Use of Radiofrequency Ablation in the Treatment of Bone Tumors

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Summary: Radiofrequency ablation is a well-established treatment tool utilized in musculoskeletal oncology. It is a safe, minimally invasive, and cost-effective treatment for many lesions. Most frequently utilized for treating osteoid osteomas, the technique is also helpful for controlling selected lesions from metastatic bone disease and other benign bone disorders, such as, chondroblastomas and osteoblastomas. The procedure requires considerable preoperative planning and organization to assure a smooth, efficient experience. Our intent is to review the indications for radiofrequency ablation as a treatment option for musculoskeletal tumors and to give a detailed description of the planning, set-up and technique of the procedure. Key Words: Radiofrequency ablation—RFA—Osteoid osteoma—Metastatic bone disease—Minimally invasive.

Radiofrequency ablation (RFA) is a relatively new technique for the treatment of bone tumors that offers reduced morbidity with excellent success. In RFA, alternating current (100–500 kHz) is delivered to pathologic tissue by the probe tip. This causes ionic agitation and frictional heat that causes local tissue coagulation in a small area around the tip of the probe.

Many companies are currently distributing RFA devices for clinical use including: Boston Scientific, RITA Medical System, Radionics, Tyco Healthcare, and Berchtold Medical Electronics. Although the RITA and Radionics devices are most well known to these authors, a similar tissue response and safety profile can be expected from all approved devices (Figs. 1 and 2). The RITA device consists of a 50 to 150 W alternating current generator and a 15-gauge electrode. The probe has a movable hub and eight retracting curved electrodes that are deployed from the tip after its positioning into the tumor. An array electrode can increase the coagulation zone enabling a higher rate of complete necrosis. The probe tips can be seen on computed tomography (CT) scan and can be adjusted based on the area intended to treat. Each needle tip can also register the temperature in the heated area. Radionics distributes a probe that consists of a straight needle with an internal channel. Inside this channel, saline solution circulates for cooling. Holes are present to permit the leakage of saline solution to increase tissue conductivity.

Radiofrequency ablation is most often used for treating osteoid osteomas, but its indications are expanding to include other benign and malignant lesions such as chondroblastoma and metastatic bone disease. Osteoid osteoma is a benign, bone-forming tumor that most commonly occurs in children and young adults. It classically produces pain that is worse at night and relieved by anti-inflammatory medication. The nidus in the center of the tumor rarely exceeds 1.5 cm in diameter.² Classically, they arise in diaphyseal bone, however, they have also been reported in the epiphyseal and metaphyseal bone of the axial and appendicular skeleton.¹¹ Although there is evidence that many of these lesions will regress spontaneously, patients are usually unwilling or cannot tolerate prolonged NSAID use and the unpredictable duration of the disease.

Historically, these lesions were widely excised with open surgical procedures.¹⁸,¹⁹ The development of less invasive techniques have been explored by many authors to avoid the complications of wide open excision such as infection, soft tissue damage, creation of a stress riser, increased postoperative pain, and difficulty finding the lesion.¹⁶ It is also more cost effective.³ Radiofrequency ablation provides an attractive alternative to open excision of the nidus and is a superior alternative for most uncomplicated cases of osteoid osteoma. In addition,
RFA is well established as having a high success rate with a low incidence of complications.\textsuperscript{4,15} This is true for both primary lesions and recurrences after attempted open surgical procedures.\textsuperscript{13}

It is our intent to share with the orthopaedic community our preoperative thought process, a detailed step-by-step account of our room set-up and procedure, and what to expect postoperatively.

**INDICATIONS FOR RFA FOR BONE LESIONS**

In addition to using RFA for osteoid osteoma, reports of using computed tomography (CT) guided-RFA for the treatment of other bone lesions are increasing. Bone metastasis measuring as large as 7 cm in size have been treated successfully with this technique.\textsuperscript{6} Radiation therapy is the current standard of care for local treatment of tumors, however, it may be contraindicated or not effective for pain relief. Many physicians are considering RFA an option for pain relief in metastatic disease because of the reasonable early results and reduced morbidity for the patient.\textsuperscript{12,20} Kojima et al. have also showed good pain relief using RFA for the treatment of metastatic bone lesions.\textsuperscript{14} Good outcomes with pain relief have also been reported with radiofrequency ablation of spine metastases.\textsuperscript{7,8}

