CLINICAL ARTICLE

Open Surgery for Osteoid Osteoma with Three Dimensional C-arm Scan under the Guidance of Computer Navigation

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Objective: To evaluate the clinical outcomes of open surgery for osteoid osteoma with three-dimensional (3-D) C-arm scan under the guidance of computer navigation.

Methods: The clinical data of 14 patients who had undergone 3-D C-arm scan under the guidance of computer navigation during open surgery for osteoid osteoma from March 2012 to June 2015 were analyzed retrospectively. There were nine male and five female subjects aged from 9 to 55 years (mean, 26 years). Eight of the tumors were located in the femur, four in the tibia, one in the humerus and one in the scapula. Preoperative pain visual analogue scale (VAS) scores ranged from 2 to 6 (mean $\pm$ SD, 4.7 ± 1.1). Conventional surgical approaches were used to expose the tumor surfaces depending on their locations. Involved regions were scanned by 3-D C-arm fluoroscopy during the procedure and then the tumors were accurately located and their niduses removed under the guidance of computer navigation. Afterwards, repeat 3-D C-arm scans of the surgical region were performed to confirm tumor eradication. None of the patients received postoperative intravenous analgesia. Eight patients received oral non-steroidal anti-inflammatory drugs on the day of surgery, these drugs being discontinued on the second postoperative day. Postoperative pathological diagnoses were recorded. At the follow-up visits, imaging and VAS scores were obtained to evaluate the therapeutic effect and any evidence of recurrence.

Results: All the patients successfully underwent computer navigation-guided surgery. The duration of surgery ranged from 60 to 135 min (mean, 94 min) and the amount of bleeding from 50 to 150 mL (mean, 80 mL). None of the patients needed bone grafting or internal fixation. No complications were seen. All patients were followed up for 4 to 36 months (mean, 16 months). Postoperative pathological diagnoses of osteoid osteoma were made in 12 patients; thus, the rate of pathologically confirmed diagnosis was 86%. VAS scores decrease to an average of 1.4 ± 0.6 3 days after surgery and were zero for all patients 4 months after surgery. No tumor recurrence was found by X-ray or CT scan examination during follow-up.

Conclusions: The niduses of osteoid osteomas can be eradicated by open surgery with 3-D C-arm scan under the guidance of computer navigation with minimal damage to bone structure and a high rate of pathologically confirmed diagnoses.

Key words: C-arm scan; Computer navigation; Osteoid osteoma

Introduction

Osteoid osteomas (OOs) are benign bone tumors that primarily present in children and young adults with a male predominance, accounting for approximately 12% of all primary benign bone tumors¹. Their characteristic symptom is extensive bone pain that is most severe at night. The pain

may be relieved by non-steroidal anti-inflammatory drugs (NSAIDs). The typical appearance of an OO on computed tomography (CT) scan consists of a nidus (several millimeters) with surrounding reactive bone sclerosis. The lesions show low to moderate intensity on T1-weighted MRI and high intensity on T2-weighted MRI with extensive

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surrounding edema. The diagnosis is not difficult to make because of these characteristic manifestations².

Osteoid osteomas have traditionally been treated by open surgical resection of the nidus^{3,4}. Development of minimally invasive therapies has greatly improved treatment options. Percutaneous radiofrequency ablation (PRFA), the most commonly used of these therapies⁵⁻⁷, was introduced by Rosenthal *et al.* in 1992⁸. PRFA has the advantages of involving little surgical trauma and enabling accurate positioning of the nidus; however, it also has some problems and is not suitable for all patients. On one hand, percutaneous puncture has a high requirement for accurate anatomical location of the nidus. It is difficult to perform when there are crucial neurovascular structures around the nidus or in the puncture path. Additionally, the mechanism of radiofrequency ablation is thermal destruction of tumor tissue and it is difficult to control the degree of heating during the procedure. Also, because the niduses of OO are usually smaller than 1 cm, it is difficult to accurately confine the heating created by PRFA to inside the nidus and more extensive heating can damage surrounding structures. This risk makes it difficult to administer PRFA when there are important structures around the nidus. In addition, PRFA may cause adjacent skin necrosis when the nidus is located superficially parts, which further limits the use of PRFA to treat OOs. Thus, open surgery is still performed in cases for whom PRFA is contraindicated.

