Relationship of bipolar and unipolar electrogram voltage to scar transmurality and composition derived by magnetic resonance imaging in patients with nonischemic cardiomyopathy undergoing VT ablation

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BACKGROUND Bipolar voltage mapping has a role in defining endocardial-based scar in postinfarct patients undergoing ventricular tachycardia catheter ablation. The utility of bipolar and unipolar voltages in characterizing scar has not been evaluated in patients with nonischemic cardiomyopathy.

OBJECTIVE To relate left ventricular (LV) endocardial bipolar and unipolar voltages in these patients to scar transmurality (endocardial vs nonendocardial) and composition (homogeneous core vs heterogeneous gray).

METHODS Ten consecutive cardiomyopathy patients undergoing endocardial LV tachycardia ablation were included (age 48 ± 14 years; left ventricular ejection fraction 43% ± 15%). Preablation late gadolinium-enhanced magnetic resonance imaging was used to quantify core and gray scar by using signal-intensity thresholding. Electroanatomic LV endocardial mapping provided bipolar and unipolar voltages. Electroanatomic maps and late gadolinium-enhanced magnetic resonance imaging were rigidly registered in order to relate voltage to scar (registration error 3.6 ± 2.9 mm).

RESULTS Bipolar voltage was lower in endocardial core than in no scar ($P < .001$). Unipolar voltage was lower in endocardial core and nonendocardial core than in no scar ($P < .001$). Endocardial and nonendocardial gray scar had an effect similar to that of core in reducing bipolar and unipolar voltages ($P < .001$). The mass of healthy myocardium and endocardial core scar independently predicted bipolar and unipolar voltages using general estimating equation modeling. With receiver operating characteristic curve analysis, bipolar voltage >1.9 mV and unipolar voltage <6.7 mV had a high negative predictive value (91%) for detecting nonendocardial scar from either endocardial scar or no scar.

CONCLUSIONS In patients with nonischemic cardiomyopathy, LV endocardial bipolar voltage is dependent on endocardial core and gray scar, while the unipolar voltage is influenced by core and gray scar across the LV wall as defined by late gadolinium-enhanced magnetic resonance imaging.

KEYWORDS Bipolar; Unipolar; Electrogram; Magnetic resonance imaging; Cardiomyopathy; VT ablation

ABBREVIATIONS **GEE** = general estimating equation; **LGE-MRI** = late gadolinium-enhanced magnetic resonance imaging; **LV** = left ventricular; **NPV** = negative predictive value; **PPV** = positive predictive value; **ROC** = receiver operating characteristic; **RV** = right ventricular; **SI** = signal intensity; **VT** = ventricular tachycardia

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Introduction

Endocardial bipolar voltage mapping can reliably identify endocardial-based scar in postinfarction patients with ventricular tachycardia (VT), thereby delineating potential targets for catheter ablation.[1–3] However, in nonischemic cardiomyopathy, the scar may not be endocardial, but rather intramural or epicardial with endocardial sparing.[3] Consequently, the sensitivity of the bipolar electrogram with its narrower "field of view" in detecting the scar may be compromised. In contrast, the unipolar electrogram incorporates a larger region of myocardial electrical activity and has shown promise during right ventricular (RV) and left ventricular (LV) endocardial voltage mapping in identifying abnormal epicardial substrate when the endocardial bipolar voltage mapping is normal.[4,5]

Scar localization with late gadolinium-enhanced magnetic resonance imaging (LGE-MRI) is becoming increasingly refined with sufficient spatial resolution to delineate the transmural extent of the scar and distinguish core scar from heterogeneity along the scar border. In patients with

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postinfarction VT in which the scar is predefined by LGE, unipolar voltage mapping can discriminate between subendocardial and intramural core scar[6] and may also identify regions of midwall core not detected with bipolar mapping of the subjacent epicardium or endocardium.[7]

The voltage characteristics of scarred myocardium identified by LGE have not been studied in nonischemic cardiomyopathy, which may be relevant to localizing arrhythmogenic substrate and guiding VT ablation. Our objective was to evaluate the relationship between LV endocardial bipolar and unipolar voltages acquired during electroanatomic mapping and the transmural distribution and composition (core vs gray) of scar defined by LGE-MRI in patients with nonischemic cardiomyopathy undergoing VT ablation.

