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Comparison of Ablation Performance between Octopus Multipurpose Electrode and Conventional Octopus Electrode

Sae-Jin Park[1], Jae Hyun Kim[1, 2], Jeong Hee Yoon[1, 2], Jeong Min Lee[1, 2, 3]

[1]Department of Radiology, Seoul National University Hospital, Seoul, Korea; [2]Department of Radiology, Seoul National University College of Medicine, Seoul, Korea; [3]Institute of Radiation Medicine, Seoul National University Medical Research Center, Seoul, Korea

Objective: To compare Octopus multipurpose (MP) electrodes, which are capable of saline instillation and direct tissue temperature measurement, and conventional electrodes for radiofrequency ablation (RFA) in porcine livers *in vivo*.

Materials and Methods: Sixteen pigs were used in this study. In the first experiment, RFA was performed in the liver for 6 minutes using Octopus MP electrodes (n = 15 ablation zones) and conventional electrodes (n = 12 ablation zones) to investigate the effect of saline instillation. The ablation energy, electrical impedance, and ablation volume of the two electrodes were compared. In the second experiment, RFA was performed near the gallbladder (GB) and colon using Octopus MP electrodes (n = 12 ablation zones for each) with direct tissue temperature monitoring and conventional electrodes (n = 11 ablation zones for each). RFA was discontinued when the temperature increased to > 60°C in the Octopus MP electrode group, whereas RFA was performed for a total of 6 minutes in the conventional electrode group. Thermal injury was assessed and compared between the two groups by pathological examination.

Results: In the first experiment, the ablation volume and total energy delivered in the Octopus MP electrode group were significantly larger than those in the conventional electrode group (15.7 ± 4.26 cm^3 vs. 12.5 ± 2.14 cm^3, $p = 0.027$; 5.48 ± 0.49 Kcal vs. 5.04 ± 0.49 Kcal, $p = 0.029$). In the second experiment, thermal injury to the GB and colon was less frequently noted in the Octopus MP electrode group than that in the conventional electrode group (16.7% [2/12] vs. 90.9% [10/11] for GB and 8.3% [1/12] vs. 90.9% [10/11] for colon, $p < 0.001$ for all). The total energy delivered around the GB (2.65 ± 1.07 Kcal vs. 5.04 ± 0.66 Kcal) and colon (2.58 ± 0.57 Kcal vs. 5.17 ± 0.90 Kcal) were significantly lower in the Octopus MP electrode group than that in the conventional electrode group ($p < 0.001$ for all).

Conclusion: RFA using the Octopus MP electrodes induced a larger ablation volume and resulted in less thermal injury to the adjacent organs compared with conventional electrodes.

Keywords: *Radiofrequency ablation; Octopus MP electrode; Conventional electrode; Ablation volume; Thermal injury*

INTRODUCTION

Radiofrequency ablation (RFA) is a potentially curative treatment for early-stage hepatocellular carcinoma (HCC) and a bridging therapy for patients awaiting liver transplantation [1-5]. Additionally, RFA is preferred over surgical resection for very early-stage HCC (single HCC < 2 cm), according to the Barcelona Clinic Liver Cancer Staging and Treatment Strategy Guidelines [5]. However, one of the major drawbacks of RFA is the high rate of local tumor progression (LTP) compared with that of surgical resection [6,7]. An important factor related to this limitation is the concentration of high-frequency current within 5 mm of the tissue around the electrode that causes an excessive increase in the impedance and charring around the electrode during RFA [8-10]. Moreover, a typical lesion

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Corresponding author: Jeong Min Lee, MD, Department of Radiology, Seoul National University Hospital, 101 Daehak-ro, Jongno-gu, Seoul 03080, Korea.
• E-mail: jmsh@snu.ac.kr

created by a linear RF electrode is elliptical in shape, with the major axis parallel to the electrode shaft [10]. However, malignant liver tumors could present irregular shapes rather than spherical or oval shapes, and controlling the short axis of the ablation zone to ensure complete ablation while minimizing unnecessary loss of functional hepatic parenchyma remains a challenge [11]. In addition, because RFA can ablate not only tumors but also adjacent liver parenchyma, complications may occur in the gallbladder (GB), biliary tract, stomach, and colon [12,13]. Therefore, while the creation of ablation zones conformable to the tumor index and safety margin is warranted, decreasing unnecessary thermal damage to adjacent vital structures is also considered crucial.

