Radiofrequency Ablation: Review of Mechanism, Indications, Technique, and Results

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Radiofrequency tissue ablation is a rapidly evolving in situ tissue ablation technique and has received increased attention in the past few years. The applications evolved from ablation of cardiac aberrant conduction fiber, to tumor ablation in bone, liver, kidney, breast, brain, and lung. Among them, hepatic primary and secondary tumor ablation is the most widely studied subject. In this article, we review the mechanism, procedure, results, and the prospects of this technique, with emphasis on hepatic tumor ablation.

Key words: Radiofrequency ablation, Liver tumor, Intervventional procedure.

Radiofrequency (RF) ablation is a rapidly evolving minimally invasive technique that provides in situ tissue ablation for a variety of benign and focal malignant diseases. It was first introduced for the ablation of the neural tissue to control pain or other neurologic disorders [1-4], and to ablate the aberrant neurofibril bundle in symptomatic cardiac arrhythmia [5-7]. Recently, RF ablation has been applied percutaneously, laparoscopically, or intraoperatively into the superficial or deep tissue to treat a variety of neoplasms, such as osteoid ostema [8-10], primary and metastatic liver tumor [11-13], renal cell carcinoma [14, 15], prostate cancer [16, 17], breast cancer [18,19], and metastatic lymphadenopathy.

In this article, we review the mechanism, current research and applications, clinical experience, as well as the prospects, of RF in tumor ablation.

MECHANISM AND PROBE DESIGNS

The concept of radiofrequency tumor ablation derives from the RF electrocautery device. In 1891, d'Arsonval [20], showed that the radiofrequency range alternative current when passed through living tissue causes an elevation in tissue temperature without causing neuromuscular excitation. The observation inspired the later development of surgical Bovie knife [21]. The device consists of an alternating electric current generator operated in the range of radiofrequency, a small knifelike electrode, and a large grounding pad. When the RF current flows through the tissue, driving the ions in the tissue electrolytes to
Radiofrequency ablation

move back and forth between the electrode and the ground pads, which results in localized frictional heat surrounding the electrode and the grounding pad \[1\]. The grounding pad acts as a large dispersive electrode that allows the current to pass freely through the patient without producing any significant heat. At the electrode point, desiccation and charring of the superficial tissue occurs. With the tissue desiccation and charring, the electrocautery controls hemorrhage.

When the electrode is inserted deep into the tissue, the emitted electric current agitates the regional ions, causing frictional heat that extends to adjacent tissue by conduction. When the local heat reaches the temperature of 50°C for more than 3-6 minutes, intracellular protein denaturation and melting of lipid bilayers results in coagulative necrosis \[22,9\]. However, to produce the same coagulation in vivo, 58°C is necessary due to the tissue perfusion by vessels carrying away the delivered heat \[9, 23, 65\].

In abdominal tumor ablation, the procedure is performed by inserting a 14-21 gauge partially insulating electrode into the tumor, with 1.5-3.5 cm exposed tip length, percutaneously, laparoscopically, or intraoperatively, under imaging guidance (ultrasonography [US], computed tomography [CT], or magnetic resonance imaging [MR]). A 460-500 kHz alternative RF current from the generator is connected between the electrode probe and the dispersive grounding pads at the patient’s back or thighs. A thermocouple is embedded in the electrode tip to continuously monitor the local temperature (Fig 1)

The final size of the heat-ablated tissue depends on the conductive heat emitted form the tissue, which is proportional to the square of the RF current, also known as the RF power density. The RF current density decreases in proportion to the square of the distance from the electrode. Therefore, resistive heat decreases from the ablation electrode with the distance to the fourth power \[24\]. The tissue temperature falls rapidly with increasing distance away from the electrode \[27\]. In theory, the RF method can be used to
create the precise tumor coagulation necrosis to match the extent of tumor. However, a significant limitation to the RF application is the tissue impedance. Increased generator power (in watts), exposure time or both, results in an increased amount of delivered energy around the electrode. When the tissue temperature surrounding the electrode increases to more than 100°C, the impedance also increases significantly because of desiccation, tissue boiling, and carbonization around the electrode tip. This leads to an abrupt fall in lesion current, which results in no more additional tissue heating in the surrounding tissue occurs. This is an important factor in lesion size limitation [28, 29]. A maximal transverse diameter of 10-16 mm has been typically reported using a conventional straight probe [30-32]. The longitudinal dimension, however, simply depends on the length of the uninsulated part of the electrode [30]. Unfortunately, the elongated cylindrical volume of necrosis created by a conventional straight probe does not approximate the spherical shape of most metastasis and primary liver tumor. Multiple treatments are usually needed to achieve a complete tumor necrosis. This limitation increases the procedure time in the ablation and also limits the application in larger tumors. To overcome this limitation, many technical innovations have been developed to achieve a larger tumor necrosis in a single treatment session.