Whichever treatment method is chosen, clear identification of the nidus of an OO is crucial to achieving favorable treatment outcomes. With PRFA, identification of the nidus and embedding of the needle in the lesion largely depend on guidance by CT scanning. With open surgical resection, identification largely depends on intra-operative radiographs and the experience of the surgeon. On one hand, the nidus is characteristically so small that it is hard to accurately locate it under the guidance of traditional intra-operative fluoroscopy devices. On the other hand, although the nidus has its own characteristic texture and color, it is nonetheless not clearly distinguishable from the surrounding reactive tissue. Especially when there is bleeding, it is difficult to discriminate the nidus from surrounding bone tissue with the naked eye. These factors are prone to result in failure to either fully remove the lesion, which leads to incomplete relief of symptoms, or excessive bone excision, which leads to risk of fracture and therefore necessitates bone grafting.

Recently, 3-D C-arm scan and computer-assisted navigation system have been widely used in various bone surgeries⁹. Three-D C-arm scan uses equipment that is similar to traditional C-arm fluoroscopy to obtain tomographic images of a surgical site. Although the image definition is not as good as with CT, the tomographic images it provides are superior to traditional C-arm scan for identifying the nidus. A combination of imaging and navigation technology can guide the procedure in real time. The nidus can be accurately located and then removed while observing changes in the relative positions of the surgical instruments and tumor

nidus, which greatly facilitates accurate tumor clearance with minimal loss of normal bone mass. Additionally, a 3-D C-arm scan of the surgical region must be repeated to confirm clearance of the tumor nidus and the extent of removal of bone mass, which further increases the reliability of the operation.

In 2012, open surgery for OOs under the guidance of computer navigation was introduced in our department. 3-D C-arm scans were to identify the lesion and confirm its elimination. The aim of this study was to retrospectively evaluate the clinical outcomes of open surgery with 3-D C-arm scan under the guidance of computer navigation for OO.

Materials and Methods

Patient Selection

Between March 2012 and June 2015, 41 patients with OO who had undergone surgery at the authors' institution were identified. Twenty-six of these patients had undergone treatment with PRFA and 15 by open surgery. The reasons for these 15 patients did not undergoing PRFA were as follows. The nidus was too tiny (less than 3 mm) to locate it; or there were critical nerves or vessels or both around the puncture pathway or the nidus (only loose connective tissue between nerves or vessels and niduses); or the nidus was subcutaneous, meaning that PRFA would likely damage the skin. By critical nerves, we mean major nerves like the sciatic, common peroneal and axillary nerves whereas by critical vessels we mean irreplaceable ones such as the popliteal and brachial arteries. Of those who had undergone open surgery, 14 patients had undergone open surgical resection of the nidus with 3-D C-arm scan under the guidance of computer navigation. These 14 patients were included in our study.

Patient Characteristics

The study cohort comprised nine male and five female subjects aged from 9 to 55 years (mean, 26 years). Eight of the lesions were located in the femur, four in the tibia, one in the humerus and one in the scapula (Table 1). All patients had experienced an average of 5.5 months (1–12 months) of preoperative pain. Their preoperative pain visual analogue scale (VAS) scores ranged from 2 to 6 (mean, 4.7 ± 1.1). X-ray films, CT and MRI scans were examined in all patients preoperatively. X-ray films showed local bone hyperplasia and sclerosis in nine cases of cortical bone type and five of spongy bone type. Bright circular areas in the proliferative centers were visible in some cases. CT scans clearly showed local defects of cortical bone, the locations of the niduses being characterized by low-density circular regions with clear boundaries in hyperplastic bone. The niduses were within cortical bone or within 1 cm of cortical bone and they ranged in size from 1 to 5 mm. Calcification was visible in the niduses, which showed low to medium signals in the T1-weighted MRI and high in the T2-weighted MRI, accompanied by evidence of surrounding tissue edema (Fig. 1). The niduses were close to critical vessels or nerves in four cases.

TABLE 1 Patient characteristics

Patient number	Sex	Age (years)	Lesion site	VAS score			Pathological diagnosis	Follow-up (months)
				Before surgery	3 days after surgery	4 months after surgery		
1	Male	14	Femur	5	1	0	Yes	32
2	Male	22	Tibia	6	1	0	Yes	36
3	Male	51	Femur	6	1	0	Yes	24
4	Female	49	Tibia	5	2	0	Yes	13
5	Male	19	Tibia	4	1	0	Yes	13
6	Male	25	Femur	5	1	0	Yes	12
7	Female	9	Femur	5	2	0	Yes	11
8	Female	14	Femur	3	1	0	No	6
9	Male	43	Scapula	4	3	0	No	4
10	Female	55	Humerus	5	1	0	Yes	4
11	Male	12	Femur	2	1	0	Yes	26
12	Female	13	Femur	6	2	0	Yes	11
13	Male	21	Femur	5	1	0	Yes	8
14	Male	20	Tibia	5	1	0	Yes	30

