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Technical note

A novel "cooled-wet" electrode for radiofrequency ablation

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Abstract. In the light of growing demands for improved applicability of radiofrequency ablation (RFA), recently we have developed a novel "cooled-wet" electrode by taking the advantages of both internally cooled and saline-enhanced electrodes. The efficacy of the electrode was evaluated in both ex vivo and in vivo liver RFA under both low and high power output levels. The ablation volume created with the "cooled-wet" electrode appeared to be much larger than that reported up to now with the use of other monopolar electrodes. The mechanisms on how this device optimizes the RF energy delivery are also discussed.

Key words: Liver – Interventional procedure – Radiofrequency ablation – Electrode

Introduction

During recent years, radiofrequency ablation (RFA) has emerged as a promising minimally invasive therapy for liver malignancies. However, limited ablation volume still remains a bottleneck compromising broader applicability of this therapy. Many strategies including the use of bipolar [1], saline enhanced [2, 3,4], internally cooled [5,6], expandable [7], and clustered-cooled [8] electrodes have been attempted to overcome this problem. Recently, we have developed a novel monopolar yet multifunctional "cooled-wet" electrode by combining the advantages of both internally cooled and saline enhanced electrode [9]. The design, mechanism and validation of this device are introduced in this short communication.

Materials and methods

Design of cooled-wet electrode

The present cooled-wet electrode features simultaneous intra-electrode cooling perfusion and interstitial electrolytic liquid infusion. This 18-gauge electrode contains two coaxial lumina that enable the circulation of cooling water through the electrode and a separate channel for saline interstitial infusion (Fig. 1).

RFA setting

Radiofrequency current (480 kHz) was generated from an RFG-3 E RF generator (Radionics, Burlington, MA, USA) and delivered from the electrode into the liver under power control mode predetermined for 10 minutes. Cooling perfusion (40 ml/min) and 5 % saline infusion (1 ml/min) were applied by using separate pumps. The power output was set at low (50 watts) and high (90 watts) levels for ex vivo (excised beef liver) and at low (90 watts) and high (150 watts) levels for in vivo (12 swine weighing 50–60 kg) experiments respectively. For evaluation of the efficacy of this electrode, 20 RFA lesions each were thus created in four groups of different power output levels.

Quantification in the experiment

After RFA, the liver was sectioned across the ablation site either perpendicular to the electrode (ex vivo study) or along the needle track (in vivo study). The maximal transverse diameter of each lesion was measured. Other parameters including impedance, power output, current, and tip temperature were also documented.

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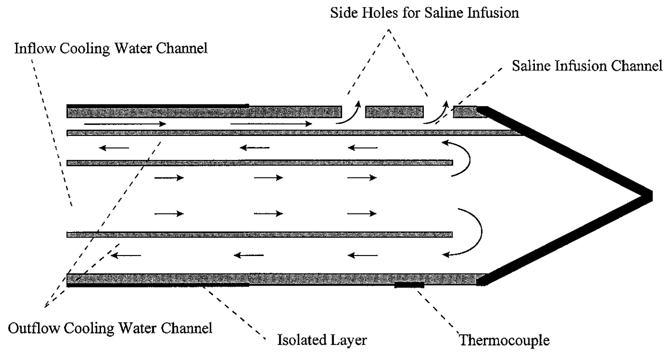

Fig. 1. Illustration of the "cooled-wet" electrode

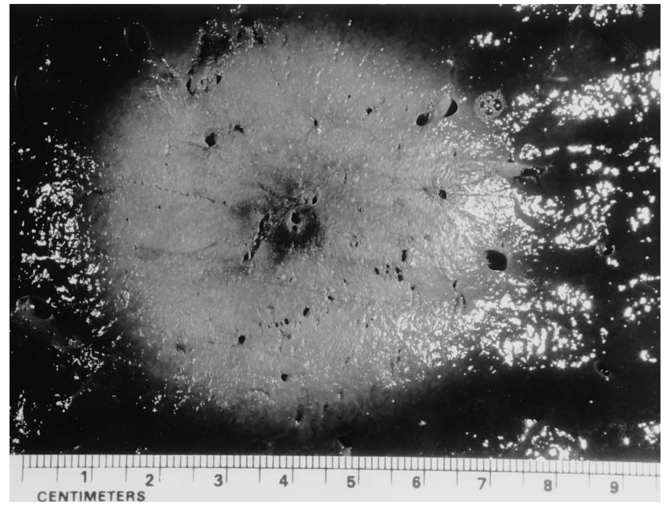

Fig. 2. Transverse section of a radiofrequency ablation (RFA) lesion created on excised beef liver with a cooled-wet electrode at 90 W for 10 min in ex vivo experiment. The pale coagulation lesion is well demarcated, pretty spherical and over 6 cm in diameter