**Pulsed RF Deposition**

Goldberg et al [33] investigated methods deliver the RF energy in a pulsed algorithm rather than a continuous manner. An automated, programmable algorithm for pulsed-RF deposition was designed to permit high-current deposition by periodically reducing current for 5-30 seconds during RF application. It allows brief periods of heat dissipation to prevent tissue vaporization and carbonation and to increase the current density and hence the volume of tissue necrosis. They showed a variable peak current algorithm for pulsed-RF deposition could increase coagulation necrosis diameter over other ablation strategies. A computer chip, with thermocouple embedded in the exposed tip of the electrode, is now available to monitor the impedance and temperature around the electrode to control the period of RF pulsed application, to minimize tissue carbonization and achieving maximal volume of tissue necrosis.

**Intraparenchymal Saline Injection During the Radio-frequency Tissue Ablation**

Livraghi et al [34] described an intraparenchymal injection of a bolus of saline before RF application or continuously (1 mL/min) during RF application to increase the RF lesion size. He explained the potential benefits of saline injection including the enlarged effective electrode surface by means of augmented tissue tonicity, local cooling effect to decrease the tissue impedance, and direct effect of the heated saline that diffuses into the tissue. Although the authors achieved the lesion size up to 3.9 cm, it was noted that the necrosis was irregular in shape and the lesion volume was difficult to predict [34]. This method was not widely used by other investigators. Despite this, Miao et al [61] reported a simultaneous internal-cooling perfusion (“cooled”) and interstitial hypertonic

![Figure 2. Recurrence of tumor after Ablation of metastatic colon cancer. a. Position of probes in a difficult lesion near the vena cava b. Contrast enhanced CT scan 3 months after treatment demonstrates some enhancement (arrow) suggesting recurrence of tumor.](image-url)
saline infusion (wet) RF system to create an ex vivo lesion of 6.6-cm hepatic lesion in liver. No in vivo study was available.

**Internally Cooled Electrode**

The key factor that prevents the delivery of RF energy is the high temperature around the electrode, which causes tissue charring and vaporization. To control this, Lorentzen [24] designed a 14-gauge RF needle, through which room temperature cool water could be circulated within the needle to prevent from tissue charring. This allowed a significant increase in the duration of ablation, which resulted in a significant increase in the delivered energy and lesion size when compared with the conventional needle electrode. Goldberg et al [25] developed a 17-gauge needle with perfusion of the electrode tip using 0 degree Celsius saline. Both energy deposition and coagulation necrosis were found to be significantly greater in the internally cooled electrode than conventional electrode. Using this technique, Goldberg’s group achieved in vivo liver lesions of 2.4 cm.

**Multiprobe Array**

Many multiprobe array designs of the electrode are now available to increase the RF lesion size in every single treatment session. Goldberg et al [26] developed a cluster array of three 17-gauge, separate internally cooled electrodes equally spaced 0.5 cm apart (Fig 1a) (Radionics, Burlington, Mass). In their study, a single 12-15-minute application of RF to an electrode cluster can induce 4.5-7.0 cm of coagulation necrosis in colorectal metastases, and 3.1 cm in vivo liver [26]. LeVeen [35] used a 14-gauge insulated cannula that contains 10-12 individual hook-shaped electrode arms (Fig 1c) (RadioTherapeutics, Sunnyvale, CA) deployed in vivo porcine liver, to produce a 3.5 cm spherical coagulation necrosis by applying 80 W of power for 10-12 minutes. Siperstein et al [36] produced 3.5 to 4 cm lesions in a porcine liver by applying 30 to 50 W of power for 15 minutes to a 15-gauge, four to nine-pronged umbrella needle system (Fig 1b) (RITA Medical System, Mountain View, CA). In general, the maximal lesion that can be created in a single treatment is about 4 cm in diameter. To date, there have been no studies that document a definite advantage of one needle design over the other.

