RADIOFREQUENCY ABLATION

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Hyperthermic (thermal) coagulation necrosis:
Coagulation necrosis denotes "irreversible thermal damage to cells even if the ultimate manifestations of cell death do not fulfill the strict histological criteria of coagulative necrosis".

42 ° C cells die but it may take a significant amount of time (approximately 60 min).
42 - 45 ° cells are more susceptible to damage by other agents like radiation and chemo.
46 - 60 ° irreversible cellular damage occurs depending upon duration of exposure.
50 – 52 ° cellular death in 4 – 6 minutes.
The objective is to heat tissues to 50 – 100 degrees for 4 – 6 minutes without causing charring or vaporization.

Between 50 and 100 degrees there is almost instantaneous cellular protein denaturation, melting of lipid bilayers and destruction of DNA, RNA and key cellular enzymes.

Microbubbles are produced. These represent gases, primarily nitrogen, that are released from the cells.

Temperatures greater than 105 degrees cause boiling, vaporization and carbonization, all of which decrease energy transmission and consequently impede ablation.

The extent of coagulation necrosis is dependent on the energy deposited, local tissue interaction minus the heat lost.
Coagulation necrosis = energy deposited X local tissue interactions – heat loss

Sources of thermal ablation:
Microwave
High intensity ultrasound
Laser
RFA
Injection of heated fluids (saline, ethanol, contrast)

Benefits of thermal ablation:
Imaging guidance
Tumor ablation in non-surgical candidates
Reduced morbidity
Outpatient procedure

RFA (radiofrequency ablation):
The strategy of RFA is to create a closed-loop circuit including the needle electrode, the patient (tissue) and grounding pads in series.

The radiofrequency electrode (14 -18 ga) is introduced into the lesion. The needle electrode is comprised of a metal shaft that is insulated except for an exposed conductive tip.
An electrical circuit is set up between the uninsulated needle tip and the grounding pads on the thighs or legs. It creates a voltage or electric field between the electrode and the pads. The alternating current proceeds from the needle to the grounding pads.

Using alternating current the ions are agitated (as they attempt to move with the changing current) and the resulting friction causes heat.

There is heterogeneity of heat deposition through tumor. The greatest heat is deposited surrounding the probe. There is a rapid fall off of heat moving away from the probe because of poor heat conductivity of the tissues.

Heating should be slow and gradual to avoid rapid charring or vaporization adjacent to the tines or electrode. Charring and vaporization reduce the distance of heating and coagulation necrosis, which causes incomplete destruction.

Increasing the heat is limited as vaporization, carbonization and boiling occur over 105 ° C. Basically, when gas is formed it serves as an insulator to heat and increases tissue impedance. Heat dissipation is precluded, which reduces the distance of heating and coagulation necrosis**.**

With time, the area of coagulation necrosis is absorbed and replaced with fibrosis and scar tissue.

Needle electrodes:
Two types of needle electrodes exist, the single electrode and those with multiple tines.
Three units are commercially available (approved by the FDA):
1. Radionics (Radionics Inc., Burlington MA)
2. RITA Medical Systems (Mountain View CA) (multiple tines)
3. Le Veen (Radiotherapeutics Moutain View, CA) (multiple tines)

Radionics:
Radionics (cool-tip) probe (needle) is available in one size 17 Ga and 10,15 and 25 cm lengths. It is a single or cluster electrode with a tip exposure of 2 – 4 cm.
This is an internally cooled device that also uses pulsing sequences to improve heating.

RITA:
The RITA (radiofrequency interstitial tumor ablation) probe is a 15 ga, with various types of arrays.
It uses temperature of tissue to monitor its effect. The tines have a thermocouple at the tip that registers the temperature of the heated tissue.

LeVeen Probe (Radiotherapeutics):
This needle has multiple (10, 12) tines. There are 2.0, 3.0, 3.5 and 4.0 cm diameter needles.

It relies on impedance feedback.

Radionics and RITA allow for heating of the tract whereas Radiotherapeutics must have the tines deployed to heat.

Methods to increase the area of coagulation necrosis:
Multiple punctures with several electrodes. This is time consuming and associated with increased complications.

Bipolar electrodes:
2 electrodes spaced approximately 4 cm apart. The problem is that the coagulation necrosis is elliptical and not wide in the center. This shape is unlike most tumors and is not practical.

Multiple array needles (hooked arrays or tines):
They increase the volume of coagulation necrosis.

Internally cooled electrodes:
This electrode is closed and has 2 lumens. One lumen receives chilled perfusate and the other removes the warmed perfusate. This keeps the area adjacent to the needle cooled and prevents charring and vaporization.

Saline-enhanced RFA:
The injection of heated saline can cause better dissemination of heat than a solid tumor.

Pulsing:
Pulsing with alternating high and low energy may increase the area of ablation. The area around the electrode preferentially cools more in-between pulses and greater energy can be applied affecting the surrounding tissue. Pulsing and internally cooled needles are synergistic.

Decreasing vascular flow:
Local or adjacent blood flow may create a heat sink and cause cooling and dissipation of heat. This is called “perfusion mediated cooling”. Vessels > 3 mm can impede or prevent complete ablation. An attempt to limit this can be performed surgically with the “Pringle” maneuver or percutaneously by embolization.

Improved tissue heat conduction:
Besides saline, other agents can also improve heat conduction or sensitize the tissue to heat creating a larger area of coagulation necrosis.

Thermosensitizers reduce the temperature at which coagulation necrosis occurs. Known thermosensitizers include hypoxia (embolization), chemotherapy and radiation.

Imaging guidance for RFA:
As noted above, when a lesion or tissue is vaporized microbubbles are released.