Considering studies on improving the efficiency of RF devices for creating ablation zones, several reports showed that an internally cooled wet electrode capable of perfusion of saline into the tissue during RFA could create a large ablation zone compared to conventional RF electrodes [14-16]. However, these perfusion electrodes have the risk of irregularly shaped ablation, distal heating, and ablation of non-tumor-containing areas; moreover, there is a possibility of organ damage if the tumor is located in the subcapsular region or adjacent to other internal organs [17,18]. In clinical practice, a large ablation zone with a perfusion electrode is not always beneficial for the management of malignant liver tumors [11].

Therefore, to improve the efficiency of creating a large ablation zone while preventing damage to adjacent organs, we developed new electrodes (Octopus multipurpose [MP]) that are composed of two separable electrodes with an adjustable active tip and a thin applicator with open holes, capable of both saline instillation and temperature measurements. In this study, we aimed to compare Octopus MP electrodes and conventional electrodes for RFA in porcine livers *in vivo*.

MATERIALS AND METHODS

This study was approved by our Institutional Animal Care and Use Committee, and all experiments were conducted following institutional guidelines (IACUC No. 20-0222-S1A0[1]).

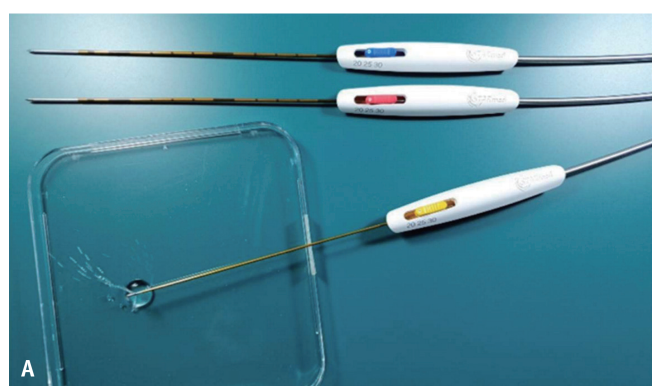
The RFA Equipment

A multichannel RF system was employed to deliver the RF energy in single-switching monopolar mode using two electrodes. RF energy (maximum 200 W) was applied to one of the two electrodes, which was switched between the two electrode tips of the separable clustered electrode based on tissue impedance changes. The new RF electrodes, Octopus MP (Octopus electrode; STARmed), used a thin applicator with open holes capable of both saline instillation (19 gauge) and temperature measurements and two internally cooled electrodes (17 gauge). These cooled electrodes had a 2.5-cm long adjustable active tip (Fig. 1) that can be used by adjusting the active tip length according to the size of the target. The saline applicator/temperature probe does not participate in active ablation (Fig. 1). Temperature sensing monitors the actual temperature of probe and measures the temperature displayed in the multichannel RF system.

Since the impedance rise starts 2 minutes after the start of ablation, chilled normal saline was infused into the lumen of the applicator to lower the impedance at a rate of 0.5 mL/1 min from minute 2 until the end of the ablation (6 minutes). A peristaltic pump (VIVA Pump; STARmed) was used to keep the tip temperature below 25°C. Technical parameters, including the average power output, electrical impedance, applied current, and total energy delivered, were continuously monitored and recorded using monitoring software (VIVA Monitor Software V 1.0; STARmed).

