et al. Circ Arrhythm Electrophysiol October 2014
A conducting channel is defined by the presence of a corridor of consecutive electrograms differentiated by higher voltage amplitude than the surrounding area. The effect of different levels of voltage scar definition was analyzed.

The majority of channels were identified when the scar voltage was set at <0.2 mV.

Late potentials are recorded more frequently at the inner than at the entrance of channels.

Pacing from these channels gave rise to a long-stimulus QRS interval.
Substrate Modification or VT Induction, Mapping and Ablation as the First Step?

- Simplified substrate ablation procedure with scar dechanneling as the first step (group 1, n=24) or standard procedure with VT induction, mapping and ablation followed by scar dechanneling (group 2, n=24).

- VT induction and mapping prior to substrate ablation prolongs the procedure, radiation exposure and the need for electrical cardioversion without improving acute and long-term outcomes.

Fernández-Armenta et al. Heart Rhythm 2016