Comparison of Internally Cooled Wet Electrode and Hepatic Vascular Inflow Occlusion Method for Hepatic Radiofrequency Ablation

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Background/Aims: Various strategies to expand the ablation zone have been attempted using hepatic radiofrequency ablation (RFA). The optimal strategy, however, is unknown. We compared hepatic RFA with an internally cooled wet (ICW) electrode and vascular inflow occlusion. Methods: Eight dogs were assigned to one of three groups: only RFA using an internally cooled electrode (group A), RFA using an ICW electrode (group B), and RFA using an internally cooled electrode with the Pringle maneuver (group C). The ablation zone diameters were measured on the gross specimens, and the volume of the ablation zone was calculated. Results: The ablation zone volume was greatest in group B (1.82±1.23 cm³), followed by group C (1.22±0.47 cm³), and then group A (0.48±0.33 cm³). The volumes for group B were significantly larger than the volumes for group A (p=0.030). There was no significant difference in the volumes between groups A and C (p=0.079) and between groups B and C (p=0.827). Conclusions: Both the usage of an ICW electrode and hepatic vascular occlusion effectively expanded the ablation zone. The use of an ICW electrode induced a larger ablation zone with easy handling compared with using hepatic vascular occlusion, although this difference was not statistically significant. (Gut Liver 2012;6:471-475)

Key Words: Liver; Catheter ablation

INTRODUCTION

Radiofrequency ablation (RFA) has been successfully used for the treatment of small hepatic tumors. However, previous studies reported that large hepatic tumors greater than 5 cm were incompletely treated because RFA failed to induce a large enough ablation zone to cover the entire tumor with an appropriate tumor free ablative margin. Sequentially overlapping single electrode ablation has been attempted for large hepatic tumors. However, repositioning of the electrode to an untreated tumor portion is difficult, which takes a long time for procedure. Therefore, there have been various attempts to expand the ablation zone during a single session of RFA. Several needle electrodes such as internally cooled (IC), perfused, bipolar, expandable, and clustered electrodes have been developed to expand the RFA zone. Using multiple electrodes is another strategy to expand the ablation zone. Recently another energy source such as microwave has been used for thermal ablation to treat large hepatic tumors.

Saline administration is one of the strategies to expand the ablation zone by modulating the biologic environment of the treated tissue. Saline infusion into tissue improves the electrical and thermal conductivity of tissue during RFA. An IC wet (ICW) electrode system has been developed for administering saline into hepatic tissue during RFA and for the simultaneous internal cooling of the needle electrode. Hepatic vascular inflow occlusion is another strategy to expand the ablation zone by reducing the heat sink effect, which can be induced by the Pringle maneuver because it has been used by surgeons for hepatic vascular inflow occlusion after an open laparotomy.

To the best of our knowledge, no studies have simultaneously compared these two modified RFA methods to expand the ablation zone in the liver. We compared the usability of RFA with saline administration using the ICW electrode and RFA with hepatic vascular inflow occlusion using the Pringle maneuver, in vivo, using canine liver model.
MATERIALS AND METHODS

The study protocol was approved by the Committee on the Ethics of Animal Experiments. Eight mongrel dogs (11 to 20 kg, mean 14.3±2.9 kg) were randomly allocated into one of three groups: RFA using an IC electrode (group A, n=2), RFA using an ICW electrode with 0.9% normal saline (group B, n=3) and RFA using an IC electrode after occlusion of hepatic perfusion by the Pringle maneuver (group C, n=3). Group A was a control group.

1. RF equipment and protocol

A 200-W radiofrequency current (480-kHz) generator (CTRF-220; Valleylab, Boulder, CO, USA) was used. An 18-gauge IC electrode with a 1-cm active tip (Jet tip®; RF Medical Co., Ltd., Seoul, Korea) was used in the groups A and C. An 18-gauge ICW electrode with a 1-cm active tip and a microhole (Jet tip®; RF Medical Co., Ltd.) was used in the group B (Fig. 1). One microhole was located 6 mm from the distal tip of the ICW electrode. The diameter of the microhole was 0.03 mm. Saline solution infusion was conducted through the microhole placed on the needle electrode. The tissue infusion rate was 0.7 mL/min. A peristaltic pump (PE-PM; Radionics, Burlington, MA, USA) IC the electrode and simultaneously infused saline into the tissue, using chilled 0.9% normal saline at a flow rate that was sufficient to maintain the electrode temperature below 25°C. The applied current, power output and impedance were automatically recorded by a computer program (Real Time Graphics software version 2.0; Radionics). RF was applied to the livers in the monopolar mode and RF energy was delivered to the electrodes for 5 minutes. Energy delivery was performed at half power (100 W) in the impedance control mode. The applied current, power output, impedance and temperature at the tip of electrode were monitored during RFA.