Anesthesia and Surgery in Animals

Sixteen male pigs (mean weight, 65 kg; range, 60–70 kg)



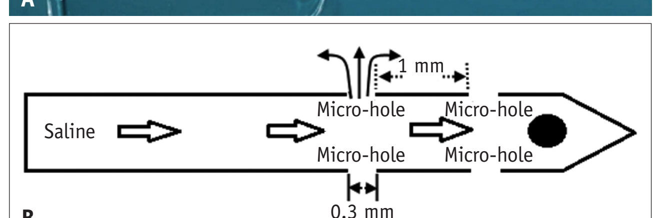


Fig. 1. Prototype Octopus multipurpose electrodes (A) and diagram of the thin applicator (B).

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were used in the *in vivo* studies. Animals were sedated by intramuscular administration of zolazepam (5 mg/kg, Zoletil; Virbac) and xylazine (10 mg/kg; Rompun, Bayer-Schering Pharma), intubated and ventilated during the experiments. Anesthesia was maintained with 1%–4% isoflurane (IsoFlo1, Abbott Laboratories) inhalation in pure oxygen gas with mechanical ventilation. Before the midline incision, the pigs were placed in the supine position and draped sterile. One of the authors (with three years of experience in RFA experiments) performed the ablation procedures under the guidance of ultrasonography (6–12 MHz linear transducer; Accuvix XQ; Medison). The vital signs of the animals, including the pulse rate, electrocardiogram, and temperature, were carefully monitored during the entire procedure.

In Vivo Experimental Setting

We performed two *in vivo* experiments to compare the efficiency and safety of RFA techniques in porcine liver using Octopus MP electrodes. Two ablation zones for saline instillation experiments and four ablation zones for temperature measurement experiments were generated in the liver of each animal. Therefore, 96 ablation zones were created in 16 pigs.

Experiment 1 compared the feasibility and efficiency of saline instillation using the Octopus MP electrode by assessing the ablation zone. In this experiment, the pigs were divided into two groups: the Octopus MP electrode with saline instillation (n = 16) and the conventional electrode group (n = 16). In the Octopus MP electrode group, saline was instilled between the two electrodes, and ablation was performed for 6 minutes each. In both groups, clustered separable electrodes were inserted into the liver parenchyma through a triangular acryl plate containing multiple holes to maintain an interelectrode distance of 2 cm (Fig. 2).

Experiment 2 was conducted to evaluate the safety of the Octopus MP electrode by measuring the temperature. In this experiment, the pigs were divided into two groups: the Octopus MP group (n = 16) and the conventional electrode group (n = 16). In the Octopus MP electrode group, ablation was immediately stopped after the tissue temperature reached 60°C. In the conventional electrode group, ablation was performed for 6 minutes without interruption. As a safety parameter, the presence of thermal injury in adjacent organs or structures, including the gallbladder (GB) and colon was controlled during the procedure. The Octopus MP applicator was inserted into the liver 1 cm away from the GB and colon (Fig. 2). The other two electrodes were inserted through the same acrylic plate used in Experiment 1, thereby ensuring an interelectrode distance of 2 cm and not exceeding 1.5 cm from the liver margin.

Ablation Protocols

In Experiment 1, RF energy was applied in single-switching monopolar mode for 6 minutes. The maximum delivered RF energy was 200 watts. In Experiment 2, the thermal injury was evaluated. The maximum RF energy and ablation times were the same as those used in Experiment 1.

