

Feasibility of Rapid Linear-Endocardial and Epicardial Ventricular Ablation Using an Irrigated Multipolar Radiofrequency Ablation Catheter

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Background—A common strategy for ablation of scar-based ventricular tachycardia is delivering multiple lesions in a linear pattern.

Methods and Results—We tested the efficacy of a novel linear irrigated multipolar ablation catheter capable of creating linear lesions with a single application. Healthy swine underwent endocardial and epicardial linear ablation using a novel linear irrigated ablation catheter; control animals underwent focal lesions in a linear pattern over 3.5 cm with an irrigated radiofrequency catheter. The linear catheter contained 7 irrigated electrodes spaced over 3.5 cm and could deliver ≤ 25 W to each electrode. Linear ablation required significantly less radiofrequency time than focal ablation (56 ± 11 versus 497 ± 110 seconds; $P < 0.0001$). At gross pathology, linear ($n=18$) epicardial lines were longer than focal ($n=8$) epicardial lines (3.3 ± 0.7 versus 2.1 ± 0.9 cm; $P < 0.0005$), with greater volume (3.8 ± 2.9 versus 1.5 ± 1.6 cm³; $P = 0.002$). There was no difference between linear ($n=22$) and focal ($n=7$) endocardial line length or volume. Gaps (length 2.8 ± 0.9 mm) were present in 53% of focal lines and 0% of linear ablation lines. No perforations, steam pops, or thrombus were noted.

Conclusions—Compared with sequential focal radiofrequency ablation in a linear pattern, an irrigated multipolar linear ablation catheter safely delivers contiguous endocardial or epicardial lesions without gaps in a single ablation. This catheter shows promise for decreasing ventricular tachycardia ablation procedure time and improving outcome.

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Key Words: catheter ablation ■ electrodes ■ endocardium ■ tachycardia ■ tachycardia, ventricular

Strategies for ablation of scar-based ventricular tachycardia (VT) include linear lesions through pace- or entrainment-mapped sites,¹ extensive ablation of late and abnormal potentials,²⁻⁴ and core isolation of scar.⁵ Ablation by these methods requires delivery of many focal lesions, typically in a linear pattern, resulting in long radiofrequency and procedural times. In the first study of linear radiofrequency ablation for VT by Marchlinski et al,¹ a mean of 14.7 lesions was required to create lines of 3.9-cm mean length. In the recently published VISTA trial (Ablation of Clinical Ventricular Tachycardia Versus Addition of Substrate Ablation on the Long Term Success Rate of VT Ablation) assessing the utility of substrate-based ablation for postinfarction VT, mean procedure and radiofrequency times were 4.2 hours and 68 minutes, respectively.³ Radiofrequency ablation around scar borders to achieve core isolation has been demonstrated as a promising approach for the treatment of VT but is also associated with long procedure time (mean 5.4 hours) and a large number of individual radiofrequency applications (111 lesions).⁵ Thus, tools to create contiguous linear

radiofrequency lesions rapidly could significantly enhance these VT ablation strategies by significantly decreasing procedure and radiofrequency time.

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The nMARQ ablation catheter (Biosense-Webster, Diamond Bar, CA) is a circular catheter with 10 externally irrigated electrodes designed for the purpose of achieving rapid pulmonary vein isolation; its safety and efficacy for left atrial ablation have been assessed in clinical studies.⁶⁻⁹ We hypothesized that such a catheter, straightened to a linear shape, could be useful for linear ablation of VT. In a swine model, we tested the ability of this novel irrigated linear catheter to create linear-endocardial and epicardial lesions in the left ventricle (LV) and compared it with point-by-point focal ablation using a standard focal irrigated radiofrequency ablation catheter.

Methods

Female farm swine (50–60 kg) were intubated and underwent general anesthesia with inhaled isoflurane 2% to 3%. Swine were randomly allocated to either linear or focal ablation. Each pig underwent both

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WHAT IS KNOWN

- Ablation strategies for scar-based ventricular tachycardia require extensive ablation, often delivering multiple focal lesions in a linear pattern.
- These ablations can be associated with long procedural and radiofrequency times.
- Point-by-point linear ablation may also leave conductive gaps within a linear lesion.

WHAT THE STUDY ADDS

- A novel, irrigated, multipolar linear radiofrequency catheter can generate endocardial or epicardial linear lesions with a single radiofrequency application.
- When compared with point-by-point ablation, the novel linear catheter generates linear lesions that are of similar or greater length and volume, while reducing radiofrequency and procedure times and irrigation volume.
- This novel approach may significantly decrease procedure times and enhance outcomes of ventricular tachycardia ablation procedures.

endocardial and epicardial ablation with the same catheter type, taking care not to create endocardial and epicardial lesions directly opposite each other.

This protocol was approved and monitored by the University of California San Francisco Institutional Animal Care and Use Committee under guidelines set forth by the Association for the Assessment and Accreditation of Laboratory Animal Care.