All radiofrequency generators are operated at 460-500 kHz at a power setting of 50-200 W. The cost of the generator ranges from $12,000 to 30,000. The needle electrodes cost $500-1,000 per needle (non-reusable) [37].

**RADIOFREQUENCY ABLATION OF HEPATIC MALIGNANCY**

Surgical resection is considered the only curative therapy for malignant hepatic tumor, but few patients with hepatic tumor are ideal candidates for surgery. Less than 10-15% of patients with liver-only solid tumor metastases are candidates for resection [38, 39]. Many in-situ tumor ablation modalities, including percutaneous ethanol injection (PEI), transarterial chemoembolization, cryoablation, and many thermal energy resources such as radiofrequency (RF), Laser, and microwave, have shown promising results in those patients who are ineligible for surgery due to age, the extent of

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**Figure 3.** Schematic representation of volumetric approach to treat a tumor. Multiple insertions need to be performed to insure that the total volume of the tumor is treated in a 3 dimensional framework. (courtesy of Dr. Dodd III, San Antonio, USA)
disease, or surgical morbidity. PEI is easy, safe, inexpensive, and repeatable. However, it requires multiple sessions to treat even the smallest tumor and has been shown ineffective in liver metastasis [40, 41]. Chemoembolization appears to offer the best hope of controlling tumors greater than 5 cm in diameter or more than four tumors in number. However, regional therapy is not as effective as localized high-energy devices in killing individual tumors [37]. Cryoablation requires a laparotomy or laparoscopy with general anesthesia. Consequently, it is substantially more expensive than a percutaneous procedure. Laser ablation has the advantage of being fully compatible with MR imaging, but produce a smaller size of ablation than RF. A single ablation time required in microwave ablation is very short (<60 seconds), but the shape of necrosis is usually elliptical [42]. In two independent study in 1990, McGahan et al [11] and Rossi et al [12] first reported the RF ablation for the treatment of hepatic tumor. Overall, the interest and enthusiasm for radiofrequency thermal ablation has far exceeded that for either microwave or laser ablation [49].

**Patient Selection and Procedure**

Most investigators are limiting the application of RF procedure to patients with unresectable primary or secondary hepatic metastasis, fewer than 4 or 5 lesions and up to 5 cm in diameter, and no extrahepatic tumor [43, 27, 44]. Patients with a coagulopathy are included if the coagulopathy is correctable. Ablation of tumor adjacent to some vital structure needs careful considerations. Tumor close to the large portal triad can cause increased pain and poses the risk of damage to the associated bile ducts. Tumors adjacent to the large blood vessels are more difficult to treat because that the blood flow cool the applied heat in the adjacent tumor (heat sink effect) (Fig 2). Some investigators use RF ablation with a Pringle maneuver (temporary interrupting hepatic arterial and portal venous flow during the application of RF) during the operation to decrease the amount of heat that is “stolen” by the vessels, and to create a larger zone of necrosis [27, 64]. Tumor adjacent to the GB and bowel loop imposes the risk of post RF cholecystitis and thermal injury of the bowel loop [45]. Ablation of tumors adjacent to the diaphragm and liver capsule will cause more pain during and after the procedure.

Preprocedural evaluation including image study to exclude extrahepatic metastasis, hematological and liver function evaluation to exclude contraindications such as uncorrected coagulopathy and severe infection. Biopsy is done before the procedure also. All of the RF devices can be used percutaneously, laparoscopically, or intraoperatively. Percutaneous procedure can be performed on an outpatient basis with the use of conscious sedation consisting of a combination of local (Xylocaine 2%), intravenous benzodiazepam (midazolam 1.0-2.5 mg), and opiate (Fentanyl 50-150 µg) [46], or more potent and short-acting agent propofol [47]. Blood pressure, respiration, pulse, and electrocardiogram are monitored continuously. To prevent infection, antibiotic prophylaxis with cephalosporin is given in some institutions [48, 49].

