Radiofrequency Ablation of Osteoid Osteoma with Use of Intraoperative Three-Dimensional Imaging and Surgical Navigation

Edward Y. Cheng, MD, and Sameer M. Naranje, MBBS, MRCS(Glasgow)

Based on an original article: *J Bone Joint Surg Am.* 2014 May 7;96(9):735-42.

Introduction

During the performance of radiofrequency ablation of osteoid osteomas, the use of intraoperative cone-beam computed tomography (CT) imaging with surgical navigation lowers radiation exposure while allowing real-time targeting of the nidus.

Radiofrequency ablation (RFA) for tumors was initially performed in diagnostic CT radiology suites as it required CT for guidance of the probe insertion. With the advent of intraoperative CT, performing RFA in the operative setting is possible and has several advantages. The sterile environment reduces the risk of contamination and, when a lesion is adjacent to critical structures, limited operative exposures can be performed to move the structure away from the nidus, thereby allowing an RFA to be performed without incurring the morbidity of an osseous resection. In addition, three advances have helped facilitate the performance of RFA in the operative suite with easier targeting of the nidus and less radiation exposure (Video 1):

1. Whereas surgeons traditionally had only two-dimensional fluoroscopic imaging for surgical guidance, the development of intraoperative CT scans such as the O-Arm unit (Medtronic, Minneapolis, Minnesota) allows repeated CT scans to be performed readily in the operating room as needed.

2. Real-time surgical navigation is possible with use of infrared optical tracking arrays. These are typically attached to the target as well as to surgical hand pieces that the surgeon manipulates relative to the anatomic target.

3. The use of cone-beam CT technology reduces the radiation dose exposure to the patient compared with that associated with conventional sixty-four-slice CT scanners.

Osteoid osteomas are unusual bone tumors, accounting for 3% to 4% of all bone tumors but 11% to 12% of all benign bone tumors^{1,2}. Patients typically are adolescents or young adults, and there is a slight

predilection for males³⁻⁵. Nearly all patients have non-activity-related pain related to inflammatory cytokines elaborated by the tumor's focal point, known as the nidus. The natural history is spontaneous resolution, but this may take many years. Characteristically, aspirin or anti-inflammatory agents relieve the pain, but patients must continue to take medications. For this reason, most choose to have surgical treatment. In the past, this consisted of surgical excisions, either by en bloc resection or intralesional curettage. Currently, radiofrequency ablation is considered the standard of care unless critical structures, such as major neurovascular structures, are in close proximity to the nidus⁴⁻¹¹. Some authors have reported successful RFA treatment even when neural structures were adjacent to the nidus¹². The advantage of RFA relative to other treatment options is that, whereas surgical resection involving curettage, en bloc resection, or wide resection and bone-grafting has had success rates of 90% to 100%, the complication rate has been as high as 20% in some series, with a 4.5% incidence of fractures^{3,8,13}; in contrast, radiofrequency ablation is minimally invasive, is successful in relieving pain in >92% of patients, and has a lower risk of complications than surgical excision^{8,14,15} (Video 2). However, despite the minimal complications^{16,17}, one disadvantage of RFA is the radiation exposure incurred during the CT guidance that is required to accurately place the RFA. As osteoid osteoma frequently affects the pediatric and young adult age group, it is preferable to limit the radiation exposure as much as possible¹⁸⁻²⁴.

In surgical navigation, an optical infrared camera is used to track a target attached to an optical array. These arrays are attached to the target and any surgical instruments. The advantage of surgical navigation is the ability to see the target continuously, in real time, on a virtual image, *without any radiation being emitted*. Three common platforms for surgical navigation are the Medtronic StealthStation, Brainlab, and Stryker navigation suite (Video 3). The principles for performing the procedure are the same, regardless of the navigation

platform used. Nonetheless, some of the details described in the following steps pertain to the Medtronic StealthStation instrumentation and therefore slight modification may be required depending on the platform employed.

The O-Arm uses cone-beam CT technology. This emits only half the radiation dose of a conventional CT. Image contrast is excellent and bone visualization is superb. However, soft tissues are poorly seen. A conventional sixty-four-slice CT scanner emits a higher radiation dose but provides diagnostic-quality images of both bone and soft tissue (Video 3).