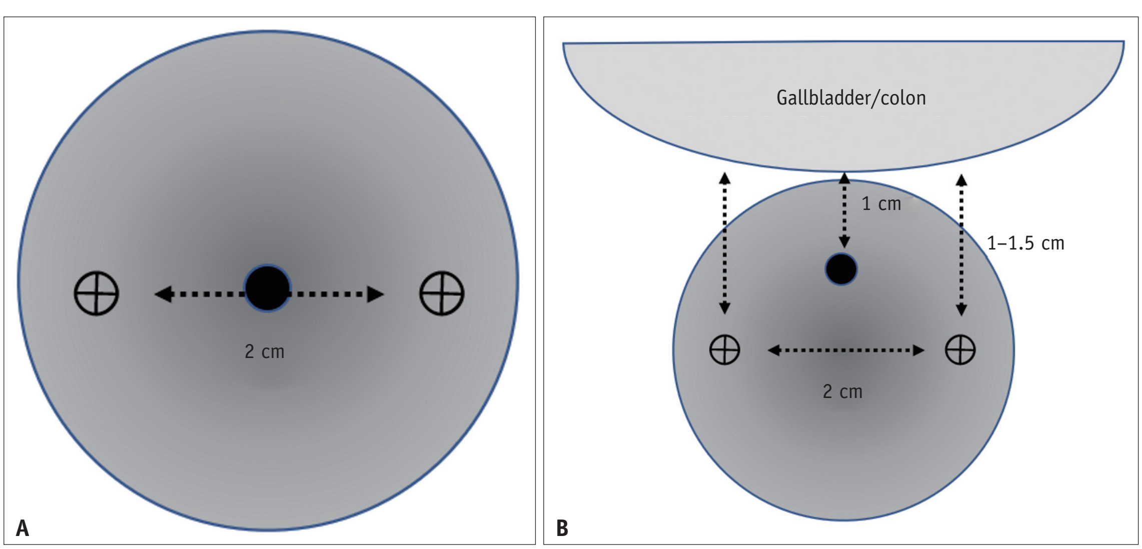

Fig. 2. Diagram for electrode positions for experiments 1 (A) and 2 (B). Black circle: saline instillation/temperature measurement electrode. Cross circle: active ablation electrode.

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Assessment of the Ablation Zone

All animals were euthanized by intravenous injection of potassium chloride immediately after the RFAs. The livers were removed *en bloc*, and liver segments with ablation zones were excised along the electrode tract and were subsequently sliced in the transverse plane perpendicular to the electrode tract axis at 5–7 mm intervals such that the sections included the largest areas of the ablation zone. To prevent any bias in the ablation size measurements, the slices were photographed beside a ruler on a copy stand using a digital camera (Nikon Coolpix S6900; Nikon Inc.). Two observers (a technician with 3 and 5 years of experience in RFA experiments, respectively) measured the vertical diameter (Dv) in the vertical plane and the long-axis diameter (Dmx) and short-axis diameter (Dmi) of the RF-induced ablation zones at the transverse plane with the maximum area in consensus [19]. The ablation volume was calculated using the following formula: π (Dv x Dmx x Dmi)/6.

Assessment of Thermal Injury

Thermal injury to the adjacent organs was evaluated as a safety parameter. After sacrificing the animals, GB and colon were resected and fixed in a 40 g/L formaldehyde solution. Specimens were cut into 3-mm thick slices, embedded in paraffin, and stained with hematoxylin and eosin for analysis under a light microscope. The slides were then reviewed to determine the presence and depth of thermal injury.

Statistical Analysis

For each ablation, the results are presented as mean ± standard deviation (SD). Technical parameters were compared using the *t* test. The rate of thermal injury was compared using the chi-square test. For all statistical analyses, p values < 0.05 were considered statistically significant using the MedCalc statistical software (version 20.0; MedCalc Software).

RESULTS

Comparison between the Octopus MP and Conventional Electrode Groups in Experiment 1

We excluded one ablation zone in the Octopus MP electrode group and four ablation zones in the conventional electrode group owing to the perivascular location of the large vessels (> 3 mm). Therefore, 15 and 12 ablation zones in the Octopus MP and conventional electrode groups, respectively, were included. The ablation volume (15.7 ± 4.26 cm^3 vs. 12.5 ± 2.14 cm^3), the Dv of the ablative zone (3.10 ± 0.56 cm vs.2.57 ± 0.27 cm), and the total energy delivered (5.48 ± 0.49 Kcal vs. 5.04 ± 0.49 Kcal) were significantly higher in the Octopus MP electrode group than in the conventional electrode group (p = 0.027, 0.005, 0.029, respectively). The mean electrical impedance of the Octopus MP electrode group was significantly lower than that of the conventional electrode group (74.1 ± 4.01 Ω vs. 80.5 ± 10.0 Ω, p = 0.047) (Table 1, Fig. 3).

