Applications of Electrosurgery: Radio Frequency Ablation of Liver Tumors

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INTRODUCTION

Radio frequency ablation (RFA) is an evolving technology that is under investigation for the treatment of a wide variety of tumors. Radio frequency ablation has been studied in the treatment of heart, breast, lung, adrenal, renal, brain, prostate, and bone tumors. But its largest area of application has been the treatment of liver tumors, and it is not far short of general clinical use.

Radio frequency ablation holds particular promise for the treatment of liver tumors. Like cryosurgery, it offers the ability to precisely ablate the tumor while causing only minimal injury to the surrounding hepatic parenchyma. This is especially important in the liver, because surgical resection is quite often impossible, even for primary liver tumors. Hepatocellular carcinoma can be treated with curative surgical resection in only 5% to 15% of newly diagnosed cases.1–6 The remainder have multifocal disease, tumor close to or invading significant vascular or biliary structures, or inadequate functional reserve due to coexistent cirrhosis. For these patients RFA offers a chance for destruction of the tumor without the resection of normal hepatic parenchyma seen with standard surgical resection.

Radio frequency ablation has been studied in the treatment of metastatic liver tumors as well. Long-term survival benefit in 20% to 35% of patients undergoing resection of isolated liver metastasis has been demonstrated with standard surgical resection.7–10 Unfortunately, only 10% to 15% of patients with metastatic liver tumors are candidates for resection.11,12 Tumors may be unresectable due to bilobar disease, more than 4 metastases, or proximity to major vascular or biliary structures. Radio frequency ablation may allow for destruction of otherwise inoperable tumors.

PHYSICS

Destruction of the tumor is accomplished by directing high-frequency alternating current into the tumor. The current originates from an electrosurgical generator and is conducted to the tumor through an active electrode. The tissue surrounding the active electrode acts as a resistive element, converting electrical current to heat. Heating of tumor cells above 40°C to 50°C denatures intracellular proteins and melts the lipid bilayer of the cell membrane.13–16 The tissue desiccates and becomes escharotic. The injury is basically the same as desiccation produced by electrosurgery. Because current density decreases rapidly with increasing distance from the active electrode, it is difficult to ablate tissue more than 1 or 2 cm from the electrode. The desiccated tissue around the electrode has a low moisture content and acts as a high-impedance barrier to the passage of current. Again, this limits the effect of the current to a radius of 1 or 2 cm around the electrode. This is a serious limitation to the technique, and several strategies have been devised to overcome it. These include electrode arrays, injection of electrolyte to lower tissue impedance, and cooling of the electrode. These are discussed below.

EQUIPMENT

As with clinical electrosurgery, a radio frequency generator, active electrode, and passive electrode are required. A generator capable of producing 100 W at a frequency of 480 to 500 kHz is used. The generator produces continuous radio frequency energy, which makes it very similar to the cutting mode of a standard electrosurgery unit. It also monitors tissue impedance during the ablation procedure. Tissue impedance rises as the tissue around the electrode desiccates. It is important for the generator to have a relatively flat power curve, so that the power does not drop off rapidly as tissue impedance rises (Fig. 1).

The technique is quite sensitive to the impedance in the system. It has been noted that it is important to place the grounding pad on the back rather than the thigh, as this lowers impedance in the circuit and markedly improves the efficiency of energy delivery to the target tissue.17 As will be noted below, 1 of the 2 most used protocols relies on the tissue impedance to determine the duration of therapy. Several active electrodes have been studied to increase the area of tissue destruction, including the arrayed,17,18 saline injection,19,20 and saline-cooled tips.21–24 The arrayed probe consists of a needle containing multiple retractable curved elec-

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trodes that deploy in an array, as in an umbrella. The saline infusion electrode infuses saline simultaneously with the application of radio frequency energy. Infusion of the saline prevents impedance rise by preventing the tissue from drying. Instead, energy is conducted through the saline to a greater distance from the metal electrode. This allows ablation of larger lesions. The saline-cooled needle infuses cooled saline into a cooling lumen in the active electrode. This saline cooling allows a greater duration of delivery of radio frequency energy and produces a larger volume of tissue ablation (Fig. 2).

FIGURE 1. A commercial device for radio frequency ablation, showing the generator, the return pad, the foot pedal and, in the background, the “umbrella spoke” electrode in the extended position. (Courtesy of RITA, Inc.)

FIGURE 2. A close-up of the “umbrella spoke” electrode in the extended position. During insertion, the electrode wires are retracted into the metal cannula. The cannula has a bevelled point that allows it to be inserted into the tumor, after which the electrode wires can be extruded to fan out into the parenchyma to be ablated. (Courtesy of RITA, Inc.)

TECHNIQUE

Radio frequency ablation of liver tumors has been performed both laparoscopically and open. Regardless of the approach, intraoperative ultrasound (IOUS) is required to identify the tumors and guide placement of the active electrode. Intraoperative ultrasound has been demonstrated to be the most sensitive method of intraoperative tumor localization. Bilchik and colleagues, in a series of 50 patients treated with RFA for hepatic tumors, used IOUS to identify additional lesions in 32% of patients. Other studies also demonstrate the high sensitivity and accuracy of IOUS. But although it is accurate, ultrasound is not as easy to do in RFA as it is in cryosurgery. The line of demarcation between ablated tissue and normal tissue is not as well defined as the ice ball of cryosurgery. For that reason, a high quality ultrasound system and trained operators are required.
After ultrasound-guided placement of the active electrode, radio frequency energy is applied. Various protocols for the positioning and repositioning of the electrode and the application of power are described. These may be time and temperature based, or impedance based.

