RELATION BETWEEN THE SIZE OF LESIONS AND
ARRHYTHMIAS PRODUCED BY MICROWAVE
CATHETER ABLATION WITH A SPECIAL
ELECTRODE DEVICE

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The purpose of this study was to examine the effects of microwave catheter ablation of ventricular myocardium. Microwave energy with a frequency of 2450 MHz was delivered via a coaxial catheter with an electrode ball tip. Microwave energy was applied to canine isolated left ventricular endocardium in vitro and to 6 anesthetized dogs in vivo at 50 watts for 15—150 sec. Ventricular arrhythmia was not observed during ablation in any of the dogs when microwave energy was applied for less than 45 sec. When the duration of microwave ablation was greater than 45 sec, ventricular premature contractions were observed in all of the dogs. Nonsustained ventricular tachycardia developed when the duration of microwave delivery was greater than 90 sec. After the cessation of ablation, ventricular arrhythmias did not occur and ventricular programmed stimulation did not induce ventricular tachycardia in any of the dogs. Except for ventricular arrhythmia, no declines in the hemodynamic status were observed in any of the 6 dogs. The size of the ablated lesion was significantly greater as the duration of ablation was increased (p<0.05). When ablation lasted for more than 120 sec, the coagulation layer was extended to the epicardium in all 6 dogs.
The results of this study suggest that microwave ablation is feasible for the treatment of tachyarrhythmias from deep focus of ventricular myocardium with relatively small proarrhythmic effects. (Jpn Circ J 1994; 58: 214—221)

Catheter ablation using radiofrequency energy has been used with great success and few complications for the elimination of accessory pathways in patients with Wolff-Parkinson-White syndrome1—4 and for the treatment of atrioventricular nodal reentrant tachycardia5—8. However, as a treatment for ventricular tachycardia, this technique has been used almost exclusively in patients with idiopathic ventricular tachycardia and in some hemodynamically stable patients with coronary artery disease9—11. The failure to eliminate ventricular tachycardia by ablation using radiofrequency energy, especially in patients with structural heart disease, may be due to the small size and the shallow depth of the radiofrequency lesion produced12,13. Therefore, these patients are usually treated with direct-current ablation. However, the efficacy of the latter procedure varies widely and serious complications have

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MATERIALS AND METHODS

Microwave Generator and Electrode Catheter

The microwave current was generated by a constant power source (Model HS-15M, Heiwa Electronic Inc., Osaka) which delivered an unmodulated sinusoidal signal at 2450 MHz (Fig. 1). The device was designed for use in hepatic surgery. The power of the microwave current was set at 50 watts and the duration of the output was controlled from 15 to 150 (15, 30, 45, 60, 75, 90, 105, 120, 135, 150) sec.

A closed bipolar electrode coaxial catheter (Model E-18B, Heiwa Electronic Inc., Osaka) with an electrode ball tip was used for ablation (Fig. 2). The catheter was 1.8 mm in diameter and 120 cm long, with a tip electrode width of 1.6 mm and an interelectrode distance of 1 mm. The microwave current was delivered in a bipolar fashion between the electrodes. Another 6F quadrupolar USCI electrode catheter was inserted into a femoral vein to record the intracardiac electrogram and for ventricular stimulation after ablation.

Experimental Protocol in Vitro

Microwave catheter ablation was performed on isolated free wall of canine left ventricular myocardium in a bath filled with canine heparinized blood. The microwave current was delivered under conditions of an assumed electrode-tissue impedance. To investigate the endocardial surface area and the maximum depth of the ablated lesions, microwave energy was applied to 5 sites for 3 different lengths of time (30, 60 and 90 seconds). The ablated lesions were measured after being fixed in a 10% formalin solution and stained with hematoxylin-eosin.

Experimental Procedure in Vivo

Six mongrel dogs of either sex and weighing 9 to 15 kg were studied. After they had been anesthetized with intravenous sodium pentobarbital (20~30 mg/kg), they were intubated and ventilated with a Harvard volume ventilator apparatus. The coaxial catheter electrode for ablation was introduced into either the right femoral vein or artery using a cut-down procedure and positioned under fluoroscopic guidance against the right or left ventricular endocardial sur-
EXTERNAL APPEARANCE

INTERNAL STRUCTURE

![Diagram of a closed bipolar electrode coaxial catheter with an electrode ball tip.](image)

Fig.2. Schematic presentation of the closed bipolar electrode coaxial catheter with an electrode ball tip.