Comparison between the Octopus MP Electrode and Conventional Electrode Groups in Experiment 2

In eight procedures in the Octopus MP electrode group and ten in the conventional electrode group, the ablation zones passed through a large vessel. These ablations were excluded from the results because the ablation volume and time to reach 60°C were affected by the heat sink effect. Therefore, 12 ablations for each anatomical location (i.e., either near the GB or the colon) were analyzed in the Octopus MP electrode group, and 11 for each location were analyzed in the conventional electrode group. The total energy delivered around the GB (2.65 ± 1.07 Kcal vs. 5.04 ± 0.66 Kcal) and colon (2.58 ± 0.57 Kcal vs. 5.17 ± 0.90 Kcal)

Table 1. Comparison of Technical Parameters between Octopus MP Electrode with Saline Instillation and Conventional Electrode in the First Experiment

Parameters	Octopus MP Electrode (n = 15)	Conventional Electrode (n = 12)	*P*
Total energy delivered, Kcal	5.48 ± 0.49	5.04 ± 0.49	0.029
Impedance, Ω	74.1 ± 4.01	80.5 ± 10.0	0.047
Dmx, cm	3.97 ± 0.48	3.68 ± 0.37	0.109
Dmi, cm	2.41 ± 0.33	2.53 ± 0.18	0.282
Dv, cm	3.10 ± 0.56	2.57 ± 0.27	0.005
Ablation volume, cm^3	15.7 ± 4.26	12.5 ± 2.14	0.027

Data are mean ± standard deviation. Dmi = minimum diameter of the ablative zone, Dmx = maximal diameter of the ablative zone, Dv = vertical diameter of the ablative zone, MP = multipurpose

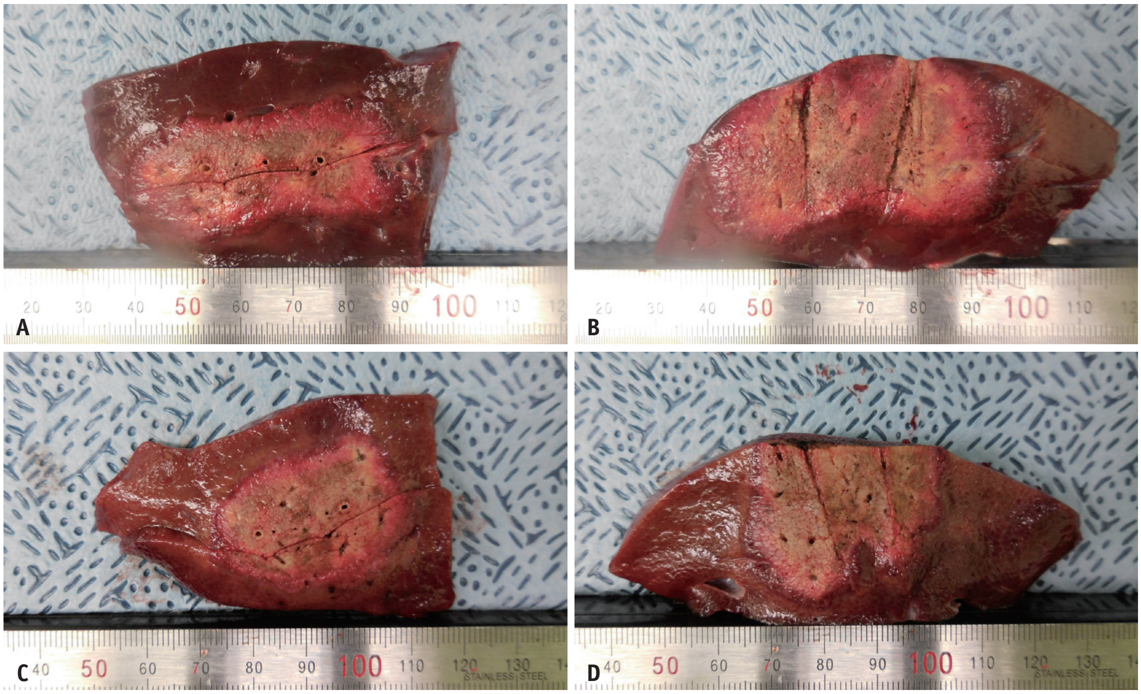

Fig. 3. Photographs showing transverse planes of the specimen for experiments 1.
A, B. Saline instillation, ablation volume = 18.8 cm^3. **C, D.** Without saline instillation, ablation volume = 11.4 cm^3.

