Lesion Formation by Ventricular Septal Ablation With Irrigated Electrodes

– Comparison of Bipolar and Sequential Unipolar Ablation –

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Background: Ablation of ventricular tachycardia originating from the interventricular septum (IVS) is often limited by the presence of re-entrant pathways deep in the IVS. We compared the efficacy of bipolar ablation vs. sequential unipolar ablation in creating a transmural lesion across the porcine IVS.

Methods and Results: Seventeen excised swine hearts were superfused by pulsatile saline flow. Bipolar ablation (at 30 W, 50 W or 70 W for 120 s) was performed between 2 saline-irrigated (20 ml/min) 4-mm tip electrodes, 1 on the left and 1 on the right side of the IVS. Sequential unipolar ablation (at 30 W, 50 W or 70 W for 120 s) was performed on the left and right sides of the IVS with an irrigated-tip catheter. Bipolar ablation produced a narrower, deeper lesion than did unipolar ablation. A transmural lesion was created by sequential unipolar ablation in 7.7%, 8.3% and 0% of tissue preparations and by bipolar ablation in 50.0%, 46.7% and 71.4% of tissue preparations at 30 W, 50 W and 70 W.

Conclusions: Bipolar ablation of the IVS was highly effective for creating a transmural IVS lesion. (*Circ J* 2011; **75**: 565–570)

Key Words: Bipolar radiofrequency ablation; Cooled-tip ablation; Interventricular septum

Radiofrequency (RF) ablation of ventricular tachycardia (VT) associated with structural heart disease relies on interrupting critical reentrant pathways.¹ The post-ablation VT recurrence rate varies and depends on both the patient selection criteria and the ablation strategy. Reported rates of VT recurrence after RF ablation aided by electroanatomic mapping are 12–47%.^{2–4} Ventricular arrhythmias involving the interventricular septum (IVS) may be responsible for a number of ablation failures; a reentrant circuit involving the septum may be complex and located in part at deep intramural sites. The introduction of irrigated catheters has increased our ability to produce larger lesions by RF ablation,^{5–7} but the IVS remains a difficult ablation target. VT circuits involving the septum can break out in either the left ventricle (LV) or right ventricle (RV) and may require the creation of a transmural ablation lesion across the IVS.^{8–10} Given the complexity and significant risks associated with ablation of VT in patients with structural heart disease, simpler and higher efficacy septal ablation techniques are desirable. To this end, we evaluated a 2-catheter bipolar ablation configuration in comparison with sequential left and right

unipolar septal ablation in swine hearts in vitro. Saline irrigation was used for electrode cooling with both systems.

Methods

In Vitro Swine IVS Preparation

The in vitro setup is shown in **Figure 1**. The care of all animals used in the study conformed to the Position of the American Heart Association on Research Animal Use (*Circulation* 1985; **71**: 849A–850A) and was done in accordance with accepted guidelines for the care and treatment of experimental animals at Nihon University School of Medicine.

Seventeen freshly excised swine hearts weighing 469–511 g were used. The IVS was isolated and fixed on a silicone rubber plate in a circular plastic chamber filled with 6 L of saline, and the entire chamber was heated to 37.0°C. The flow rate within the chamber was maintained at 2 L/min, and the saline overflow was directed to the edge of the chamber. A lead plate was placed at the bottom of the chamber to serve as the indifferent electrode. Two irrigation catheters (Sprinkler, 7Fr, 4-mm tip electrode; 10 irrigation holes: 1 at

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Table 1. Comparison of Thickness of the IVS and Incidence of Transmural Lesion Formation Between Sequential Unipolar Ablation and Bipolar Ablation Groups

	Sequential unipolar ablation group	Bipolar ablation group	P value (for between-group difference)
IVS thickness (mm)			
30 W	15.8±2.5 (13)	15.9±3.9 (14)	NS
50 W	17.4±2.1 (12)	16.2±2.7 (15)	NS
70 W	16.8±1.9 (6)	15.9±2.2 (7)	NS
Transmural lesion			
30 W	1/13 (7.7%)	7/14 (50%)	0.016
50 W	1/12 (8.3%)	7/15 (46.7%)	0.032
70 W	0/6 (0%)	5/7 (71.4%)	0.003

Number of experiments is shown in parentheses.
IVS, interventricular septum; NS, not significant.
Note that within-group differences in IVS were NS.

the central tip of the catheter, 3 distally, 3 in the middle and 3 proximally; Medtronic Inc, Minneapolis, MN, USA) were positioned manually on opposite sides of the IVS with parallel contact, and both sequential unipolar and bipolar ablation were tested (Figure 1). The irrigation rate was set at 20 ml/min during ablation. A Radionics RFG-3E RF lesion generator (Radionics Inc, Burlington, MA, USA) was used for RF energy delivery.

