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Original Article

Mini-open excision of osteoid osteoma using intraoperative O-arm/Stealth navigation

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ABSTRACT

Background: Although osteoid osteomas have traditionally been treated by surgical excision, radiofrequency ablation (RFA) has gained favor as a less invasive procedure. However, RFA is contraindicated for osteoid osteomas close to the skin or crucial neurovascular structures, and is not covered by national health insurance in Japan. The aim of the present study was to evaluate the efficacy of surgical excision of osteoid osteomas using intraoperative navigation.

Methods: We performed a retrospective review of five patients with osteoid osteoma who underwent a mini-open excision using O-arm/Stealth navigation at our institution. The osteoid osteomas were excised using a cannulated cutter or curetted out with the assistance of navigation.

Results: Complete excision was achieved in all patients, which was confirmed by pathological examination. The mean skin incision was 2.1 cm (range, 1.5 to 3.0 cm) and the mean duration required for setup three-dimensional image was 15 min (range, 12 to 20 min). Although the mean visual analog scale score was 7 (range, 4 to 8) before surgery, all patients experienced relief from their characteristic pain immediately after surgery, with the mean scores of 2.2 (range, 1 to 3) and 0 at 2 days and 4 weeks after surgery, respectively. There was no intra-operative complication related to the navigation and no recurrence was observed during the mean follow-up period of 25 months (range, 13 to 33 months).

Conclusions: Mini-open excision using intraoperative O-arm/Stealth navigation is a safe and accurate procedure for patients with osteoid osteoma, which could cover the limitation of RFA.

1. Introduction

Osteoid osteomas are small, benign osteoblastic bone tumors that commonly occur in the diaphysis of long bones in children and young adults [1,2]. It accounts for approximately 12% of all benign bone tumors and typically presents with extensive pain, which often worsens at night and is usually relieved by non-steroidal anti-inflammatory drugs (NSAIDs) [2,3]. Osteoid osteomas have a nidus of several millimeters surrounded by dense sclerotic bone [1,3]. Traditionally, osteoid osteomas have been treated by surgical excision for the management of pain that is resistant to NSAIDs, which is the first line of treatment [4,5]. While success rate by surgical excision is high (90%–100%) [6–12], recent introduction of radiofrequency ablation (RFA) has provided less invasive treatment [3,7,13,14] with relatively high success rate [7,9,12,15–19]. Regardless of treatment type, accurate localization of the nidus is crucial during procedures [4].

The computer navigation system has been effective in musculoskeletal tumor resection, mostly on the basis of preoperatively acquired CT-based technology [20–22]. The latest development, O-arm/Stealth navigation, is a technology that includes the acquisition of high-resolution images and three-dimensional (3D) data sets on the operating table [23]. Furthermore, the technology allows almost fully automatic registration, without any point-to-

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point matching with preoperative CT data [23–25]. Because the nidus can be accurately identified by CT imaging rather than plain radiograph, this technology can be reliable to identify the nidus with simple intraoperative procedures.

Recently, navigation-assisted RFA has been established [7]. Although the success rate is relatively high, RFA has certain limitations and is not applicable for all patients. Because it can damage the surrounding structures, RFA is still contraindicated for osteoid osteomas with a proximity to crucial neurovascular structures or a superficial location [4]. Furthermore, RFA has not been covered by national health insurance in Japan. Therefore, surgical excision with computer navigation may solve these problems with less invasiveness and may be applied to patients with osteoid osteoma with such limitations or those who want to manage their medical cost covered by national health insurance. This study aimed to evaluate clinical outcomes of mini-open excision with the assistance of O-arm/Stealth CT navigation system in patients with osteoid osteoma.

2. Patients and methods

2.1. Patients

This study was approved by the Institutional Review Board at the institute of the authors. From July 2014 to October 2016, a total of 14 patients with osteoid osteoma were treated at our institution; nine of these patients underwent RFA and the remaining five underwent surgical excision using O-arm/Stealth navigation. Patients with osteoid osteoma were initially treated with NSAIDs, but if the symptom was resistant or uncontrollable, RFA or surgical excision was performed. Treatment procedure was decided after discussing with patients; RFA was recommended if the surgical excision would be a risk of fracture (e.g. femoral neck) or surgical approach would be difficult (e.g. spine), while surgical excision was recommended if the tumor was easy to access surgically or located near the neurovascular bundle or the skin. In this study, surgical resection was chosen in five patients because of the superficial location of the nidus or the financial reasons; RFA has not been covered by national medical insurance in Japan. All patients who underwent surgical excision consented to the procedure with a mini-open procedure using O-arm/Stealth navigation.

