ORIGINAL ARTICLE

Gut and Liver, Vol. 6, No. 4, October 2012, pp. 471-475

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

Mi-Hyun Park*, June-Sik Cho[†], Byung Seok Shin[†], Gyeong Sik Jeon[‡], Byungmo Lee[§], and Kichang Lee[||]

*Department of Radiology, Dankook University Hospital, Dankook University College of Medicine, Cheonan, [†]Department of Radiology, Chungnam National University Hospital, Chungnam National University School of Medicine, Daejeon, [‡]Department of Radiology, Bundang CHA Hospital, CHA University College of Medicine, Seongnam, [§]Department of Surgery, Inje University Seoul Paik Hospital, Inje University College of Medicine, Seoul, and [||]Department of Veterinary Radiology, Chonbuk National University College of Veterinary Medicine, Iksan, Korea

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 cm^3), followed by group C (1.22±0.47 cm^3), and then group A (0.48±0.33 cm^3). 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.[1,2] 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.[3-5] Sequentially overlapping single electrode ablation has been attempted for large hepatic tumors.[6] 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.[7] 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.[8-10] Recently another energy source such as microwave has been used for thermal ablation to treat large hepatic tumors.[11-13]

Saline administration is one of the strategies to expand the ablation zone by modulating the biologic environment of the treated tissue.[14-26] Saline infusion into tissue improves the electrical and thermal conductivity of tissue during RFA.[14] 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.[22-26] 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.[27-30] 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.

Correspondence to: June-Sik Cho
Department of Radiology, Chungnam National University Hospital, Chungnam National University School of Medicine, 282 Munhwa-ro, Jung-gu, Daejeon 301-721, Korea
Tel: +82-42-280-7333, Fax: +82-42-253-0061, E-mail: jscho@cnu.ac.kr
Received on August 6, 2011. Revised on December 3, 2011. Accepted on December 30, 2011. Published online on August 7, 2012.
pISSN 1976-2283 eISSN 2005-1212 http://dx.doi.org/10.5009/gnl.2012.6.4.471

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 (Big 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.

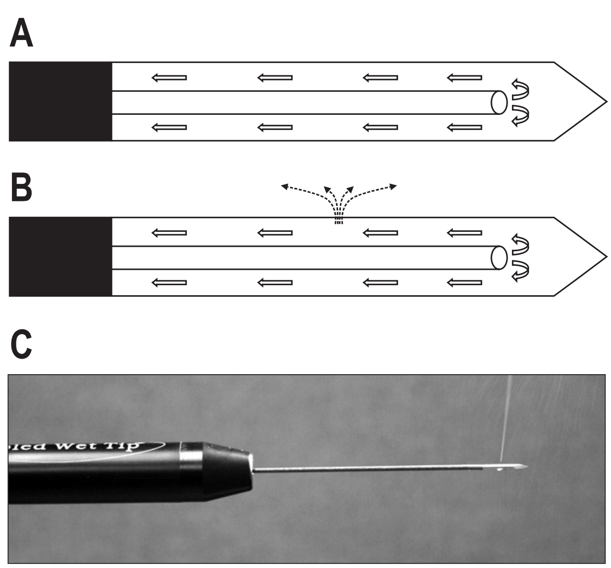

Fig. 1. The radiofrequency needle electrode system. (A) Diagram of the internally cooled electrode system. Chilled saline is circulated during ablation for internal cooling. The arrows indicate the direction of the saline flow. (B) Diagram of the internally cooled wet (ICW) electrode system. The microhole on the needle surface allows the saline to be infused into the tissue (dotted line). (C) Photograph showing an 18-gauge ICW electrode with a 1-cm active tip and a microhole on the needle electrode (Jet tip®) with a saline jet through the microhole.

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 Pharmceuticals, 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 A (n=4)	Group B (n=7)	Group C (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.

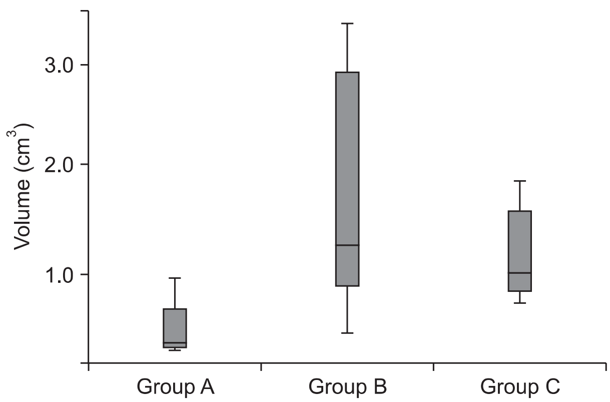

Fig. 2. Comparison of the radiofrequency ablation (RFA) zone volume between the groups. There were significant differences in the RFA zone volumes between groups A and B (p=0.030). There were no significant differences between groups B and C (p=0.827) or between groups A and C (p=0.079). The volume of 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: 1/6×π×T long×T max×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.