Protocol

Sequential unipolar RF ablation and bipolar ablation were performed at energy settings of 30 W, 50 W and 70 W for 120 s. Any change in impedance ($[\Omega]$) and any occurrence of steam pop during RF delivery were recorded.

Pathologic Examination

At the end of the procedure, the IVS was dissected along the long axis connecting the RV and LV IVS ablation lesions. The maximum width and maximum depth of the lesions, as

well as the frequencies of transmural lesion formation and intramural pop lesions, were assessed macroscopically.

Statistics

Values are shown as mean±SD. Differences in continuous variables were analyzed by Mann-Whitney U test, and differences in categorical variables were analyzed by Fisher's exact probability test. All statistical analyses were performed with Stat View 5.0 software (SAS Institute, Cary, NC, USA). $P<0.05$ was considered significant.

Results

IVS Thickness

Mean IVS thickness before ablation was 16.1 ± 2.8 mm and did not differ significantly between tissues subjected to sequential unipolar ablation (unipolar ablation group) and tissues subjected to bipolar ablation (bipolar ablation group) at corresponding power settings, and also did not differ within each

Figure 2. (a) Gross appearance of lesions produced by sequential unipolar (Left upper and Lower panels) and by bipolar (Right upper and Lower panels) ablation at 30 W for 120 s. Note that a transmural lesion was created by bipolar ablation (Right lower panel). (b) Gross appearance of lesions produced by sequential unipolar (Left upper and Lower panels) and by bipolar (Right upper and Lower panels) ablation at 50 W for 120 s. Note that the unipolar ablation lesions are wide but shallow. Note also the intramyocardial tear resulting from steam pop (Left upper panel). The bipolar ablation lesion is relatively narrow but deep (Right upper panel). Note the transmural lesion formation (Right lower panel). (c) Gross appearance of lesions produced by sequential unipolar (Left upper and Lower panels) and bipolar (Right upper and Lower panels) ablation at 70 W for 120 s. Note that the unipolar ablation lesion is wide but shallow, and note the large intramyocardial tear resulting from steam pop (Left upper panel). The bipolar ablation lesion is relatively narrow and deep (Right upper panel). Note the transmural lesion formation (Right lower panel).

Table 2. Comparison of Width and Depth of the Lesion Between Sequential Unipolar Ablation and Bipolar Ablation Groups

	Sequential unipolar ablation group	Bipolar ablation group	P value (for between-group difference)
Lesion width (mm)			
30 W	10.0±2.0 (25)	7.8±5.3 (27)	0.0004
50 W	11.7±2.7 (24)*	9.7±2.4 (29)	NS
70 W	10.4±2.3 (12)	8.7±2.5 (13)	NS
Lesion depth (mm)			
30 W	6.0±1.5 (23)	5.3±1.4 (13)	NS
50 W	6.9±1.7 (22)	7.0±1.7 (15)**	NS
70 W	6.7±1.5 (12)	8.3±2.1 (3)†	NS

*P=0.016 vs. 30 W; **P=0.008 vs. 30 W; †P=0.008 vs. 30 W.

NS, not significant.

Number of experiments is shown in parentheses.

Table 3. Comparison of Width/Depth Ratio of the Lesion and the Incidence of Steam Pop Between Sequential Unipolar Ablation and Bipolar Ablation Groups

	Sequential unipolar ablation group	Bipolar ablation group	P value (for between-group difference)
Lesion width/depth ratio			
30 W	1.71±0.39 (23)	1.51±0.44 (13)	NS
50 W	1.87±0.66 (22)	1.49±0.52 (15)	NS
70 W	1.58±0.27 (12)	0.83±0.05 (3)**	0.0004
Steam pop			
30 W	4/26 (15.4%)	1/28 (3.6%)	NS
50 W	11/24 (45.8%)†	2/30 (6.7%)	0.001
70 W	8/12 (66.7%)††	2/14 (14.3%)	0.016

*P=0.048 vs. 50 W; **P=0.021 vs. 30 W; †P=0.020 vs. 30 W; ††P=0.003 vs. 30 W.

NS, not significant.

Number of experiments is shown in parentheses.

Table 4. Comparison of Impedance at the Beginning and End of Radiofrequency Energy Delivery Between Sequential Unipolar Ablation and Bipolar Ablation Groups

	Impedance (Ω)			
	Sequential unipolar ablation group		Bipolar ablation group	
	Start	End	Start	End
30 W	66.6±5.4	61.6±3.5	235.2±12.7	126.3±12.7
50 W	62.5±2.3**	58.4±3.8††	230.6±9.8	113.7±7.1
70 W	59.8±1.8†	56.1±0.8†	222.8±13.5	107.0±6.6‡

*P=0.012 vs. 30 W; **P=0.032 vs. 70 W; †P<0.001 vs. 30 W ††P=0.035 vs. 30 W; ‡P=0.003 vs. 30 W.

group when compared per power setting (Table 1).