2. Operating procedure

After the animals underwent premedication with an intramuscular injection of atropine sulfate 0.04 mg/kg (atropine sulfate; Jeil Pharm., Seoul, Korea), general anesthesia was induced with intravenous administration of propofol 6 mg/kg (Provive injection; Myungmoon Pharmaceuticals, Seoul, Korea). After endotracheal intubation, the anesthesia was maintained with isoflurane 0.8% to 1.25% (Ifran®; Hana Pharm. Co., Ltd., Hwasung, Korea) in oxygen with a semiclosed circle breathing circuit. The analgesic effect was supplemented with medetomidine, tiletamine, and zolazepam. The cardiac and respiratory parameters were monitored throughout the entire observation time. The dogs were placed in a supine position. The upper area of the back was shaved for the grounding pads. Grounding for the RF procedure was done via two external grounding pads. The upper area of the abdomen and epigastrium were shaved and sterilized. A midline incision was made and the liver was exposed.

Three sets of in vivo experiments were performed. A total of 18 RFA zones were induced for this study, and up to three ablations were performed in each animal. In the group B, a saline jet through the microhole was checked before ICW electrode placement into the liver. One ablation was performed in each lobe. The lobes for large enough to accommodate an ablation zone (usually two or three large lobes in each animal) were selected. The tip of needle electrode was placed approximately 1.5 cm deep relative to the liver capsule. In the Pringle group C, and before RFA, the hepatoduodenal ligament, which contained the hepatic artery, portal vein and bile duct, was identified and occluded using an atraumatic vascular clamp. The Pringle maneuver was performed during 20 minutes in each animal. After cessation of the RFA, the hepatic blood flow was immediately restored to the liver. After completion of the RFA in each animal, the dogs were euthanized with intravenous pentobarbital, and each liver was removed en block.

3. Assessment of the ablation zone

The liver blocks were sectioned along the longitudinal plane (the electrode insertion axis) and then they were cut transversely perpendicular to the longitudinal plane (the transverse plane). The central white zone of coagulation was measured and the variable rim of hyperemia was excluded. The three diameters of the ablation zone were measured by consensus of two observers: the longitudinal diameter was defined as the maximum diameter along the electrode insertion axis (T long) and the transverse diameter was defined as the two diameters perpendicular...
Table 1. Comparison of the Radiofrequency Ablation Data

| Group      | n=4   | n=7   | n=7   |
|------------|-------|-------|-------|
| Temperature, °C | 11.1±5.4 | 10.1±1.5 | 10.6±2.6 |
| Watt, W    | 10.1±2.3 | 19.1±3.5 | 7.7±1.8  |
| Impedance, Ω| 135±19  | 108±16  | 139±17  |
| Current, mA | 277±71 | 407±61  | 215±30  |

Data are presented as mean±SD. *p<0.05 vs group A; †p<0.05 vs group B; ‡p<0.05 vs group C.

Table 2. Comparison of the Radiofrequency Ablation Zone

| Group      | n=4   | n=7   | n=7   |
|------------|-------|-------|-------|
| T long, mm | 12.6±1.3 | 16.3±3.4 | 15.4±1.6* |
| T max, mm  | 9.0±2.2  | 14.6±3.7* | 12.9±2.5* |
| T min, mm  | 7.8±2.9  | 12.7±4.3* | 11.4±1.8  |
| Volume, cm³| 0.48±0.3  | 1.82±1.23* | 1.22±0.47* |
| Sphericity | 0.7±0.12 | 0.89±0.14 | 0.84±0.12 |

Data are presented as mean±SD. *p<0.05 vs group A; †p<0.05 vs group B; ‡p<0.05 vs group C.

Fig. 2. Comparison of the radiofrequency ablation (RFA) zone volume between the groups. There were significant differences in the RFA zone volumes between groups A and B (p=0.030). There were no significant differences between groups B and C (p=0.827) or between groups A and C (p=0.079). The volume of the RFA zone in group B showed more variation compared with the volume of group C.

to the electrode insertion axis in the transverse plane, that is, the maximum diameter (T max) and the minimal diameter (T min). The RFA zone was considered as ellipsoid in shape, and its volume was calculated using the formula: \( \frac{1}{6} \times \pi \times T_{long} \times T_{max} \times T_{min} \). The shape of the ablation zone was assessed by the ratio of T long to T max. The ratio closer to 1 indicates more spherical shape.

4. Statistical analysis

The three diameters, the calculated ablation zone volume and the ratio of T long to T max were reported as means±standard deviations. These were compared among the three groups using the Kruskal-Wallis test. When a significant group difference was found using the Kruskal-Wallis test, Turkey’s multiple comparison test was done to determine significance. Statistically significant differences were defined as p<0.05.

RESULTS

A total of 18 ablation zones were induced: four in the group A, seven in the group B, and seven in the group C. The temperature was measured by a thermosensor at the needle electrode tip and it was kept at 8°C to 17°C during RFA. The mean impedance during RFA in the group B was significantly lower than that in the groups A and C. The mean current during RFA in the group B was higher than that in the groups A and C. Saline administration into the hepatic tissue significantly decreased the tissue impedance and increased the current flow into the tissue. The results are summarized in Table 1.

