Epicardial Ablation With Irrigated Electrodes
– Effect of Bipolar vs. Unipolar Ablation on Lesion Formation –
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Background: Ablation of ventricular tachycardia originating from the left ventricular (LV) epicardium is often limited by the radiofrequency power delivery. We compared the effect of bipolar vs. unipolar epicardial ablation on lesion size.

Methods and Results: Eleven excised pig hearts were superfused with saline (2L/min). Unipolar ablation (25 or 30W for 120s) was performed between the LV epicardial saline-irrigated electrode and an indifferent electrode (n=33 lesions). Bipolar ablation (25 or 30W for 120s) was performed between a 4-mm saline-irrigated-tip (20ml/min) electrode on the LV epicardium and an opposing 10-mm non-irrigated-tip electrode on the LV endocardium (n=38 lesions). Wall thickness did not differ between experiments (15.4±2.4 vs. 15.3±2.1 mm). Impedance was lower at the beginning and end of unipolar ablation than at the beginning and end of bipolar ablation (163.2±20.3Ω and 109.9±16.0Ω vs. 194.6±23.3Ω and 127.1±16.4Ω, respectively) (P<0.001). Epicardial lesion width did not differ between unipolar and bipolar ablation (10.1±2.7 vs. 10.2±2.4 mm), but lesion depth was greater with bipolar ablation (10.6±2.7 vs. 7.5±1.0 mm) (P<0.001). Unipolar ablation produced no transmural lesion, but bipolar ablation produced 15 (46%) (P<0.001). Steam pop occurred in 11 (29%) and 3 (9%) cases, respectively (P=0.036).

Conclusions: Bipolar ablation of the LV free wall is highly effective at creating an appropriately deep epicardial lesion. (Circ J 2012; 76: 322–327)

Key Words: Bipolar radiofrequency ablation; Epicardial myocardium; Irrigated-tip ablation

Radiofrequency (RF) ablation of ventricular tachycardia (VT) associated with structural heart disease relies on interrupting critical reentrant pathways. The post-ablation VT recurrence rate varies and depends on patient selection criteria and the ablation strategy. Reported rates of VT recurrence after RF ablation aided by electroanatomic mapping are 12–47%. The introduction of irrigated catheters has increased the ability to produce larger lesions by means of RF ablation; however, the presence of epicardial circuits may adversely affect RF catheter ablation of VT. Epicardial VT circuits can be ablated via a percutaneous subxiphoid approach with an irrigated-tip electrode catheter. Recent studies have shown extensive epicardial electrogram abnormalities for VTs associated with left ventricular (LV) nonischemic dilated cardiomyopathy (NICM) or arrhythmogenic right ventricular cardiomyopathy/dysplasia (ARVC/D) and that these VTs require ablation of the epicardial substrate. Monomorphic VT is rare in patients with hypertrophic cardiomyopathy, and epicardial VT mapping with ablation is often required for successful ablation therapy. However, the success rate is limited because of the increased ventricular wall thickness. Bipolar ablation of the interventricular septum (IVS) has been shown, both in vivo and in vitro, to be more efficient than sequential unipolar ablation for creating a transmural lesion. Also, successful bipolar RF ablation of VT originating from deep within the IVS has been reported in 2 cases. With the aim of improving subepicardial ablation efficacy, we compared bipolar 2-catheter epicardial-to-endocardial ablation and unipolar epicardial ablation in pig heart preparations.

Methods
LV Free Wall Preparation
The in vitro setup is shown as a schematic 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 and was in accordance with accepted guidelines for the care and treatment of experimental animals at Nihon University School of Medicine.
Eleven freshly excised pig hearts weighing 449–521 g were used in the study. The LV free wall was isolated, fixed to a silicone rubber plate in a round plastic chamber filled with 6L saline, and the entire chamber was heated to 37.0°C. The flow rate within the chamber was maintained at 2L/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 an indifferent electrode. The epicardial surface was not superfused with saline. A Sprinklr® irrigation catheter (7Fr, 4-mm-tip electrode; 10 irrigation holes: 1 at the central tip of the catheter, 3 at distal sites, 3 in the middle and 3 at proximal sites; Medtronic Inc, Minneapolis, MN, USA) was positioned manually on the epicardial surface with parallel contact, and a large-tip conventional catheter (6Fr, distal electrode 10-mm in length, Elecath Inc, Rahway, NJ, USA) was positioned at the endocardial surface opposite the epicardial electrode (Figure 2). Irrigation was set to 20ml/min during ablation. A Radionics RFG-3E RF lesion generator (Radionics Inc, Burlington, MA, USA) was used for RF energy delivery.

RF Ablation Protocol
Unipolar epicardial RF ablation and bipolar epicardial-endocardial ablation were each performed at energy settings of 25 W and 30 W for 120 s. Any change in impedance (Ω) and any occurrence of steam pop during RF delivery were recorded.