Transmural Lesion Formation

Transmural lesion formation was noted after bipolar ablation in 50%, 46.7% and 71.4% of tissue preparations at energy settings of 30 W, 50 W and 70 W, respectively, and in 7.7%, 8.3% and 0% of preparations after sequential unipolar ablation at the respective power settings (Figures 2a–c). The between-group differences were significant (P=0.016, P=0.032 and P=0.003, respectively) (Table 1).

Lesion Width

The widths of the lesions produced by sequential unipolar and

bipolar ablation at power settings of 30 W, 50 W and 70 W are shown in Table 3. Lesions produced by bipolar ablation were significantly narrower than lesions produced by sequential unipolar ablation (7.8±5.3 mm vs. 10.0±2.0 mm, P=0.0004). Lesion width did not differ significantly between sequential unipolar and bipolar ablation performed at 50 W or 70 W. Width of lesions produced by sequential unipolar ablation at 50 W was significantly greater than that produced at 30 W (11.7±2.7 mm vs. 10.0±2.0 mm, P=0.016), but there were no statistical differences in the widths of lesions produced at the other power settings used during sequential unipolar ablation or bipolar ablation (Table 2).

Lesion Depth

The depths of the lesions produced by sequential unipolar and bipolar ablation at power settings of 30 W, 50 W and 70 W are shown in Table 4. Transmural lesion formation experiments were excluded from this analysis. Lesions produced by sequential unipolar ablation at 30 W, 50 W and 70 W did not differ significantly in depth from those produced by bipolar ablation at the corresponding power settings. Lesions produced by sequential unipolar ablation did not differ significantly in depth, despite the different power settings. However, lesions produced by bipolar ablation at 50 W and 70 W did differ in depth from those produced at 30 W (30 W: 5.3±1.4 mm; 50 W: 7.0±1.7 mm; 70 W: 8.3±2.1 mm; P=0.008, 30 W vs. 50 W; P=0.008, 30 W vs. 70 W) (Table 2).

Lesion Configuration

Lesion configuration was examined by calculating each lesion's width/depth ratio. The only significant between-group difference in this ratio was between lesions produced by bipolar ablation at 70 W and those produced by sequential unipolar ablation at 70 W (0.83 ± 0.05 vs. 1.58 ± 0.27 , $P=0.0004$). Within-group differences were produced by bipolar ablation at 70 W compared with bipolar ablations at 30 W and 5 W (0.83 ± 0.05 vs. 1.51 ± 0.44 and 1.49 ± 0.52 ; $P=0.021$ and $P=0.048$, respectively) (Table 3).

Impedance

Impedance at the onset of sequential unipolar ablation ranged from 58 to 77 Ω and decreased by 2–10 Ω by the end of ablation. Impedance at the onset of bipolar ablation ranged from 213 to 257 Ω and decreased by approximately 50% by the end of ablation (Table 4).

Steam Pop

Steam pop occurred as a result of sequential unipolar ablation in 15.4%, 45.8% and 66.7% of tissue preparations at power settings of 30 W, 50 W and 70 W, respectively (Table 3). Steam pop occurred as a result of bipolar ablations in 3.6%, 6.7% and 14.3% of tissue preparations at the respective power settings. The between-group differences in steam pop that occurred at 50 W and at 70 W were significant ($P=0.001$ and $P=0.016$, respectively). Within-group differences in the incidence of steam pop were produced by unipolar ablation at 50 W and 70 W compared with 30 W ($P=0.020$ and $P=0.003$, respectively). There were no statistical differences in the incidence of steam pop resulting from bipolar ablation at the different power settings. RF energy delivery was terminated prematurely during sequential unipolar ablation because of loud audible pops associated with movement of the catheter tip during application of RF energy at 30 W ($n=1$), 50 W ($n=5$) and 70 W ($n=3$) (Table 3).