Fig. 1 Man aged 25 years with posterior left knee pain for 2 months. (A) X-ray film showing bone proliferation in the inferior femoral segment and osteolytic damage. The arrow indicates the nidus of an osteoid osteoma. (B) CT scan image showing the nidus lies in the posterior femoral inferior segment, close to blood vessel bundles in the popliteal fossa. Local bone proliferation and lesion of high intensity are also seen. (C) MRI T1WI image showing the nidus has low intensity. (D) MRI T2WI image showing increased intensity in the nidus and extensive surrounding edema. (E) X-ray film 4 months after computer navigation-guided surgery showing small amount of local bone loss.

Operative Procedure

The procedure was assisted by a Siemens Arcadis Orbic intra-operative 3-D C-arm (Sacramento, CA, USA) and a Medtronic Stealth station Tria Plus computer navigation

system (Minneapolis, MN, USA). Commonly used operative routes were selected according to the tumor location. The position of the patient depended on the anatomical site of tumor, supine or prone positions being usual.

Crucially, the tumor site was carefully positioned in the center of the operating table for C-arm scanning. A lateral position of 45° was used for patients with tumors of the upper limb or scapula to make it easier to place the tumor site in the center without impeding the C-arm scan. The cortex of bone in the tumor nidus area was then exposed based on preoperative image data and the navigation reference frame fixed on the bone near the lesion. Plane X-ray fluoroscopy was used first to ascertain the position of the nidus. Next, real-time 3-D image scanning was performed and transferred to the navigator after achieving network connection between the 3-D C-arm and navigator. A navigation probe was used to search the exposed bone cortex surface for the shortest route to the nidus. After identification of the site of nidus, the cortex was progressively abraded with a high-speed to approach the nidus. The depth of the lesion was repeatedly confirmed by navigation probe during this process (Fig. 2). When the nidus surface had been reached, the lesion was completely excised by curettage and 1 mm of surrounding bone abraded with a high-speed burr (Fig. 3). A 3-D C-arm scan of the pathological region was then performed to confirm elimination of lesion by comparing the pre- and post-procedure scan images (Fig. 4). Because of the very small bone defects, the incisions of all study patients were sutured after routine repair of soft tissues without bone graft.

Postoperative Treatment and Follow-up

None of the patients received epidural analgesic tube after surgery. Eight subjects took NSAIDs orally only the day of surgery and ceased them on the second postoperative day. Patients with lower limb tumors started off-bed activity with crutches 3 days after surgery and those with upper limb tumors started active function practice of adjacent joints on the second postoperative day. VAS scores were obtained from all patients on the third postoperative day. Postoperative pathological diagnoses were classified as definitive diagnosis of osteoid osteoma or indefinite pathological diagnosis. After discharge, patients were followed up at 2, 4 and 6 months and thereafter half yearly. At follow-up visits X-ray films, CT scans and VAS scores were obtained and any complications documented.

Results

All study patients underwent successful computer-guided navigation surgery. The duration of surgery was from 60 to 135 min (mean, 94 min). The duration of 3-D scan and establishment of images before removal of the nidus ranged from 25 to 85 min (mean, 47 min). The amount of bleeding ranged from 50 to 150 mL (mean, 80 mL).

All patients underwent intra-operative 3-D C-arm scans before and after the procedure; accurate resection of the miduses was confirmed by comparing the scan images. None of the patients needed bone grafting or internal

Fig. 2 Images from the navigation probe used to pinpoint the nidus during surgery for femoral shaft osteoid osteoma.

Fig. 3 Procedure for removal of the nidus.

(A) A navigation probe is used to pinpoint the nidus. (B) The reactive bone hyperplasia around the nidus is removed with a high-speed burr until the navigation probe has reached the surface of the nidus. (C) The nidus is fully removed with a curette. (D) A small amount of surrounding bone is abraded with a high-speed burr.

fixation. Twelve Diagnoses of osteoid osteoma were confirmed by pathological examination in 12 cases whereas no definite diagnoses were made in the other two cases; thus, the rate of pathological confirmation of the preoperative diagnosis was 86%. No complications were identified.

Follow up

All the patients followed up for from 4 to 36 months (mean, 16 months). At the follow-up visits visit X-ray films, CT scans and VAS scores were obtained and any complications documented.