Linear Catheter

For this preclinical study, the circular nMARQ catheter was straightened to a linear shape using 7 irrigated platinum-coated 3-mm electrodes (spaced 4 mm apart) and a unidirectional steerable curve (Figure 1). Each electrode was perforated with 10 irrigation holes (5 around the perimeter of each edge) for external irrigation provided by an external infusion pump that delivered 42 mL/min during ablation (6 mL/electrode/min) and 2 mL/min during mapping. The catheter is used with a radiofrequency generator

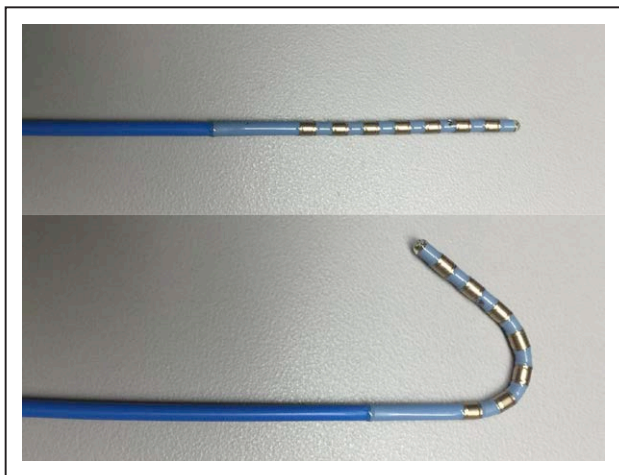


Figure 1. Linear ablation catheter with seven 3-mm electrodes spaced 5-mm apart covering a 3.5-cm distance in both straight (top) and deflected with unidirectional curve (bottom) configurations. There are irrigation ports between each electrode, requiring irrigation flow of 42 mL/min during catheter ablation.

(GENIUS; Biosense-Webster) that can deliver radiofrequency energy at ≤ 25 W simultaneously to all electrodes in unipolar or bipolar mode. A thermocouple was attached to each electrode at its proximal edge so that power could be automatically and individually titrated to each electrode, such that electrodes reaching 45°C might be power limited, but others were allowed to deliver the full 25 W. Two radiofrequency grounding pads were placed on each swine and connected to the generator.

Epicardial Ablation

Subxyphoid percutaneous pericardial access was obtained using the method described by Sosa et al,¹⁰ modified by using the needle-in-needle approach.¹¹ After serial dilation, a 10F sheath was advanced into the pericardial space. The side arm of the sheath was attached to wall suction to continuously drain irrigation fluid.

Epicardial 3-dimensional electroanatomic voltage maps were acquired using the Carto3 mapping system and a multispline catheter (PentaRay NAV; Biosense-Webster). Left coronary angiography was performed via femoral arterial access to define the coronary anatomy. For focal-epicardial lesions, 3.5-cm design lines were drawn on the electroanatomic map, in long-axis orientation around the LV, avoiding the coronary arteries. Point-by-point ablation lesions were made with a Thermocool (Biosense-Webster) catheter to create a contiguous line of adjacent lesions using 3-mm ablation tags over the design line; as many ablation lesions as needed to contiguously cover the 3.5-cm distance without visual gaps were used. Focal radiofrequency application was started at 25 W, with titration of power upwards as needed to achieve a 12 to 15 Ω impedance drop for each lesion. Irrigation was delivered at 17 or 30 mL/min depending on radiofrequency power. Linear-epicardial lesions were made with the linear catheter in a long-axis orientation around the LV (Figure 2A), taking care to avoid the left circumflex and left anterior descending coronary arteries delineated by angiography. Each electrode was programmed for 25 W unipolar power (maximum power allowed by the radiofrequency generator), maximum temperature 45°C , and ablations continued for 60 seconds. Power, temperature, and impedance were recorded at each of the 7 electrodes and exported from the generator console for analysis.

After ablation, the multispline mapping catheter was used to create a limited voltage map over the area of linear ablation, to identify new low-voltage areas due to ablation (Figure 3).

Endocardial Ablation

Endocardial mapping and ablation studies were performed via retrograde aortic access from the femoral artery. Intravenous heparin was administered before catheter insertion. Endocardial voltage maps were acquired using a multispline mapping catheter. Focal-endocardial (Figure 2B) and linear-endocardial lesions were made in the same manner as in the epicardium. Endocardially, focal and linear catheter positioning was guided by fluoroscopy, Carto surface proximity indicators, and detailed inspection with intracardiac echocardiography (Acuson; Siemens, Inc, Munich, Germany) to assure contact with the endocardium.

Porcine Chronic Infarct Model

A separate group of 2 healthy 40-kg swine first underwent a percutaneous myocardial infarction using transient (90 minute) balloon occlusion of the mid-left anterior descending coronary artery guided by fluoroscopy, as previously described.¹² The animals were recovered and survived for 4 weeks.

Subsequently, swine underwent endocardial and epicardial electroanatomic mapping with both the linear and multispline catheters, creating separate chamber geometries and voltage maps with each catheter, and recording local electrograms at each electrode bipole. Epicardial and endocardial LV surface areas of the electroanatomic maps were recorded. Voltage thresholds on the electroanatomic map were adjusted to clearly delineate areas of scar <1.5 mV (for endocardial maps) and <1.0 mV (for epicardial maps), and surface area

