Bipolar Radiofrequency Ablation Using Dual Internally Cooled Wet Electrodes: Experimental Study in Ex Vivo Bovine Liver
두 개의 내부냉각습식 전극을 사용한 양극성 고주파열치료: 체외 소간 실험 연구

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Purpose: To determine the optimized protocol for bipolar radiofrequency ablation (RFA), using dual internally cooled wet (ICW) electrodes in the ex vivo bovine liver.

Materials and Methods: RFA was applied to the explanted bovine liver, using two 3 cm active tip electrodes with 3.5 cm spacing. A total of 25 ablation zones were created by five groups; group A: 70 W-20 minute (min), group B: 70 W-25 min, group C: 90 W-15 min, group D: 90 W-20 min, and group E: 90 W-25 min. We measured the total energy and size of ablation zones with a color of grey or pink. Statistical analysis was done using Kruskal Wallis test and Mann Whitney U-test.

Results: The mean energy, mean volume of ablation zone with grey and pink color of groups A to E were 16.7, 23.9, 16.7, 21.8, 29.2 kcal, 25.7, 34.3, 29.5, 36.2, 45.2 cm³, and 60.0, 88.0, 71.5, 87.4, 104.5 cm³, respectively. Those were significantly different (p < 0.05). The volume of ablation zone of group E with grey color was larger than groups A, B and C (p < 0.05).

Conclusion: Bipolar RFA, using dual ICW electrodes, can produce a large ablation zone with the protocol of 90 W-25 min.
Bipolar Radiofrequency Ablation Using Dual Internally Cooled Wet Electrodes

Radiofrequency Protocol

RFA was performed in the fresh explanted bovine livers. Two ICW electrodes with 3 cm active tip were placed parallel into the liver vertically with 3.5 cm spacing at room temperature (Fig. 1B). Prior to placing the electrode, we checked the path of a large vessel in the explanted bovine liver with a long screw driver for avoiding inadequate ablation by leakage of perfused normal saline. As a pilot study, RFA was done with two protocols of 60-200 W (Power automatically increase 20 W every minute) for 15 min and 70 W for 15 min. The results of the pilot study showed an incomplete ablation between the two electrodes. We also found that the power could not reach more than 120 W because the impedance quickly elevated during 120 W power. We decided five groups of different power output and duration of RFA. Group A was 70 W power for 20 min duration of RFA. Group B was 70 W power for 25 min duration. Group C was 90 W power for 15 min duration. Group D was 90 W power for 20 min duration. Group D was 90 W power for 25 min duration. We performed five RF ablations in each groups. Total numbers of RFA were 25.

Measurement of Ablation Size

RF ablated lesions were sliced along the electrode insertion axis and then cut perpendicular plane at the middle, between the two electrodes. We measured both the grey colored central area of the ablation zone only, including the marginal pink colored area.

Dt is the long transverse diameter between the two electrodes and Dv (long dotted arrow) is the longitudinal diameter along the axis of electrodes.

Ds (short dotted arrow) is the short transverse diameter of perpendicular plane at the middle between the two electrodes.

Statistical Analysis

Statistical analysis of the difference in size of ablation and applied total energy among the groups was done using Kruskal Wallis test and Mann Whitney U-test. Spearman correlation analysis is used for the correlation between the total energy and the volume of the ablation zone. A p-value of less than 0.05 was considered as statistically significant. SPSS software (Version 13.0, SPSS Inc., Chicago, IL, USA) was used for all statistical analysis.
RESULTS

The mean applied energy in group A to E was 16.7, 23.9, 16.7, 21.8 and 29.2 kcal, respectively. The average Dt, Ds, Dv of the ablation zone and volume with grey color and pink color and total energy of each group were seen in Table 1. All these parameters of the ablation zone, volume and total energy were significantly different among the group by Kruskal Wallis test ($p < 0.05$). The Dt of the ablation zone with grey color of group B and E was longer than group A and C ($p < 0.05$), but there