In 2004 Goetz et al. reported on 31 patients who where treated with RFA of metastatic disease for pain relief. A multi-tip needle probe was inserted into the lesion and heated to 100°C for 5 minutes. Pain scores decreased from an average of 7.9/10 before the procedure to 3.0/10 and 1.4/10 at 12 and 24 weeks, respectively, after the procedure. Opioid usage was also significantly decreased. Three complications were noted including a skin burn from the ground pad, transient bowel and bladder incontinence from treatment of a sacral lesion, and an acetabular fracture after treatment of an acetabular lesion.\textsuperscript{1}

The minimally invasive technique used with CT-guided RFA has increased the armamentarium for treating difficult to access lesions. A primary example would be chondroblastoma of the femoral head. Although complication rates may be significant because of the close proximity of the probe tip to the joint surface, this technique may be an attractive option compared with an open procedure.\textsuperscript{17} Open treatment of chondroblastoma of the femoral head poses a significant risk to the vascularity of the femoral head, the articular cartilage, the growth plate, and also increase the risk for postoperative fracture. Osteoblastoma may also be treated with RFA in the future with multiple sites of treatments or a larger probe to target the larger lesion. There is limited data in the literature to truly know the efficacy for lesions other than osteoid osteomas and metastatic bone disease. One must be careful in applying this technique without careful preoperative diagnostic imaging since tissue cannot reliably be obtained for definitive histologic diagnosis.

**PREOPERATIVE EVALUATION**

Diagnosis of bone lesions is beyond the scope of this review, but it cannot be overstated the importance of the initial patient evaluation at arriving at an accurate clinical and radiographic diagnosis. Patients with osteoid osteomas will frequently present with a classic history of pain relieved by NSAIDs, but this will not be true in all cases. Radiographic assessment with thin cut CT with coronal and sagittal reconstructions will usually identify the nidus of an osteoid osteoma better than magnetic...
resonance imaging (MRI). Bone scans are useful for targeting the lesions when plain radiographs do not demonstrate the lesion. It is not uncommon in the pediatric population to have varied lower extremity pain complaints secondary to referred pain that can lead to many unnecessary imaging modalities on incorrect regions of the patient. A dynamic contract CT can also be used when trying to distinguish between a nidus of osteoid osteoma and a Brodie’s abscess.

PREOPERATIVE PLANNING

Once a lesion amenable to RFA is found and the diagnosis is confirmed radiographically, the patient can be scheduled for outpatient radiofrequency ablation. The procedure usually takes approximately 1 to 1.5 hours and requires the collaborative efforts of the radiology, anesthesia, and operating room staff. All anesthesia equipment and the sterile equipment needed for the procedure are brought into the room with the CT scanner. It is useful to have a checklist to be assured that all personnel, rooms, and equipment necessary for the procedure will be available (Table 1). This will increase the efficiency of the procedure and help avoid frustration. For larger patients make sure the weight limit of the CT table can safely support the patient.

The surgeon should preoperatively plan the starting position and angles anticipated to safely and accurately enter the lesion using X-rays or CT scans if available.
Areas with important neurovascular structures should be avoided if possible because working around these structures can lead to inadvertent injury. Open surgical removal of the nidus should be considered if it is within 1 or 1.5 cm of important neurovascular structures. Open surgical removal of the nidus should be considered if it is within 1 or 1.5 cm of important neurovascular structures. Skin should also be respected as severe burns have been reported. When planning a point of entry for the bone introducer or drill bit it is helpful to choose a flat bone surface that is perpendicular to the lesion. To avoid neurovascular structures and to assist with patient positioning it is not uncommon to drill through the anterior cortex of a bone to get to the lesion on the posterior cortex.

PROCEDURE ROOM SET-UP

It is preferable to have a large CT room to house all of the equipment, and personnel needed to safely perform the procedure (Fig. 3). A sterile table will be needed for the surgical equipment and space will also be needed for the anesthesia and RF ablation machines. The anesthesiologist and anesthesia machine are preferably on the opposite side of the patient from the surgeon to allow for maximum access to the patient and to reduce the chance for sterile table contamination. A radiology technician, circulation nurse, anesthesiologist, and surgeon are usually the only people needed, however, a radiologist and surgical assistant may also be an asset.