Table 2. Comparison of the Radiofrequency Ablation Zone

	Group A (n=4)	Group B (n=7)	Group C (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±0.33†,‡	1.82±1.23*	1.22±0.47*
Sphericity	0.71±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.

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 cm^3), followed by the group C (1.22±0.47 cm^3), and then the group A (0.48±0.33 cm^3). The mean ablation zone volume in the groups B were 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.[14-26] The ICW electrode with the microholes is capable of internally cooling the electrode and simultaneously infusing saline into the hepatic tissue during RFA.[24-26] 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. Therefore, 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*.[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.[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.[31-34] 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.[35,36] 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*.[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.

REFERENCES

1. Poon RT, Fan ST, Tsang FH, Wong J. Locoregional therapies for hepatocellular carcinoma: a critical review from the surgeon's perspective. Ann Surg 2002;235:466-486.
2. Tateishi R, Shiina S, Teratani T, et al. Percutaneous radiofrequency ablation for hepatocellular carcinoma. An analysis of 1000 cases. Cancer 2005;103:1201-1209.
3. Solbiati L, Goldberg SN, Ierace T, et al. Hepatic metastases: percutaneous radio-frequency ablation with cooled-tip electrodes. Radiology 1997;205:367-373.
4. Livraghi T, Goldberg SN, Lazzaroni S, et al. Hepatocellular carcinoma: radio-frequency ablation of medium and large lesions. Radiology 2000;214:761-768.
5. de Baere T, Elias D, Dromain C, et al. Radiofrequency ablation of 100 hepatic metastases with a mean follow-up of more than 1 year. AJR Am J Roentgenol 2000;175:1619-1625.
6. Dodd GD 3rd, Frank MS, Aribandi M, Chopra S, Chintapalli KN. Radiofrequency thermal ablation: computer analysis of the size of the thermal injury created by overlapping ablations. AJR Am J Roentgenol 2001;177:777-782.
7. Goldberg SN, Gazelle GS. Radiofrequency tissue ablation: physical principles and techniques for increasing coagulation necrosis. Hepatogastroenterology 2001;48:359-367.
8. Haemmerich D, Lee FT Jr, Schutt DJ, et al. Large-volume radiofrequency ablation of ex vivo bovine liver with multiple cooled cluster electrodes. Radiology 2005;234:563-568.
9. Lee FT Jr, Haemmerich D, Wright AS, Mahvi DM, Sampson LA, Webster JG. Multiple probe radiofrequency ablation: pilot study in

an animal model. J Vasc Interv Radiol 2003;14:1437-1442.

