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ORIGINAL

ADVANCING ATHLETIC PERFORMANCE: THE ROLE OF CT-GUIDED PRECISE RESECTION IN TREATING OSTEOID OSTEOMA IN ATHLETES

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ABSTRACT

Purpose: This study aimed to evaluate the effectiveness of CT-guided minimally invasive open surgery for treating osteoid osteoma (OO) in athletes, focusing on its clinical safety and efficacy. **Methods:** We reviewed medical records and imaging data of 14 athletes treated for OO from January 2014 to December 2018 using intraoperative CT-guided mini-open resection. Variables such as operation time, blood loss, incision length, and visual analogue scale (VAS) scores were analyzed to assess the outcome. **Results:** All 14 athletic patients, predominantly male with an average age of 21, underwent successful tumor removal, confirmed by pathological examination. Over an average follow-up of 37.9 months, significant improvements in pain were recorded, with no complications or recurrences related to the procedure. The mean operation metrics included a time of 27.8 minutes, blood loss of 31.1 ml, and incision length of 3.6 cm. The mean postoperative VAS scores significantly decreased, indicating effective pain management. **Conclusion:** CT-guided open surgery proved to be a safe and effective method for managing OO in athletes, enhancing recovery and return to sports activity without significant complications. This approach provides a viable option for surgeons treating athletes affected by this condition

KEYWORDS: Osteoid osteoma, Computed tomography, Intraoperative CT, Minimally invasive medicine, Open surgery

1. INTRODUCTION

The intersection of advanced medical technologies and sports performance has opened new avenues for treating athletes with musculoskeletal conditions. Osteoid osteoma (OO), a benign but painful bone tumor commonly affecting young athletes, can significantly impair physical performance and quality of life. Traditional treatment methods, while effective, often involve significant recovery time and risk of complications, which can be particularly detrimental for athletes' careers(Boscainos, Cousins, Kulshreshtha, Oliver, & Papagelopoulos, 2013; Pfaff & April, 2016). The evolution of medical imaging and surgical techniques has introduced CT-guided precise resection as a forefront method in treating OO, especially appealing in the sports context due to its minimally invasive nature and potential for precise tumor removal. This technique leverages computed tomography (CT) to offer real-time, three-dimensional guidance, allowing surgeons to achieve a high level of accuracy in excising the tumor while preserving surrounding healthy tissue. Such precision is crucial in sports medicine, where the preservation of bone integrity and function is paramount(Gallaway, Ahn, & Callan, 2020; Lindquester, Crowley, & Hawkins, 2020). This study aims to delve deeper into the clinical efficacy and safety of CT-guided precise resection for OO in athletes. By examining a cohort of athletes undergoing this innovative procedure, the research seeks to substantiate its benefits in terms of reducing operative and recovery times, minimizing procedural complications, and enabling quicker rehabilitative processes(Rosenthal et al., 1998), (Singh et al., 2022).

The overarching goal is to provide evidence that supports the integration of this advanced surgical approach into standard practice for treating athletes with OO, thereby not only addressing the pathological condition but also optimizing the athlete's overall functional recovery and return to peak performance(Sundararajan et al., 2019). In exploring the use of CT-guided precise resection, this paper will discuss the technique's technological underpinnings, its application in clinical settings, and the specific advantages it offers for the treatment of athletes. Through a detailed review of athletic patient outcomes, surgical metrics, and postoperative recovery trajectories, the study will highlight the role of this procedure in advancing athlete healthcare, situating it within broader discussions about the intersection of advanced technology, surgical innovation, and sports performance enhancement. (Liu, Kujak, Roberts, & de Chadarevian, 2011).

2. Methods

Following institutional review board approval, a query was performed on our database to identify all athletic patients with osteoid osteoma in the lower extremity. Medical records and imaging data were reviewed for all athletic patients diagnosed with OO from January 2014 to December 2018 at our institution. The demographics, clinical and radiographic data were recorded and further analyzed.

2.1 Population Inclusion and Exclusion Criteria

Twenty-three athletic patients who underwent CT-guided open surgery in our department from January 2014 to December 2018 were retrospectively reviewed. Based on bone windows with thin slices (1 mm), people whose CT scan showed the lucent nidus and surrounding reactive bone sclerosis were preliminarily diagnosed with osteoid osteoma. The diagnosis was not difficult to make because of these characteristic imaging manifestations. The final diagnosis was confirmed by postoperative pathological examination. Nine patients were excluded, as the preliminary diagnoses would not be proved by postoperative pathology. In all, fourteen athletic patients were included in our study.

2.2 Data

We retrospectively reviewed the demographic and medical data of all the 14 athletic patients, and the operation time, blood loss, incision length and other related indicators were recorded to evaluate the clinical safety and efficacy of the operation. Because the characteristic symptom of OO is extensive bone pain that is most severe at night, one of the crucial determinant factors in evaluating the efficacy of treatment is pain-relief(Lindner, Ozaki, Roedl, Gosheger, & Winkelmann, 2001). Thus, Visual Analogue Scale (VAS) was assessed before operation, on the first day, one month and one year after operation to evaluate the operation effect, respectively. Notably, one male athletic patient (Case No.14) received a second operation in our department because pain was not relieved after being operated in another hospital, with the remaining being the first time to be operated on.