**TABLE I** COMPARISON OF THE SIZE OF THE ABLATED LASION AT EACH DURATION

<table>
<thead>
<tr>
<th>Delivery time</th>
<th>Ablated lesions in vitro</th>
<th>Endocardial surface area (mm²)</th>
<th>Maximum depth (mm)</th>
</tr>
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<tbody>
<tr>
<td>30 seconds</td>
<td>3 ± 1</td>
<td>20 ± 3</td>
<td></td>
</tr>
<tr>
<td>(n=5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60 seconds</td>
<td>5 ± 1*</td>
<td>29 ± 2*</td>
<td></td>
</tr>
<tr>
<td>(n=5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90 seconds</td>
<td>7 ± 1**</td>
<td>36 ± 2**</td>
<td></td>
</tr>
<tr>
<td>(n=5)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Data are expressed as mean ± standard deviation (SD).
*p < 0.05 in comparison with 30 seconds
**p < 0.05 in comparison with 30 and 60 seconds

After the procedure, ventricular programmed stimulation was performed to induce ventricular tachyarrhythmias. One hour after ablation, but before fixation with 10% formalin, all of the hearts were opened and the region of the ventricular endocardium was carefully inspected.

**Statistical Analysis**

Data are expressed as means ± standard deviation. Differences between independent quantitative samples were tested by the Wilcoxon method for paired values. A P value < 0.05 was considered to be statistically significant.

**RESULTS**

**In Vitro Evaluation of Ablated Lesions**

The endocardial ablated lesions were roughly spherical. However, there was no clear demarcation from the normal myocardium. Craters were not formed in the central areas with any of the applications. The ventricle was not perforated at any duration of ablation. The size of the ablated lesion increased significantly as the duration of ablation increased from 30 to 60 to 90 sec, with a mean surface area of 20, 29 and 36 mm², and a mean depth of 3, 5 and 7 mm,
Fig. 3. Effect of microwave delivery on His bundle electrogram. Noise was not recorded on the electrogram during microwave ablation.

Fig. 4. Monitoring of electrocardiogram and arterial pressure during microwave ablation. Ventricular premature contractions occurred and developed nonsustained ventricular tachycardias as ablation was prolonged.

Fig. 5. Ventricular double extrastimuli from the apex of the right ventricle after microwave ablation. Ventricular tachycardias were not induced by ventricular programmed stimulation.
respectively ($p<0.05$) (Table I). Baro-
trauma, which is caused by rupture of small
amounts of air produced in the endocar-
dium, was observed in all of the applications
when microwave ablation time exceeded 5
sec. However, this was not observed again
in any of the applications during microwave
delivery.

**In Vivo Evaluation of Different Pulse Durations**

The surface electrocardiogram and intra-
cardiac electrogram were recorded clearly
since noise did not occur during ablation
(Fig. 3). Ventricular arrhythmia did not
occur during ablation in 5 of the 6 dogs when
microwave catheter ablation was applied for
less than 45 sec. In 1 dog transient isolated
ventricular premature contractions were
noted about 5 sec after the onset of micro-
wave delivery. However, ventricular arrhy-
thmias were not observed thereafter until
40 sec. When the duration of microwave
catheter ablation was longer than 45 sec,
ventricular premature contractions were
observed in all 6 dogs. When ablation was
continued for a even longer the dogs de-
veloped nonsustained ventricular tachycardias
(Fig. 4). However, after stopping the cur-
rent, ventricular arrhythmias were not obser-
vied in any of the dogs. Ventricular program-
med stimulation after ablation did not induce
ventricular tachycardia in any of the dogs
(Fig. 5). ST-T changes were not noted dur-
ing or after ablation. No adverse effects,
other than ventricular arrhythmia, were
observed in any of the 6 dogs during the 1
hour monitoring period after ablation. In
particular, there was no detectable change in
arterial pressure.