10. Laeseke PF, Sampson LA, Haemmerich D, et al. Multiple-electrode radiofrequency ablation creates confluent areas of necrosis: in vivo porcine liver results. Radiology 2006;241:116-124.
11. Strickland AD, Clegg PJ, Cronin NJ, et al. Experimental study of large-volume microwave ablation in the liver. Br J Surg 2002;89:1003-1007.
12. Wright AS, Lee FT Jr, Mahvi DM. Hepatic microwave ablation with multiple antennae results in synergistically larger zones of coagulation necrosis. Ann Surg Oncol 2003;10:275-283.
13. Aramaki M, Kawano K, Ohno T, et al. Microwave coagulation therapy for unresectable hepatocellular carcinoma. Hepatogastroenterology 2004;51:1784-1787.
14. Goldberg SN, Ahmed M, Gazelle GS, et al. Radio-frequency thermal ablation with NaCl solution injection: effect of electrical conductivity on tissue heating and coagulation-phantom and porcine liver study. Radiology 2001;219:157-165.
15. Ahmed M, Lobo SM, Weinstein J, et al. Improved coagulation with saline solution pretreatment during radiofrequency tumor ablation in a canine model. J Vasc Interv Radiol 2002;13:717-724.
16. Lee JM, Kim YK, Lee YH, Kim SW, Li CA, Kim CS. Percutaneous radiofrequency thermal ablation with hypertonic saline injection: in vivo study in a rabbit liver model. Korean J Radiol 2003;4:27-34.
17. Schmidt D, Trübenbach J, Brieger J, et al. Automated saline-enhanced radiofrequency thermal ablation: initial results in ex vivo bovine livers. AJR Am J Roentgenol 2003;180:163-165.
18. Hänsler J, Frieser M, Schaber S, et al. Radiofrequency ablation of hepatocellular carcinoma with a saline solution perfusion device: a pilot study. J Vasc Interv Radiol 2003;14:575-580.
19. Kettenbach J, Köstler W, Rücklinger E, et al. Percutaneous saline-enhanced radiofrequency ablation of unresectable hepatic tumors: initial experience in 26 patients. AJR Am J Roentgenol 2003;180:1537-1545.
20. Lee JM, Han JK, Kim SH, et al. Comparison of wet radiofrequency ablation with dry radiofrequency ablation and radiofrequency ablation using hypertonic saline preinjection: ex vivo bovine liver. Korean J Radiol 2004;5:258-265.
21. Lobo SM, Afzal KS, Ahmed M, Kruskal JB, Lenkinski RE, Goldberg SN. Radiofrequency ablation: modeling the enhanced temperature response to adjuvant NaCl pretreatment. Radiology 2004;230:175-182.
22. Lee JM, Han JK, Chang JM, et al. Radiofrequency ablation of the porcine liver in vivo: increased coagulation with an internally cooled perfusion electrode. Acad Radiol 2006;13:343-352.
23. Kim SK, Gu MS, Hong HP, Choi D, Chae SW. CT findings after radiofrequency ablation in rabbit livers: comparison of internally cooled electrodes, perfusion electrodes, and internally cooled perfusion electrodes. J Vasc Interv Radiol 2007;18:1417-1427.
24. Ni Y, Miao Y, Mulier S, Yu J, Baert AL, Marchal G. A novel “cooled-wet” electrode for radiofrequency ablation. Eur Radiol 2000;10:852-854.
25. Miao Y, Ni Y, Yu J, Marchal G. A comparative study on validation of a novel cooled-wet electrode for radiofrequency liver ablation. Invest Radiol 2000;35:438-444.
26. Cha J, Choi D, Lee MW, et al. Radiofrequency ablation zones in ex vivo bovine and in vivo porcine livers: comparison of the use of internally cooled electrodes and internally cooled wet electrodes. Cardiovasc Intervent Radiol 2009;32:1235-1240.
27. Chinn SB, Lee FT Jr, Kennedy GD, et al. Effect of vascular occlusion on radiofrequency ablation of the liver: results in a porcine model. AJR Am J Roentgenol 2001;176:789-795.
28. Patterson EJ, Scudamore CH, Owen DA, Nagy AG, Buczkowski AK. Radiofrequency ablation of porcine liver in vivo: effects of blood flow and treatment time on lesion size. Ann Surg 1998;227:559-565.
29. Curley SA, Izzo F, Delrio P, et al. Radiofrequency ablation of unresectable primary and metastatic hepatic malignancies: results in 123 patients. Ann Surg 1999;230:1-8.
30. Wiersinga WJ, Jansen MC, Straatsburg IH, et al. Lesion progression with time and the effect of vascular occlusion following radiofrequency ablation of the liver. Br J Surg 2003;90:306-312.
31. Denys AL, De Baere T, Mahe C, et al. Radio-frequency tissue ablation of the liver: effects of vascular occlusion on lesion diameter and biliary and portal damages in a pig model. Eur Radiol 2001;11:2102-2108.
32. de Baère T, Risse O, Kuoch V, et al. Adverse events during radiofrequency treatment of 582 hepatic tumors. AJR Am J Roentgenol 2003;181:695-700.
33. Kim SK, Lim HK, Ryu JA, et al. Radiofrequency ablation of rabbit liver in vivo: effect of the pringle maneuver on pathologic changes in liver surrounding the ablation zone. Korean J Radiol 2004;5:240-249.
34. Ng KK, Lam CM, Poon RT, Shek TW, Fan ST, Wong J. Delayed portal vein thrombosis after experimental radiofrequency ablation near the main portal vein. Br J Surg 2004;91:632-639.
35. Sugimori K, Nozawa A, Morimoto M, et al. Extension of radiofrequency ablation of the liver by transcatheter arterial embolization with iodized oil and gelatin sponge: results in a pig model. J Vasc Interv Radiol 2005;16:849-856.
36. Iwamoto T, Kawai N, Sato M, et al. Effectiveness of hepatic arterial embolization on radiofrequency ablation volume in a swine model: relationship to portal venous flow and liver parenchymal pressure. J Vasc Interv Radiol 2008;19:1646-1651.