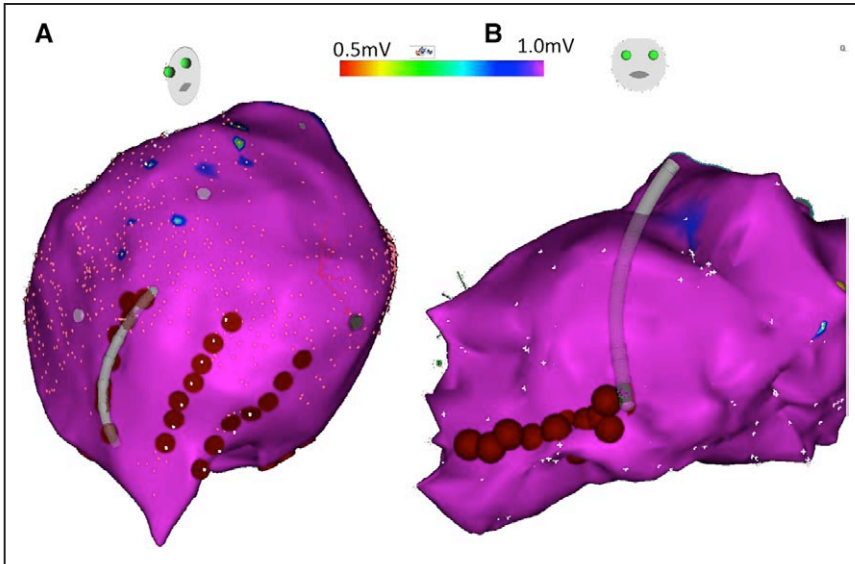


Figure 2. Electroanatomic voltage maps of linear (LIN; **A**) and focal (FOC; **B**) ablation approaches. **A**, LIN-epicardial lateral wall lines with catheter projecting over the most anterior line. Each line was with a single LIN radiofrequency (RF) application along the long axis of the left ventricular epicardium. The system tags the location of each RF electrode with a single red tag. **B**, FOC-endocardial anteroapical line with catheter projecting over the most basal RF application. FOC RF applications were made adjacently over the course of a 3.5-cm line as measured by electroanatomic mapping. Ablation tags are standardized to 3 mm each.

of scar was measured using the electroanatomic mapping system. Electrograms were individually analyzed and categorized as normal, fractionated, late, or very late potentials based on previously published criteria.¹³

Gross Pathology and Histology

At the end of each study, 10 g of 2,3,5-triphenyl-2H-tetrazolium chloride dissolved in 50 mL normal saline was injected intravenously to enhance lesion visualization. Hearts were excised intact and fixed in 10% formalin for 7 to 10 days. After formalin fixation, hearts were sectioned and imaged in short-axis slices of 2-mm thickness for gross pathology. Selected lesion slices were further sectioned at a thickness of 10 μ m and stained with hematoxylin and eosin and Masson trichrome for histological analysis to assess for thrombus at the ablation surface and lesion characteristics.

Statistical Analysis

Lesions were photographed and then measured in 3 dimensions using ImageJ software (National Institutes of Health, Bethesda, MD), as was the length of any visible gaps in the lines on gross pathology. Lesion volume for each line was calculated using the half-elliptic cylinder: $\pi \times D \times (W/2) \times (L-G)$, where D =lesion depth, W =width (along the cardiac short axis), L =line length (along the cardiac long axis), and G =distance of gap (if any) along the length of the line on gross pathology. The same approach to measurements was used for focal and linear lesions. This equation was adapted from those previously used for assessment of individual radiofrequency lesion volumes.¹⁴⁻¹⁶

Impedance and power at each linear electrode during each second of ablation was recorded by the ablation generator and was exported for statistical analysis. For focal lesions, starting and nadir impedance and maximum power were recorded manually. Impedance drop at each individual linear electrode or focal lesion was calculated as

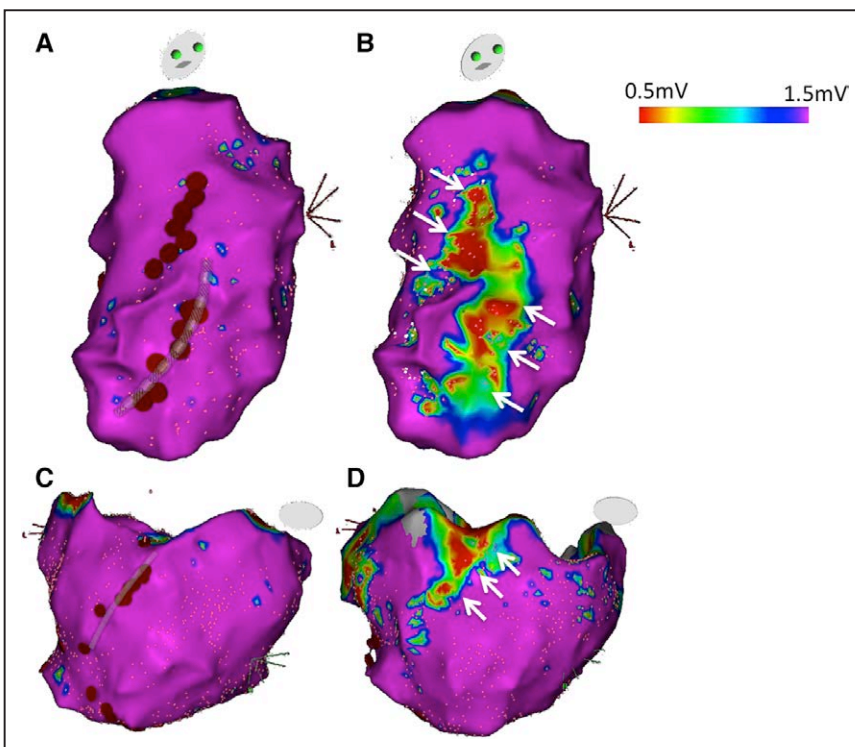


Figure 3. Electroanatomic voltage maps of linear (LIN)-endocardial ablation over anterior left ventricle (LV; **A**) and LIN-epicardial ablation over posterior LV (**C**). Preablation (**A** and **C**) and postablation (**B** and **D**) voltage maps are shown, demonstrating a linear area of reduced voltage after one line of LIN ablation (white arrows).

the starting impedance minus the nadir impedance over the course of a 60-second application. A given line's impedance drop was then calculated as the mean impedance drop of all 7 linear electrodes or of all individual lesions in a focal line.