Methods

Patient population

We enrolled 10 consecutive patients with nonischemic cardiomyopathy who underwent endocardial LV VT catheter ablation and had previously acquired LGE-MRI. Nonischemic cardiomyopathy was defined as regional or global LV dysfunction, dilatation, or hypertrophy not attributed to significant coronary artery disease (stenosis >50%). The indication for VT ablation was sustained monomorphic or polymorphic VT refractory to antiarrhythmic drug therapy. Informed consent was obtained from all patients for clinical LGE-MRI and VT ablation.

Magnetic resonance imaging

LGE-MRI was performed prior to VT ablation by using a 1.5-T (Magnetom, Avanto, Siemens, Erlangen, Germany) scanner equipped with 32-receiver channels. Base-to-apex short-axis cine steady-state free precession images were acquired with breath-holding and electrocardiogram gating. Between patients, slice thickness and interslice gap varied from 6 to 10 mm and from 0 to 2 mm, respectively. Imaging parameters were as follows: repetition time, 3.5 ms; echo time, 1.3 ms; flip angle (α), 45°; matrix, 224 × 128 pixels; and field of view, 36 × 36 cm.

LGE images were acquired 10–15 minutes after bolus injection of 0.2 mmol/kg gadobutrol (Gadovist, Bayer Schering Pharma, Berlin, Germany) by using an inversion recovery gradient echo pulse sequence. Images were obtained at short-axis locations matching that of the cine sequence. Optimal inversion time was individually adjusted to null the normal myocardium. Technical parameters were as follows: repetition time, 7.2; echo time, 3.2; α, 15°, voxel size 1.3 × 1.3 × 6 mm; inversion time, 180–220 ms.

LGE-MRI scar analysis

LGE-MRI images were analyzed with custom software developed in Matlab (version 7.14.0, MathWorks, Inc, Natick, MA). Scar volume and heterogeneity were quantified by using a previously described signal intensity (SI) thresholding technique based on the full-width at half maximum method.[8] The LV endocardial and epicardial borders were manually traced, and the maximal SI within the scar region was determined. A region of remote (normal) myocardium was manually identified, and the maximum SI of this region was determined. Core scar was defined as myocardium with SI ≥50% of the maximal SI. Gray scar was defined as myocardium with SI greater than the maximum remote SI but less than 50% of the maximal SI.

The scar-annotated images were used to evaluate the extent of transmural core and gray scar associated with each electroanatomic point acquired during LV endocardial mapping. For this purpose, a cylindrical LV volume of 5 mm radius radiating from each electroanatomic point was constructed from the endocardium to the epicardium. Each cylinder was divided into an inner, middle, and outer third corresponding to the endocardium, midmyocardium and epicardium, respectively. The mass of core and gray was obtained for each of the thirds after calculating the respective scar volumes and multiplying by the average density of the myocardium (1.05 g/mL). Each third containing more than 40% core and/or gray was defined as scar; otherwise, it was considered to be healthy. Regions with scar localized to the inner third or inner two-thirds (inner + middle third) were classified as endocardial. Regions with scar localized to the middle third, outer third, or outer two-thirds (outer + middle third) were classified as nonendocardial. Regions in which scar was present in each of the thirds were classified as transmural, and regions in which each of the thirds were considered to be healthy were classified as no scar. Finally, the endocardial, nonendocardial, and transmural scar regions were further classified as core or gray depending on the predominant scar type.

Electroanatomic mapping and registration with LGE-MRI

Endocardial LV electroanatomic mapping was performed during sinus rhythm or RV apical pacing by using a retrograde aortic approach via the femoral artery. Systemic anticoagulation was initiated with unfractionated heparin to achieve a target activated clotting time of ≥250 seconds. A roving 3.5-mm tip irrigated mapping catheter with 2-mm ring electrode and 1-mm interelectrode spacing (Navistar, Biosense Webster, Diamond Bar, CA) was used to construct a 3-dimensional shell of the LV endocardium while recording electrograms from the regions sampled. Fluoroscopy and local electrogram characteristics were used to verify the stability of catheter contact with the endocardium before electroanatomic points were acquired. Bipolar and unipolar electrograms were filtered at 30–400 Hz and 0.5–400 Hz, respectively, and displayed at 100 mm/s on the mapping system (CARTO 3, Biosense Webster). For each electroanatomic point, the bipolar and unipolar electrograms were analyzed for stability, amplitude, duration, morphology, and timing relative to the surface QRS complex. Maximum peak-to-peak bipolar and unipolar electrogram voltages were measured automatically by the mapping system, manually verified, and displayed as isopotential maps.

The electroanatomic map of the LV endocardium was then exported and registered offline to the endocardial con-