The sterile surgical equipment that should be available is: skin prep solution, draping supplies, local anesthetic, number 11 blade, gauze, drill with multi-size drill bits, bone introducer, RF probe and cord, saline, suture, and dressings (Fig. 4A). Confirm that all equipment is present and working properly before any anesthesia is administered. Two dispersion (grounding) pads should be placed on the patient with good skin contact. The pads should be placed approximately equidistant and in opposite directions from the operative site. Correct placement of these pads is a critical step in the procedure and should not be delegated to other members of the team. This step should follow strict product manufacturing recommendations (see Appendix at end of article).

ANESTHESIA

General anesthesia or a spinal block is generally preferred to conscious sedation and local anesthesia for both the comfort of the patient and facilitation of ablating the lesion. Younger patients can often remain anxious with sedation even if they are pain free because of the unfamiliar environment and emotional stress of the procedure. In addition, patients will often uncontrollably move the effected limb during the ablation or imaging stages that can result in movement of the probe or additional radiation exposure needed.

PATIENT POSITIONING AND LESION TARGETING

Once the patient is under anesthesia, the next task is to determine the correct starting point. The anticipated
path that the probe will follow should be planned preoperatively. A grid can be placed on the patient’s skin over the working area before the first CT scan to help with localization of a starting point (Fig. 4B). Markings on the grid can be seen on the CT scan and can be used to estimate distance across the skin (Fig. 5A). For example, the starting point may be between the 3rd and 4th line on the grid in the medial to lateral direction. Proximal to distal movements can be estimated by using the CT slice thickness and counting how many images the lesion is from a point of reference.

CT TECHNIQUE

Before beginning the procedure, a dose of intravenous prophylactic antibiotic is given to the patient. A first generation cephalosporin or equivalent is appropriate. Once the patient is anesthetized and on the CT table, a preliminary study is done with wide cuts (3.0 mm cuts) to localize the lesion. Next, the imaging area is narrowed and the slice width is decreased to 1 mm sections to assist with targeting the center of the lesion. The small area to be ablated can be repeatedly scanned when drilling to confirm that the angles and depth of drilling is correct.
Lead is usually not required for the procedural team as the surgeon can safely and steriley enter the CT control room during scanning. Retreat into the control room also allows the surgeon to read the images in real time to make any adjustments of the probe. A lead apron usually can be placed on the patient except in certain pelvic or sacral lesions.

**BONE INTRODUCER PLACEMENT**

After the skin is marked the region can be prepped and draped for the procedure (Fig. 5B). An 11 blade is used to puncture the skin and the bone introducer can be placed. If thick cortical bone needs to be penetrated to access the lesion, a drill bit will be necessary to facilitate placement of the introducer. A drill guide should be inserted to protect soft tissue and pressed firmly against the bone. A 3.5 mm drill hole should be made in the near cortex (Fig. 5C). The bone introducer can then be inserted into the hole and advanced at the presumed angle necessary to enter the center of the lesion (Fig. 5D). Once resistance is encountered, a repeat CT should be done to confirm that the needle is pointing toward the lesion (Fig. 5E). A goniometer can be used on the CT monitor to estimate any adjustments to precisely adjust the angle of advancement into the lesion.

Once the tip of the introducer is confirmed in the center of the lesion, the center portion can be removed and a core biopsy of bone can be removed and sent for pathology evaluation. This is often not done, however, because it usually does not change management and the core biopsy frequently does not yield adequate tissue to make a diagnosis.18

**PROBE PLACEMENT AND RFA**

The tip of the RF probe can then be inserted into the introducer and advanced to the lesion (Fig. 5F). This tip position should also be confirmed with another CT image to assure the final position is correct (Fig. 5G). Several tips are available including a single tip probe to precisely deliver heat from one point and a multi-tip that has an umbrella type array of electrodes at the end for a larger area of treatment. The divergence of the probes on the multi-tip can be adjusted to broaden or narrow the area of treatment and the individual probes can usually be seen on CT. This is one of the key differences among manufactures. Rita medical systems only use umbrella-type multi-tip probes and Radionics only has single-tip probes. For treatment of an osteoid osteoma, a single probe with approximately 5 mm of exposed tip is all that is required since the nidus is <1.5 cm. When treating metastatic bone disease the lesions vary substantially in size and having a multi-tip probe becomes handy and allows for a broader area of tissue necrosis with each RFA cycle. With the tip of the probe in position, the correct end of the cord can be passed off and plugged into the RF machine. The cord should be secured to the patient with one or two clamps to avoid any traction while the CT table moves in and out of the scanner. All equipment should be inspected before each CT scan is performed to assure it will not be incidentally displaced when the table moves into the scanner. It is important to add saline to the system to help decrease impedance and facilitate ablation without over “cooking” the lesional area (Fig. 5H).