The procedure is performed with the following steps.

Step 1: Preoperative Planning (Video 4, time point 0:37)

Review all images to confirm a high level of confidence in the radiographic diagnosis.

- Initiate preoperative planning by reviewing all radiographs as well as CT scans, bone scan, or possibly a magnetic resonance image.
- Determine the best route of approach and angle of insertion of the probe into the center of the nidus. Avoid neurovascular structures and determine the best position of the patient on the operating table to facilitate the probe insertion.
- Assess the nidus size, as large lesions may require two or more probes, depending on the volume and size of the necrotic zone created by the probe being used.

Step 2: Patient Positioning and Setup (Video 4, time point 01:11)

Be sure to position and set up properly.

- Use a radiolucent operating table.
- Tuck the patient's arms alongside the trunk, instead of laying them out on an armboard. This allows room for the O-Arm to move laterally, toward the patient's head or foot, out of the way from the surgical field.
- Be sure that there is a clear line of sight from the target to the StealthStation infrared camera and position the O-Arm screen and StealthStation screens opposite the surgeon for easy viewing.

Step 3: Placement of Tracking Optical Array (Video 4, time point 1:43)

Attach the optical array to the target bone.

- The tracking array should ideally be placed in the same target bone as the lesion to provide

structural rigidity between the nidus and the tracking array, an essential requirement for accurate navigation. If the array cannot be placed in the same bone as the target bone and there is motion between the two bones, temporarily stabilize the adjacent bone with a Kirschner wire.

- Select a site that has a sufficient distance from the nidus to avoid interfering with the probe placement.
- Affix the tracking array with two half-pins (as shown in Video 4), using the same technique as external fixator pin placement. Alternatively, in cancellous bone (e.g., the posterior iliac crest), a splined cruciate stem (Medtronic StealthStation) pounded into the bone may provide superior fixation. Ensure that all connections between the array and the target bone are secure, as rigid fixation of the tracking array is necessary to optimize navigation accuracy.

Step 4: O-Arm Setup, Initial CT Imaging for Surgical Navigation, and Remote Mouse Registration (Video 4, time point 2:32)

Set up the intraoperative CT (O-Arm) machine and acquire the initial images for surgical navigation.

After placing the tracking array, place the plastic drape provisionally around the O-Arm, then rotate the O-Arm to close it around the patient, and complete the draping by sliding the plastic around the closed unit.

- Center the target nidus within the field of view by using the O-Arm's anteroposterior and lateral scout fluoroscopic imaging.
- Perform a CT spin. The image data acquired are transmitted wirelessly to the StealthStation for analysis, and a virtual image is merged with the surgical instruments that are navigated.
- Use a sterile mouse to manipulate the image for analysis.

Step 5: CT Data Interpretation and Approach Planning (Video 4, time point 3:31)

Analyze the initial images, rotated or positioned as necessary, to allow you to proceed with the planned direction and angle of approach to the nidus.

- The CT scan is formatted on a separate three-dimensional workstation with the use of the sterile mouse. Scroll through and interpret the images to analyze the best approach and angle of placement for the radiofrequency probe. Video 4 demonstrates use of the sterile mouse

to locate the target nidus. The field scrolls through images, while the upper left mouse button selects the image for analysis, as indicated by the yellow outline.

Step 6: Surgical Navigation Setup (Video 4, time point 3:48)

Register the surgical instruments with the surgical navigation unit.

- To track the surgical instruments, register them with the StealthStation. Typically, a pointer and a Kirschner wire drill guide are needed. Use the Kirschner wire, with a diameter slightly larger than the probe, to drill the pilot hole for the probe. If you use a Covidien probe (Mansfield, Massachusetts), a cannulated dilator for a 0.06-in (1.6-mm) Kirschner wire from a biopsy trephine set (Innomed) is the perfect size required.
- The workstation then utilizes the CT data that have been collected, matches them up with the surgical instruments, and displays both the bone and the instrument relative to each other on the screen as a virtual image that constantly updates in real time.

Step 7: Nidus Localization and Kirschner Wire Insertion (Video 5)

Target the nidus and then insert the Kirschner wire into its center.

