Radiofrequency ablation has been used recently as an alternative minimally invasive therapy for treatment of primary and secondary liver tumors [1–4]. One remaining challenge for the successful thermal ablation of large tumors, including liver tumors, is the diameter of necrosis that can be created with a single radiofrequency application. Further optimization of constant tissue heating is necessary to maximize the coagulation volume. Modulation of the tissue environment is a promising strategy by which to reach this aim. Cooling the needle has proven to significantly increase the size of necrosis compared with using conventional electrodes [2]. However, the effect of preventing overheating in the area around an internally cooled active electrode is limited.

The purpose of our ex vivo experiments was to determine the effects of continuous saline solution flow during radiofrequency ablation to increase the size of lesions in relation to the applied power using an automated impedance-controlled electrode perfused to the outside.

Materials and Methods

All experiments were performed at sites (n = 408) of fresh ex vivo bovine livers at room temperature. We used an open perfused electrode; the flow rate of the saline solution (0.9% NaCl) was determined automatically on the basis of the pre-selected power setting and ranged between 38 and 120 mL/hr. A syringe pump (Pilot C; Fresenius Vial, Brezins, France) connected to the radiofrequency generator provided the continuous saline solution flow through the six micropores of the active part (diameter, 2.0 mm; tip exposure, 1.5 cm) of the electrode (Fig. 1). For each application, the electrodes were inserted at least 4 cm into the liver.

We also used an impedance-controlled monopolar radiofrequency generator (Elektrotom HiTT 106 [375 kHz]; Berchtold, Tuttlingen, Germany) with a maximum power of 60 W. As a result of the automatically regulated application of radiofrequency power, a power curve was generated in the low impedance range between 100 and 350 W. For example, when an increase of more than 350 W occurred, the radiofrequency power was automatically decreased in accordance with a constant voltage curve to guarantee the lower impedance range. If the impedance exceeded the programmed value of 700 ± 50 W, radiofrequency power was reduced to 5 W until the impedance had decreased to less than 400 ± 50 W. Then the higher power—the nominal power that was selected before beginning—was switched on again to continue the power curve in the lower impedance range of 300 ± 100 W. This control automatically regulated heat in the biotissue during a constant flow of saline solution. If the impedance exceeded 900 ± 50 W, the automated remote control of the syringe pump released a bolus of 1.2 sec duration with five times the value of the nominal flow. For example, if the continuous saline solution flow for a power of 40 W was set to 90 mL/hr, a bolus of 0.15 mL of saline was added into the tissue. This bolus was permitted only within time intervals of 5 sec in the case of increased tissue impedance.

Moreover, the power (range, 5–60 W) and the ablation time (range, 2–60 min) were varied to examine the combined effects of saline solution flow, power, and ablation time. After radiofrequency ablation, the lesion was measured macroscopically by two investigators. For this measurement, the ablated liver site was cut in two pieces along the electrode track.

Histopathologic investigations of the ablation zones, as described by Patterson et al. [5], helped us differentiate between the area of coagulation necrosis and the area of normal liver tissue. We measured the lesions with different diameters for the short and long axes because the geometry, not only the volume, of the induced lesion is important for the success of tumor ablation.

Results

We observed that a power setting of between 40 and 60 W and an ablation time of up to 40 min are the optimal parameters with which to create reproducible lesions. As a control, radiofrequency ablation without saline solution was performed; in this group of lesions, the short-axis and long-axis diame-
ters of coagulative necrosis were the smallest (mean ± SD, 1.1 ± 0.2 cm). An increase in the size of the induced lesion correlated with an increase in the volume of saline solution and an increase in power and ablation time up to a power of 30 W (rate of saline solution flow, 75 mL/hr). None of the lesions enlarged more than 5.6 ± 0.5 cm (mean maximum short-axis diameter ± SD) with a power setting of between 30 and 60 W and an ablation time of 60 min (Fig. 2).

The most homogeneous and spherical lesions were observed when a power setting of between 40 and 60 W (saline solution flow rate: range, 90–120 mL/hr) was used with a maximum energy deposition of between 120 and 190 kJ. The lesions produced with lower power (<40 W) and shorter ablation times (<30 min) were more elliptical than the others. In 57% of all our experiments, the shape of necrosis was irregular, especially if several vessels were located in the ablated area. The phenomenon of charring around the electrode tip was observed in 30% of the cases when a power setting of between 50 and 60 W was used.

The maximum short-axis diameter (5.6 cm) of a lesion was observed when the perfused electrode was used with a power setting of 30 W and an ablation time of 50 min. The long-axis diameter of this lesion was 5.7 cm (Fig. 3). Increasing the power from 30 to 60 W did not create a clinically relevant increase in the short-axis diameters of necrosis; however, the lesions created at the higher power setting were more homogeneous and the shape of the necrotic area was more uniform, especially when an ablation time of up to 50 min was used (Fig. 4).

Discussion

Radiofrequency ablation is a promising alternative treatment for patients with malignant liver tumors [1]. However, in a long-term study of percutaneous radiofrequency ablation of liver metastases in patients with colorectal liver metastases, investigators have reported a local tumor recurrence in 39% of the cases because of an insufficient ablation of pathologic tissue [4]. Some investigators have reported encouraging results in terms of increasing the size of the induced lesion using electrodes with expandable hooks or clus-
Radiofrequency Thermal Ablation

Modulation of the tissue environment during radiofrequency ablation is an interesting strategy of optimization because increasing electrical conductivity inside the tissue leads to an improvement of heat transfer with the subsequent enlargement of the area of coagulation necrosis [6, 7]. We observed that the use of saline solution (0.9% NaCl) increases the short-axis diameter of necrosis in a reproducible way up to a maximum of 5.6 cm (SD ± 0.5 cm) for ablation times of up to 60 min. When impedance-controlled internally cooled electrodes are used in combination with high power (200 W), a given short-axis diameter of coagulation (4.5 cm) can be induced in less than 15 min [8]. Although we observed that more time was needed to create lesions of equal size when using open perfused electrodes, we found that the lesions created with the open perfused electrodes were more homogeneous because of the effects of the boiling saline solution.

Another advantage of using open perfused electrodes is that this electrode has a smaller diameter than cluster electrodes and expandable hooks; this feature is helpful for percutaneous approaches. Most radiofrequency devices propagate power of up to 200 W, but treatment with less power may be safer for patients. Using a power of 60 W, we induced homogeneous lesions that were similar in size to those produced with other radiofrequency devices. An explanation for our findings could be that the continuously applied current may work more effectively because the increased movements of ions in a higher concentration allow improved tissue heating and higher energy deposition, respectively. Furthermore, the impedance-controlled application of saline solution and power together with the high current density in the area of a 1.5-cm electrode tip may optimize the tissue heating to create more reproducible lesions.

In vivo experiments with saline-enhanced radiofrequency ablation are necessary because few investigators have described this technique. In addition, the rate of major complications, especially for patients with different liver tumors, should be studied and has not, to our knowledge, been evaluated yet [6]. Theoretically, the in vivo removal of infused saline by blood flow is possible; if so, then the number and size of vessels in an ablated area may influence the predicted size and shape of the area of coagulation necrosis [5]. In conclusion, open perfused electrodes can induce homogeneous and large areas of coagulative necrosis (up to 5.6 ± 0.5 cm) in ex vivo bovine liver; the shape of these areas is irregular and unpredictable. Further in vivo research will be necessary to determine the potential local and systemic effects of the boiling saline solution perfused into the tissue as a preparation for clinical trials.

References