2.2. Surgical technique

Surgical procedures were assisted by the O-arm (Medtronic, Minneapolis, MN, USA) and StealthStation S7 (Medtronic). Patients were positioned depending on the anatomical site of tumor on a Jackson radiolucent table (Mizuho OSI, Union City, CA, USA). Intraoperatively, a reference frame was attached to an uninvolved region on the tumor-affected bone using two screws (Fig. 1a). The O-arm was then brought into the surgical field (Fig. 1b), and 3D intraoperative images of the instrumented region were automatically reformed and visualized at the StealthStation S7 (Fig. 1c). Notably, obtaining an intraoperative CT scan with a StealthStation reference avoids any further landmark registration during surgery; the pointer and drill guide probe were registered and calibrated only at the point of the center of the reference frame (Fig. 1a,c). A 2-mm Kirschner wire was inserted through a registered guide toward the nidus under the real-time guidance of the navigation system (Fig. 1d). The tumor was then excised using a Kirschner wire-guided cannulated cutter (Fig. 1e,f), which was 2 mm wider in diameter than the size of the nidus, or curette with minimal skin incision. A synthetic bone graft material was used to fill the dead space depending on the cases.

3. Results

Four males and one female, with a mean age of 14 years (range, 9–23 years), underwent mini-open excision with the assistance of O-arm/Stealth navigation. Individual demographic details such as tumor location, pain scores, and clinical outcomes, are summarized in Table 1. The tumor was located on the femur in two patients and one each on the tibia, radius, and cuboid. The mean tumor size was 6.0 mm (range, 3.0–9.6 mm). All patients had a 2-month to 2-year history of localized unrelenting pain, and the mean duration of preoperative pain was 16 months. The visual analog scale (VAS) scores of their preoperative pain ranged from 4 to 8 (mean, 7). In all patients, O-arm/Stealth CT navigation provided real-time multiplanar images of the lesion that enabled the precise localization of the nidus. The nidus and reactive bone hyperplasia was excised using an cannulated cutter in four patients (patients 1–4; Fig. 2a–g) and curetted in one patient (patient 5; Fig. 3a–g). After tumor excision, O-arm/Stealth CT scan reconstructed images confirmed the complete excision of the nidus in all patients (Figs. 2c and 3e).

The skin incision ranged from 1.5 to 3 cm (mean, 2.1 cm) in length (Table 1). The duration of the procedure ranged from 63 to 118 min (mean, 84 min) with minimal blood loss. The required duration for initial setup of navigation reference, O-arm setting, image acquisition, and image verification was 12–20 min (mean, 15 min).

All patients had immediate postoperative relief of their characteristic pain. VAS scores before surgery ranged from 4 to 8 (mean, 7), whereas those 2 days after the surgery ranged from 1 to 3 (mean, 1.8). All patients were pain free (VAS score, 0) 4 weeks after surgery. Complete resection and histological diagnosis were confirmed by pathological examination in all patients (Fig. 2e–g, 3f,g). We observed no postoperative complications including fracture or infection. Early recovery to their daily activities or social life was possible in all patients. There was no recurrence or late complications during the mean follow-up at 25 months (range, 13–33 months).

4. Discussion

Recently, RFA has gained favor as a less invasive alternative to surgical excision because of potentially less bone destruction. Although the reported success rate of RFA has been reported to be over 70% [7,9,12,15–19], the drawbacks of RFA include a relatively long time for procedures, contraindications for tumors involving subcutaneous area close to the skin and crucial neurovascular structures [3,4], and high cost to the patient because RFA is not covered by national health insurance in Japan. Traditional treatment has been the surgical excision of the nidus. However, the conventional method using an X-ray image intensifier is associated with a risk of complications including massive bone destruction and incomplete excision of the nidus because of the possible inaccurate localization. In this study, we could accurately identify and excise the nidus using intraoperative O-arm/Stealth navigation without massive bone destruction. Our indications of the navigated tumor excision are as follows: the nidus is superficially located to the skin or nearly located by critical nerves and vessels, or the financial reasons of the patient. The indications for the present cases were the financial reason (patient 1–4) and superficial location to the skin (patient 5).

An accurate localization of the nidus is crucial whichever treatment is performed [4]. It is sometimes difficult to intraoperatively localize the nidus with an X-ray image intensifier. Inaccurate localization of the nidus sometimes leads to an incomplete resection or massive bone destruction. Computer navigation

