Morphometric analysis of radiation dose and procedure time during percutaneous radiofrequency ablation of osteoid osteomas

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Purpose

Osteoid osteoma (OO) is a small painful benign tumor, which has a relatively common occurrence. In the Mayo Clinic review of 11,087 primary bone tumors, which were subject to either biopsy or complete surgical resection, it has accounted for 13.5% of all benign tumors (6) and 2-3 % of all primary bone tumors (3). OO is readily identifiable by its clinical and radiographic features. Patients are typically less than 30 years old. The long tubular bones of the lower extremity are most commonly affected. Lesion are round or oval on imaging, and measure up to 1.5 cm in diameter (Fig.1.). (9)

Surgical excision has been the treatment of choice, yet minimally invasive therapies, such as percutaneous excision followed by ethanol sclerotization, percutaneous radiofrequency ablation (RFA) and laser ablation has recently become available. (5) The first attempt to percutaneous radiofrequency ablation of OO with CT-guidance was published by Rosenthal et al. (9). Studies on larger patient cohorts have been reported in the last 5-7 years. (4, 8) Some of these contain thorough discussion of procedural details. Rehnitz et al. correlated the morphology on imaging (CT/ MR) and contrast-enhancement characteristics with clinical outcome. (7)

Patients are typically children or young adults with essential need for radiation dose reduction. Dose reduction techniques have been tested in studies aiming to discern the CT technique with the lowest achievable dose. Meanwhile, image quality needs to be maintained for guiding the RFA. The feasibility of the low-dose CT technique has been confirmed (1) by correlating patient dose with clinical outcome; and comparison between cases where different electrode localization techniques had been used. (2)

In our study multivariate analysis of morphometric variables has been conducted to identify risk factors of excess procedure time and radiation dose.

Images for this section:
Fig. 1: Axial CT scan with bone window shows a nidus of osteoid osteoma in the left femoral diaphysis. Lesion is round shape and localized intracortically with sclerotic periosteal reaction. The nidus size is less than 15mm.
Methods and materials

Ninety-two patients (60 male, 32 female) with osteoid osteoma aged between 7 to 60 years were treated in our department from January 2009 till August 2014.

Each patient had CT or MR imaging, as well as a bidirectional radiography from the affected bone previously with clinical and radiologic features of osteoid osteoma.

Patient were included despite evidence of relevant histological result since we considered previous reports in which clinical and imaging features are so accurate that biopsy may not be required; and non-diagnostic biopsy findings are common in osteoid osteoma.(5, 7)

Written informed consent was obtained. During the procedure the nidus was localized on a high-resolution CT scan (Philips Brilliance 16) with bone kernel. The approach was planned to avoid neurovascular structures.

In most of the cases low-dose technique(1) was used (Fig.2.) for guiding a Kirschner-wire or coaxial drill-bit (Fig.3.) into the nidus before inserting the Cool-tip ACT1507 (Covidien) RF-electrode (Fig.4.). We preferred a perpendicular approach in patients in the supine position. (Fig.5.)

An example on low-dose technique dose info shown in the schedule (Fig.6.). The patients who had been treated before the introduction of the low-dose protocol were excluded from the analysis to avoid misinterpretations from data collection.

List of demographic and morphologic variables:

- Age and gender
- Affected bone and localisation (intracortical, intramedullar, etc.) (Fig.7.)
- Size of nidus (mm) (Fig.8.)
- Size of sclerosis surrounded the nidus
- Radiation dose parameters:
  - CTDI and DLP basic: for planning the approach
  - CTDI and DLP targeting: positioning the electrode
  - DLP total: DLP basic+ targeting
- Number of repositions (reach the nidus by Kirschner-wire)
- Number of repositions (positioning the tip of electrode into the nidus)
- Procedure time
- Distance between skin surface and center of nidus (Fig.9.)
- Approach to the bone cortex: perpendicular or angulated
- Approach to the nidus: perpendicular or angulated (angle)
- Length of electrode route
• Length of bone canal (from periosteum to the center of nidus)

Morphologic data were collected retrospectively and analyzed with the R 2.10.0 statistical package.

Images for this section:

Fig. 1: Axial CT scan with bone window shows a nidus of osteoid osteoma in the left femoral diaphysis. Lesion is round shape and localized intracortically with sclerotic periosteal reaction. The nidus size is less than 15mm.
**Fig. 2:** Axial CT slices in the same level of femoral head with bone window. (A) The left femoral head with a radiolucent nidus in the center, the scan was performed with standard acquisition parameters (tube voltage 140kV, tube current 250mA, CTDI 30.2 mGy). (B) Image of the same lesion with low-dose acquisition parameters (tube voltage 90kV, tube current 70mA, CTDI 2.3 mGy). The signal to noise ratio is higher on the low dose image, but the nidus is still well detectable.
Fig. 3: These instruments can be used to access the nidus center in osteoid osteomas: (A) Kirschner-wire with 2mm in diameter with a sharp tip helps to cross the thin cortical surface above a superficially localised osteoid osteoma. (B) Drill equipment with a canulated drill-bit 3.5mm in diameter, which is used to access deep lying osteoid osteomas through a bone channel.
Fig. 4: Cool-tip™ RF Ablation System Cool-tip™ ACT1507 electrode inserted in a femoral osteoid osteoma. The active tip is 7mm in length. Cool-tip™ RF generator with 200W power source from Radionics. The ablation time is 6 minutes at continuous 90 Celsius.
**Fig. 5:** Axial CT slices in the level of the femoral head with a bone window. A 3D volume rendered reconstruction is shown in the left upper corner, the patient is in supine position. The radiolucent nidus is centrally located, the image was taken with low-dose acquisition (tube voltage 90kV, tube current 70mA, CTDI 2.3 mGy). Within the lucent nidus the radiopaque electrode tip is well visible due to the high contrast.
**Fig. 6:** An example on dose info scheduling is shown. The average tube voltage is 90kV, tube current is 30-70 mA depending on the body region. A baseline acquisition is followed by surface marker positioning and entry route planning. The number of position-reposition steps depends on the nidus size, localisation, angulation and other variables. The total dose length product in this representative case is low: 59.8 mGy*cm.
Fig. 7: Axial CT section in the level of left tibial diaphysis in prone position, bone window, low-dose technique. On the dorsal skin surface the radiopaque surface marker helps in the planning of the RF approach. The radiolucent well-circumscribed nidus is located, intracortically and, intramedullary. In this case the nidus involved the endosteal surface causing definitive sclerosis within the medulla.
Fig. 8: Axial CT section in the level of left tibial diaphysis in prone position, bone window, low-dose technique. (A) The thin yellow lines mark the diameter of the OO nidus. The blue arrow shows the length of the bone channel from periosteum to the center of nidus. (B) Electrode tip is located within the nidus following the planned route.
**Fig. 9:** Axial CT section in the level of left tibial diaphysis in prone position, bone window, low-dose technique. The orange arrow shows the skin surface-nidus distance in the plane of planned electrode route. Light blue arrow represents the shortest nidus to skin surface distance.
Results

Sixty-seven cases involving the lower extremity were analyzed. Eight cases in the pelvis and 17 other localizations were currently not analyzed (Fig.10.).

Nidus diameter (mean±SD: 5.1±4 mm, range 2-13 mm, $R^2=0.16$, inversely proportional, p<0.015) (Fig.11.) and number of repositions (1.7±1.54, range 1-9, $R^2=0.35$, directly proportional, p<0.001) (Fig.12.) were independent predictors of procedure time in multivariate analysis.

Meanwhile, procedure time (42±18 min, range 15-115 min) showed non-significant correlation ($R^2=0.03$, p<0.08) with total dose length product (median 164mGy*cm). (Fig.13.). Total dose length product and total CT dose index values according to number of osteoid osteoma cases show an expected logaritmic distribution (Fig.14.).

The number of repetitions referred to all procedures shows a Gaus-curve which approximate normal distribution. This verifies that success of the nidus accessing manuevre is dependent on multiple variables. (Fig.15.)

In 59 cases the entry route was tilted from the vertical direction more than 15 degrees to avoid sensitive structures. (Fig.16.) However, tilting was less likely (p<0.05) with increasing soft tissue thickness. (Fig.17.)

Images for this section:
**Fig. 10:** The pie char shows distribution of OO cases according to bone region. In total of 67 cases were used in the multivariate analysis. Shoulder, calcaneal, pelvic lesions and patients, who had been treated prior to the dose reduction, were excluded due to large differences in DLP values.
Fig. 11: The procedure time shows significant negative correlation with nidus diameter (mean±SD: 5.1±4 mm, range 2-13 mm, R²=0.16, p<0.015), which means that RFA procedure time gets shorter with a larger nidus.
Fig. 12: The procedure time shows significant positive correlation with the number of repositions (1.7±1.54, range 1-9, R2=0.35, p<0.001) which means more attempts require more procedure time.
Fig. 13: A scatter plot diagram represents that procedure time (42±18 min, range 15-115 min) showed positive tendency, but not in a significant correlation (R2=0.03, p<0.08) with total dose length product (median 164mGy*cm).
Fig. 14: Histograms of radiation dose parameters show that the distribution of (A) total dose length product and (B) total CT dose index values follow a logarithmic distribution.
**Fig. 15:** Frequency plot represents the number of aiming attempts with a Kirschner-wire. The distribution of the repetitions approximates the normal distribution. This verifies that success of the nidus accessing manœuvre is dependent on multiple variables.
**Fig. 16:** Axial CT section in the level of left tibial diaphysis in prone position, bone window, low-dose technique. Drawing demonstrates an angulated approach which deviates from the vertical (perpendicular) route with more than 15 degrees in order to avoid neurovascular structures.
Fig. 17: Diagrams represent the correlation (A) between the angulation of the access route to the nidus and skin-nidus distance or (B) length of the electrode. The increasing skin-nidus distance and the consequently longer electrode route significantly (p<0.05) lowered the likelihood of an angulated approach.
Conclusion

- Targeting of small, deep situated lesions can be challenging and practical skill is required to avoid high patient dose.

- The perpendicular approach is the safest route but avoiding sensitive anatomic structure in particular cases suggested an angulated perspective.

- Based on the literature and our experience the use of cannulated drill-bits or appropriate biopsy needles proposed in order to achieve a good clinical success rate while Kirschner-wire alone provides quick access to more superficial lesions.

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References