The settings on the RF machine we use are 90°C for 4 to 6 minutes with a power of 100. The machine will slowly raise the temperature and start a timer when 90°C is reached (Fig. 5I). After the 4 to 6 minutes is complete, the machine will cool down back to room temperature. The probe can usually be removed before cool down finishes. Rosenthal et al. use these same parameters for treatment of osteoid osteomas.2 There is more discrepancy in length of ablation time than ablation temperature from institution to institution. Ablation times vary from 2 to 8 minutes. The only basic research evaluating the zone of tumor necrosis or kill is based on one dog study that demonstrated approximately a 1 cm necrosis zone from the tip of the probe when using 80°C for 4 minutes.

**SPECIFIC CONSIDERATIONS BASED ON LOCATION OF TUMOR**

RFA of spinal lesions put the dura and neural structures at risk therefore conscious sedation and local anesthesia is preferable in this setting to allow better monitoring of the patients.9 Complications can be reduced by interrupting treatment or repositioning the probe if local temperature rise begins to cause symptoms. Gronemeyer et al. used RFA to treat 10 spine lesions ranging from 1.5 cm to 9 cm with good pain relief and no complications.7

Chondroblastomas located in the femoral head is another possible indication for RF ablation. To address this lesion with an open procedure would pose significant risk to the articular cartilage, the growth plate, and the vascular supply to the femoral head. CT-guidance can allow for accurate placement of an introducer and ablation probe to treat the lesion with significantly less morbidity and risk.

Osteoblastoma may also be treated with RFA. Because osteoblastomas can usually range from 1.5 to 2 cm in size, they may need to be treated with a multi-tip array
probe to increase the treatment area to cover the whole lesion.13

POSTOPERATIVE CARE

Compared with surgical removal of a lesion, radiofrequency ablation offers a quicker, safer return to preoperative function. The creation of a stress riser because of bone removal is decreased with RF ablation therefore patients can usually weight bear as tolerated and return to normal activities as they feel comfortable. Hospital stay is also reduced and a majority of these patients can go home the same day because of less anesthesia time and less insult to the procedure site. Overnight admission is uncommon after this procedure but may be necessary in a select few patients with uncontrolled pain. Pain is usually greatest in the immediate postoperative period because of the local necrosis but this should become much more tolerable in the first 24 hours. Most patients will be off pain relieving medications within a week of the procedure. Patients are seen two weeks postoperatively to check their incision, remove sutures if used, and for a postoperative radiograph. Patients with superficial lesion locations should especially be assessed for skin necrosis and should be seen at a shorter initial postoperative follow up interval. The majority of patients treated for an osteoid osteoma will be pain-free at this time interval and completely off medication. A short-term follow up is useful at 3 months postprocedure and then a follow up at 1 year with a new radiograph is offered to the patient. There are no studies that have addressed the long-term radiographic follow up of patients with an osteoid osteoma treated with RFA. Many patients will ask what will happen to the lesion on the follow-up radiographs. There is no data in the literature to help answer this question and is an area for future research.

PEARLS AND PITFALLS

- RFA is indicated for use in treating osteoid osteomas, metastatic bone disease, and some other bone lesions.
- Planning and organization are crucial to having a successful experience.
- Placement of the dispersion (grounding) pads is important to prevent heat related complications of the procedure.
- Larger lesions may require multiple ablation cycles and repositioning of probe for optimum results.
- Return to preoperative activity level is rapid and it is uncommon to need any restrictions on activity level.