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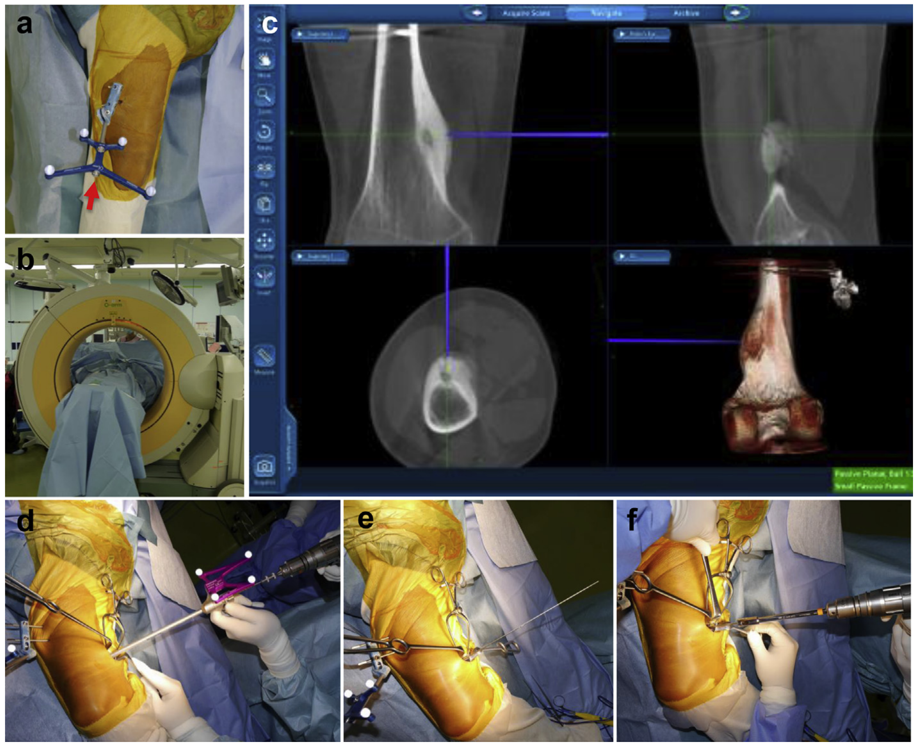

Fig. 1. Intraoperative setup and tumor excision using O-arm/Stealth CT navigation. (a) Insertion of a reference frame. The pointer and drill guide prove were registered and calibrated at the center of the frame after CT scan (arrow). (b) O-arm set up. (c) Screenshot of the intraoperative 3D image. (d,e) Insertion of a K-wire using the navigated guide. (f) Tumor excision using a cannulated cutter.

Table 1
Patient characteristics and details of treatment with the assisstance of O-arm/Stealth navigation.

Patient No.	Age	Gender	Tumor location	Tumor size (mm)	Duration of symptoms (months)	VAS score			Skin incision (cm)	Pathological diagnosis	Operating time (minutes)	Complication	Recurrence	Follow-up (months)
						Before surgery	2 days after surgery	4 weeks after surgery						
1	16	Male	Femur	5.9	2	7	3	0	2	+	97	−	−	33
2	9	Male	Femur	9.6	24	8	1	0	3	+	118	−	−	25
3	14	Male	Tibia	5.7	4	8	1	0	2	+	74	−	−	21
4	9	Male	Radius	3.0	4	8	2	0	1.5	+	70	−	−	13
5	23	Female	Cuboid	5.7	48	4	2	0	2	+	63	−	−	32

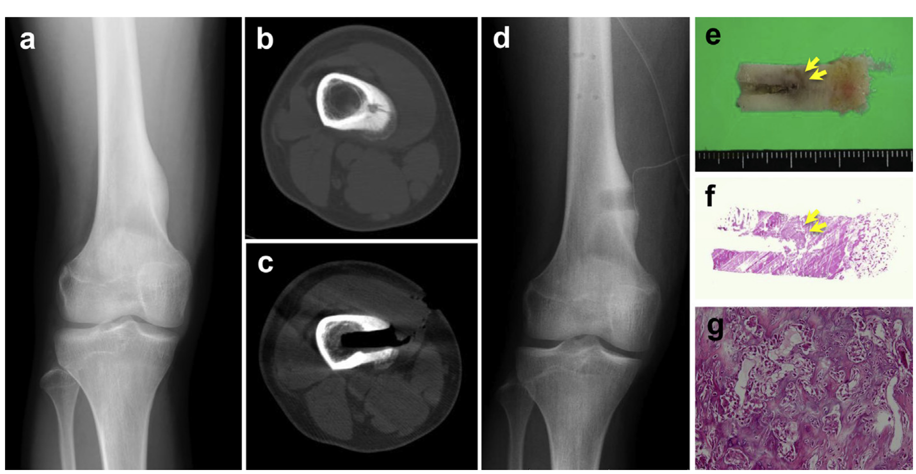

Fig. 2. An osteoid osteoma on the right distal femur (Patient 1). (a, b) Preoperative radiograph (a) and axial CT imaging view (b). (c) Intraoperative screenshot following tumor excision. (d) Postoperative radiograph. (e) Macroscopic view of the excised nidus (yellow arrows). (f, g) Macroscopic (f) and microscopic (g) images with HE staining. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

