Imaging Guided Ablation Therapy: Technologies and Techniques for Minimally Invasive Treatments

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Diego A. Covarrubias, MD
Kaiser Permanente West Los Angeles Medical Center
Interventional Radiology

Disclosure of Commercial Interest

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Objectives

At the conclusion of this presentation, the attendee will:
• Be familiar with:
  – Ablation technologies
  – Understand clinical indications for their application
• Have a thorough knowledge of:
  – Intra-procedural imaging guidance use and procedure techniques
  – Potential complications of ablation procedures
  – Imaging follow up algorithms
• Briefly review outcomes of ablation therapies, including comparison to conventional therapies and touch on new developments
The Role of the Radiologist

- Moved beyond simply diagnosis
- Multiple established interventional therapeutic options currently available
- Widespread acceptance of minimally invasive treatments continues to drive increasing demand for such procedures

Ablation

- Direct application of energy to achieve eradication or substantial tumor destruction
- Advantages of imaging-guided ablative therapies compared w/ traditional cancer treatments:
  - Lower morbidity and mortality
  - Lower procedural cost
  - Real-time imaging guidance
  - Outpatient Tx
  - Synergy with other treatments
  - Repeatability
- Focus on "Thermal" modalities
  - Radiofrequency ablation (RFA)
  - Microwave ablation (MWA)
  - Cryoablation (CA)

RFA

- Most commonly used thermal modality (most data/experience)
- Generator sends alternating current to an electrode tip positioned in the target lesion
  - Friction from oscillation of ions in target tissue causes resistive heating and irreversible coagulative necrosis extending to adjacent tissue through conductive heat transfer in a fixed distance depending on electrode/system
  - Tissues nearest electrode tip receive the most concentrated thermal energy
- Cell death occurs at 55°C
RFA

- Requires use of grounding pads to "complete the circuit" to allow current to flow

RFA

- Physics creates limitations
  - Heating with electric current is self-limiting
  - Water vapor, desiccation, charring created by RF increases tissue impedance
  - Impedance limits application of more current and heat
  - Biologic tissues are inefficient conductors with limited ability to overcome relatively minor competing processes, such as perfusion and ventilation

MWA

- Heats by agitating water molecules in the tissue, producing friction leading to cellular death via coagulation necrosis

MW oscillating at $9.2 \times 10^8$ Hz: charge changes signs nearly 2 billion times/sec = $H_2O$ in tissue "flips" 2–5 billion times/second
MWA

- Volume of ablation zones depends on the power applied, duration of treatment, antenna design, and microwave frequency

MWA

- Disadvantages:
  - Theoretically, increased power comes with potential for increased complications related to collateral damage to adjacent structures
  - This has not proven to be the case in clinical practice

RFA vs. MWA

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<th>MWA</th>
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Cryoablation

- Freezing tissue
  - Intracellular and extracellular ice crystal formation: both kill cells, but by different mechanisms
  - Location of ice formation varies with freezing rate
    - Fast freezing to lower temps = intracellular ice = cell death due to direct damage to cell membrane, organelles
    - Slower freezing = extracellular ice = change of osmolality in extracellular space = cell dehydration and death
  - Freezing leads to cell membrane disruption, release of cellular contents
  - Ablation zone is reperfused after ice ball melts, resulting in rapid release of cellular debris into systemic circulation

Necessary temperature to cause reliable cellular necrosis: 
$-35^\circ\text{C}$ to $-20^\circ\text{C}$

Cryoablation

- Expansion of compressed argon gas inside the probe tip cools the probe and leads to freezing of the surrounding tissue
- Thawing is achieved by warming the probe with circulating helium

Cryoablation

- Main benefit: ice ball (i.e., ablation zone) is well visualized
  - US, CT, and MR: during procedure
  - Allows precise monitoring of treatment not possible with heat-based systems
Cryoablation

- Ice ball size dependent on probe
  - Multiple probes are synergistic
  - Allows for treatment of much larger lesions than heat based therapy
  - Of course, complications associated w/ placement of multiple percutaneous needles and large ablation zone also increase proportionately
- Essentially, you can make the ICE BALL as big as you want!