Data are presented as mean±SD. Lesions were compared using linear mixed models regression for continuous data (ablation parameters, lesion length, and volume) and Fisher exact test for categorical data (presence of gaps). $P<0.05$ was considered statistically significant.

Results

Ablation Parameters

Seven healthy swine underwent ablation with the novel linear catheter, with 22 linear-endocardial and 18 linear-epicardial ablation lines. Five healthy swine underwent focal ablation of 15 lines (8.6±2.0 radiofrequency lesions per line), 7 of which were focal-endocardial (9.4±2.2 radiofrequency lesions per line) and 8 of which were focal-epicardial (8.0±1.4 radiofrequency lesions per line). Total radiofrequency time per line was significantly greater for focal compared with linear ablation (497±111 versus 56±9 seconds; $P<0.0001$), as was the total volume of catheter irrigant volume infused (78±39 versus 39±7 mL; $P<0.0001$; Table), despite a higher total flow rate with linear catheter ablation (42 mL/min). Mean radiofrequency power used for focal lesions was greater than that used for linear lesions (27±6 versus 23±5 W; $P<0.0001$), although linear ablation demonstrated larger impedance drops (20±13 versus 17±11Ω; $P<0.05$). There was no difference between linear-endocardial and focal-endocardial impedance drops (Table). Maximum radiofrequency power required to achieve prespecified impedance drops was 45 W for focal-epicardial ablation and 35 W for focal-endocardial ablation. Linear catheter electrodes were temperature limited to 45°C, and 38% of individual electrodes did not reach maximal power of 25 W (32% of linear-epicardial ablation and 43% of linear-endocardial ablation).

No steam pops or evidence of coagulum on the ablation electrodes was noted during ablation studies. On gross pathology immediately after euthanasia, no char was noted on delivered lesions. No skin damage was noted below the grounding pads.

Lesion Characteristics

Linear ablation lines were significantly longer than focal lines (3.1±0.7 versus 2.4±0.8 cm; $P=0.011$), although this difference was only noted in epicardial lines (linear-epicardial ablation 3.3±0.7 versus focal-epicardial ablation 2.1 versus

0.9 cm; $P<0.0005$), as there was no difference in length of linear-endocardial and focal-endocardial lines (2.8±0.7 versus 2.9±0.5 cm; $P=0.72$; Figure 4A). Similarly, linear lesion volume was greater for linear-epicardial compared with focal-epicardial lines (3.8±2.9 versus 1.5±1.6 cm³; $P=0.002$) but not for linear-endocardial versus focal-endocardial lines (2.8±1.1 versus 3.2±1.5 cm³; $P=0.59$; Figure 4B) or when both groups were pooled (linear 3.2±2.1 versus focal 2.3±1.7 cm³; $P=0.054$). There were no differences in mean lesion depth between linear-epicardial and focal-epicardial lines (6.7±2.4 versus 5.5±1.8 mm; $P=0.08$), linear-endocardial and focal-endocardial lines (7.3±2.7 versus 8.6±1.8 mm; $P=0.27$; Figure 4C), or pooled linear and focal groups. There was also no difference between groups in lesion width.

Selected voltage maps (n=7 endocardial and n=7 epicardial) performed after linear ablation demonstrated linear regions of low voltage (Figure 3) after ablation. Endocardial area of voltage <1.5 mV was 8.6±3.6 cm², and epicardial area of voltage <1.0 mV was 10.6±6.1 cm².

On gross pathology, macroscopic gaps in the lines were present in 8 of 15 focal lines (53%; 4 of 7 focal-endocardial and 4 of 8 focal-epicardial) but in none of the 40 linear ablation lines ($P<0.001$). Mean focal line gap length was 0.28±0.09 mm (0.28±0.10 mm focal-endocardial and 0.28±0.10 mm focal-epicardial) comprising 11±2% of line length (Figure 5A).

Infarct Animals

In the 2 chronic infarct swine, 4 linear-endocardial-infarct and 4 linear-epicardial-infarct lines were ablated. Compared with linear lesions performed in healthy myocardium, linear-infarct lesions were slightly shorter (2.5±0.8 versus 3.1±0.7 mm; $P=0.015$), although this difference was only noted when comparing endocardial (1.9±0.5 versus 2.8±0.7 mm; $P=0.004$) and not epicardial lines (3.0±0.6 versus 3.3±0.7 mm; $P=0.36$). Lesion volume was smaller in linear-infarct lines compared with linear lines (1.9±1.5 versus 3.2±2.1; $P=0.33$), but this difference was only noted when comparing linear-infarct-endocardial to linear-endocardial lines (0.9±0.2 versus 2.8±1.1 cm³; $P<0.0005$), and this was not noted in the epicardium. There were no differences between linear-infarct and linear lesion depth (Table I in the Data Supplement).