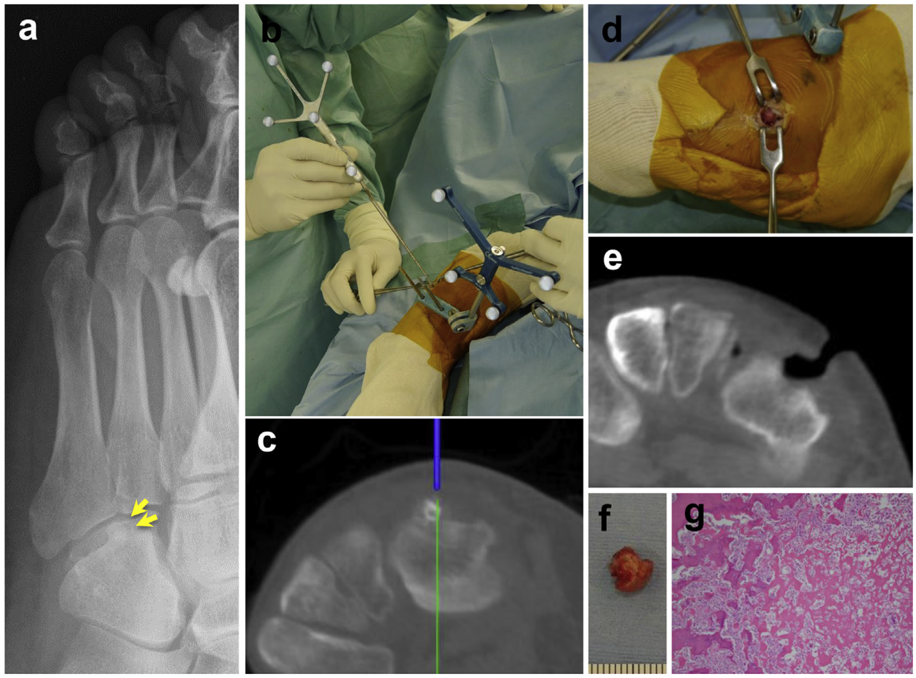

Fig. 3. An osteoid osteoma on the left cuboid (Patient 5). (a) Preoperative radiograph (yellow arrows; nidus). (b) Intraoperative real-time localization of the nidus. The reference frame was stabilized with two pins inserted into the cuboid and navicular, respectively. (c) Screenshot of the intraoperative 3D image. (d) A small incision above the nidus. (e) Intraoperative screenshot following tumor excision. (f) Macroscopic view of the excised specimen. (g) Microscopic image with HE staining. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

can assist accurate localization of the nidus, which provides the appropriate and shortest anatomical approach to the lesions [4]. There are several advantages in the O-arm/Stealth navigation system. 1) Technical simplicity: it does not require surface-matching with preoperative CT data but only one-point registration at the center of the reference frame (Fig. 1a), which creates minimum errors of approximately 0.20 mm [26]. 2) High resolution image: the O-arm/Stealth system provides a wider field of view for navigation with better image clarity than the C-arm-based navigation system [27]. 3) Possibility to confirm complete excision of the nidus intraoperatively: an additional scan with O-arm clearly demonstrates whether the nidus is excised or not. 4) No radiation exposure for treating staffs: all medical staff could avoid radiation exposure by leaving the operation room during CT scanning. On the other hand, we acknowledge several drawbacks of this system. 1) Radiation exposure for patients: the total radiation dose of one O-arm-based 3D scan for patients is less than C-arm-based 2D scan, but approximately half dose compared to a 64 multi-slice CT scanner involving the same body region [28,29]. 2) Placing the reference frame: this might be a risk of intra- or postoperative fracture or wound complication around it. However, we have, so far, no experience of the complication associated with the placement of reference frame. 3) Additional surgical time: this system requires additional time for scanning and registration. However, the procedure required approximately 15 min, which would not be a critical risk of complication. Despite these drawbacks, we believe that this system provides benefit for patients with osteoid osteoma in terms of avoiding incomplete excision and massive bone destruction.

This study has several limitations. First, this study was based on the small number of patients and has no comparison group. Second, a precise cost analysis associated with O-arm/Stealth navigation was not performed. Third, our data did not show the radiation dose to patients, although previous reports have indicated that it is less than half of conventional CT. Despite these limitations, we believe that this technique provides an advantage to precisely localize the nidus and to completely excise the tumor with minimal bone destruction.

In conclusion, a complete excision and pathological confirmation of osteoid osteomas with minimal skin incision and bone destruction was achieved using intraoperative O-arm/Stealth CT navigation. Patients with osteoid osteomas can be treated by the differential use of these techniques—RFA or navigated mini-open excision.

Conflict of interest

The authors declare that they have no conflict of interest.

Ethical review committee statement

Ethical approval was obtained from the Institutional Review Boards of Okayama University Hospital, Okayama, Japan.

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