The longest mean T long, T max and T min values were seen in the group B (T long, 16.3±3.4 mm; T max, 14.6±3.7 mm; T min, 12.7±4.3 mm), followed by the group C (T long, 15.4±1.6 mm; T max, 12.9±2.5 mm; T min, 11.4±1.8 mm) and then the group A (T long, 12.6±1.3 mm; T max, 9.0±2.2 mm; T min, 7.8±2.9 mm). The calculated mean ablation zone volume was largest in the group B (1.82±1.23 cm³), followed by the group C (1.22±0.47 cm³), and then the group A (0.48±0.33 cm³). The mean ablation zone volume in the group B was significantly larger than that of the group A. The volume of group B was 279% greater than that of the group A (p=0.030). The volume of group C was also 154% greater than that of the group A (p=0.079). However, no significant difference in the mean ablation zone volume was observed between the groups B and C (p=0.827). The ablation zone volume in the group B showed more variation than that of the groups A and C (Fig. 2). The most spherical ablation zone was induced in the group B, followed by the group C and then the group A. However, there was no statistically significant difference in the ablation zone shape between the groups. There was no asymmetry of the RFA zone according to the microhole location in the group B. These results are summarized in Table 2.

DISCUSSION

Among the various modified RFA procedures, RFA with saline administration has been considered an effective strategy to expand the RFA zone, and different methods for saline administration into tissue have been developed.\(^1\)\(^-\)\(^2\)\(^6\) The ICW electrode with the microholes is capable of internally cooling the electrode and simultaneously infusing saline into the hepatic tissue during RFA.\(^2\)\(^6\) Saline, which cools the needle electrode, was infused into the tissue through the microhole on the side of the needle electrode without any additional equipment or procedure. The amount of saline infused into the tissue was controlled by the very small size of the microhole on the needle electrode. There-
fore, the ICW electrode with the microhole is easy to handle. A 0.9% normal saline solution is used for the ICW electrode with the microhole instead of the more concentrated NaCl solution because salt crystallization in the concentrated saline solution can lead to obstruction of the microhole. Cha et al.\textsuperscript{26} reported that RFA with the ICW electrode with the microhole induced a larger ablation zone in an animal study, as compared to that of the RFA with the IC electrode. Our study showed that the ablation zone volume induced by RFA with the ICW electrode was 279\% greater than that induced by RFA with the IC electrode. RFA using the ICW electrode with the microhole was effective to expand the RFA zone.

On the other hand, RFA with hepatic vascular inflow occlusion has also been considered effective to expand the ablation zone for which the Pringle maneuver is effective.\textsuperscript{27-30} Thus, we used the Pringle maneuver for hepatic vascular inflow occlusion in this study. Our study showed that the ablation zone volume induced by RFA with the Pringle maneuver was 154\% greater than that induced by RFA only. However, the Pringle maneuver is an invasive method that requires an open laparotomy and also leads to thermal injury of the hepatic vessel and bile duct.\textsuperscript{11-14} Invasiveness and the risk of thermal injury to the hepatic vessel and bile duct are the drawbacks of using the Pringle maneuver during RFA. Transarterial embolization (TAE) has recently been attempted to expand the ablation zone by hepatic vascular inflow occlusion or reduction. This induced a larger ablation zone than that induced by RFA only in animal studies.\textsuperscript{31-34} But TAE also requires an additional invasive procedure and the associated cost. Furthermore, our comparative study showed that RFA with saline administration using the ICW electrode induced a larger ablation zone than those induced by RFA with hepatic vascular inflow occlusion using the Pringle maneuver, although there was no statistical difference. We speculated that the effectiveness of TAE to expand the RFA zone was similar or less, as compared to that using the Pringle maneuver. Therefore RFA using the ICW electrode is an effective method for expanding the RFA zone without additional invasiveness.

However, the use of the ICW electrode induced more variation of the ablation zone volume, as compared to that of the IC electrode with or without the Pringle maneuver in our study. Cha et al.\textsuperscript{26} reported low reproducibility of RFA using the ICW electrode, which could have been caused by the non-uniform distribution of spilled saline according to the different surrounding tissues and microhole obstruction by the ablated tissue during RFA. In our study, microhole obstruction was observed when the ICW electrode was removed from the liver right after RFA was finished. Microhole obstruction could account for the low reproducibility of RFA using the ICW electrode. Inducing a consistent ablation zone is important for RFA planning in clinical practice. Further studies are needed to clarify the cause of the low reproducibility of RFA using the ICW electrode.

This study had certain limitations. First, IC or ICW electrodes with a 1 cm active tip and a lower level RF energy during a shorter time period were used due to the relatively small canine liver. Using a 1-cm active tip needle could positively affect the expansion of the RFA zone when the ICW electrode is used. Further study with a 2- or 3-cm active tip needle is needed. Second, the diameter of the ablation zone was measured on the gross specimens instead of using an image modality such as computed tomography, which can more accurately determine the volume and shape of the RFA zone.

In conclusion, both usage of an ICW electrode and hepatic vascular inflow occlusion are effective to expand the ablation zone. The use of an ICW electrode is minimally invasive with easy handling, which is in contrast to the Pringle maneuver for hepatic vascular inflow occlusion. RFA using the ICW electrode could induce a larger ablation zone than that induced by RFA with the Pringle maneuver. RFA with an ICW electrode can be useful to treat large hepatic tumors.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

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