General Results

Computer navigation-guided surgery was successful in all study patients. The duration of surgery was from 60 to 135 min, with an average of 94 min and the amount of bleeding ranged from 50 to 150 mL, with an average of 80 mL. None of the patients needed bone grafting or internal fixation.

Oncological Results

No tumor recurrences were identified on follow-up X-ray films or CT scans in any participants.

Functional Outcomes

Pathological diagnoses of osteoid osteoma were made in 12 cases and no definite diagnosis in the other two; thus, the rate of pathological confirmation of the preoperative diagnosis was 86%. The average VAS score 3 days after surgery had decreased to 1.4 ± 0.6 and all patients' VAS scores were zero 4 months after surgery.

Complications

No complications were detected in this group by the last follow-up.

Discussion

Indications for Open Surgery for Osteoid Osteoma

Currently, the main treatments for osteoid osteoma are conventional open surgery, CT-guided radiofrequency ablation and computer navigation-guided open surgery. Compared with open surgery, CT-guided radiofrequency ablation has the advantages of less operative trauma and more accurate localization of the nidus¹⁰. However, its drawbacks include difficulty in precise control of the radiofrequency dosage and inability to detect damage intra-operatively, which leads to failure to relieve symptoms in some

Fig. 4 Male aged 14 years with right hip pain for 7 months. (A) CT scan image showing bone proliferation in the femoral lesser trochanter and a high intensity lesion in the nidus. (B, C) Intra-operative 3-D C-arm scan images showing that the nidus lies in the femoral lesser trochanter. (D) CT scan image 4 months after surgery shows that bone healing has occurred in the region of the lesion. The symptoms have been completely alleviated with a VAS score of zero.

patients^{11,12}. Additionally, radiofrequency ablation is relatively contraindicated for some anatomic locations, such as when the nidus is near a major blood vessel or nerve or located subcutaneously^{13,14}. Another major problem is that definite pathological diagnoses are often not made with minimally invasive surgery; however, confirmation of diagnosis is unnecessary in many cases^{2,9}. Therefore, there are still some indications for open surgery in the management of osteoid osteoma. The indications for open surgery of osteoid osteoma are as follows: the nidus is too tiny to accurately locate; there are critical nerves or vessels or both around the puncture pathway or the nidus; and the nidus is so superficial that radiofrequency ablation would damage the skin.

Pinpointing the Nidus under the Guidance of Computer Navigation

With open surgery, the main challenge is accurate localization of the nidus¹⁵. In general, the nidus is smaller than 1 cm, often varying from 1 to 2 mm. Moreover, the surrounding reactive bone proliferation makes it for the surgeon to target the nidus. Consequently, conventional open surgery has two potential pitfalls. On the one hand, over

dissection and excision of bone may lead to a more frequent requirement for bone grafting and internal fixation and a higher risk of pathological fracture, and on the other hand, inadequate resection may result in residual symptoms and reduced efficacy, or even the necessity for secondary surgery. Unlike with conventional surgery, computer navigation is a proven accurate means of localizing lesions, identifying the shortest anatomical path to the target and achieving complete resection with minimal bone destruction. Thus, it reduces the incidence of bone grafting and internal fixation. None of the present cases needed bone grafting or internal fixation and there were no pathological fractures during follow-up. Given that the niduses of osteoid osteomas are usually tiny and accompanied by extensive surrounding reactive hyperplasia, obtaining a specimen that will enable a pathological diagnosis to be made is challenging. Mistakenly excising adjacent tissues for pathological examination is bound to fail to achieve the correct diagnosis. Thus, another advantage of navigation is that the real-time intra-operative images it supplies enable accurate excision of the whole nidus and consequently reliable pathological diagnoses. The rate of pathological confirmation of the preoperative diagnosis was 86% in this group of patients.

Intra-operative 3-D C-arm Scan Enables Confirmation of Complete Excision of the Nidus

Another key problem with open surgery for management of osteoid osteomas is how to confirm the complete excision of the nidus. The small size of the nidus and the reactive bone proliferation around it mean that conventional intra-operative fluoroscopy technology is often inadequate for confirming its complete removal. This is particularly true for some anatomic locations, such as the spine and femoral trochanter. Intra-operative 3-D C-arm scanning reliably solves this problem. Comparison of scans performed before and after the procedure enables confirmation of clearance of the nidus. Accurate and complete resection of the nidus was achieved in all study patients and their pain was immediately

alleviated. Wang *et al.* believe that, compared with pre-operative CT data, intra-operative C-arm navigation has the following advantages: ease of operation, no need for intraoperative registration between the pre-operative CT data and navigation system and minimal invasion¹⁶. Even more important, C-arm scanning can confirm clearance of the nidus. With the resultant superior accuracy, the efficacy and reliability of surgery is improved.