Table 1. Results of Bipolar RFA with Dual Internally Cooled Wet Tip Electrodes in Five Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>A, 70 W-20 min</th>
<th>B, 70 W-25 min</th>
<th>C, 90 W-15 min</th>
<th>D, 90 W-20 min</th>
<th>E, 90 W-25 min</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td></td>
</tr>
<tr>
<td>Dt</td>
<td>Grey</td>
<td>4.4 (0.2)</td>
<td>4.8 (0.2)</td>
<td>4.8 (0.3)</td>
<td>5.2 (0.3)</td>
<td>$p &lt; 0.05^*$</td>
</tr>
<tr>
<td></td>
<td>Pink</td>
<td>5.9 (0.2)</td>
<td>6.3 (0.3)</td>
<td>6.2 (0.3)</td>
<td>6.2 (0.4)</td>
<td></td>
</tr>
<tr>
<td>Ds</td>
<td>Grey</td>
<td>3.2 (0.2)</td>
<td>3.6 (0.2)</td>
<td>3.1 (0.1)</td>
<td>3.6 (0.1)</td>
<td>$p &lt; 0.05^†$</td>
</tr>
<tr>
<td></td>
<td>Pink</td>
<td>4.3 (0.3)</td>
<td>5.2 (0.4)</td>
<td>4.4 (0.2)</td>
<td>4.9 (0.3)</td>
<td>$p &lt; 0.05^‡$</td>
</tr>
<tr>
<td>Dv</td>
<td>Grey</td>
<td>3.5 (0.3)</td>
<td>3.8 (0.1)</td>
<td>3.7 (0.4)</td>
<td>4.0 (0.4)</td>
<td>$p &lt; 0.05^‡$</td>
</tr>
<tr>
<td></td>
<td>Pink</td>
<td>4.6 (0.3)</td>
<td>5.2 (0.2)</td>
<td>5.0 (0.4)</td>
<td>5.5 (0.5)</td>
<td>$p &lt; 0.05^‡$</td>
</tr>
<tr>
<td>Vol</td>
<td>Grey</td>
<td>25.7 (2.4)</td>
<td>34.3 (3.0)</td>
<td>29.5 (5.3)</td>
<td>36.2 (5.8)</td>
<td>$p &lt; 0.05^§$</td>
</tr>
<tr>
<td></td>
<td>Pink</td>
<td>60.0 (8.0)</td>
<td>88.0 (10.8)</td>
<td>71.5 (10.2)</td>
<td>87.4 (13.9)</td>
<td></td>
</tr>
<tr>
<td>TE</td>
<td>kcal</td>
<td>16.7 (1.4)</td>
<td>23.9 (2.2)</td>
<td>16.7 (2.2)</td>
<td>21.8 (2.4)</td>
<td>$p &lt; 0.05^</td>
</tr>
</tbody>
</table>

Note. $^*$Difference in the groups (A, C) and (B, E).
$^†$Difference in the groups (A, C) and (B, D, E).
$^‡$Difference in the (A, B, C) and (E).
$^§$Difference in the (A, B, C, D) and (E).
$||$Difference in the (A, B, C, D, E) with grey color and in the (A, C) and (B, D, E) with pink color.

min = minutes, RFA = radiofrequency ablation, SD = standard deviation, TE = total energy, Vol = volume

Fig. 3. Cut surfaces of coagulated necrosis along the axis of electrodes in the five groups. (A) group A; 70 W-20 min, (B) group B; 70 W-25 min, (C) group C; 90 W-15 min, (D) group D; 90 W-20 min, (E) group E; 90 W-25 min. Long transverse diameter between the two electrodes (arrows) of necrosis of 25 min groups (group B and E) is longer than that of group A and C. Longitudinal diameter along the axis of electrode of necrosis of group E is longer than that of group A, B, and C.
was no significant difference between group B and group E (Fig. 3). The Ds of the ablation zone with grey color was significantly longer in groups B, D and E than in groups A and C \( (p < 0.05) \) (Fig. 4). There was also no significant difference in Ds among the groups B, D and E. Dv of the ablation zone with grey color was longer in group E than in groups A to C \( (p < 0.05) \) (Fig. 3). The mean volume of the ablation zone with grey color was 25.7, 34.3, 29.5, 36.2 and 45.2 cm\(^3\) in groups A to E. The mean volume of the ablation zone with pinkish color in each group was 60.0, 88.0, 71.5, 87.4 and 104.5 cm\(^3\), respectively. There was strong positive linear correlation between the total energy and the volume of the ablation zone with grey \( (\rho = 0.877, p < 0.05) \) and pink \( (\rho = 0.88, p < 0.05) \) color. The volume of the ablation zone of group E with grey color was larger than groups A, B and C \( (p < 0.05) \), but not than group D. Volume of the ablation zone of groups A and C with pink color was smaller to groups B, D and E \( (p < 0.05) \). Total energy of group E was significantly higher than the others \( (p < 0.05) \). Total energy was also significantly higher in the longer time group with the same power output.