- Locate the nidus, and determine where the stab incision should be made, by using the pointer, which is tracked continuously in real time and shown on the virtual CT image. Use the information displayed on the virtual CT image to position the pointer directly over the target nidus (Video 5, time point 1:15). Pivot the pointer in different angles relative to the target to determine the best approach angle to enter the nidus (Video 5, time point 1:28).
- Make a stab incision and dilate the soft tissues down to the target bone and the location of the nidus using a clamp or other instrument.
- Preload the Kirschner wire in the wire guide and place it at the appropriate location for the target nidus. Using the StealthStation software, one can measure the distance from the outer cortex to the far side of the nidus to determine how far to insert the Kirschner wire and then mark this depth on the wire using a marking pen or sterile adhesive strip. Under direct vision, watch the real-time virtual image to keep the guide targeted and aligned properly along the proper angle of entry while drilling and inserting the Kirschner

wire into the center of the nidus (Video 5, time point 1:58).

- Perform a CT scan to confirm proper placement. Perform any necessary adjustments, and make another CT scan for confirmation.

Step 8: Exchanging Kirschner Wire for a Radiofrequency Probe (Video 5, time point 3:14)

Once the accuracy of the Kirschner wire placement is confirmed, exchange it for the radiofrequency probe and perform a CT scan to confirm proper probe placement.

The probe size determines the size of the necrotic zone and may vary depending on the probe manufacturer. If the nidus is <2 cm in diameter, a single 1-cm probe is usually satisfactory. However, if the nidus is large (for example, >2 cm), then two or more equally spaced probes may be required (Fig. 1).

- Pre-position the probe and place it parallel to the Kirschner wire so that it can be immediately inserted into the same hole without losing the alignment and location of the cortical hole. This can be challenging when the nidus is in a deeply situated bone. The use of a soft-tissue protector sleeve to maintain access to the cortical hole after removal of the Kirschner wire is helpful.
- Remove the Kirschner wire and place the probe in the same hole in which the Kirschner wire was placed. Be careful to place the probe at the same location and depth as the Kirschner wire to ensure its proper position.

Step 9: Confirmation of RFA Probe Placement (Video 5, time point 4:17)

Perform a CT scan to confirm proper placement of the probe within the center of the nidus.

- It is critical to perform a CT scan to confirm the proper placement of the probe within the center of the nidus. It is imperative that the RFA probe be in the exact location planned to ensure success of the procedure.
- If placement is suboptimal, repeat the targeting process until the probe is in the correct location.

Step 10: Activation of the Radiofrequency Probe and Closure (Video 5, time point 4:59)

Perform the radiofrequency treatment to ablate the cells within the nidus.

- After the probe is in place, attach it to the radio-frequency generator.
- Turn on the generator and adjust the voltage to maintain the temperature at 90°C for six minutes. It may be necessary to do this twice if two probes are placed. Alternatively, some manufacturers have a dual probe setup that enables simultaneous treatment.
- Withdraw the probe, suture the wound, and place a sterile dressing.

Results

We conducted a study²⁵ of three different techniques of radiofrequency ablation. In the first group of patients, the O-Arm was used with surgical navigation. In the second group, only the O-Arm CT scan was used, without surgical navigation. In the third group, a diagnostic-quality CT scan in a radiology suite was used. We looked at the radiation exposure, which is especially important in this group of children and adolescents. The radiation exposure for those undergoing the CT scan technique was nearly twice as great as that for the patients treated with the O-Arm with or without navigation. This difference was significant ($p < 0.05$).

The outcomes of treatment were statistically the same regardless of which technique was used to target the lesion. Overall, 92% of the sixty-three patients were pain-free at a mean of fifty-three months postoperatively. The vast majority of relapses occurred within the first year or two (Video 6).

What to Watch For

Indications

- Painful osteoid osteoma with symptoms unresponsive to analgesics.
- Painful osteoid osteoma with symptoms responsive to medication but when prolonged course of treatment is considered undesirable.
- Secondary deformity such as a scoliosis, which is rare.

Contraindications

- Patients who have a critical structure in close

proximity to the nidus that cannot be surgically displaced out of the RFA treatment zone and therefore is at risk of being harmed by the RFA.