REFERENCES

RFA of Osteoid Osteoma Protocol
Compatible Devices: StarBurst™ XL, SEMI-FLEX, MRI & SDE

SETUP
1. Sterilize BLACK (Model 1500) or GREEN (Model 1500X)
   - Main Cable according to instructions for use.
2. Place one Dispersive Electrode (Pad) anteriorly on each thigh.
   - The two dispersive electrodes should be placed on clean, dry
     surface over large, well-perfused muscle mass.
   - Hair should be removed before applying the dispersive electrodes.
   - Electrodes should be oriented with the longest edge toward the
     target ablation site with at least 25cm distance between the
     ablation site and dispersive electrodes. Dispersive electrodes
     should be equivalent distances from the active electrode.
   - Electrodes should not be placed over bony prominences, scar
     tissue, skin covering an implanted metal prosthesis, hairy
     surfaces, pressure points, or areas distal to tourniquets.
   - Avoid placement in areas where liquid may pool, under thermal
     blankets, and in areas where heat may be retained, e.g., under
     blankets or positioning bags.
   - Other dispersive electrodes (electrosurgical cutting device) shall
     not be placed further away from
     the ablation location and the dispersive electrodes used with the RITA RF Generator.
   - Insulate patients’ leg by placing a towel between the patient thighs.
   - Dispersive Electrodes should not be placed under compression socks or leg compressors.
3. Flush the Device with NORMAL (0.9%) saline, through infusion port, prior to use.
4. Connect Power Cord to Generator and plug into appropriate outlet.
5. Connect Foot Pedal and Dispersive Electrodes to Generator.
6. Turn Generator on with the switch on the back.
7. After self-test is complete, depress RF ON/OFF button.
8. Default control mode is “A” – “Average of all”.
9. Set Power, Temperature, and Time according to the parameters in the table below. (Always
   start with the parameters for a 2 cm deployment.)

Caution: If the patient has a pacemaker, consult the patient’s
cardiologist prior to doing this procedure. Using the RF
Generator in the presence of an internal or external pacemaker
may require special considerations.

Caution: If the patient has metal implants, the RF current may
pass through the metal implant and cause an unintended burn at
the implant site. Orientating the dispersive electrodes in such a
manner that the metal implants are not in the field of energy
(not in the field between the target tumor and the dispersive elec-
trode) may reduce this risk.

Caution: If an introducer is desired for use with the RITA devices,
use only the RITA tissue access system. Do not use an introducer
made of an electrically conductive material.

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APPENDIX. Rita Medical Systems RFA protocol for treatment of osteoid osteomas.
RFA of Osteoid Osteoma Protocol (cont.)

PLACEMENT: Using Starburst™ XL, SEMI-FLEX, MRI and SDE Devices for Osteoid Osteoma

1. Connect the Device to the Main Cable and the Main Cable to the RF Generator. Verify the temperature display and the impedance reading. Test the temperature response of the Device by holding each array tip and observing a temperature increase on the RF Generator display.

2. Using imaging guidance, place the Device by holding along the main body. Note: For SEMI-FLEX device, hold the main body with one hand and the trocar (at the point of insertion) with the other hand. Do not hold the deployment shaft handle during placement, as this could inadvertently cause deployment of the array. The device should be positioned such that the un-insulated tip (for XL, SemiFlex and MRI device equals 0.5 cm and SDE equals 1.4 cm) of the trocar is in the nidus of the tumor. (Note: RITA StarBurst Hard Tissue Access System should be used.)

3. Monitor the ablation with imaging to ensure that it is positioned in the proper area. This intended ablation area should be at least 1 cm from tissue not intended for ablation.

Caution: If the area targeted for ablation is superficial, i.e., in close proximity to the skin surface, monitor the temperature of the superficial tissues for excessive heating. If the area becomes too warm, consider applying a chemical cool pack (isolated from the skin with dry cloth) to prevent tissue damage.

ABLATION

1. Connect Device to Main Cable and Main Cable to Generator. Verify temperature display and impedance reading.

2. Start the RF power using the foot pedal or RF ON/OFF button.

3. Set the parameters on the RF Generator using the following as a guideline.

Table: Guidelines for Time at Target Temperature*

<table>
<thead>
<tr>
<th>Target Temp (Average, °C)</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wattage</td>
<td>35-60**</td>
</tr>
<tr>
<td>Time at Target Temp (min)</td>
<td>5</td>
</tr>
</tbody>
</table>

* These ablation parameters have been developed from published experience RFA in Osteoid Osteomama’s.