Limitations of the study include the small sample size and relatively short duration of follow-up. However, it is still clear that computer navigation-guided open surgery with 3-D C-arm scan for managing osteoid osteomas has the advantages of minimizing bone loss and accurate clearance of the nidus.

References

1. Greenspan A. Benign bone-forming lesions: osteoma, osteoid osteoma, and osteoblastoma. Clinical, imaging, pathologic, and differential considerations. *Skeletal Radiol*, 1993, 22: 485–500.
2. Akhlaghpour S, Aziz Ahari A, Ahmadi SA, Arjmand Shabestari A, Gohari Moghaddam K, Alinaghizadeh MR. Histological evaluation of drill fragments obtained during osteoid osteoma radiofrequency ablation. *Skeletal Radiol*, 2010, 39: 451–455.
3. Kaiser MS, Rahman W, Hossain M, *et al.* Evaluation of outcome of surgical excision of the nidus of osteoid osteoma of long bone. *Mymensingh Med J*, 2014, 23: 686–694.
4. Ozaki T, Liljenqvist U, Hillmann A, *et al.* Osteoid osteoma and osteoblastoma of the spine: experiences with 22 patients. *Clin Orthop Relat Res*, 2002, 397: 394–402.
5. de Palma L, Candelari R, Antico E, *et al.* Treatment of osteoid osteoma with CT-guided percutaneous radiofrequency thermoablation. *Orthopedics*, 2013, 36: e581–e587.
6. Neumann D, Berka H, Dorn U, Neureiter D, Thaler C. Follow-up of thirty-three computed-tomography-guided percutaneous radiofrequency thermoablations of osteoid osteoma. *Int Orthop*, 2012, 36: 811–815.
7. Cakar M, Esenyel CZ, Seyran M, *et al.* Osteoid osteoma treated with radiofrequency ablation. *Adv Orthop*, 2015, 2015: 807274.
8. Rosenthal DI, Alexander A, Rosenberg AE, Springfield D. Ablation of osteoid osteomas with a percutaneously placed electrode: a new procedure. *Radiology*, 1992, 183: 29–33.
9. Yu F, Niu XH, Zhang Q, Zhao HT, Xu LH, Deng ZP. Radiofrequency ablation under 3D intraoperative Iso-C C-arm navigation for the treatment of osteoid osteomas. *Br J Radiol*, 2015, 88: 20140535.
10. Alemdar C, Çağan MA, Dusak A, Özkul E, Atiç R, Kapukaya A. A comparison of percutaneous trephine excision and open surgery in the treatment of osteoid osteoma. *Int Orthop*, 2015 [Epub ahead of print], doi:10.1007/s00264-015-3044-8.
11. Knudsen M, Riishede A, Lucke A, Gelineck J, Keller J, Baad-Hansen T. Computed tomography-guided radiofrequency ablation is a safe and effective treatment of osteoid osteoma located outside the spine. *Dan Med J*, 2015, 62: A5059.
12. Rehnitz C, Sprengel SD, Lehner B, *et al.* CT-guided radiofrequency ablation of osteoid osteoma and osteoblastoma: clinical success and long-term follow up in 77 patients. *Eur J Radiol*, 2012, 81: 3426–3434.
13. Finstein JL, Hosalkar HS, Ogilvie CM, Lackman RD. Case reports: an unusual complication of radiofrequency ablation treatment of osteoid osteoma. *Clin Orthop Relat Res*, 2006, 448: 248–251.
14. Rosenthal DI, Hornicek FJ, Wolfe MW, Jennings LC, Gebhardt MC, Mankin HJ. Decreasing length of hospital stay in treatment of osteoid osteoma. *Clin Orthop Relat Res*, 1999, 361: 186–191.
15. Rinsky LA, Goris M, Bleck EE, Halpern A, Hirshman P. Intraoperative skeletal scintigraphy for localization of osteoid-osteoma in the spine. Case report. *J Bone Joint Surg Am*, 1980, 62: 143–144.
16. Wang T, Zhang Q, Niu XH, *et al.* Computer navigation-guided excision of osteoid osteomas. *Zhonghua Wai Ke Za Zhi*, 2011, 49: 808–811 (in Chinese).