Cryoablation

- Disadvantages:
  - Cumbersome set up – lots of big gas tanks!
  - Longer treatment times relative to heat based therapies
  - 25-30 minute freeze/thaw cycles
  - Multiple probes likely required
  - Potential for “cryoshock”
    - SIRS/sepsis-like response
  - Increased risk of hemorrhage – no coagulation necrosis

Clinical Indications

- Ablation becoming widely accepted for treatment of benign and malignant tumors of lungs, liver, kidneys, bone, and soft tissues
  - Established roles in HCC, RCC, early or non-surgical lung cancer, osteoid osteoma, treatment of metastases, palliation

- Decisions to attempt ablative therapy will be patient and tumor specific
Ablation Patients

- Advanced age
- Co-morbid conditions precluding surgery
- Organ specific – limited liver reserve, emphysema, solitary kidney, etc.
- Multiple tumors or the predisposition to develop multiple tumors (i.e. VHL)
- Treatment of local or single distant metastatic lesions
- Treatment of recurrence after attempted surgical treatment or prior ablation
- Pre-procedure evaluation should include:
  - History and physical examination
  - Current (within 2 weeks) laboratory tests: hematocrit, platelet count (>50,000), PT, INR (<1.5), PTT, creatinine, and eGFR
  - Discussion of procedure, including risks, benefits, alternatives
  - Planning for sedation/anesthesia and necessary adjunctive maneuvers
  - Explanation of follow up imaging requirements

Hepatocellular Carcinoma

- 5th most common type of cancer worldwide
- 2nd and 6th leading cause of cancer-related death in men & women respectively
- Incidence of HCC more than tripled in US over last 30 years
- Most commonly occurs in setting of chronic liver disease/cirrhosis
- Risk factors vary geographically
  - In US, most commonly due to Hepatitis B & C, alcohol abuse, non-alcoholic fatty liver disease

HCC Indications

- Indicated for patients who are not candidates for liver resection or as a bridge to transplant but have relatively preserved liver function & good performance status
- Lesions < 3 cm (single or up to 3 lesions), primary or metastatic
- Single lesion < 5 cm
- Suitable location (i.e. away from crucial structures such as bowel or potential for creation of a suitable window using adjuvant techniques such as hydrodissection)

Recommendations for treatment of HCC based on Barcelona Clinic Liver Cancer staging system, which incorporates degree of tumor burden, Child-Pugh Classification, & performance status.
Hepatic Metastases

- Most common location for solid organ metastasis
  - ~50% of cancer patients die with liver metastases present
- Common etiologies:
  - Colon, breast, neuroendocrine, pancreas, stomach, melanoma
- Why treat?
  - Survival benefit (colorectal)
  - For treatment of a solitary lesion
  - For symptomatic relief (neuroendocrine)
  - For cytoreduction (ovarian)

Renal Cell Carcinoma

- Most common malignancy affecting the kidney
- 3rd most common urologic malignancy in the United States
- Incidence increased >35% over last 30 years
- >½ of RCCs discovered incidentally on cross-sectional imaging studies
  - typically at an early stage and small size: suited to percutaneous, minimally invasive treatment

RCC Indications

- Tumor size
  - ≤ or equal to 3 cm have best treatment response.
  - Up to 92% complete ablation rates in 3-5 cm tumors
- Tumor location
  - Exophytic tumors more easily and efficiently treated than central lesions
  - Successful treatment of central lesions reported in multiple series
- Anatomic relationship to adjacent structures should be considered
  - Collecting system/urinary
  - Renal vasculature
  - Bowel or extra-renal organs
  - Adjunctive maneuvers can ensure treatment of tumors adjacent to vital structures
Lung Cancer

- Primary lung cancer is leading cause of cancer-related mortality in the US
  - 160,000 deaths per year
- 2nd most common site of metastasis
- Up to 40% of other malignancies
- Non-small-cell lung cancers (NSCLCs) most common histologies
- >15% of all patients, and 30% of those 75 or older, with stage I/II NSCLC have medically inoperable disease
- Small cell cancers more aggressive and generally treated w/ chemotherapy

Lung Lesions Indications

- Ablation candidates usually are those that are candidates for sublobar resection
  - Inadequate pulmonary reserve to tolerate lobectomy
  - No significant difference in pulmonary function on multiple follow-up visits after pulmonary ablation
  - High risk for surgery (for reasons other than pulmonary reserve)
  - Patients who refuse surgery
- For primary tumors – unresectable, stage I/II tumors
- For salvage therapy – local progression after initial treatment with other modalities, such as surgery, chemotherapy, radiation
- Metastatic disease – from lung primary or other sites (ie. Colorectal)

MSK Lesions

- Osteoid osteoma
  - Benign bone tumor that causes significant pain
  - Ablation has replaced surgery as primary treatment for non-spinal osteoid osteoma
  - High success rate w/ little or no complications

RFA is the standard modality b/c of its ability to produce a reliable, small ablation zone (1 cm or less)
MSK Lesions

- Palliative treatment of bone and soft tissue tumors/metastases
  - Just as in tx of osteoid osteoma, goal of treatment is pain relief
  - Need to treat the “tumor/bone” interface to achieve pain relief

Care should be taken to avoid nerve damage. This is one area where CA holds an advantage as nerves in CA treatment zones have been shown to regenerate and regain function, which is not the case w/ heat based therapies.