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RFA of Osteoid Osteoma Protocol (cont.)

TRACK ABLATION

1. For Track Ablation, retract the arrays fully, and depress the Track Ablation ON/OFF button. When ready depress the RF ON/OFF button to start track ablation.

Note: for XL, SEMI-FLEX, and MRI watch only temperature #5. When it reaches 70°C, retract approximately 1 cm. Repeat until entire track is ablated.

Note: for SDE watch only temperature #3. When it reaches 70°C, retract.

Caution: To prevent unintended tissue damage following Track Ablation, discontinue RF power prior to withdrawing device from target organ.

TROUBLESHOOTING - Temperature w/ Impedance [8.01 Software & Lower]

If one temp is very different from the others:
- If one temp is very low, but impedance is okay (35-100 ohms), then consider leaving it as is.
- If one temp is very low and impedance is very high (>100 ohms) or very low (<35 ohms), consider removing the low temp from the algorithm.
- If one temp is very high and impedance is okay (35-100 ohms), consider taking it out of the algorithm to allow the power to increase bringing the other temperatures up.

If impedance is high (>100 ohms):
- If it is high at the beginning of the case, check the dispersive electrode for proper placement.
- If it is high during the case, consider lowering the target temperature, taking out the lowest temperature.
- If power is also high, consider decreasing the power.

If it impedes out:
- If it impedes out at the start of the ablation, check all connections and restart.
- If it impedes out in the middle of an ablation, and the impedance increased sharply, check all connections and consider rotating and continuing the ablation.
- If it impedes out at the end of an ablation, check cool down temperatures to determine if continued ablation is necessary.

Cleaning arrays due to tissue build-up:
- Soak in hydrogen peroxide and wipe.

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RFA of Osteoid Osteoma Protocol (cont.)

TROUBLESHOOTING - Temperature w/ Low Efficiency Readings (6.12 Software & Higher)

If one temp is very different from the others:

- If one temp is very low, but efficiency is okay (6-10), then consider leaving it as is.
- If one temp is very low and efficiency is low (0-5), consider removing the low temp from
  the algorithm.
- If one temp is very high and efficiency is okay (6-10), consider taking it out of the algorithm
  to allow the power to increase bringing the other temperatures up.

If efficiency is low (0-6):

- If it is low at the beginning of the case, check the dispersive electrode for proper
  placement and ensure that the Device is fully deployed to desired ablation size.
- If efficiency is low at the start of the ablation, check all connections and restart.
- If efficiency becomes low in the middle of an ablation, and the efficiency was gradually
  decreasing, consider retracting the array, rotating 45 degrees, redeploying and continuing
  the ablation.
- If efficiency becomes low in the middle of an ablation, and the efficiency decreased
  sharply, check all connections and consider rotating and continuing the ablation.
- If it is low (0-5) during the case, consider lowering the target temperature, taking out the
  lowest temperature, or retracting the array and rotating the device.

Error Messages:

- System Failure 1: RAM Check – Turn the power off and contact Customer Service
- System Failure 2: CRC Check - Turn the power off and contact Customer Service
- System Failure 3: Power Supply – Turn the power off and contact Customer Service
- System Failure 4: Internal Load Low – Turn power off and then turn power back on. If
  error persists, contact customer service.
- System Failure 5: Internal Load High – Turn power off and then turn power back on. If
  error persists, contact customer service.
- System Failure 6: TEMP REF – Turn power off and contact Customer Service.
- System Failure 7: WATCHDOG – Turn power off and then turn power back on. If error
  persists, contact customer service.
- System Failure 8: LOOP OVERRUN – Turn power off and then turn power back on. If error
  persists, contact Customer Service
- System Failure 10: LONG – Turn power off and then turn power back on. If error persists,
  contact Customer Service
- System Failure 11: SPURIOUS INTERRUPT – Turn power off and then turn power on. If
  error persists, contact Customer Service

If having difficulty retracting array:

- Consider infusing normal saline and working shaft back and forth to loosen cooked tissue.
- Cleaning the array in between ablations can help prevent difficulty in retraction (use a soft
  bristle brush).

Cleaning arrays due to tissue build-up:

- Soak in hydrogen peroxide and wipe.

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