Pitfalls & Challenges

- Correct probe placement is the key to success of the procedure.
- To ablate all of the cells within the entire nidus, the necrotic zone of the probe being used must be known, and the probe must be positioned so that the necrotic zone extends beyond the borders of the nidus.
- The necrotic zone created by a single probe may be too small for some larger nidi. A larger probe could be used, but this may result in excessive tissue ablation as most probes create a somewhat spherically shaped necrotic zone and most larger nidi have a longer ovoid shape rather than being spherical. A solution is to insert two probes in parallel fashion, with each probe placed into the center of the two halves of the nidus (Fig. 1).
- Be sure that the probe is placed at the correct depth.
- Advance the electrical current setting of the generator slowly up to 90°C as some generators may automatically shut off if the temperature exceeds the set limit, and one must then restart the ablation.
- Monitor the current setting and adjust it as necessary to maintain 90°C.

Clinical Comments

- When an osteoid osteoma is located in an anatomical site where a critical structure (e.g., a nerve root) is in close proximity and therefore is in danger of being damaged, a limited surgical exposure can be performed and the nerve moved away from the necrotic zone or protected from damage by using saline solution irrigation.
- If the initial Kirschner wire placement is inaccurate, repeat the Kirschner wire placement using a Kirschner wire repositioning guide with parallel tracks to enable this task.

Edward Y. Cheng, MD

Sameer M. Naranje, MBBS, MRCS(Glasgow)

Department of Orthopaedic Surgery, University of Minnesota, 2512 South 7th Street, R 200, Minneapolis, MN 55454. E-mail address for E.Y. Cheng: cheng002@umn.edu

Disclosure: One or more of the authors received payments or services, either directly or indirectly (i.e., via his or her institution), from a third party in support of an aspect of this work. In addition, one or more of the authors, or his or her institution, has had a financial relationship, in the thirty-six months prior to submission of this work, with an entity in the biomedical arena that could be perceived to influence or have the potential to influence what is written in this work. No author has had any other relationships, or has engaged in

