Radiofrequency Ablation

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Last Updated:

Wednesday, February 8, 2023

Keyword

radiofrequency ablation, electrosurgery, kidney cancer, percutaneous renal mass ablation, radiofrequency safety

Summary

- Radiofrequency ablation describes a form of electrosurgery using radiofrequency waves (375-500 kHz) which is applied to pre-planned volumes of tissue for tissue desiccation.
- Protein coagulative necrosis and tissue desiccation occurs at temperatures between 60°C and 100°C, whereas temperatures exceeding 100°C leads to charring of tissue (increased impedance) with potential for insufficient and/or ununiform treatment.
- Image guided percutaneous radiofrequency ablation is currently indicated for treatment of solid, enhancing renal cortical tumors (< 3 cm in diameter).
- Complications associated with radiofrequency ablation include inadvertent heat injury to nearby visceral structures, puncture injury through entry and placement of probes, and skin burns at site of grounding pads (for monopolar devices).

1. PHYSICS/INTRODUCTION

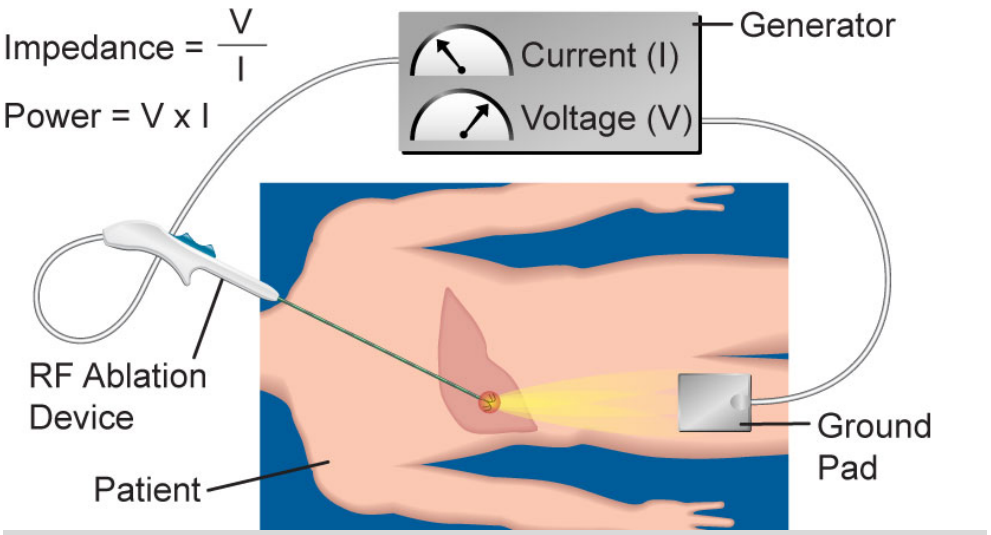

Figure 1: Source: Angiodyanmics, Latham, NY

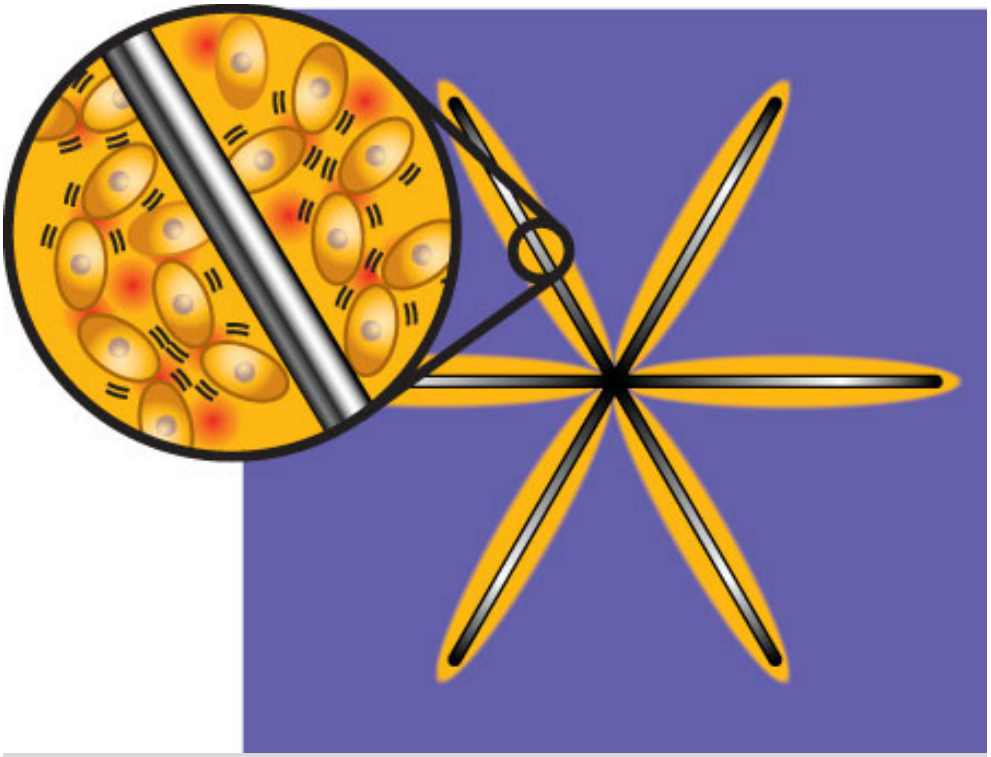

Figure 2: Frictional Heating (Source: Angiodynamics, Latham, NY)

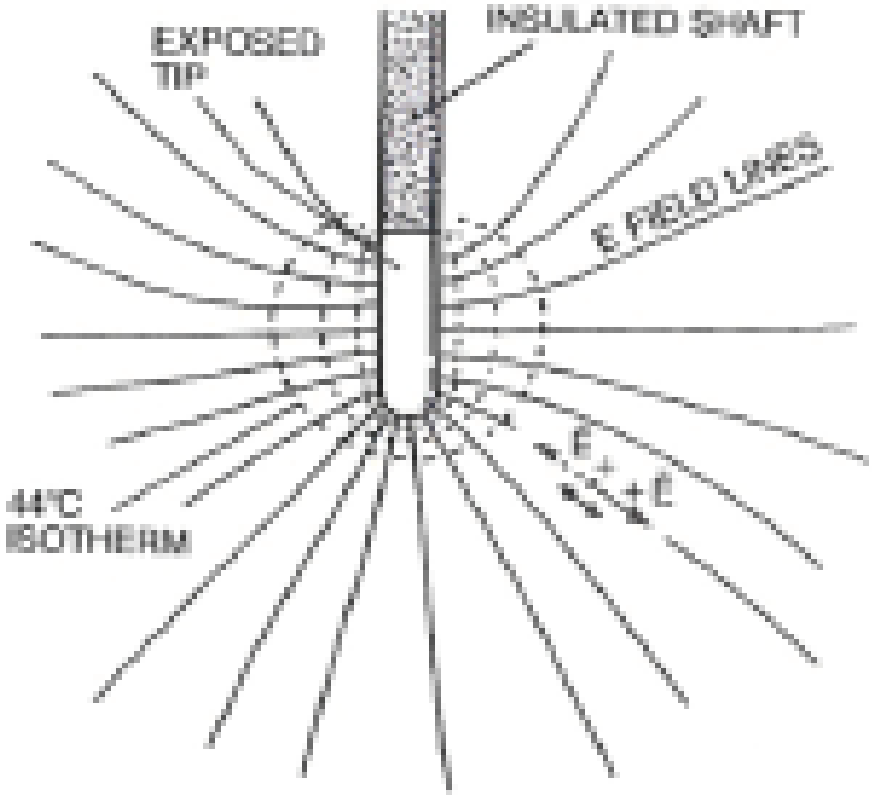

Figure 3: Source: NeuroTherm, Wilmington, MA
Photos courtesy of AngioDynamics, Inc

Figure 4: Source: Angiodynamics Inc, Latham, NY

Radiofrequency ablation (RFA) is a form of electrosurgery, which aims to predictably coagulate and destroy pre-planned volumes of tissue.

All radiofrequency (RF) systems (**Figure 1**) are composed of an active electrode (probe), the electrosurgical unit (generator) and a dispersive electrode (grounding pad for monopolar devices). Within the generator, cables and the probe, free electrons in metals serve as the charge carrier. Once transmitted into the patient's body, the electric current is conducted through ions (Na^+, K^+, Cl-, charged proteins and lipids) to the dispersive electrode which then completes the RF circuit.

