Voltage mapping for delineating inexcitable dense scar in patients undergoing atrial fibrillation ablation: A new end point for enhancing pulmonary vein isolation

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BACKGROUND Characterization of left atrial scar using bipolar voltage (BiV) mapping is not well defined. We have previously shown that the BiV range of 0.2–0.45 mV can identify chronic scar from prior pulmonary vein isolation (PVI).

OBJECTIVE This study sought to determine a BiV range that can identify atrial inexcitable dense scar (IDS) in patients acutely and chronically after PVI.

METHODS Thirty consecutive patients undergoing first time (n = 15) or redo (n = 15) PVI were included. A left atrial shell was created using electroanatomic mapping, and IDS was defined by inability to capture at an output of 10 mA and a pulse width of 2 ms in sinus rhythm, circumferentially at the edge of PVI-related scar (≤5 mm). At each pacing site, BiV amplitude and atrial capture were recorded.

RESULTS Overall, 837 pacing sites were assessed. BiV predicted IDS (receiver operating characteristic curve area 0.93 for first time PVI and 0.90 for redo PVI). In first time PVI, the best BiV value to predict IDS was 0.45 mV for the left pulmonary vein–left atrial appendage (LAA-LPV) ridge (sensitivity 0.98; specificity 1.0) and 0.2 mV for other localizations (sensitivity 0.91; specificity 0.86). In redo PVI, the best BiV value to predict IDS was 0.2 mV for the LAA-LPV ridge (sensitivity 0.77; specificity 1.0) and 0.15 mV for other localizations (sensitivity 0.81; specificity 0.82).

CONCLUSION BiV reproducibly identifies acute and chronic IDS using a cutoff value of 0.2 mV (0.45 mV for the LAA-LPV ridge) in patients undergoing first time PVI and 0.15 mV (0.2 mV for the LAA-LPV ridge) in patients undergoing redo PVI. IDS thus identified may be a rigorous tool for validating PVI.

KEYWORDS Atrial fibrillation; Electroanatomic mapping; Ablation; Scar

ABBREVIATIONS **AF** = atrial fibrillation; **BiV** = bipolar voltage; **CMRI** = cardiac magnetic resonance imaging; **EAM** = electroanatomic mapping; **EGM** = electrogram; **EI** = electrical inexcitability; **ICE** = intracardiac echocardiography; **IDS** = inexcitable dense scar; **LA** = left atrium/atrial; **LAA** = left atrial appendage; **LPV** = left pulmonary vein; **PV** = pulmonary vein; **PVI** = pulmonary vein isolation; **RFA** = radiofrequency ablation; **ROC** = receiver operating characteristic

(Heart Rhythm 2014;11:1904–1911) Published by Elsevier Inc. on behalf of Heart Rhythm Society.

Introduction

Pulmonary vein isolation (PVI) has become the cornerstone of atrial fibrillation (AF) ablation.[1–3] Unfortunately, durable electrical isolation of pulmonary veins (PVs) still remains a challenge.[4] Since reconnection of previously isolated PVs has been implicated as the likely mechanism underlying AF recurrence, various approaches have been proposed to enhance durability of PVI. These include testing for bidirectional (entry and exit) block, use of adenosine, and more recently the pace-and-ablate approach. The latter has been proposed as a way of enhancing PVI by achieving electrical inexcitability (EI) at the site of the radiofrequency ablation (RFA) lesion. This requires high-output pacing after each RFA application, with additional radiofrequency energy delivery in case local capture is demonstrated. A concern with this approach is that high-output pacing may result in a wide bipole and/or large virtual electrode that may capture tissue beyond the site of the RFA lesion. If so, this could result in additional unnecessary ablation to achieve local EI during PVI.[5–7]

We have previously shown that the bipolar voltage (BiV) range of 0.2–0.45 mV during electroanatomic mapping (EAM) of the left atrium (LA) was reproducibly able to identify chronic scar resulting from previous PVI.[8] Scar

Dr Squara has received research grant from the Fédération Française de Cardiologie, Sorin Group, and Endosense. Dr Marchlinski is on the advisory panel of Biosense Webster, and it has sponsored his research unrelated to this study. Dr Callans has received speaker's honoraria from Biosense Webster. **Address reprint requests and correspondence:** Dr Sanjay Dixit, Electrophysiology Section, Cardiovascular Division, Hospital of the University of Pennsylvania, 9 Founders Pavilion, 3400 Spruce St, Philadelphia, PA 19104. E-mail address: Sanjay.Dixit@uphs.upenn.edu.

1547-5271/$-see front matter Published by Elsevier Inc. on behalf of Heart Rhythm Society. http://dx.doi.org/10.1016/j.hrthm.2014.07.027

identified thus correlated closely with the distribution of delayed enhancement abnormalities seen on cardiac magnetic resonance imaging (CMRI). In this study, we sought to verify whether this BiV range would be able to delineate the zone of acute injury after antral PVI. We also sought to establish the BiV range that would correlate with local EI in the ablated zone acutely and chronically after PVI.