Histology

Hematoxylin and eosin-stained and trichrome-stained sections of linear ablation demonstrated acute myocyte disruption with a core of dense coagulation necrosis and a rim of

Table. Ablation Characteristics of Focal and Multipolar Linear Ablation Catheters

	Focal-All (n=15)	Linear-All (n=40)	P Value	Linear- Endocardial (n=7)	Linear- Endocardial (n=22)	P Value	Focal- Epicardial (n=8)	Linear- Epicardial (n=18)	P Value
Lesions per line	8.6±2.0	NA	...	9.4±2.2	NA	...	NA	8.0±1.4	...
Radiofrequency time, s	497±111	56±9	$P<0.0001$	537±122	58±6	$P<0.0001$	461±93	54±12	$P<0.0001$
Power, W	27±6	23±5	$P<0.0001$	25±1	22±5	$P<0.0001$	28±8	24±4	$P<0.0001$
Impedance drop, Ω	17±11	20±13	$P=0.049$	14±9	13±7	$P=0.637$	21±12	29±14	$P=0.0004$
Irrigation infused, mL	78±39	39±7	$P<0.0001$	64±35	41±5	$P=0.004$	88±40	38±9	$P<0.0001$

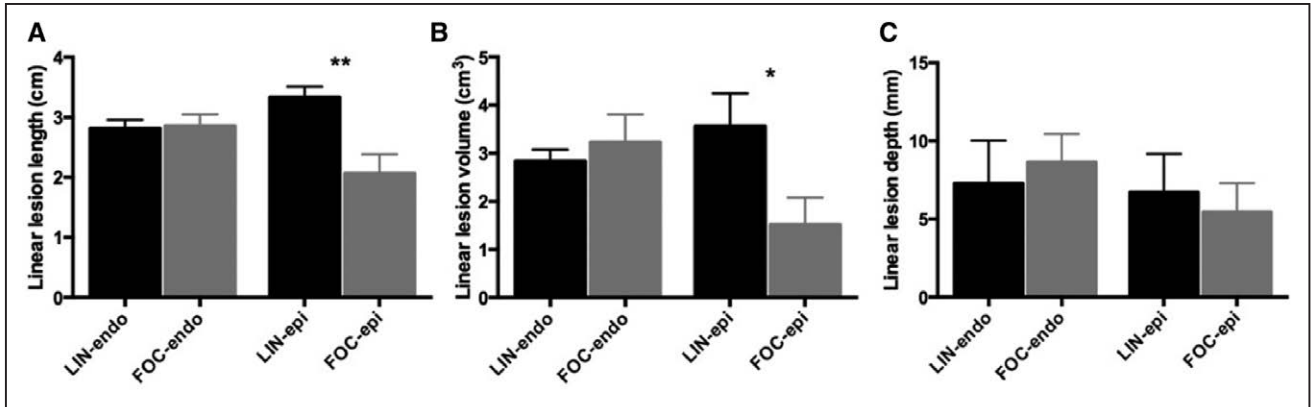


Figure 4. Comparison of radiofrequency (RF) lesion indices formed by simultaneous multipolar linear (LIN) and focal (FOC) ablation. **A**, lesion length; **B**, lesion volume; **C**, lesion depth. ** $P < 0.001$, * $P < 0.05$, and other comparisons not significant for LIN vs FOC. Error bars denote 1 SD. Endo indicates endocardial; and epi, epicardial.

incomplete necrosis characteristic of radiofrequency ablation lesions (Figure 5C and 5D).¹⁷

Linear Catheter Mapping

Electroanatomic scar mapping of the linear catheter was compared with the multispline catheter by creating endocardial (Figure 6) and epicardial (Figure 7) chamber geometries and voltage maps in the chronic infarct pigs. Endocardial LV chamber geometries appeared similar on electroanatomic maps. Endocardial surface area by linear mapping was 175 ± 10 cm² compared with 193 ± 31 cm² by multispline mapping ($P = 0.52$). Similarly, there were no differences between linear and multispline epicardial map volumes or surface areas. Voltage mapping with linear catheter was also able to approximate areas of scar: endocardial scar area (< 1.5 mV) was 47 ± 15 cm² by linear mapping and 58 ± 20 cm² by

multispline mapping ($P = 0.59$); epicardial scar area (< 1.0 mV) was 15 ± 2 cm² by linear mapping and 35 ± 8 cm² by multispline mapping ($P = 0.07$). Compared with multispline catheter mapping, linear mapping resulted in similar proportions of endocardial electrograms that were fractionated (linear $19.2 \pm 1.7\%$ versus multispline $18.6 \pm 3.6\%$ $P = 0.85$), late ($1.1 \pm 0.6\%$ versus $1.7 \pm 1.2\%$, $P = 0.58$), or very late ($0.1 \pm 0.1\%$ versus $0.3 \pm 0.1\%$, $P = 0.22$). Results were similar for epicardial linear versus multispline mapping.

Discussion

Radiofrequency ablation catheters were originally developed to treat arrhythmias requiring discrete ablation, such as accessory pathways, AV node reentry, and focal atrial tachycardias. As more complex arrhythmias became amenable to catheter ablation, it became clear that focal catheters were