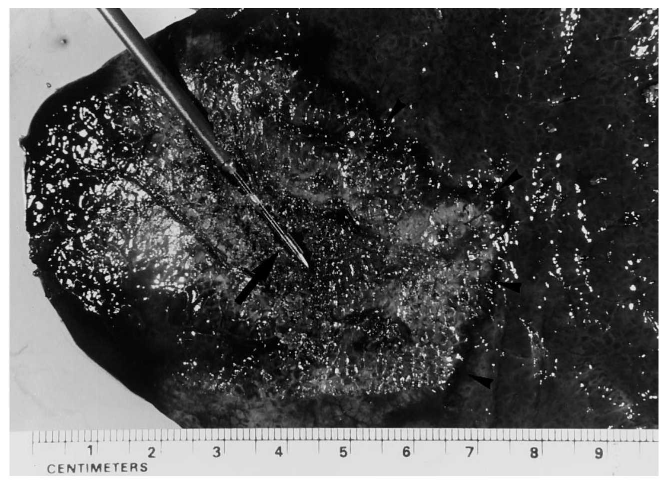

Fig. 3. Longitudinal cross section of an RFA-produced liver lesion during an in vivo porcine experiment at power output 150 W for 10 min. The uninsulated electrode tip *(arrow)* is positioned in the middle of the necrotic area. *Arrowheads* indicate the peripheral congestive rim

Results

RFA lesion

On cross sections, the ablated lesions appeared as pale, well-demarcated areas of spherical or ellipsoid shapes depending on the length of uninsulated electrode tip (Fig. 2). On the section of in vivo experiment, the area of coagulation necrosis was surrounded by a dark brown rim corresponding to vascular congestion (Fig. 3).

The lesion sizes were 4.90 ± 0.60 cm (50 W) and 6.60 ± 0.99 cm (90 W), and 4.20 ± 0.35 cm (90 W) and 5.22 ± 1.04 cm (150 W) in ex vivo and in vivo ablation, respectively.

Other parameters

During RFA, the impedance was kept constantly low at about 50 Ω in most of the sessions. The tip temperature was maintained below 40° C and RF energy delivery was stable at predetermined power output levels.

Discussion

During RFA application, RF current translates into ion agitation and frictional heat, resulting in cellular death in a form of coagulation necrosis. However, with conventional RF electrode, significant resistive heating occurs only within a narrow rim of tissue in direct contact with the metal electrode as a result of local excessively high current density. This leads to tissue overheating and carbonization, rapid impedance rise, subsequent cessation of RF energy deposition and eventually a small lesion size. The previously developed "wet" [2, 3, 4] and "cooled" [5,6] electrodes represent effective but suboptimal solutions to enhance the RFA efficacy.

Regarding the "wet" function, interstitial hypertonic saline infusion forms a virtual liquid electrode beyond the metal electrode. So, the total electrode surface area is augmented. In the mean time, both electrical and thermal conductivity of the tissue is also improved by incorporating abundant conductive ions and water. The higher tissue conductivity lowers impedance, lessens resistive heating near the electrode and spreads the current density away from the electrode into a more diffused area. All these may prevent desiccation and impedance rise and allow greater energy input and larger lesion size [2, 3, 4].

Regarding the "cooled" function, the temperature around the electrode can thus be maintained below 100 °C. This may avoid boiling, steaming and charring at the electrode-tissue interface [5, 6].

As demonstrated in this study, the dramatic improvements in RF energy delivery and lesion size with current novel electrode were resulted from a coordination of both "cooled" and "wet" functions. This electrode allowed applying power output at a higher level for a longer exposure time, hence a larger lesion. As exemplified by Figs. 2 and 3, to our knowledge, this cooled-wet electrode enables to create the largest RFA lesion size so far in comparison with other existing monopolar electrodes under similar exposure conditions [2, 3, 4, 5, 6, 7]. The lesion can be further enlarged with a prolonged RF current application.

In conclusion, the current design of monopolar cooled-wet electrode can significantly increase the RF ablation volume. Both internal cooling perfusion and interstitial saline infusion prove to be indispensable for an adequate RF energy delivery. This technical innovation may render RFA as a curative therapy in clinical oncology. More comprehensive studies are warranted to validate this technique.

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