When the commercially available electrosurgical unit is activated, it produces an alternating current at the radio frequency range (375-500 kHz), using a proprietary algorithm. This results in rapidly alternating polarity of electrical output from the probe. Electrons within the probe move back and forth up to 500,0000 times a second, causing ions and charged proteins within tissues adjacent to the probe to oscillate in synchrony with the generator's output frequency. Frictional forces between these oscillating ions and charged proteins lead to rapidly rising local tissue temperatures (**Figure 2**) by electrical resistive tissue heating. If this temperature reaches between 60°C and 100°C, protein coagulation and tissue desiccation occur, leading to the desired effects of cellular death and tissue destruction. Ideal temperatures for RFA should not exceed 100°C as tissue charring occurs which reduces the water content of the tissue. This effect results in increased tissue impedance (resistance to delivered electric current) and insufficient or incomplete treatment of targeted field.[1,2]

The degree and shape of isotherms of local heat generation are dependent on the magnitude of the local electrical field density generated around the electrode, tissue conductivity, and the presence of any adjacent heat sinks. Heat sinks occur in highly vascularized areas which allows thermal energy

to preferentially disperse into cooler vasculature rather than targeted tissue posing a risk for incomplete treatment. Each of the active electrodes has a small surface area compared to the dispersive electrode(s). This focuses the RF current on the interface between the active electrode and target tissue, (**Figure 3**) while at the dispersive electrode- tissue interface, the same total current is spread over a much larger surface area, such that no or only moderate temperature elevation increase occurs. Nonetheless, skin burns at the dispersive electrode pad are one of the possible complications of RFA, particularly if prolonged ablation is used at high power settings, or if the dispersive electrode pad is of insufficient surface area or manufactured incorrectly.

The kinetics of cell death from thermotherapy depends on both temperature and time. For example, it takes a few minutes to kill all cells at 50° Celsius, whereas it takes only seconds to kill cells at 60° Celsius. In the clinical setting, best results are achieved when target tissue temperatures are raised to cause protein denaturation and tissue coagulation while avoiding tissue vaporization and carbonization (> 100° Celsius), which can lead to non-uniform electric field density and uneven tissue necrosis (skip lesions). Manufacturers of RFA systems produce generators with proprietary power output algorithms (temperature vs. impedance controlled) that allow for thermal coagulation of the desired tissue volume without the undesired tissue carbonization.

2. MECHANISM OF DELIVERY

Commercially available RF generators control power generation in one of three ways.

1. Power control:
    - Electrical voltage is applied to the RF electrode and adjusted to keep the applied RF power constant.
2. Temperature control:
    - One or more thermal sensors are integrated into the RF probe and applied RF power is adjusted to keep the measured temperature at a defined value.
3. Impedance control:
    - RF power is varied depending on changes in the tissue impedance. When the tissue is heated, impedance rises and RF power output is decreased or halted before charring occurs (very high impedance).

Monopolar vs Bipolar Platforms

Each generator manufacturer also manufactures RF probes, but two principle RFA platforms are available clinically - namely monopolar and bipolar. Also available are probes with cooled tips to increase the ablative zone.

In the monopolar system, there exists an active electrode (probe), the electrosurgical unit (generator) and one or more dispersive electrodes (grounding pad). The probe is usually made of stainless steel, platinum, or nickel-titanium alloys. The shaft of the probe is typically electrically insulated to avoid heat generation in these insulated areas.

In the bipolar system, the probe contains both the active and dispersive electrodes. In this case, both electrodes are in close proximity to each other, such that each is essentially "active," leading to thermal ablation of the tissues between the electrodes. This platform obviates the need for a dispersive electrode pad placed at a different location in the body and its attendant potential complications.

Placement of Probes

All RF platforms use image guidance (computed tomography or ultrasound) to place one or more probes into the target tissue. While appropriate initial probe placement can be confirmed using real time imaging, critics point out that RF ablation is limited because there is no real time intra-procedural imaging feedback on ablation zone growth. Proponents of RF argue, however, that imaging is not required during ablation if adequate monitoring of temperatures in the center and the peripheral margins of the ablation zone is performed. If proper target temperatures are achieved for appropriate durations, cell death can be assured.

Designs for Enhancing Ablation Field

The size and shape of the ablation is varied by several mechanisms. Some devices have multiple tines that are extended from the probe tip after placement in the target tissue (**Figure 4**). An alternate system uses multiple needle type electrodes to achieve the desired ablation zone. Another means to change the ablative zone is using actively cooling probe tips via saline or water infusion into the tips of the probe. This prevents premature desiccation and carbonization of the tissues immediately next to the probe and typically leads to larger ablation zones.

3. SAFETY

RFA systems have been FDA approved for urologic, cardiac, neurosurgical, hepatic, pulmonary and breast indications. This modality has been shown to be very safe when used in appropriate clinical settings by well-trained physicians. Patients should be prepared to undergo general anesthesia or monitored anesthetic care. Patients should stop anticoagulation medications during the perioperative period, if possible.