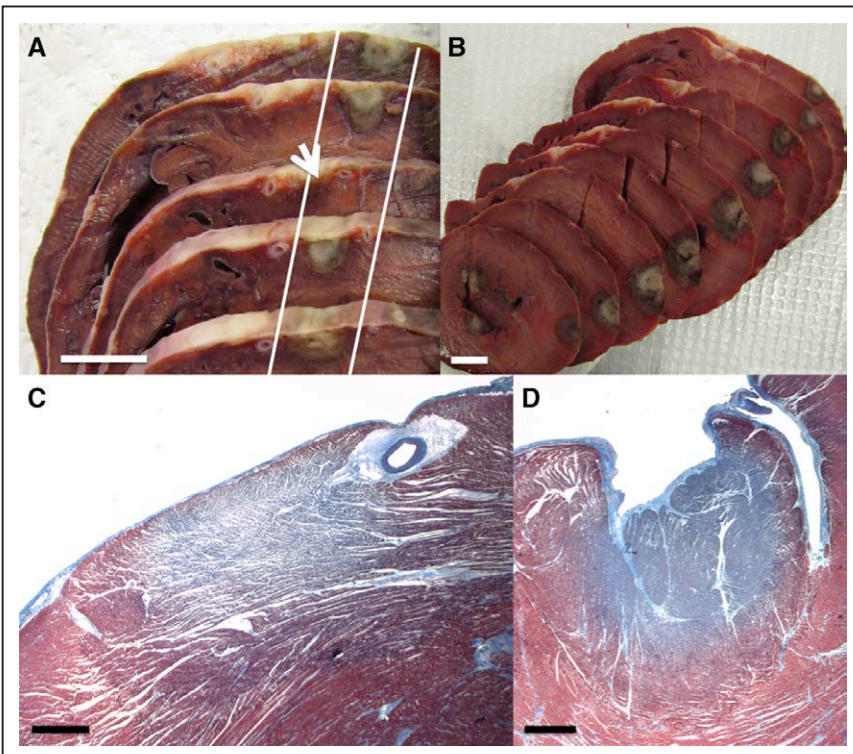


Figure 5. Gross pathology of anteroseptal focal (FOC)-epicardial (epi; **A**) and anterolateral linear (LIN)-epi (**B**) linear lesions demonstrates a gap in the FOC but not LIN line. Trichrome stain of LIN-epi (**C**) and LIN-endocardial (endo; **D**) demonstrate acute myocyte disruption with a core of dense coagulative necrosis and a rim of incomplete necrosis characteristic of radiofrequency ablation lesions. White arrow demonstrates gap in FOC line. White bars=1 cm; black bars=1 mm.

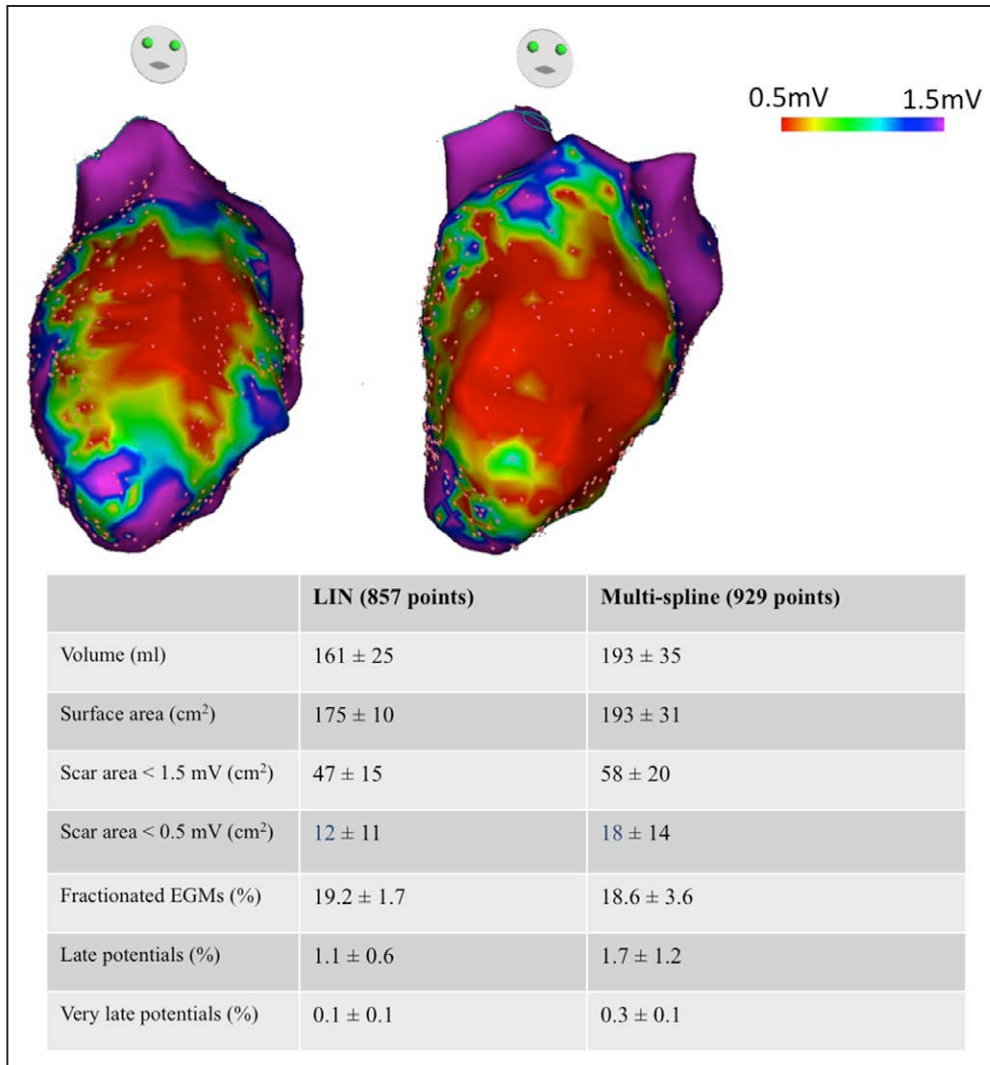


Figure 6. Endocardial voltage maps of the same chronic infarct swine made with linear nMARQ (LIN; **A**) and multispline (**B**) catheters, with mean±SD values for electroanatomic map and electrogram characteristics quantified below.

not ideally suited to more complex ablation approaches. For complex arrhythmias such as atrial fibrillation, specialized tools such as the Cryoballoon¹⁸ have been developed, which allow more complex lesions to be delivered with a single-shot approach. For VT, linear ablation has become commonplace, yet there has been no technology to specifically address this need.