Pathologic Examination
After the ablation procedure, the LV wall was dissected along the lesion in the epicardial-to-endocardial direction. The maximum width of each lesion on the epicardial surface and the maximum depth of each lesion from the epicardial surface were determined macroscopically. The incidences of transmural lesion formation and intramural pop lesion formation were also determined.

Statistical Analysis
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
LV Wall Thickness
LV wall thickness of specimens treated by unipolar and bipolar 25-W ablation was 15.4±2.4 mm (n=38 lesions) and 15.3±2.1 mm (n=33 lesion), respectively (P=0.3874). LV wall thickness of specimens treated by unipolar and bipolar 30-W ablation was 16.2±1.8 mm (n=8 lesions) and 18.4±4.4 mm (n=9 lesions), respectively (P=0.2685). LV wall thickness did not differ significantly between specimens treated by unipolar and bipolar ablation at 25 W or between specimens treated by unipolar ablation and bipolar ablation at 30 W (P=0.888 for 25 W and P=0.226 for 30 W).
Figure 3. Gross appearance of lesions produced by 25-W unipolar epicardial ablation (Left, Upper and Lower) and bipolar epicardial-to-endocardial ablation (Right, Upper and Lower). Upper panels show experiments in which steam pop occurred during ablation and lower panels show experiments without steam pop. Note that lesion depth from the epicardium is greater with bipolar ablation.

Figure 4. Gross appearance of lesions produced by 30-W unipolar epicardial ablation (Left) and bipolar epicardial-to-endocardial ablation (Right). Steam pop occurred in more than half of the experiments with 30-W unipolar and bipolar ablation.
Steam Pop
Steam pop occurred as a result of 25-W unipolar and bipolar ablation in 11/38 (28.9%) and 3/33 (9.1%) specimens, respectively (P=0.036). Steam pop occurred as a result of 30-W unipolar or bipolar ablation in 7/8 (87.5%) and 5/9 (55.6%) of specimens, respectively (P=0.183). Among specimens treated by unipolar ablation, the incidence of steam pop was higher at 30 W than at 25 W (P=0.036). The incidence of steam pop among specimens treated by bipolar ablation was also higher in the 30 W group (P=0.006). Because of the high incidence of the steam pop at 30 W, the comparison of unipolar and bipolar ablation was performed only for ablation at 25 W.

Lesion Width and Depth
Lesion width on the epicardial surface resulting from 25-W unipolar ablation (n=38) was 10.1±2.7 mm and from 25-W bipolar ablation (n=33) was 10.2±2.4 mm (P=0.580). Lesion depth from the epicardial surface resulting from 25-W unipolar ablation (n=38) was 7.5±1.8 mm and from 25-W bipolar ablation (n=33) was 10.6±2.7 mm (P<0.001) (Figures 3, 4).

Transmural Lesion Formation
Transmural lesion formation after unipolar and bipolar ablation at 25 W was 0/38 (0%) and 15/33 (45.5%), respectively (P<0.001).

Impedance
Impedance at the onset of unipolar ablation at 25 W was 163.1±20.3Ω and decreased to 109.9±16.0Ω at the end of ablation. Impedance at the onset of bipolar ablation at 25 W was 194.6±24.9Ω (P<0.001 vs. unipolar ablation) and decreased to 127.1±16.4Ω (P=0.0001 vs. unipolar ablation) at the end of ablation.

Discussion
RF catheter ablation uses the resistive heating generated by the RF current flow into tissues. Therefore, RF current density, as the heat source, is critical for generating large lesions. In the unipolar ablation, the RF current density decreases in proportion to the square of the distance from the catheter-tip which produced shallower lesion depth because of low RF current density by dispersion. However, RF current density in bipolar ablation can be maintained relatively higher than in unipolar ablation because the 2 electrodes are closer to each other.

In this experimental study, lesion depth from the epicardial surface was deeper with bipolar epicardial-to-endocardial ablation than that with unipolar epicardial ablation. Furthermore, the incidence of steam pop was lower with bipolar ablation.

Starting in 1996, several groups reported their experiences with epicardial ablation via percutaneous pericardial puncture. In a multicenter study, epicardial ablation was performed in 121 of 913 (13%) procedures for VT, and an epicardial VT substrate was observed most often in association with ARVC/D (41% of such cases) and NICM (35% of such cases), followed by ischemic cardiomyopathy (16% of such cases). Sosa et al reported the need for epicardial ablation in 28% of VTs occurring late after myocardial infarction, and freedom from VT recurrence in 71%. Epidermal VT circuits can be ablated by standard RF ablation; however, the lack of convective cooling of the ablation electrode by local blood flow will limit power delivery in the pericardial space. Despite this, the reported arrhythmia control rates of 63% and 71% by conventional ablation and of 77% and 78% by irrigated-tip ablation are similar.