Ultrasonography is the most common method

**Figure 4.** Successful RF ablation of a hepatoma. a. CT scan demonstrates a single probe in a small hepatoma in segment 4 (arrow). b. CT scan 6 months later demonstrates a 4 cm margin of necrosis, easily encompassing the tumor area with a wide margin. Note the parenchymal scar adjacent to the necrotic tumor (arrow).
used to guide percutaneous radiofrequency tumor ablation because of its real-time capabilities, vascular visualization, availability, and low cost. However, the primary disadvantage of sonography is a limited ability to assess the effectiveness, and completeness of an ablation. Usually, the ablation process produces a dense echogenic response that obscures the margins of the tumor being treated, particularly the posterior margins, and makes the electrode position difficult to assess. Thus, when multiple placements of the RF needle electrode is needed under US-guidance, the deep junction of the tumor and surrounding parenchyma should be treated first. The needle then can progressively be pulled back more superficially in 2-cm intervals [27]. Both CT and MR imaging have been reported to be more reliable in this regard [50]. A single ablation takes about 8-20 minutes to raise the local tissue temperature to above 60-degree Celsius. The goal of the thermal ablation is to burn the target lesion with the circumferential adjacent 5-10 mm of normal liver parenchyma. Multiple overlapping ablations are often necessary to achieve a complete tumor ablation (Fig 3). To treat a lesion of 3 cm in diameter, at least six overlapping ablations are needed to cover the tumor free margin [49]. On occasion, the lesion size created by RF is greater than expected. This is particularly true in hepatocellular carcinoma (Fig 4). It has been described as “oven effect”, whereby cirrhotic liver surrounding individual HCC nodules act as a thermal insulator that increases tissue heating within the tumor during RF therapy [48, 40].

Unlike metastasis, in which a 5-10-mm rim of normal liver around the tumor must be treated (Fig 5), for nodular HCC, it is generally sufficient to treat just the tumor itself [40]. Thus, a well-capsulated nodular HCC may need fewer ablations than a metastatic lesion of the same size (Fig 6).

The RF can also be applied laparoscopically or intraoperatively. A higher-frequency US probe can be used in both techniques, which allows a more precise determination of the extent and number of the tumors [51]. The other advantage is the application of Pringle maneuver in the procedure to increase the RF lesion size. However, unlike the percutaneous approach that allows US probe and needle to be moved to any position of the upper abdomen for the best angle of approach, the laparoscopic placement of needle and US probe is limited by the existing laparoscopic ports and can not be easily mastered [49]. The increased associated morbidity, mortality and cost are also drawbacks.

**Images Follow up**

Ultrasonography provides limited information in the follow-up study of residual or recurrent tumor. Recent preliminary study with US microbubbles contrast agent have been reported [52, 53] with results only slightly less than reported with CT. Contrast-enhanced CT is the most widely used technique in the follow up study after RF ablation. An immediate post-RF CT is usually performed for the effectiveness and possible complications. However, the accuracy of
the completeness assessment on the CT scan taken within one month after the RF may be limited because it is difficult to distinguish the enhancing residual or recurrent tumors from the ablation-induced hyperemic rim around the margin of the ablated tissue. A follow-up CT performed at 1 month after the procedure and then at 3-month interval is feasible. Usually, the recurrent tumor shows focal, irregular area of enhancement both in CT (Fig 7) and MR studies. A successfully treated tumor may shows stable low-density area or progressive decrease in size (Fig 8). Recent studies with contrast-enhanced MR imaging report a correct diagnosis of complete or partial tumor necrosis was made in 32 (86%) of the 37 patients with the use of unenhanced and dynamic gadolinium-enhanced MR images. Hypointensity on T2-weighted images and loss of enhancement on dynamic MR images corresponded to completely necrotic lesions in all patients [54]. Tumor markers such as α-fetoprotein and carcinoembryonic antigen levels before and every 3 months after RF ablation may be helpful in assessing the subtle image findings.

RESULTS

There are a number of published literature available for the results of RF ablation of liver malignancies. The results of RF ablation were compared with those obtained from surgery and other ablative procedures. In general, RF ablation is associated with lower complication rates and shorter hospital stays, but it is less effective than surgery for larger tumors. The results of RF ablation are also influenced by the size and location of the tumor, the technique used, and the experience of the operator. The results of RF ablation are also influenced by the size and location of the tumor, the technique used, and the experience of the operator. The results of RF ablation are also influenced by the size and location of the tumor, the technique used, and the experience of the operator.