Time-and-temperature protocols call for heating of the tissue surrounding the probe to a given temperature for a defined time period. Buscarini and colleagues applied a variable power level to keep the needle tip temperature at 90°C for 2 to 6 minutes. Bilchik et al delivered 50 W to achieve a temperature of 90°C for 8 minutes (Fig. 3).

In the largest published series to date, Curley et al monitored impedance to guide therapy. They used a 2-phase application of power, beginning with 50 W of power and increasing it by 10-W increments each minute for 4 minutes, to a maximum of 90 W or until power “roll-off” occurred. Roll-off indicated a significant drop in power output due to increased tissue impedance. After a rest period, a second phase of power was applied, beginning at 75% of the maximum power achieved during the first phase, and continued until power roll-off occurred again. Large tumors required repositioning of the electrode within the tumor. For small tumors a single electrode placement was adequate. Again, IOUS was used to visualize the area of coagulative necrosis. The goal of therapy was an ablative zone extending 1 cm beyond the tumor.

Other strategies to increase the volume of ablated tissue include hepatic inflow occlusion and bipolar ablation. Hepatic inflow occlusion (Pringle maneuver) increases the ablative zone. The decrease in cooling from decreased blood flow into and around the tumor results in a larger zone of coagulative necrosis. It may be possible to achieve the same effect pharmacologically. Bipolar ablation, with current passing between 2 electrodes placed on either side of the target area or with multiple electrodes placed all around the target, also increases the volume of tissue destruction. Although promising, bipolar ablation has not been as widely used as monopolar. Other suggested techniques to increase ablation include intralesional ethanol injection and selective hepatic arterial embolization.

COMPLICATIONS

Because use of RFA of hepatic tumors is relatively new and the size, number, and location of tumors treated vary among studies, the complication rate is difficult to determine. In addition, RFA is frequently employed in conjunction with other treatments such as open surgical resection or cryoablation, further
complicating evaluation of the complication rate. In treatment of 123 patients with hepatic tumors with RFA, Curley and colleagues reported no posttreatment deaths and an overall complication rate of 2.4%. They emphasize the importance of avoiding tumors involving the perihilar region to prevent formation of biliary fistulas. Bilchik et al reported treatment of 50 patients with hepatic tumors with RFA. They also reported no deaths. Two complications occurred (1 intrahepatic abscess and 1 postoperative hemorrhage). Buscarini et al describe 1 case of self-limiting hemoperitoneum and 2 cases of pleural effusion with fever in their experience.

RECURRENT
Recurrence of liver tumors treated with RFA is difficult to determine due to variations in follow-up protocols and imaging modalities as well as the imperfections inherent to each imaging technique. In addition, we have relatively short-term follow-up data at this point. Curley and colleagues reported the median follow-up time in their series of 123 patients to be 15 months. Tumor recurred at the site of RFA in 3 of 169 treated tumors. Two of these recurrences were in tumors greater than 6 cm in diameter. The third occurred in a tumor near the inferior vena cava between the right and middle hepatic veins. In a more recent editorial, Curley and Izzo stated they have now treated over 300 patients with RFA with a local recurrence rate of approximately 9% of the tumors treated. They also report over 80% of these recurrences occurred in tumors with a diameter greater than 6 cm. They no longer perform RFA for tumors greater than 6 cm.

Siperstein et al reported their experience with 43 patients treated with laparoscopic RFA of hepatic tumors. At a mean follow-up of 13.9 months (median of 12 months) 22 of 181 tumors treated recurred (14 definite recurrences and 8 suspected recurrences). The local recurrence rate was 12% of tumors. Twelve of 43 patients (28%) had local recurrences. Adenocarcinomas and sarcomas were more prone to recurrence. Bilchik et al, at a median follow-up of 6 months, found local recurrences in 3 of 50 patients treated (6%).

SURVIVAL
With the limited follow-up currently available, long-term survival following RFA of hepatic malignancies is unknown. It is clear that, as with other local treatments, the majority of patients are not cured by RFA alone. Curley et al noted new sites of metastatic disease in 27.6% of patients with median follow-up of 15 months. Buscarini and Rossi reported a series of hepatocellular carcinomas observed for a mean time of 23 months with median survival of 44 months. They also report on 2 small series of metastases, with the percentage of disease-free survivors at 1 year ranging from 11% to 69%. Bilchik and colleagues noted 54% disease-free survival at a median follow-up of 6 months. Long-term follow-up will be required to clarify survival of patients treated with RFA for liver malignancies.

CONCLUSION
Radio frequency ablation is an emerging technology for the treatment of hepatic tumors. It offers hope for local control of otherwise unresectable tumors. But although it can ablate a high percentage of tumors smaller than 6 cm, there are little data on long-term follow-up and ultimate outcome. Future areas of investigation include RFA combined with other treatment modalities such as regional and systemic chemotherapy and development of more effective active electrode arrays. Investigation of other applications of RFA in treatment of the heart, lungs, prostate, breast, adrenals, and other areas continues as well. Radio frequency ablation has special promise in the treatment of aberrant conduction pathways in the heart, and has been tried extensively by a number of cardiologists. Radio frequency ablation is a promising technology warranting continued investigation.

REFERENCES