Choosing an Ablation Modality

- Largely decided by operator preference and system availability
  - “Hot”
    - Liver
    - Lung
    - Peripheral kidney
    - Adrenal
  - “Cold”
    - Central renal tumors
    - Lung lesions close to the chest wall/mediastinum
    - Bone lesions
  - RFA: osteoid osteoma

Technique – Goal of Treatment

- To kill tumor in a selective manner
- Target lesion and rim of normal tissue
  - 5-10mm considered appropriate
  - Think of as analogous to “surgical margin”
- 3D model of tumor important
Technique – Imaging Modality

Modality for image guidance subject to preference of individual operators and availability

- **CT** – most widely used modality
  - **Advantages:** availability, familiarity and ease of use, rapid image acquisition, wide field of view, high spatial resolution depicting the tumor and surrounding anatomy
  - **Disadvantages:** use of ionizing radiation

- **Ultrasound**
  - **Advantages:** real-time imaging without ionizing radiation
  - **Disadvantages:** limited depth of penetration, ultrasound artifacts are produced, rendering visualization of the tumor difficult

- **MRI**
  - **Advantages:** superior contrast resolution, multiplanar imaging capabilities, lack of ionizing radiation, potential for use of perfusion and thermography sequences that can provide additional information about the ablation process
  - **Disadvantages:** requires MR-safe equipment, not as widely available as CT or US, patient issues (e.g., pacemaker, claustrophobia)

Often, ultrasound can initially be used for placement of the electrodes, followed by monitoring of the ablation and repositioning of the probes under CT guidance for further treatment as necessary.

Technique – Sedation

- Typically performed as an outpatient procedure or with overnight observation stay (23 hr admit)
- Conscious sedation well tolerated with MWA and CA
  - Patient position may be awkward/difficult which could necessitate use of general anesthesia for long procedures (CA)
- RFA more painful and may require general anesthesia

Ablation: Technique Overview

- Lesion is localized: in this case, a 20 gauge needle was placed in the approximate location and IV contrast was administered, showing the target lesion.
- Probe placement: the probe was placed parallel to the guiding needle into the lesion.
- Treatment: Four overlapping ablations were performed
- Post-procedure scans: immediate post-procedure scan and one month follow-up scans demonstrate the ablation zone – note lack of enhancement following contrast administration, denoting excellent result.
Technique – Patient Positioning

• Should allow best possible access to lesion
  – Supine: liver, some lung
  – Prone: shortest route to kidney
  – Ipsilateral decubitus: limits renal motion, collapses lung
  – Oblique (ipsilateral side up): mobilization of bowel away from kidney

Technique – Probe Placement

Cryoaulation

• Initial freeze cycle of 8 to 15 minutes followed by a 10 minute partial thaw
• 5-15-minute refreeze, tailored to mass size
• Length of initial freeze cycle determined by intermittent CT images showing low-density ice extending 1 cm beyond visible tumor margins
• If insufficient ice coverage suspected at conclusion of first freeze cycle, additional cryoprobe may be placed near tumor margin during thaw cycle to allow more complete coverage during second freeze

Technique – Adjunctive Techniques: Hydrodissection

• Performed to displace adjacent structures (i.e. bowel, spleen, liver, pancreas, etc.) to avoid unintended thermal injury
  – Injury can occur when structures are within 1-2 cm of target lesion
• D5W used in RFA case, b/c ionic NS may actually propagate/conduct thermal energy
• For MWA or CA, can use NS or even contrast RF electrode (arrow) and a 20 gauge needle (arrow) in position. This 20 gauge needle was used to displace the adjacent duodenum (arrow) using hydrodissection with D5W.
Technique – Adjunctive Techniques:

Hydrodissection

Hydrodissection is performed by image-guided placement of a needle into space between tumor and an adjacent structure. A. Contrast-enhanced axial image from a diagnostic CT demonstrates a renal lesion with both central and exophytic characteristics (arrow). The lesion is in close proximity to the adjacent duodenum (arrow). B. A 20 gauge needle was placed between the lesion and bowel and D5W was administered. C. The instilled fluid (arrow) has widened the space between the lesion and the bowel, allowing for safe performance of RFA.