Table 1. Percutaneous RF treatment Liver Malignancy

<table>
<thead>
<tr>
<th>Researcher</th>
<th>No. of Patients (Tumors)</th>
<th>Tumor</th>
<th>Average size (cm)</th>
<th>Average sessions</th>
<th>Mean FU (month)</th>
<th>Complete necrosis %</th>
<th>Electrode type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Livraghi [40]</td>
<td>42(52)</td>
<td>HCC</td>
<td>2.3</td>
<td>1.2</td>
<td>&gt;4</td>
<td>90%</td>
<td>A</td>
</tr>
<tr>
<td>Rossi [57]</td>
<td>23(26)</td>
<td>HCC</td>
<td>2.5</td>
<td>1.5</td>
<td>10</td>
<td>92%</td>
<td>B</td>
</tr>
<tr>
<td>Francica [55]</td>
<td>15(20)</td>
<td>HCC</td>
<td>2.2</td>
<td>NA</td>
<td>15</td>
<td>90%</td>
<td>A</td>
</tr>
<tr>
<td>Rossi [58]</td>
<td>39(41)</td>
<td>HCC</td>
<td>&lt;3.5</td>
<td>3.3</td>
<td>22.6</td>
<td>95%</td>
<td>B</td>
</tr>
<tr>
<td>de Baere [43]</td>
<td>47(88)</td>
<td>Met</td>
<td>2.2</td>
<td>1.2</td>
<td>17.3</td>
<td>90%</td>
<td>A</td>
</tr>
<tr>
<td>Rossi [57]</td>
<td>14(19)</td>
<td>Met</td>
<td>2.5</td>
<td>1.3</td>
<td>12</td>
<td>93%</td>
<td>B</td>
</tr>
<tr>
<td>Rossi [58]</td>
<td>11(13)</td>
<td>Met</td>
<td>&lt;3.5</td>
<td>3.1</td>
<td>11</td>
<td>82%</td>
<td>D</td>
</tr>
<tr>
<td>Solbiati [59]</td>
<td>16(31)</td>
<td>Met</td>
<td>1.5-7.5</td>
<td>4.7</td>
<td>18.1</td>
<td>58%</td>
<td>D</td>
</tr>
<tr>
<td>Solbiati [68]</td>
<td>29(44)</td>
<td>Met</td>
<td>1.3-5.1</td>
<td>1.2</td>
<td>10.3</td>
<td>66%</td>
<td>A</td>
</tr>
<tr>
<td>Livraghi [34]</td>
<td>14(25)</td>
<td>Met*</td>
<td>3.1</td>
<td>NA</td>
<td>6</td>
<td>52%</td>
<td>E</td>
</tr>
</tbody>
</table>

* With one case of cholangiocarcinoma
A: cool-tip needle (Radionics)
B: four-pronged umbrella needle (RITA)
C: LeVeen needle (RadioTherapeutics)
D: conventional straight needle
E: conventional straight needle with intraparenchymal saline injection
P: percutaneous, L: laparoscopy, O: intraoperative
tumor [34, 44, 45, 51, 55-62]. As the RF is a fairly new technique, long-term results have only begun to be available. Most of the reports should be considered as preliminary reports of short-term efficacy. As the tumor characteristics, tumor biology, and the histology of the surrounding liver parenchyma are quite different between hepatocellular carcinoma and hepatic metastasis, it is feasible to discuss the results according to the tumor types and approaching methods. In most percutaneous series, complete necrosis can be achieved in 90% of lesions in hepatocellular carcinoma with mean size less than 3cm (Table 1). In these series, follow-up period was between 6 to 23 months. Livraghi et al reported the only long-term results of RF ablations for medium-sized and large tumors. The results in 126 medium-sized (3.1-5 cm) to large (5.1-9.5 cm) hepatoma (mean 5.4 cm) in 114 patients demonstrated that complete necrosis can be achieved in 60 lesions (47.6%) and nearly complete necrosis in 40 lesions (31.7%).

For metastatic liver tumors, complete necrosis varies from 52 to 93% with mean follow-up period between 6 to 18.1 months (Table 1). The successful rate of RF ablation of HCC is higher

**Figure 7.** Example of incomplete ablation of a large metastatic colon carcinoma. **a.** An irregular large lesion in segment 7 (arrow). **b.** Post ablation demonstrates 90% complete necrosis. There are still areas enhancing with contrast that demonstrate incomplete necrosis (arrow).