If US is used this is apparent as increased echogenicity.
Unfortunately, this area does not necessarily correlate precisely with the tumor ablation or mean necrosis is complete. The echogenicity represents the microbubbles of gas and not the coagulative necrosis.
The increased echogenicity can also obscure the tumor for further ablation.

CT or MR correlates better with assessing necrosis. On CT, hypodensity and air bubbles can be visualized.

An immediate post contrast CT is good for evaluating residual viable tumor. It shows hypodensity instead of enhancement.

CT and MR can predict the region of coagulation necrosis to within 2 - 3 mm.

Advantages of RFA:
It can be performed percutaneously, laproscopically or with open surgery.
It removes less normal tissue than surgery
Less risk than surgery
Can change inoperable status to operable
Can be performed as an outpatient
It is more effective and requires less sessions than PEI
It has fewer complications than cryosurgery

Indications:
Cardiac conduction abnormalities
Trigeminal neuralgia (hyperactive neurologic foci)
Bone neoplasms –osteoid osteomas and metastasis
Liver neoplasms – primary and metastatic
Renal cell carcinoma for patients requiring nephron-sparing procedure
Other neoplasms including lung, breast, spleen, prostate, pheochromocytomas, adrenal gland, sarcomas, head and neck tumors, cerebral metastasis and neuroendocrine tumors.
Although not common, it is sometimes used for palliation

Contraindications:
Active infection
Pregnancy
Coagulopathy +/-
Lesions at the liver hilum (peri-hilar region) +/-
HCC patients with Child-Pugh C do not benefit from RFA as far as survival
Subcapsular lesions may hurt more and predispose to tumor seeding
Lesions within 1 cm from the skin when ablated can result in a skin burn
Extrahepatic disease unless the metastasis are more likely to cause mortality than the extrahepatic disease

Grounding pads:
Grounding pads complete the electromagnetic circuit traveling through the patient and receive the same amount of heat at the grounding pad surface as the tissues surrounding the electrode. They receive as much heat as the electrode distributes.

Second-degree burns occur with temperatures exceeding 42 degrees C and 3rd degree burns occur greater than or equal to 52 degrees C.

Factors that influence heat below the grounding pad:

- Size of the pad. A greater surface area is better to distribute the heat (> 100 cm2).
- Number of grounding pads. Multiple pads should be used.
- Orientation of the pad – horizontal orientation with the longest edge of the pad directed towards the electrode.
- Foil pads prevent skin burns better than mesh pads
- Gel pads or gel between the pad and skin help distribute the heat
- Shaving the area and cleaning the skin helps with conductivity
- Placing the pad over muscle (thigh) is better than fat

Procedure:
Place 4 grounding pads on patient's legs.
Prophylactic antibiotics =+/-
Conscious sedation
CT or Ultrasound guidance. We prefer CT.

Placing the needle electrode:
Once the lesion is localized and the patient is prepped and draped we approach the lesion with an 18 ga. Hawkins blunt needle.
When access to the lesion is confirmed we place the back end (firm) of a 50 cm straight guide wire through the blunt needle and exchange for a 7 Fr. sheath.
The RFA probe is then inserted through the sheath and placed with its tip at the distal periphery of the lesion. The initial placement should be along the posterior interface between the tumor and normal tissue. This produces a "margin" of coagulation necrosis. This margin should be .5 – 1 cm.

Obtain a 3 D impression of the lesion and perform as many burns as possible to necrose the entire tumor. A parallel cylindrical burn pattern is useful.
Attempt to cross the capsule only once (single puncture) and simply readjust the needle direction.
If the patient is doing well after 4 – 6 hours they can be discharged.

Complications of RFA:
Overall – 2 - 12%
Major - 5-10% (Mortality - 0.2%, Morbidity 1.7%)
Most common are focal pain, pleural effusion and regional hemorrhage.
Pain - the patient commonly only experiences pain in the first 24 hours.
Bleeding – intraperitoneal, subcapsular, intrahepatic (may be observed in up to 30%)

Diaphragm necrosis
Pleural effusion
Fever
Infection, Abscess
PTX
Portal thrombosis
Bile duct, Biloma
Thermal damage to adjacent organs e.g. cholecystitis and colonic burn
Grounding pad burns
Tumor seeding - may occur either due to the larger needles or the release of tumor cells associated with intratumoral explosion resulting from an increase in temperature.

Success:
Factors that determine success:
Size (most important)
Location (near large blood vessel)
Tumor type (HCC > breast > colorectal metastasis).

Lesions	< 2.5 cm	= 90% chance of ablation
	2.5 – 3.5 cm	= 70 – 90% chance of ablation
	3.5 – 5 cm	= 50 – 70% chance of ablation
	> 5 cm	= < 50% ablation

Cirrhotic type livers may do better because of the oven effect i.e. a firm liver surrounding (insulating) the lesion. Well circumscribed tumors do better than infiltrating.

Follow up:
Follow up includes a 3 phase CT at 1 and 3 months then every 3 months until a year.
If there is no regrowth at 6 – 12 months, treatment is considered adequate.

Complete ablation is seen as an area of low attenuation that should be larger than the original lesion. It may be spherical or oval or multilobed depending on needle position for burn and location of blood vessels. The margins should be sharp, smooth, homogeneous, circumferential and extend beyond the confines of the pretreatment tumor. A bulky irregular rim is suggestive of residual tumor.

Follow up with CT may normally demonstrates an enhancing rim that is thin and regular. This commonly persists for a month. Enhancement (non-tumoral) has been shown to occasionally persist for up to 3 – 6 months.
Enhancement may occur from granulation tissue. It may represent an inflammatory response to the thermally damaged cells.

When in doubt, PET and tumor markers are also helpful.