In the example of renal tumor ablation, pressure points should be well padded if the patient is placed in the prone position. It is critically important that the surgical team (urologist or radiologist, or a team approach of both specialists) studies the relationship of the neoplasm to important intra-renal and extra-renal structures that can be inadvertently injured. For example, the surgeon should ensure the main renal artery and vein, colon, small bowel, liver, spleen, ureter, and uretero-pelvic junction are far enough away from the ablation zone to prevent inadvertent injury.

Grounding pads should be placed by following the manufacturer’s instructions and away from any metal implants. At the end of the ablation, the grounding pad site should be examined for any skin burns.

4. DEVICES- Commonly utilized radiofrequency generators

There are numerous commercially available RF generators and probes. Probe options for each of these generators include monopolar, bipolar, multi-probe, or single probe with expandable tines - with or without active cooling of probe tips. (Neurosurgical and cardiac electrophysiological RF systems are not included below).

1. Angiodynamics RF generators. Temperature based system with tine based probes. Bipolar electrodes and actively cooled tip probes also available.
2. Boston Scientific RF 3000 system. Impedance based system using tine based probes.
3. Stryker MultiGen radiofrequency generator. This platform can treat four lesions simultaneously, and is primarily used in spine surgical indications.
4. Covidien Cool-tip RF ablation systems. This platform uses up to three monopolar RF probes and chilled sterile water is circulated in the probe to cool the tip.
5. Urologix Prostiva RF therapy for benign prostate hyperplasia. Monopolar temperature based system to ablate BPH adenomas.
6. Medtronic TUNA (transurethral needle ablation) therapy for benign prostate hyperplasia.

5. CLINICAL USE/PROCEDURES

1. **Image guided percutaneous radiofrequency ablation** for solid, enhancing renal cortical tumors. Generally < 3 cm in diameter.
2. Benign prostate hyperplasia. Recent **AUA guidelines 2018** do not recommend the use of transurethral needle ablation (TUNA) for treatment of BPH owing to modest to little prostatic volume reduction and insignificant improvement of lower urinary tract symptoms.

Please refer to the ablation section of Core Curriculum **Renal Neoplasms** for additional clinical information.

6. COMPLICATIONS

Complications from RFA generally occur via 3 different mechanisms:

1. Adjacent tissues are inadvertently heated, leading to potential destruction of non-targeted, vital tissues. (e.g. bowel, ureter).
2. The RF probe is inserted through other organs on its way to the target tissue. As a result, patients can develop hemorrhage, pneumothorax, infection, probe site pain and/or tract seeding of tumor cells.
3. As RFA can be painful and anxiety provoking for patients, most will receive moderate sedation or general anesthetic for the procedure, with its attendant risks.

The use of RFA in oncological therapy relies on the local generation of heat that is sufficient in degree and duration to destroy neoplastic tissue. Thermal injuries have been most thoroughly studied in renal tumor ablation. Injuries to the diaphragm, gastrointestinal tract (some fatal), ureter, and ureteropelvic junction have all been reported.

With regard to bowel injury, the colon is generally felt to be at higher risk than stomach or small bowel, probably due to a combination of a relatively thinner wall and decreased mobility. Adhesions from prior surgery, bleeding, or even prior RFA can also increase the risk of bowel injury. It is generally felt that a distance of approximately 1 cm between the zone of ablation and the bowel is sufficient to prevent thermal injury, with the risk increasing for closer distances; nevertheless, the exact margin of safety remains somewhat unpredictable.

Strategies to avoid thermal injury:

1. Carefully monitor the distance between the electrode and bowel wall.
2. Perform ablation laparoscopically, which allows for electrode placement under direct vision.
3. Inject sterile water or carbon dioxide around surrounding structures to sufficiently separate them from the target site.
4. Place independent thermistors to monitor temperatures near critical structures in real time, during RFA.
5. Perfuse cold fluid into/around sensitive structures, such as the ureter, via catheters (ureteral open ended catheters) positioned prior to RFA.