**Figure 8.** Evolution and retraction of a treated colon carcinoma metastasis in segment 3 of the liver. **a.** Low density necrotic area after first treatment. **b.** CT scan 6 months later shows decrease in size of the lesion with no evidence of enhancement. **c.** CT scan 2 years after first treatment demonstrating “scarring and retraction” in the area of treatment. The Patient was doing well clinically.
than that of metastatic lesions. HCC necrosis is more complete and uniform to the tumor shape due to the “oven effect” [40, 48]. However, the margin of metastatic tumors is different, and microinvasion beyond the preoperative evaluation is common. Thus, a more aggressive ablation of metastatic tumor is required to minimize local tumor recurrence.

Some laparoscopic [36, 51, 63], some combined percutaneous, laparoscopic and intraoperative [13, 27, 43, 62], or intraoperatively [60] RF ablation results had been reported (Table 2). Among them, the larger series are those from Siperstein et al [63], and Curley et al [13, 27]. Siperstein et al [63] report their experience of laparoscopic RF treatment of 43 patients with 170 metastatic and 11 primary tumors. Tumor resorption in 156 (88%) of 178 lesions were reported with a mean follow up of 13.9 months. In a similar study of Curley et al. [27], radiofrequency ablation was used to treat 169 tumors in 123 patients, including 48 patients with HCC and 75 with metastatic tumors. Of the 123 patients, 92 (75%) were treated intraoperatively and 31 (25%) were treated percutaneously. All tumors were treated with LeVeen hooked-needle electrodes, and a Pringle maneuver was used on all intraoperative cases. Overall, complete necrosis had occurred in 98% of the ablated tumors at a median follow-up period of 15 months, and 72% of the patients remained tumor-free during the same time. The authors did not analyze the outcome difference in the percutaneous and the intraoperative groups, nor did they analyze the difference between the primary and secondary tumor groups.

In the other report, Curley et al. [13] report the result of RF ablation of 110 patients with 149 HCC, including 76 patients with percutaneous, 31 with intraoperative, and 3 with laparoscopic approach. At a median follow-up period of 19 months, the local recurrence was noted in only 4 (2.7%) of the 149 treated tumor. However, recurrence at other sites in liver was noted in 37 (33.6%) cases.

### Complications

Radiofrequency ablation of the liver is considered safe, with an extremely low major complication rate observed by multiple groups. Livraghi et al. reports one mortality case of RF (0.8%), who developed Staphylococcus aureus peritonitis 3 days and died 8 days after the procedure. Major complications that required surgical, vascular or percutaneous intervention include major intraperitoneal hemorrhage (0.8%), hemothorax (2%) [40], liver abscess (6%) [43], bile leakage (3%) [57]. Minor complications include self-limited hemorrhage (1.8-8%) (Fig 9) [48], mild cholecystitis, pleural effusion, hemobilia, second degree skin burn due to inadequate ground surface or contact (3.7-10%) [26], and post-RF pain that required nonsteroid analgesics for 2-4 days (2.6-4%). Many patients experienced intraprocedural pains in conscious sedation case, which is usually controllable.

Treatment of peripherally located, subcapsular tumor are more likely to induce pain and

### Table 2. Surgical RF Treatment of Liver Malignancy

<table>
<thead>
<tr>
<th>Researcher</th>
<th>No. of Patients (Tumors)</th>
<th>Tumor</th>
<th>Approach</th>
<th>Median Tumor size (cm)</th>
<th>Mean FU (months)</th>
<th>Complete necrosis %</th>
<th>Electrode type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curley [27]</td>
<td>123(169)</td>
<td>Met(75) HCC(48)</td>
<td>P+O</td>
<td>3.4</td>
<td>15</td>
<td>98%</td>
<td>C</td>
</tr>
<tr>
<td>Curley [13]</td>
<td>110(149)</td>
<td>HCC</td>
<td>P+L+O</td>
<td>2.8 (P) 4.6(L+O)</td>
<td>19</td>
<td>97%</td>
<td>C</td>
</tr>
<tr>
<td>de Baere [43]</td>
<td>21(33)</td>
<td>Met</td>
<td>O</td>
<td>1.3</td>
<td>12</td>
<td>94%</td>
<td>A</td>
</tr>
<tr>
<td>Siperstein [63]</td>
<td>43(181)</td>
<td>Met(170) HCC(11) Met(27) HCC(8)</td>
<td>L</td>
<td>NA</td>
<td>13.9</td>
<td>88%</td>
<td>B</td>
</tr>
<tr>
<td>Jiao [62]</td>
<td>35</td>
<td>Met</td>
<td>P+O</td>
<td>NA</td>
<td>8.5</td>
<td>69%</td>
<td>A</td>
</tr>
<tr>
<td>Elias [60]</td>
<td>7</td>
<td>Met</td>
<td>O</td>
<td>1.1</td>
<td>2</td>
<td>100%</td>
<td>A</td>
</tr>
</tbody>
</table>