were significantly lower in the Octopus MP electrode group than in the conventional electrode group ($p < 0.001$, 0.001, respectively). There were no significant differences in the ablation volume among the groups (13.1 ± 6.81 cm^3 vs. 16.4 ± 5.98 cm^3, $p = 0.227$; 14.4 ± 4.4 cm^3 vs. 13.7 ± 3.51 cm^3, $p = 0.665$, respectively). The other size parameters, including diameter, were not significantly different between the groups (Table 2). The average time to reach 60°C was 172.7 ± 68 seconds in the ablation around the GB and 165.5 ± 54 seconds around the colon. Thermal injury to the adjacent GB and colon was less frequently noted in the Octopus MP electrode group than in the conventional electrode group (16.7% [2/12] vs. 90.9% [10/11], $p <$ 0.001; 8.3% [1/12] vs. 90.9% [10/11], $p < 0.001$) (Table 2, Fig. 4).

DISCUSSION

Our *in vivo* study demonstrated that RFA using the Octopus MP electrode is capable of saline instillation and direct tissue temperature measurement, showing better efficiency in creating ablation zones, and a better safety profile than RFA using a conventional internally cooled electrode. The total energy delivered and ablation volume of RFA using the Octopus MP electrodes with saline perfusion were significantly larger than those with the conventional electrode. In contrast, the electrical impedance was significantly lower in the Octopus MP electrode group than that in the conventional electrode group. In addition, in the second set of RF experiments, thermal injury to the adjacent organs was also significantly lower in the octopus MP electrode group with direct tissue temperature measurements than that in the conventional electrode group. To improve the efficiency of achieving an ablation zone for treating liver malignancies while avoiding complications, RF electrodes should ideally allow the following features: 1) complete ablation of the lesion and the surrounding margin, 2) sparing of the neighboring organs from the risk of thermal injury, 3) reduction of the damage of normal tissue, and 4) accomplishment of all the above features through one session of percutaneous insertion [20]. Based on our study results, we believe that RFA using Octopus MP electrodes may contribute to producing ablation zones conformable to the index tumor and safety margin while decreasing unnecessary thermal damage to adjacent vital structures.

In the first experiment, the mean ablation volume of RFA using the Octopus MP electrodes with saline perfusion was significantly larger than that using the conventional electrode. Several studies have demonstrated that LTP

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Table 2. Comparison of Technical Parameters between Octopus MP Electrode with Temperature Measurement and Conventional Electrode in the Second Experiment

	Octopus MP Electrode (n = 12)	Conventional Electrode (n = 11)	*P*
For ablation near the GB			
Total energy delivered, Kcal	2.65 ± 1.07	5.04 ± 0.66	< 0.001
Impedance, Ω	78 ± 8.74	74.2 ± 7.86	0.296
Dmx, cm	3.68 ± 0.66	3.97 ± 0.29	0.180
Dmi, cm	2.31 ± 0.55	2.44 ± 0.47	0.580
Dv, cm	2.81 ± 0.52	3.16 ± 0.59	0.142
Ablation volume, cm^3	13.1 ± 6.81	16.4 ± 5.98	0.227
Time to reach 60°C, sec	172.7 ± 68		
Thermal injury	2 (16.7)	10 (90.9)	< 0.001
For ablation near the colon			
Total energy delivered, Kcal	2.58 ± 0.57	5.17 ± 0.90	< 0.001
Impedance, Ω	84 ± 10.8	82.3 ± 8.15	0.661
Dmx, cm	3.93 ± 0.36	3.85 ± 0.36	0.585
Dmi, cm	2.31 ± 0.49	2.26 ± 0.29	0.360
Dv, cm	2.96 ± 0.38	2.96 ± 0.39	0.987
Ablation volume, cm^3	14.4 ± 4.4	13.7 ± 3.51	0.665
Time to reach 60°C, sec	165.5 ± 54		
Thermal injury	1 (8.3)	10 (90.9)	< 0.001