We reported the feasibility of transcatheter epicardial cryoablation on the basis of in vivo canine experiments; in chronic experiments, we achieved a lesion depth of 4.1±0.9 mm from the epicardial surface with a 9Fr, 8-mm-tip catheter. However, in recent studies, 59% and 70% of the VTs associated with hypertrophic cardiomyopathy required epicardial RF ablation; non-recurrence rates were 77% and 78%, respectively, but 1 patient required surgical cryoaolation from the epicardium for incessant VT. LV wall thickness in that case was >2 cm. Other ventricular arrhythmias responsible for a number of ablation failures involve deep intramural reentrant circuits in the IVS. We compared the efficacy of bipolar ablation vs. sequential unipolar ablation and reported that bipolar ablation of the IVS was highly effective for creating a transmural lesion. In 2 recently reported cases, unipolar RF ablation from the RV and LV aspects of the IVS was ineffective for terminating and preventing VT, but bipolar ablation between the left and right aspects of the IVS opposite the septal scar was effective. Furthermore, Kassenberg et al recently reported a case in which 2 endocardial ablation procedures and an epicardial ablation procedure were unsuccessful, but bipolar RF ablation between an epicardial and endocardial catheter was effective in ablating extrasystoles originating from the RV mid-myocardium.

We have experimented with bipolar ablation of the IVS in pig hearts using 2 irrigated-tip catheters on opposite sides of the IVS, but in the present study, a large-tip catheter was used on the endocardial side, and an irrigated-tip catheter was used on the epicardial side of the LV wall. The large-tip electrode was used on the endocardial surface because LV endocardial mapping was performed and, if appropriate, RF ablation was performed before epicardial mapping and ablation would have been attempted. Thus, the large-tip electrode was used as an endocardial electrode to decrease bipolar impedance and to minimize endocardial-side lesion formation. Steam pop during ablation using closed- or open-tip irrigation is a major complication, leading to ventricular arrhythmias and/or cardiac tamponade, so it is important to prevent its occurrence. We previously reported that steam pop occurred at catheter-tip temperature of 54±5°C (48–60°C) and a decrease in impedance of 23±9Ω (2–32Ω) during closed-loop irrigation catheter. Therefore, careful monitoring of the catheter-tip temperature and impedance might be prevent the occurrence of steam pop during unipolar epicardial ablation. However, we did not measure catheter-tip temperature and did not evaluate the relation between changes in impedance during ablation and the incidence of steam pop in the present study. Furthermore, we have previously reported that steam pop could be prevented by slowly increasing the RF power automatically to the preset temperature to 40°C. Thus, monitoring catheter-tip temperature and changes in impedance might be useful for preventing steam pop. However, the upper limit of the catheter-tip temperature and lower limit of the decrease in impedance should be determined individually for each ablation system. In addition, we speculate the reason for the higher incidence of steam pop during unipolar ablation was that the impedance was lower than in bipolar ablation. Therefore, the RF current just below the ablation catheter might be higher, resulting in excessive tissue heating. However, measurement of catheter-tip temperature and tissue temperature are needed to prove this hypothesis.
Study Limitations
The setting of this in vitro experiment was different from the actual clinical setting. In addition, a constant 2 L/min of saline flow does not perfectly mimic the blood flow in the human LV; it was not pulsatile and saline is not the same as blood in terms of specific heat capacity and density. In our study, the catheters were placed and held manually on the LV epicardium, and the 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 steam pop and thrombus increase with increases in the contact force in canine thigh muscle preparations. Furthermore, it may be difficult to exactly and continuously place a catheter on the LV epicardium and place the other catheter on the LV endocardium opposite the epicardial catheter in the beating human heart. Recently, Lee et al. reported that placing magnets assembled in ablation catheters facilitated tissue contact in bipolar ablation and created transmural lesions across the endocardium and epicardium efficiently because of the higher RF current and stronger tissue contact. Thus, robotic placement of the catheters or magnetically coupled catheters may facilitate facing epicardial and endocardial catheters at perpendicular positions across the ventricular wall.

Our experimental bipolar epicardial-endocardial LV wall ablation (vs. unipolar epicardial ablation) created relatively large lesions, and almost half of the lesions were transmural. Thus, high-density mapping of the LV endocardium and epicardium is mandatory before bipolar epicardial-endocardial ablation. However, many VTs originating from a subepicardial or deep epicardial site are associated with structural heart disease, and the site of origin is usually within scar tissue. Thus, the effect of bipolar ablation on LV function may be less than that of RF ablation in normal LV myocardium.

Conclusions
Bipolar epicardial-to-endocardial LV ablation was shown to be highly effective for creating an appropriately deep or transmural lesion, and the incidence of steam pop appears to be reasonably low.

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

References
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