All of the hearts were opened and the re-
region of the right or left ventricular endocar-
dium was carefully inspected. The ablated
lesions were present at the free wall or sep-
tum of the ventricle. The endocardial lesions
produced in vivo were roughly spherical,
however, there was no sharp demarcation
from the normal myocardium. The central
portions of the lesions were dark brown and
contained small craters. No endocardial
thrombus, charring or distinct ulceration was
observed in any of the dogs, even in those les-
sions that were associated with an impedance
rise (Fig. 6). Ablated lesions showed a
tendency to grow larger as ablation time in-
creased. When ablation lasted for more than
120 seconds, the coagulation layer extended
to the epicardium in all 6 dogs.

**DISCUSSION**

Catheter ablation with direct-current

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shocks can be used effectively to treat patients with sustained ventricular tachycardia\textsuperscript{19,20} However, this technique is associated with potentially serious side effects\textsuperscript{14,15} Radiofrequency catheter ablation has not shown equivalent successes in patients with ventricular tachycardia except in cases where idiopathic ventricular tachycardia arose from the high right ventricular outflow tract and the left ventricular apex\textsuperscript{9} and in ventricular tachycardia with mechanisms of bundle branch reentry\textsuperscript{21} The failure to eliminate ventricular tachycardia may have been due to the small, shallow lesions created\textsuperscript{12,13} It has been reported that improving electrode catheters\textsuperscript{22} increasing the power output\textsuperscript{23} decreasing the frequency\textsuperscript{24} using multiple applications\textsuperscript{23,25} and repetitive delivery\textsuperscript{26} of current can somewhat enlarge the ablated lesion created by radiofrequency energy. However, radiofrequency techniques cannot create larger lesions which may eliminate the ventricular tachycardia associated with severe structural heart disease, since the size of the lesion is limited by the impedance rise caused by coagulum formation\textsuperscript{27} Microwave surgical equipment is useful for hepatectomy, coagulation of malignant tumors, and endoscopic treatments\textsuperscript{28,29} The theory of microwave heating is based on the high-speed changes in polarity (\(+\), \(-\)) in water molecules within the tissue\textsuperscript{17} The polarized molecules follow the direction of the electric field of the microwave, and, as the electric field is changed at ultra-high speed, the microwave generates heat. Heat is generated internally, rather than being applied externally. Using this principle, microwave energy has found extensive surgical applications\textsuperscript{28,29} Computer modeling with a tissue-equivalent phantom and thermometry studies in vitro have demonstrated that microwave energy can produce a larger volume of coagulation than radiofrequency energy\textsuperscript{16} A recent study in vitro suggests that tissue heating with microwaves does not require direct contact\textsuperscript{30} In microwave ablation in vivo, blood flows across the surface of the heat source. The electromagnetic fields in blood propagate through blood cells or plasma so that the microwave application can deposit energy directly in tissue at a distance regardless of the intervening medium. In the present study, we performed in vitro and in vivo experimental catheter ablation with microwave energy using a coaxial catheter with an electrode ball tip. Our microwave technique did not limit lesion formation, and thus a larger lesion can be formed by ablation. Small craters were formed in the center of ablated lesions in vivo. These may due to the pressure exerted by the electrode of a hard catheter, rather than to the formation of necrotic tissue by a high rise in the temperature of the electrode. Concerning the arrhythmogenicity of microwave delivery, ventricular arrhythmias occurred only during prolonged ablations. In addition, ventricular tachycardia could not be induced in any of the dogs by programmed ventricular stimulation after the procedure.

The present study indicated that our microwave technique using a coaxial catheter with an electrode ball tip can produce a larger lesion, with only a few proarrhythmic events occurring during ablation. This new microwave catheter ablation technique has been used effectively and safely in 6 dogs. Catheter ablation with microwave energy may be useful for the treatment of ventricular tachycardias from deep focus of ventricular myocardium, which is resistant to radiofrequency catheter ablation.

CONCLUSIONS

The incidence and severity of ventricular arrhythmias during ablation depend on the duration of microwave energy delivery. A larger lesion can be formed by controlling the duration of delivery.

These results suggest that microwave ablation may be useful for the treatment of tachyarrhythmias from deep focus of ventricular myocardium.

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