**DISCUSSION**

During the last 10-year period, local tumor ablation methods for treatment of hepatocellular carcinoma (HCC) were used more and more. Among the various local tumor ablation methods, those percutaneous ethanol injection (PEI) and thermal-based RFA are recognized as a curative treatment of less than three and less than 3 cm sized early stage HCC. It is important to increase the volume of ablation for reducing local tumor recurrence and treating intermediate, 3 to 5 cm sized HCC. Volume of coagulation can be increased with the methods of overlapping (5, 6) or combined therapy with transarterial chemoembolization, PEI, and chemotherapeutic agent (7-10). There have been many studies to increase the ablation size with various types of electrodes, including internally cooled and perfused electrodes (11-14), clustered electrode or multiple electrodes (3, 15-20).

At this time, as far as we know, only one bipolar RF system is commercially available and that is composed of three internally cooled bipolar electrodes (CelonProSurge; Celon Medical In-
In our results, total ablation volume with pink color was at least more than two times than that with grey color. This large ablation volume with pink color could have a chance to completely necrosis with the combination of lyso-thermosensitive liposomal doxorubicin, which consists of the heat-enhanced cytotoxic doxorubicin within a heat-activated liposome (10), which has been evaluated in randomized, double-blind, dummy-controlled trial (23).

There are several limitations in this experimental study. First, number of ablated ex vivo bovine liver in this study was small. Second, ablated volume of ex vivo is usually larger than that of in vivo because the heat sink effect, which is induced by an adjacent blood flow in the large vessels (24). Third, variable size or shape of coagulation can be achieved in vivo (25). Fourth, electrical conductivity or impedance of tumor tissue could be different from that of normal tissue.

In conclusion, even though there are several limitations, bipolar RFA using dual ICW electrodes can produce large ablation zone with the protocol of 90 W for 25 minutes among several preselected fixed power output and duration. Further evaluation and optimization of the bipolar RFA using dual ICW electrodes in vivo are needed.

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struments, Telow, Germany). Seror et al. (21) reported multi-

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trodes could ablate completely and safely HCCs larger than 5.0

cm, even those that were infiltrative and involved a segmental

total portal vein. Clasen et al. (22) evaluated the relation-

tship between parameters of bipolar RFA, using internally cooled elec-

trodes and reported that prolonged RFA at lower power out-

puts produce larger volumes of coagulation, and faster RFA at

higher power outputs produces smaller volume of coagulation

and also revealed that volume of coagulation was directly pro-

portional to the duration and the amount of energy application

(3). In our study, maximum power output was not investigated

because high power, especially more than 120 W power, induced

rapid increase of tissue impedance, resulting in less duration of

energy application and incomplete fusion of the coagulation

zone between the two electrodes by our pilot experiment. In

our results, the amount of energy application proportionally

corresponded to the volume size of coagulation, and the total

energy with 90 W power in 25 minutes was significantly larger

than 70 W power in the same minutes, and the volume was

also significantly different between those two groups (p = 0.008).

We thought that there should be a threshold of power output,

which induces rapid increase of tissue impedance and the 90 W

power output in our experiment must be lower than the

threshold inducing rapid increase of tissue impedance.

Lee et al. (17) reported serially that saline enhanced bipolar

RFA was more efficient in making larger volume of thermal ab-

lation than conventional and simultaneous monopolar RFA

and bipolar RFA with the cooled-wet electrode also produce

larger tissue coagulation than with the open-perfused electrode

(18). They had used a prototype cooled-wet electrode with a

c coaxial saline perfusion system, but that type of electrode has

not been commercially available now. We used ICW electrode,

which induced significantly larger volume of coagulation than

the internally cooled electrode in the monopolar RF system

(14). In our bipolar RFA system with ICW electrode, perfused

normal saline with simultaneously internal cooling effect made

the tissue impedance low, which made longer duration of en-

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두 개의 내부냉각습식 전극을 사용한 양극성 고주파열치료: 체외 소간 실험 연구

이영준 · 변재영

목적: 체외 소간에서 두 개의 내부냉각습식 전극을 사용한 양극성 고주파열치료의 적절한 프로토콜을 정하고자 하였다.
결과: A 그룹에서 E 그룹의 평균 에너지, 회색 변성의 절제구역과 분홍색 변성을 포함한 절제구역의 크기는 각각 16.7, 23.9, 16.7, 21.8, 29.2 kcal, 25.7, 34.3, 29.5, 36.2, 45.2 cm³, 그리고 60.0, 88.0, 71.5, 87.4, 104.5 cm³였다. 평균 에너지와 절제구역의 크기는 그룹 간에 유의한 차이가 있었다(\(p < 0.05\)). E 그룹의 회색 변성의 절제구역의 크기는 A, B, C 그룹보다는 유의하게 높았다(\(p < 0.05\)).
결론: 두 개의 내부냉각습식 전극을 사용한 양극성 고주파열치료는 90 W-25분의 치료에서 큰 절제구역을 생성할 수 있다.

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