Data are mean ± standard deviation except for thermal injury for which the data are number of ablation zones (%). Dmi = minimum diameter of the ablative zone, Dmx = maximal diameter of the ablative zone, Dv = vertical diameter of the ablative zone, GB = gallbladder, MP = multipurpose

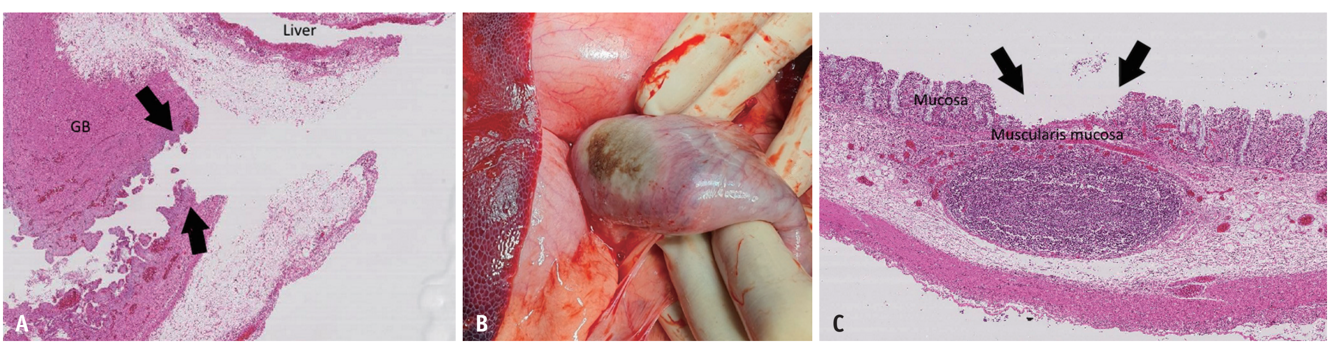

Fig. 4. GB specimen and colon specimen from the conventional electrode group, experiments 2.
A. GB perforation is occured (arrows, perforation site) (H&E stain, x 100) **B.** The colon gross specimen shows thermal injury to the mucosa. **C.** Mucosal ulceration and injury to muscularis mucosa are present in colon (arrows, injury to muscularis mucosa) (H&E stain, x 100). GB = gallbladder, H&E = hematoxylin and eosin

is significantly lowered if a safety margin of > 5 mm around the index tumor is achieved [21,22]; therefore, a large ablation zone is indispensable in RFA [23]. In our study, the RF energy was significantly higher in the Octopus MP electrode group with saline perfusion than in the conventional electrode group, while the electrical impedance was significantly lower. In the case of the conventional Octopus electrode, a larger ablation zone can be created by switching to monopolar mode compared to consecutive overlapping ablations [24]. However, because the high-frequency current is concentrated within 5 mm of the tissue around the electrodes, increased charring and high impedance may occur, resulting in inefficient RF energy delivery [9]. Therefore, if the efficiency of the energy delivered is increased by lowering the impedance with saline perfusion, a larger ablation zone can be created and achieve low LTP [25,26]. In our results, when saline instillation was performed through the Octopus MP electrode, the impedance was significantly lower than that of the conventional electrode, which increased the total energy delivered, making it possible to create a large ablation zone.