Methods

Patient selection

Consecutive patients undergoing first time or redo AF ablation at the Hospital of the University of Pennsylvania were prospectively enrolled in the study. Patient demographic characteristics were recorded, including age, sex, comorbidities, medications, and type of AF. For the patients presenting for a repeat AF ablation, details of the previous procedure(s) were reviewed to determine the ablation strategy and lesion set.

EAM

All procedures followed the institutional guidelines of the University of Pennsylvania Health System, and all patients signed a written informed consent document. Our AF ablation approach has been previously described. Briefly, decapolar catheters were placed in the coronary sinus and the posterior right atrium. Double transseptal punctures were performed through which the ablation and multielectrode circular mapping catheters (Lasso, Biosense Webster, Inc, Diamond Bar, CA; adjustable 15–25 mm circumference; 1–2 mm interelectrode spacing) were advanced into the LA. A bolus of unfractionated heparin was administered before the first transseptal puncture, and heparin infusion was titrated to maintain an activated clotting time of >325 seconds for the duration of the procedure. EAM was performed using the CARTO platform (CARTO 3, Biosense Webster). The LA shell was created using point-by-point acquisition with the NaviStar ThermoCool or ThermoCool SF catheters (Biosense Webster; 3.5 mm tip distal electrode, 2-mm ring electrode with an interelectrode distance of 1 mm). Criteria for an adequate LA shell were as follows: ≥ 150 points that were homogeneously distributed to create the entire chamber using a fill threshold of ≤ 15 (Figures 1 and 2). A denser sampling of the posterior LA and PV antrum was performed. Care was taken to ensure adequate catheter-tissue contact using a combination of intracardiac echocardiography (ICE), orthogonal fluoroscopy, and electrogram (EGM) characteristics. The mitral valve was carefully defined as were the individual PVs. The ridge between the left atrial appendage (LAA) and left pulmonary veins (LPVs) was also carefully defined using the following technique: Under ICE guidance, the mapping catheter was positioned on the PV aspect of the ridge and then slowly withdrawn while maintaining "counterclock" torque on the long sheath till the catheter flipped anteriorly into the LAA; multiple such "flip points" were acquired along the anterior aspect of LPVs that represented the extent of the ridge. Although it was not a study requirement, when computed tomography or CMRI segmented LA anatomy was available, it was merged with the EAM shell.

Bipolar signals recorded between the distal electrode pair (filtered at 16–500 Hz) were displayed at 100 mm/s on the digitalized recording system (Prucka Engineering, Inc, Houston, TX) and the CARTO platform. The CARTO system automatically uses peak-to-peak bipolar EGM amplitude for measurement. For this study, the EGM at each point acquired on the LA shell was manually reviewed to exclude PV potentials, noise, or pacing artifacts before being accepted. LA BiV was characterized using a cutoff range of 0.2–0.45 mV.

Strategy in patients undergoing first time AF ablation

Our *standard approach for AF ablation* has been previously described. Briefly, wide area circumferential PVI was performed by isolating the left and right pairs of veins en bloc (Figure 2B). This was guided by visualizing the Lasso catheter at PV ostia using orthogonal fluoroscopic views, ICE imaging, and EAM (with or without merging with the computed tomography– or CMRI–segmented LA anatomy). Energy delivery settings were as follows: power ≤ 40 W (≤ 20 W over posterior LA) and temperature ≤ 42°C. Lesions were delivered for a maximum of 40 seconds to achieve an impedance drop of ~ 10 Ω at the ablation site; over the posterior LA, lesion duration was restricted to 20 seconds. Successful PVI was defined by loss of PV potentials (entry block) and failure to capture the LA during pacing from all bipoles of the Lasso catheter (output 10 mA; pulse width 2 ms; exit block). These were repeated after 20–60 minutes to exclude acute PV reconnection for which additional RFA lesions were delivered. After PVI, a stimulation protocol was performed to identify non-PV triggers and this consisted of (1) isoproterenol infusion (initiating at 3 μg/min and incrementing every 3 minutes to 6, 12, and 20 μg/min) and (2) cardioversion of AF induced by LA or right atrial pacing (15 beat runs at an amplitude of 10 mA and a pulse width of 2 ms; decrementing by 10 ms from 250 to 180 ms and/or failure to capture).

Strategy in patients undergoing repeat AF ablation

After creating the EAM LA shell in sinus rhythm, the Lasso catheter was placed at the ostia of each PV to assess for reconnection (entry and exit). In veins demonstrating reconnection, the Lasso catheter was positioned at the ostium and its activation pattern was assessed to determine the likely localization of the reconnection (bipoles demonstrating shortest coupling interval between LA-PV EGMs). These localizations along the PV antrum were then targeted (using the same energy settings as described above) to achieve sustained entry and exit block after which the above-described stimulation protocol was performed to identify and target non-PV triggers, if any.

Characterizing atrial inexcitable dense scar

In patients undergoing first time AF ablation, after achieving wide area circumferential PVI (Figure 2B), a shell of the LA/PV antral region was reacquired with the use of the "remap" feature available on the CARTO system using the same BiV