A: cool-tip needle (Radionics)
B: four-pronged umbrella needle (RITA)
C: LeVeen needle (RadioTherapeutics)
D: conventional straight needle
E: conventional straight needle with intraparenchymal saline injection
P: percutaneous, L: laparoscopy, O: intraoperative
There are only few reports mentioning the delayed post-ablation fever that may be seen in other type of in situ tumor ablation. According to McGahan et al. [49], the typical presentation consists of flulike symptoms (low-grade fever up to 38.8°C accompanied by general malaise) that begin 3-5 days after the ablation and persists for approximately 5 days. With large-volume ablations, the syndrome begins almost immediately, causing fever as high as 39.4°C, produces severe lethargy, and lasts for as long as 2-3 weeks. Appropriate treatment of the syndrome is primarily supportive. Fever up to 38.8°C for 5 days needs a culture to rule out a septic condition [49].

In the majority of patients, the transaminase levels may increase to two to seven times over baseline during the first 3 days following therapy, but will return to baseline level in most cases by 7 days [27, 48, 57].

**Extrahepatic Tumor Ablation**

A considerable amount of reports on extrahepatic tumor ablation have been published. Rosenthal et al [8-10] treated 18 patients with osteoid osteoma with an 18 gauge conventional RF needle through the biopsy 15-gauge Ackerman coaxial needle. Symptoms were completely relieved in 16 (89%) of 18 patients. In one patient, a second procedure was required for pain relief. All but two patients underwent treatment on outpatient basis. No complication was noted. In a subsequent study [10], the author compared the result of operative treatment of 87 patents and percutaneous RF ablation of 38 patients with

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**Figure 9.** Example of treatment of a hepatoma in segment 7 high in the dome of the liver with a triple probe, which was successful, but resulted in a small perihepatic hematoma. a. CT scan with probe demonstrates the treated area encompassing the previous tumor. b. After the procedure, an area of necrosis is visualized (straight arrows). A small perihepatic hematoma (curved arrow) is also noted.

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**Figure 10.** Treatment of bone pain in a patient with colon cancer metastasis to the sacrum. A single probe is used to ablation performed with careful attention to the temperature. After several insertions, in many patients, pain can be relieved.
osteoid osteoma. The operation recurrence was 9% after 2 year, but the patient required an average hospital stay of 5 days. The recurrence rate in the percutaneous group was 12% with an average hospital stay of 0.2 day. As there is no significant difference between the two treatments with regards to the rate of recurrence, the authors concluded that percutaneous method is preferable for the treatment of extraspinal osteoid osteoma because of less hospitalization, no complication, and rapid convalescence. Palliative treatment of metastatic bone tumor has also been tried (Fig 10).

Zlotta et al [14] first report in vivo RF treatment of three renal cell carcinomas in 2 patients before nephrectomy. Extensive necrosis through the tumors was noted in the pathology. McGovern et al [66] reported a successful RF ablation of a 3-cm renal cell carcinoma in an 84-year-old patient. Hall et al [67] reported a successful combined embolization of RF ablation of a 3-cm RCC in a poor surgical candidate due to chronic debilitating disease. Gervais et al [15] reported a larger series of treatment of 9 renal cell carcinomas (mean 3.3 cm ±1.1 cm) in 8 patients. According to the tumor location, the RCC was classified as exophytic, parenchymal, central and mixed lesions (Fig 11). These patients required a total of 24 treatments during 14 sessions. At a mean follow-up period of 10.3 months, 7 (78%) tumors were completely treated (Fig 12). The smaller and exophytic tumors necessitated fewer treatments than did the larger central tumors (Fig 13).

Solbiati et al [68] performed PEI and RF ablation for the treatment of parathyroid hyperplasia and secondary hyperparathyroidism using US-guidance. As compared to the control group that received PEI only, the combined treatment allowed less treatment sessions with favorable clinical results. In the other study, Solbiati et al treated two recurrent supraclavicular metastatic lymph nodes from papillary thyroid cancer in one patient that was a poor candidate for surgery. Complete necrosis of the lymph nodes was noted at one-year follow up [69].