Discussion

In the largest reported multicenter series of postinfarct VT ablation, an increased number of inducible VTs was identified by multivariable analysis as a predictor of VT recurrence.⁴ Sivagangabalan et al studied intraseptal VT in a chronic ovine infarct model using contact and noncontact mapping from the RV and LV, and they showed that septal VTs usually had a common intramural isthmus capable of exciting either ventricle, with a very short delay between the earliest LV and RV activations.⁸ In their study, the initial RF energy delivery was directed along the septum in the ventricle with the earliest breakout. Although failure to create a transmural septal ablation lesion at the scar border resulted in persistent inducibility of septal VT and shifted the earlier activation to the opposite ventricle, ablation from both sides of the septum resulted in transmural ablation that rendered septal VT noninducible.⁸ Their study unveiled a new, highly effective method of transmural ablation of the IVS. The bipolar ablation configuration used in their model was reliable and reproducible, with efficacy and safety superior to those of the widely used sequential unipolar ablation. Using bipolar ablation may simplify the treatment of VT originating from the IVS and associated with structural heart disease.⁴

Ablation of deep septal re-entrant circuits that may be responsible for VT ablation failure remains a challenge. An effective, reproducible ablation strategy, such as the bipolar ablation strategy used in our study, will likely improve the

success rate of septal VT ablation. Ring et al first reported the safety and feasibility of catheter ablation of the ventricular septum by means of bipolar and sequential unipolar RF ablation in a closed-chest canine model, and they concluded that a possible limitation of the transeptal bipolar application of RF energy was the relatively small size of the discrete lesions and inconsistent production of endocardial lesions, especially with the delivery of RF energy at low power.¹⁰ They used a power setting of 10–15 W for the entire 10–60 s of energy delivery with conventional 2-mm-tip catheters.¹¹ In our study, lesions were significantly narrower and tended to be shallower with energy delivery at 30 W for 120 s than at the other power settings. However, lesion width and depth increased as the power was increased in the bipolar ablation mode, whereas lesion width and depth did not change in the sequential unipolar ablation mode. Imai et al compared bipolar ventricular septal ablation using conventional temperature-controlled and saline irrigated electrodes, and they reported that transmural lesions through the IVS can be produced by using 2 saline-irrigated electrodes in bipolar mode with sustained high RF power.¹² Sivagangabalan et al also reported that bipolar ablation of the IVS is highly effective for creating a transmural lesion line, requiring less ablation and creating longer lesions than sequential unipolar ablation in a phantom agar model and an ovine myocardial infarction model.¹²

In the study described herein, we compared 2-catheter bipolar septal ablation with sequential left and right unipolar septal ablation in swine IVS in vitro. Compared with irrigated-tip sequential unipolar ablation of the IVS, bipolar ablation resulted in a decreased lesion width/depth ratio, higher incidence of transmural lesion formation, and lower incidence of steam pop by constant power ablation. It may be postulated that the similar lesion widths and depths at the different power settings and the higher incidence of steam pop that resulted from sequential unipolar ablation was the result of decreased impedance during the application of RF energy, which resulted in greater current density at the catheter-tissue interface and higher tissue temperature several millimeters below the catheter-tissue interface, whereas the deeper lesions produced by the bipolar ablation configuration allowed energy to be directed uniformly through the septum, likely as a result of the greater efficacy of power transfer despite the greater impedance.

Study Limitations

In our study, the catheters were placed and held manually at the IVS, and contact force of the catheter-tip was not measured. Yokoyama et al showed that contact force is a major determinant of RF lesion size and that the incidences of both steam pop and thrombus increase with increases in the contact force in canine thigh muscle preparations.¹⁴ However, we placed the catheter parallel to the IVS. Thus, contact pressure may not have differed to a great extent between our experiments. The catheter-tip temperature was not monitored during ablation, which might have been the cause of the higher incidence of steam pop. The mean impedance during bipolar and right and left unipolar interventricular endocardial ablation in in-situ ovine experiments ($103 \pm 10 \Omega$ vs. $101 \pm 9 \Omega$ vs. $97 \pm 11 \Omega$, $P=0.001$) differed from that in our in vitro experiments.¹³ However, the incidence of steam pop was also higher in the sequential unipolar group ($n=3$) than in the bipolar ablation group ($n=1$).¹³ Furthermore, lesion depth was not calculated in the experiments in which transmural lesions were created, thus the data on lesion depth might be underestimated. Finally, we did not compare the efficacy of bipolar

irrigated-tip catheter ablation with that of conventional catheter in in-vivo experiments, because in in-situ experiments the catheter-tip may be cooled by the rapid blood flow, even when using a conventional ablation catheter. However, the high incidence of thrombus formation without impedance rise during RF ablation using electrode temperature control (69% with a catheter-tip temperature of 65°C) using 4-mm tip conventional ablation catheter was reported previously.¹⁵ Thus, an irrigation catheter might be safer conventional ablation catheter when higher power ablation is expected.

Conclusions

Bipolar ablation of the IVS with irrigated-tip catheters was shown to be highly effective for creating a transmural lesion, and the incidence of steam pop appears to be lower than with sequential unipolar ablation.

Disclosure

The authors have no conflict of interest to disclose in relation to the study described herein.

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