Technique – Adjunctive Techniques:

Pyeloperfusion

- Treatment of central RCCs with RFA/MWA poses risk of injury to the collecting system or ureter.
- To minimize risk, a ureteral catheter can be placed just prior to the procedure.
- Pyeloperfusion with cold D5W/NS under gravity drainage maintained throughout the ablation, to prevent thermal injury.
  - Feasible with lesions up to 1.5 cm of ureter, w/o change in efficacy of ablation.

Scout image from RFA planning CT scan demonstrates a ureteral stent in position for continuous pyeloperfusion during the procedure (arrows).

Technique – Adjunctive Techniques:

Pyeloperfusion

A. Non-contrast CT image prior to placement of RF electrode demonstrates a left ureteral catheter (arrow) in position for pyeloperfusion of the collecting system. B. Oblique reformatted image from the same scan shows the course of the catheter in the ureter (arrow). C. The ureteral catheter (arrow) is typically placed cystoscopically.
Technique – Adjunctive Techniques

- Other techniques:
  - Creation of an iatrogenic pneumothorax (using air or fluid)
  - Using the electrode as a lever to move the target lesion away from adjacent organs
  - External manual compression

Potential Complications

- Majority of complications are classified as minor, requiring observation without further intervention

- Can be divided into two general categories:
  - Consequence of thermal damage
  - Consequence of probe placement

Potential Complications

Consequence of probe placement

- Bleeding
  - Relatively low risk (<2%)
  - Depends on tumor location and underlying parenchyma
- Infection
  - Post-procedure sepsis or abscess
  - Increased risk in diabetics, patients with biliary-enteric communication
- Periprocedural antibiotic use is operator dependent
  - No data to support benefit
- Tumor seeding
  - Reported but thought to be exceedingly rare (<0.01%)
  - Reported in HCC
  - Consider “hot withdrawal”
Potential Complications

Consequence of thermal damage

• Injury to adjacent organs – Non-target thermal damage
  – Diaphragm, pleura, bowel, gallbladder/bile ducts, renal collecting system/ureter, vascularity, nerves
  – Depending on severity, may require further intervention
  – Drainage, embolization, surgery, etc.

Potential Complications

Consequence of thermal damage

• Specific to RFA: grounding pad burn

Potential Complications

Consequence of thermal damage

• Liver

Bile duct stricture
Potential Complications

Consequence of thermal damage

- Kidney

Potential Complications

Consequence of thermal damage

- Lung

Potential Complications

Consequence of thermal damage

- Vascular injury

Patients should be closely monitored after procedure:
- Vital signs, pain, CBC and other labs if necessary
- Consider blood bank sample prior to procedure if high risk

Need for further intervention should be continually assessed
Follow-Up Imaging

• Imaging follow-up after ablative therapy varies by institution and organ system
  – Multiphase CT or MRI acceptable for HCC/RCC f/u

In all cases, residual or recurrent disease is denoted by enhancing tissue in the treatment bed

Follow-Up Imaging

• Again, timetable and protocol of follow-up varies by institution
  – Generally 1st follow-up scan obtained within one month of ablation
  – Followed by studies at 3, 6, 9, and 12 months and bi-yearly or yearly thereafter

Exact protocol not as crucial as need for strict F/U!

Follow-Up Imaging

• Up to 70% of residual or recurrent disease is detected between 1 and 3 months after initial ablation

Residual or recurrent disease can be treated with repeat ablation
Follow-Up Imaging

Lung Lesions
• Followed with CT and/or PET/CT
• Again, institutional protocols will differ
  – Initial f/u PET/CT should not be performed until 3 months after ablation
  – Persistent uptake, even low level (1.5 SUV), suggests residual or recurrent disease

Outcomes
• HCC
  – Survival rates of 91.4% for 3 years and 83.2% for 5 years
  – Recurrence rates of up to 47% at 5 years
• Colorectal Liver Metastases
  – Overall 1-, 3-, 5- and 8-year survival from RFA 93%, 77%, 36% and 24%
  – Recurrence rates 5.6%-41%
• RCC
  – 5 year survival rate of 97%
  – Recurrence rates of 3%-6%
• Lung cancer
  – 3-year survival rates of 46%–60%
  – Recurrence rate varying from 7% to 55% between 1 and 3 years
Conclusion

• Ablative therapies are being increasingly applied to treat a variety of diseases with promising results
• Percutaneous, minimally invasive approach is beneficial to patients and to providers/organizations
• As technology improves treatment will only become more safe, precise, and effective with new applications and possibilities

Thank You!

Contact:
Diego.A.Covarrubias@kp.org

References