Dupuy et al [70] reported the experience of RF

![Figure 11. Classification of different appearances of renal cell carcinomas. The more “exophytic” the lesion the better the results and more likely the complete ablation.](image)

![Figure 12. Successful treatment of renal cell carcinoma with RF ablation. a. Initial contrast enhanced CT demonstrates a slightly exophytic (mixed lesion). b. After initial treatment, the posterior half of the lesion still enhanced with contrast, indicating viable tumor. c. CT scan after second treatment demonstrates complete treatment of the tumor.](image)
Radiofrequency ablation

ablation of 2 primary and 1 metastatic lung tumors, ranging from 2-5 cm in size. After RF ablation, one patient showed residual tumor in follow up biopsy at 3 months; the second one died of unknown cause, and the third one showed no evidence of metabolic activity at the RF lesion on a follow-up positron emission tomography scan.

Future Strategies

Radiofrequency tumor ablation, especially for the hepatic tumors, has been a promising technique and can be a substitute for surgery in patients not eligible for surgical treatments. However, despite the considerable progress that has been made to date, a number of challenges remain for the future. The future strategies include (a) increasing the volume of tissue destroyed at a single treatment session (b) the integration of RF ablation with the other in-site tumor ablation techniques and (c) the development of more suitable and accurate imaging tests.

The key factor that limits the treatment strategies is the tissue volume that can be destroyed in a single treatment. To date, the largest range that can be ablated in a single treatment is 3.5-4 cm [26, 35, 36]. To create tumor free margin of 5-10mm, a 3.25 cm lesion may need up to six precisely overlapped 3-cm thermal spheres [49]. Creation of a larger volume of tissue coagulation will ensure successful ablation of small tumors and allow us to treat patients with larger tumors. In addition, as fewer treatments are needed for a given tumor size, the technique would be less complex, the procedure time can be shortened and the hemorrhagic complication would be decreased.

Aside from RF ablation, there are a lot of in-site tumor ablation techniques such as microwave ablation, laser ablation, cryoablation, ethanol injection, and chemoembolization. Livraghi et al [40] compared the effectiveness of RF and percutaneous ethanol injection (PEI) in the treatment of small HCC. RF was shown to have a higher rate of complete necrosis, fewer sessions, but higher complication than PEI. More comparative studies are needed to elucidate the cost-effectiveness of these minimally invasive techniques for treating primary and secondary malignant tumors. The combined treatment of some of these techniques may have some promising effect in the future. For example, as the HCC receives most blood supply from the hepatic artery, the pre-RF chemoembolization of the hepatic artery may decrease the heat-sink effect in the RF procedure and create a promising tissue necrosis [71].

A successful tumor ablation depends largely on accurate pre-procedural planning, in which the image diagnosis plays the most crucial role. With respects to tumor detection, and despite remarkable progress in US, CT, and MR imaging over the past several years, no currently available imaging technique is perfectly sensitive for the detection of liver tumors. Some lesions will undoubtedly be overlooked with all imaging techniques. To determine the treatment range, an improved imaging technique should provide not only the tumor detection but also tumor margin.
Radiofrequency ablation can be performed safely in many locations in the body with promising or encouraging results. Advances in radiofrequency equipment, technics, and combined therapies will likely yield an improvement in the effectiveness, and allow the treatment of larger tumors.

**CONCLUSION**

Radiofrequency tumor ablation can be performed safely in many locations in the body with promising or encouraging results. Advances in radiofrequency equipment, technics, and combined therapies will likely yield an improvement in the effectiveness, and allow the treatment of larger tumors.

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電磁波熱燒灼術，原理，發展，技術，及其應用

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電磁波熱燒灼術，是一個快速發展的組織原位燒灼技術，其應用，由早先用在心臟燒除異常的傳導神經，直到近來應用在神經、骨骼、肝臟、腎臟、乳房、腦部、肺部等組織、腫瘤的燒除，其中，尤其以肝臟原發、次發性腫瘤的燒除，有最主要的進展。本文即探討電磁波熱燒灼術的原理、發展、技術及其臨床上的應用。

關鍵詞：電磁波熱燒灼術，肝臟腫瘤，介入性治療