We have adapted a circular multipolar irrigated catheter, originally designed for atrial fibrillation ablation, to create a catheter capable of creating 3.5-cm linear ablation lesions in a single delivery. Despite higher rate of saline irrigation delivered with each lesion (42 mL/min), the total irrigation volume was dramatically lower than serial focal ablation lesions delivered in a linear pattern. Importantly, although the mean power at each electrode was actually lower with linear ablation, linear ablations were free of any gaps in the ablation line on gross pathology, whereas over half of focal lines had small gaps between ablation lesions. This may be because linear ablation delivers radiofrequency across multiple electrodes simultaneously, avoiding edema from previous radiofrequency applications.¹⁹ Additionally, particularly for epicardial lesions, linear

lesion length and volume were greater despite lower power. This may be because of increases in tissue conductive heating with simultaneous radiofrequency from adjacent electrodes. Simultaneous ablation from linear electrodes likely improves conductive heating between electrodes, increasing lesion volume and resulting in fewer gaps. Another potential reason for larger linear lesions compared with focal lesions is that slightly smaller linear electrodes (3.0 mm compared with 3.5 mm for focal) apply a higher power density with greater resistive and thus conductive heating of tissue.

Linear lesions in chronic LAD infarct swine within areas of LV scar and border zone, although slightly shorter than those made with focal ablation, had similar depth. Thus, linear VT ablation may not only save time, number of ablation lesions, and irrigant volume but also improve the outcome of VT ablation. This represents an important paradigm shift in the field of VT ablation.

Linear ablation seems particularly promising for epicardial ablation, where lesion length, volume, and impedance drops were significantly greater than focal ablation. The difference in linear-endocardial and epicardial performance may relate to

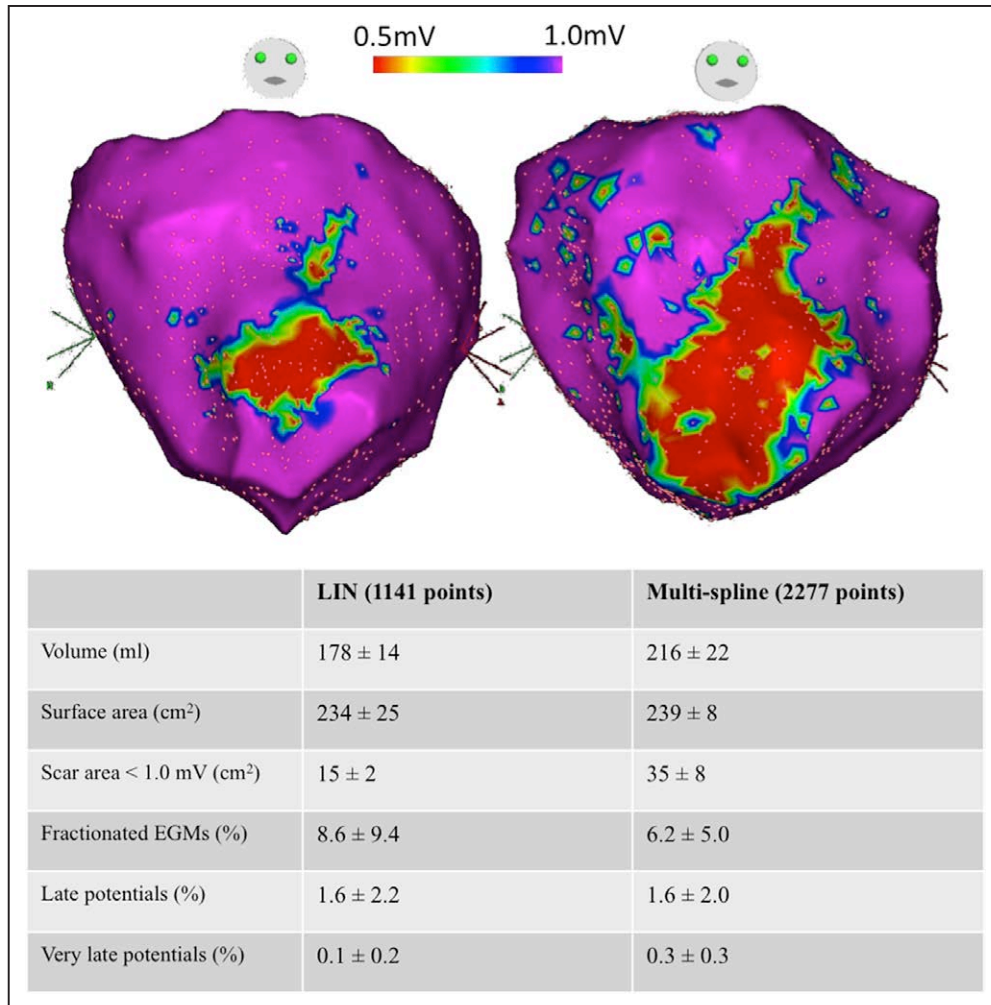


Figure 7. Epicardial voltage maps of the same chronic infarct swine made with linear (LIN; **A**) and multispline (**B**) catheters, with mean±SD values electroanatomic map and electrogram characteristics quantified below.

catheter design: with only unidirectional steering, achieving simultaneous electrode-tissue contact for all 7 linear electrodes on the endocardial surface may be challenging, and electrodes at the beginning or end of the row of 7 may not be in direct contact with the endocardium. In addition, the more uniform epicardial anatomy allows better contact over the length of the ablation catheter. Improvements in steerability, such as bidirectional steering, and varied curves may improve linear-endocardial ablation. One potential limitation with linear epicardial ablation is inadvertent ablation across coronary arteries. However, individual electrodes can be turned off if determined to be overlying or near coronary arteries during angiography.