In the second experiment, we tested the value of direct tissue temperature monitoring during RFA using Octopus MP electrodes by inserting a temperature-sensing applicator around critical organs, such as the GB or colon. The injury to the adjacent GB and colon was less frequently noted in the Octopus MP electrode group than in the conventional electrode group (16.7% [2/12] vs. 90.9% [10/11], 8.3% [1/12] vs. 90.9% [10/11], $p < 0.001$ for all). In the experimental setting, the tissue temperature near the critical organs was measured in real-time using one of the Octopus MP electrodes. and RF energy application was terminated when tissue temperature around the adjacent critical organs was over 60°C. We selected 60°C as the cutoff value because, tumor cells suffer necrosis when a temperature of 60°C or higher is reached and the effect of RFA can be maximized [9,12]; however, if thermal injury occurs in an adjacent organ, there is a higher probability of complication. In this respect, when the ablation zone of the Octopus MP group with temperature sensing was compared with that of the group that underwent RFA for 6 minutes without temperature sensing, no statistically significant difference was observed in ablation volume. Therefore, a higher level of safety could be ensured using the Octopus MP electrodes.

Other potential advantages of the Octopus MP electrodes should be considered. First, as there are two electrodes with adjustable active tip lengths the system can be used for no-touch ablation. Several recent studies have demonstrated better local tumor control of liver malignancies with this approach than conventional tumor puncture techniques, either through percutaneous or laparoscopic approaches [27-29]. Second, since the active tips of the two electrodes are adjustable from 1 cm to 3 cm with a 5 mm step variable, Octopus MP electrodes could be useful in treating asymmetric and ovoid-shaped tumors, especially those with variable diameters that require active tips of different lengths. In addition, these electrodes can be used for the ablation of multiple tumors of different sizes by adjusting the length of the exposed active tip [11]. Finally, Octopus MP electrodes can be used to avoid damage to the adjacent organs by creating a non-spherical ablation volume using different lengths of the active tips [30].

This study has several limitations. First, the feasibility and safety of the Octopus MP electrode were evaluated intraoperatively; therefore, we were unable to assess percutaneous RFA. Thus, the feasibility of using an Octopus MP electrode in percutaneous RFA should be evaluated. Second, this study tested a single-energy mode; thus, the results of the current study should be interpreted with caution. Third, this *in vivo* study was conducted using a relatively small number of animals. However, in this experiment, the effects of saline instillation and temperature measurements of the Octopus MP electrodes were confirmed. Fourth, we only tested the Octopus MP electrode with a single inter-electrode interval of 2 cm. Additional studies using larger inter-electrode intervals are warranted. Finally, RF ablation was not performed using a tumor mimicker. This prevented the evaluation of safety margins and technical success. However, because tumor mimickers possess different properties from the tissue texture of target tumors, their application in clinical practice is challenging.

In conclusion, our results demonstrated that the Octopus MP electrodes, which are capable of saline instillation and temperature measurement, induced lower electrical impedance, enabling a larger ablation volume and total energy delivery. Moreover, it demonstrated the potential to provide a better safety profile with less thermal injury to adjacent organs compared to conventional electrodes.

Availability of Data and Material

The datasets generated or analyzed during the study are available from the corresponding author on reasonable request.

Conflicts of Interest

Jeong Min Lee who is on the editorial board of the *Korean Journal of Radiology* was not involved in the editorial evaluation or decision to publish this article. All remaining authors have declared no conflicts of interest.

Author Contributions

Conceptualization: Sae-Jin Park, Jeong Min Lee. Data curation: Sae-Jin Park. Formal analysis: Sae-Jin Park. Funding acquisition: Jeong Min Lee. Investigation: Sae-Jin Park. Methodology: Sae-Jin Park, Jeong Hee Yoon. Project administration: Sae-Jin Park. Resources: Jae Hyun Kim. Software: Jae Hyun Kim. Supervision: Jeong Min Lee. Validation: Sae-Jin Park, Jeong Hee Yoon. Visualization: Sae-Jin Park. Writing—original draft: Sae-Jin Park. Writing—review & editing: Sae-Jin Park, Jeong Hee Yoon, Jeong Min Lee.

ORCID iDs

Sae-Jin Park
https://orcid.org/0000-0001-8580-3272

Jae Hyun Kim
https://orcid.org/0000-0002-6691-3932

Jeong Hee Yoon
https://orcid.org/0000-0002-9925-9973

Jeong Min Lee
https://orcid.org/0000-0003-0561-8777

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