In addition to local thermal injury predicated on proximity to the site of ablation, distant thermal injury is another concern. Specifically, monopolar radiofrequency electrodes require grounding pads to complete the high-current radiofrequency circuit, and the same amount of current is deposited at the grounding pads as the electrode itself. This puts the grounding pad sites at risk for thermal injury. Indeed, severe burns have occurred, particularly in early studies of RFA. Over time, it was realized that to disperse the energy more effectively, larger grounding pads were necessary. As a result, skin burns have become rare. Nevertheless, appropriate pad placement is essential to minimize the risk of burns as much as possible. Pads should be placed in full contact with the skin, relatively far away from the electrode and equidistant from the probe to allow for more even heat distribution. Excess hair should be removed from the skin to facilitate full grounding pad contact. It is reasonable to monitor the skin near the grounding pads during the RFA procedure. As an additional margin of safety, manufacturers have begun incorporating temperature monitors in the grounding pads.

Although the overall risks of hemorrhage following RFA have been low, severe bleeding complications have been reported. Such complications illustrate the need to be vigilant about monitoring patients for signs of bleeding in the immediate periprocedural period and to screen patients carefully for potential coagulation disorders, including the use of drugs that affect platelet function and the coagulation cascade. Although small perinephric hematomas are seen fairly often following renal RFA, major complications appear to be uncommon. Hematuria, in most series, has generally not been significant, although some have reported gross hematuria and urinary obstruction. All of these cases were related to large central tumors, and all were successfully treated with retrograde stenting.

Strictures of both the ureter and collecting system have been reported in three series, all secondary to proximity of the tumor to the structure in question. One of these was asymptomatic, two required

further drainage therapy.

Other reported complications include neural injury to the lumbar plexus in the psoas muscle, abdominal wall paresthesia with muscle weakness, and pneumothorax. Paresthesia and muscle laxity are generally self-limiting.

To date, although mild elevations in serum creatinine have been seen, there have been no reports of significant deterioration in renal function following renal RFA.

In the prostate for treatment of BPH, gross hematuria, rectal injuries, bladder neck contractures and urethral sloughing have all been reported.

Videos

Presentation Video 1

Presentations

Radiofrequency Ablation Presentation 1

References

1 B Djavan, AW Partin, MF Hoey, et al.: Transurethral radiofrequency therapy for benign prostatic hyperplasia using a novel saline-liquid conductor: the virtual electrode.Urology. 55:13-16 2000 10654886

2 A Finelli, JC Rewcastle, MAS Jewett: Cryotherapy and radiofrequency ablation: pathophysiologic basis and laboratory studies. Curr Opin Urol. 13:187-191 2003 12692439

3 Carey, R. I., Leveillee, R. J. Direct real-time temperature monitoring for laparoscopic and CT-guided radiofrequency ablation of renal tumors between 3 and 5 cm. J Endourol, 21: 807, 2007.

4 Cosman ER, Nashold BS, Ovelman-Levitt J. Theoretical aspects of radiofrequency lesions in the dorsal root entry zone. Neurosurgery 15: 945-50, 1984.

5 Goldberg, S. N., Gazelle, G. S., Solbiati, L. et al. Radiofrequency tissue ablation: increased lesion diameter with a perfusion electrode. Acad Radiol, 3: 636, 1996.

6 Hong, K., Georgiades, C.: Radiofrequency ablation: mechanism of action and devices. J Vasc Interv Radiol, 21: S179, 2010.

7 ☆ Johnson DB, Taylor GD, Lotan Y, et al: The effects of radio frequency ablation on renal function and blood pressure. J Urol 170: 2234-6, 2003.

8 ☆ Johnson DB, Solomon SB, Su LM, et al: Defining the complications of cryoablation and radio frequency ablation of small renal tumors: a multi-institutional review. J Urol 172: 874-7, 2004.

9 McGahan, J. P., Browning, P. D., Brock, J. M. et al.: Hepatic ablation using radiofrequency electrocautery. Invest Radiol, 25: 267, 1990.

10 Organ LW. Electrophysiologic principles of radiofrequency lesion making. Applied Neurophysiology. 39: 69-76, 1997.

11 Pereira PL, Trubenbach J, Schenk M, Subke J, Kroeber S, Schaefer I, Remy CT, Schmidt D, Brieger J and Claussen CD: Radiofrequency ablation: in vivo comparison of four commercially available devices in pig livers. Radiology. 232: 482-90, 2004.

12 Rehman J, Landman J, Lee D, Venkatesh R, Bostwick DG, Sundaram C and Clayman RV. Needle-based ablation of renal parenchyma using microwave, cryoablation, impedance- and temperature-based monopolar and bipolar radiofrequency, and liquid and gel chemoablation: laboratory studies and review of the literature. J Endourol. 18: 83-104, 2004.

13 Weizer AZ, Raj G, O'Connel M, et al. Complications after percutaneous radiofrequency ablation of renal tumors. Urology 66: 1176-80, 2005.