Given its relatively large electrode size (3 mm) and wide interelectrode distance (4 mm), one potential limitation of the linear catheter may be its resolution for electroanatomic voltage mapping, and the detection of pathological local electrograms within scar, particularly when compared with high-density, multispline mapping catheters.²⁰ In a subset of swine with chronic LAD infarcts undergoing mapping with both linear and multispline catheters, there was a trend toward underestimation of chamber volume, chamber surface area, and scar surface area. It is not surprising, given the complex

endocardial left ventricular geometry, that contact along the length of a linear catheter might not always be ideal, particularly near structures like papillary muscles. However, it may be sufficient in some cases to roughly depict the scar region and would be more cost effective than introducing another catheter. More dedicated mapping studies are needed to demonstrate whether this catheter may be used for multielectrode mapping and ablation.

Previous investigators have developed and evaluated linear ablation catheters using laser²¹ and radiofrequency²² energy. However, in the absence of irrigation, linear ablation has thus far been limited by the formation of char and thrombus.²³ In our study, no thrombus was observed using the current catheter for 2 reasons. First, this is the first linear catheter with irrigation delivered across each electrode, helping to prevent char and thrombus formation. Second, the generator titrates power at each electrode individually based on a set maximum temperature limit, minimizing the risk of thrombus because of overheating.

Our study has several limitations. The number of individual radiofrequency lesions used in a given focal line may vary by center and operator. We conservatively used 3-mm Carto ablation tags to represent lesions and spaced them adjacently

and evenly along a 3.5-cm design line as our clinical standard, although an even denser set of lesions may have produced fewer gaps. One could also argue that focal lines may have had fewer gaps if contact force was used. However, contact force was not available in the experimental software used, and the operators had significant experience using intracardiac echocardiography, fluoroscopy, and electroanatomic mapping to assure adequate contact with the endocardium.

It is possible that the larger human ventricle may pose unexpected challenges, although we would expect that a larger scarred ventricle would be more amenable to positioning of the linear ablation catheter, particularly endocardially. Although the linear catheter was easily positioned near scar border zones for ablation in our infarct model, clinical VT ablation occasionally requires navigation to locations in the ventricles that are more challenging to reach, not all of which were tested in a dedicated manner in this study.

Conclusions

A linear, irrigated multipolar radiofrequency ablation catheter has the ability to deliver single-shot 3.5-cm linear ablation lesions without gaps. Linear radiofrequency ablation dramatically reduces radiofrequency time and saline irrigant volume. This represents a significant advance in VT ablation technology and has the promise of improving outcome of VT ablation in humans.

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Disclosures

Dr Gerstenfeld has received honoraria from Biosense-Webster. The other authors report no conflicts.

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Feasibility of Rapid Linear-Endocardial and Epicardial Ventricular Ablation Using an Irrigated Multipolar Radiofrequency Ablation Catheter

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SUPPLEMENTAL MATERIAL

Supplemental Table One:

	FOC-endo+epi (n=15)	LIN-endo+epi* (n=40)	LIN-infarct-endo+epi† (n=8)	FOC-endo (n=7)	LIN-endo* (n=22)	LIN-infarct-endo† (n=4)	FOC-epi (n=8)	LIN-epi* (n=18)	LIN-infarct-epi† (n=4)
Length (cm)	2.4 ± 0.8	3.1 ± 0.7	2.5 ± 0.8	2.9 ± 0.5	2.8 ± 0.7	1.9 ± 0.5	2.1 ± 0.9	3.3 ± 0.7	3.0 ± 0.6
p-value	--	0.011	0.015	--	0.72	0.004	--	< 0.0005	0.36
Volume (cm ³)	2.3 ± 1.7	3.2 ± 2.1	1.9 ± 1.5	3.2 ± 1.5	2.8 ± 1.1	0.9 ± 0.2	1.5 ± 1.6	3.8 ± 2.9	2.9 ± 1.7
p-value	--	0.054	0.033	--	0.59	< 0.0005	--	0.002	0.47
Depth (mm)	6.9 ± 2.4	6.8 ± 2.7	6.3 ± 2.7	8.6 ± 1.8	7.3 ± 2.7	4.5 ± 0.4	5.5 ± 1.8	6.7 ± 2.4	8.0 ± 2.9
p-value	--	0.89	0.46	--	0.27	0.051	--	0.08	0.65

Lesion characteristics of focal (FOC) and multipolar linear ablation catheters in healthy (LIN) and infarcted (LIN-infarct) myocardium.

FOC = focal ablation; LIN = multipolar linear ablation in healthy myocardium; LIN-infarct = multipolar linear ablation in chronic infarct; endo = endocardial; epi = epicardial

* p-values for LIN-endo+epi, LIN-endo and LIN-epi are compared to FOC.

† p-values for LIN-infarct-endo+epi, LIN-infarct-endo and LIN-infarct-epi are compared to LIN