References

1. Jaffe HL. Osteoid-osteoma. *Proc R Soc Med*. 1953 Dec;46(12):1007-12.
2. Kransdorf MJ, Stull MA, Gilkey FW, Moser RP Jr. Osteoid osteoma. *Radiographics*. 1991 Jul;11(4):671-96.
3. Cantwell CP, Obyrne J, Eustace S. Current trends in treatment of osteoid osteoma with an emphasis on radiofrequency ablation. *Eur Radiol*. 2004 Apr;14(4):607-17. Epub 2003 Dec 9.
4. Rosenthal DI, Hornicek FJ, Wolfe MW, Jennings LC, Gebhardt MC, Mankin HJ. Percutaneous radiofrequency coagulation of osteoid osteoma compared with operative treatment. *J Bone Joint Surg Am*. 1998 Jun;80(6):815-21.
5. Theumann N, Hauser P, Schmidt S, Schnyder P, Leyvraz PF, Mouhsine E. [Osteoid osteoma and radiofrequency]. [French]. *Rev Med Suisse*. 2005 Dec 21;1(46):2989-94.
6. Cantwell CP, Scanlon T, Dudeney S, O'Byrne J, Eustace S. CT guided radiofrequency ablation of intra-articular osteoid osteoma of the hip. *Ir J Med Sci*. 2005 Jul-Sep;174(3):97-9.
7. Skorpil M, Söderlund V, Brosjö O. [Radiofrequency ablation an effective invasive treatment]. [Swedish]. *Lakartidningen*. 2004 Nov 25;101(48):3899-901.
8. Thanos L, Mylona S, Kalioras V, Pomoni M, Batakis N. Percutaneous CT-guided interventional procedures in musculoskeletal system (our experience). *Eur J Radiol*. 2004 Jun;50(3):273-7.
9. Vanderschueren G. Radiofrequency ablation of osteoid osteoma. *JBR-BTR*. 2009 Mar-Apr;92(2):126-9.
10. Lindner NJ, Scarborough M, Ciccarelli JM, Enneking WF. [CT-controlled thermocoagulation of osteoid osteoma in comparison with traditional methods]. [German]. *Z Orthop Ihre Grenzgeb*. 1997 Nov-Dec;135(6):522-7.
11. Martorano D, Verna V, Mancini A, Mastrantuono D, Faletti C, Gino G, Albertini U, Mellano D, Piana R, Marone S, Brach del Prever E, Linari A, Forni M. CT evaluation pre- and post-percutaneous ablation by radiofrequency of osteoid osteoma. Preliminary experience. *Chir Organi Mov*. 2003 Apr-Jun;88(2):233-40.
12. Samaha EI, Ghanem IB, Moussa RF, Kharrat KE, Okais NM, Dagher FM. Percutaneous radiofrequency coagulation of osteoid osteoma of the "Neural Spinal Ring". *Eur Spine J*. 2005 Sep;14(7):702-5. Epub 2005 Mar 3.
13. Gibbs CP, Lewis VO, Peabody T. Beyond bone grafting: techniques in the surgical management of benign bone tumors. *Instr Course Lect*. 2005;54:497-503.
14. Eggel Y, Theumann N, Lüthi F. Intra-articular osteoid osteoma of the knee: clinical and therapeutical particularities. *Joint Bone Spine*. 2007 Jul;74(4):379-81. Epub 2007 May 15.
15. Ramseier LE, Duc S, Exner GU. [Osteoid osteoma. CT guided drilling and radiofrequency ablation]. [German]. *Orthopade*. 2006 Sep;35(9):989-92.
16. Cantwell CP, Eustace S. An unusual complication of radiofrequency ablation treatment of osteoid osteoma. *Clin Orthop Relat Res*. 2006 Oct;451(451):290-1, author reply :291-2.
17. Harrod CC, Boykin RE, Jupiter JB. Pain and swelling after radiofrequency treatment of proximal phalanx osteoid osteoma: case report. *J Hand Surg Am*. 2010 Jun;35(6):990-4. Epub 2010 May 7.
18. Arch ME, Frush DP. Pediatric body MDCT: a 5-year follow-up survey of scanning parameters used by pediatric radiologists. *AJR Am J Roentgenol*. 2008 Aug;191(2):611-7.
19. Brenner DJ, Doll R, Goodhead DT, Hall EJ, Land CE, Little JB, Lubin JH, Preston DL, Preston RJ, Puskin JS, Ron E, Sachs RK, Samet JM, Setlow RB, Zaider M. Cancer risks attributable to low doses of ionizing radiation: assessing what we really know. *Proc Natl Acad Sci USA*. 2003 Nov 25;100(24):13761-6. Epub 2003 Nov 10.
20. Brody AS, Frush DP, Huda W, Brent RL; American Academy of Pediatrics Section on Radiology. Radiation risk to children from computed tomography. *Pediatrics*. 2007 Sep;120(3):677-82.
21. Doody MM, Lonstein JE, Stovall M, Hacker DG, Luckyanov N, Land CE. Breast cancer mortality after diagnostic radiography: findings from the U.S. Scoliosis Cohort Study. *Spine*. 2000 Aug 15;25(16):2052-63.
22. National Cancer Institute. Radiation risks and pediatric computed tomography (CT): A guide for health care providers. 2012. <http://www.cancer.gov/cancertopics/causes/radiation/radiation-risks-pediatric-CT>. Accessed 2014 Oct 16.
23. Preston DL, Cullings H, Suyama A, Funamoto S, Nishi N, Soda M, Mabuchi K, Kodama K, Kasagi F, Shore RE. Solid cancer incidence in atomic bomb survivors exposed in utero or as young children. *J Natl Cancer Inst*. 2008 Mar 19;100(6):428-36. Epub 2008 Mar 11.
24. Ronckers CM, Land CE, Miller JS, Stovall M, Lonstein JE, Doody MM. Cancer mortality among women frequently exposed to radiographic examinations for spinal disorders. *Radiat Res*. 2010 Jul;174(1):83-90.
25. Cheng EY, Naranje SM, Ritenour ER. Radiation dosimetry of intraoperative cone-beam compared with conventional CT for radiofrequency ablation of osteoid osteoma. *J Bone Joint Surg Am*. 2014 May 7;96(9):735-42.

Fig. 1
Line diagram outlining a long oval nidus that should be treated with two Kirschner wires.