2.3 Operation Procedure

Under general anesthesia, two senior orthopedic oncologists and one senior radiologist conducted the operation in CT-guided operation room. The optimal skin entry point was determined by coronal, sagittal and axial CT scans (Figures 1, 2,3 and 4). According to the identifying skin entry point, a 2-6 cm skin incision was made, muscle tissue being separated in turn and cortical bone being exposed clearly. Under the guidance of intraoperative CT, a thin Kirschner wire was used to enter the lesion through the safest and shortest path (Figures 5, 6,7 and 8). According to the angle and depth guided by CT, the drill ground bone cortex. We scraped off specimens with a small scraping spoon and sent them for histological examination. Then the small drill ground the inner wall of the tumor continuously. It was necessary to carry on a CT examination after the operation to confirm that the tumor was completely removed (Figures 9,10 and 11). We eventually sutured the wound and placed drainage tube if allogenic bone was implanted.

Figure 1: Accurate preoperative positioning and marking of surgical incision

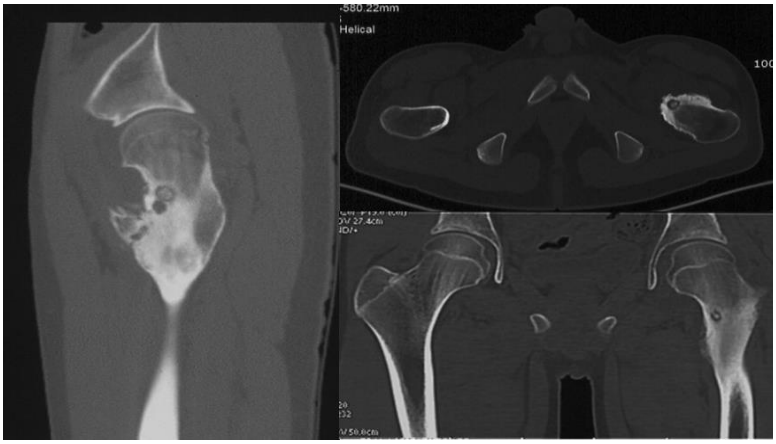

Figure 2: Case 1 Male, 16 years old, recurrence of osteoid osteoma of proximal femur after operation, 2018-10-10, preoperative CT sagittal, axial and coronal position

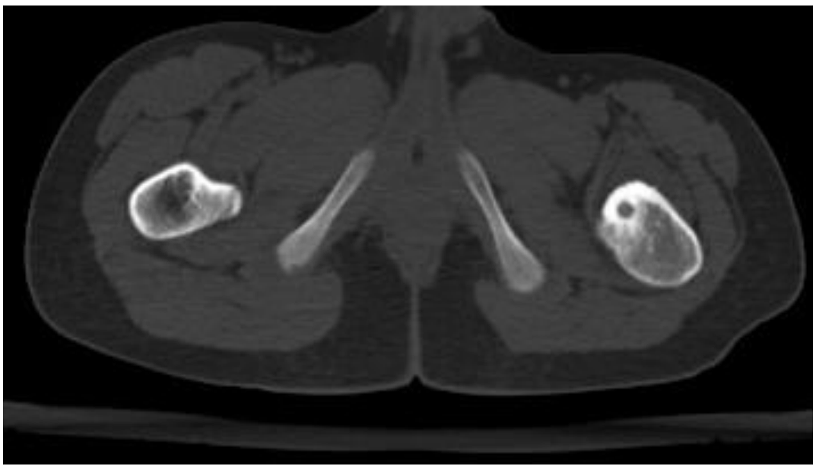

Figure 3: Case 2 Male, 14 years old, osteoid osteoma of proximal femur, 2014-9-2, preoperative CT axial position

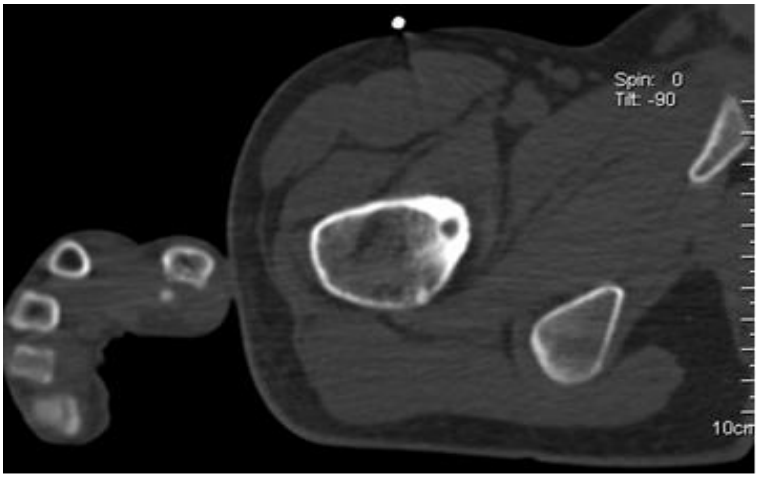

Figure 4: Case 3 Male, 18 years old, osteoid osteoma of proximal femur, 2017-2-21, preoperative CT axial position

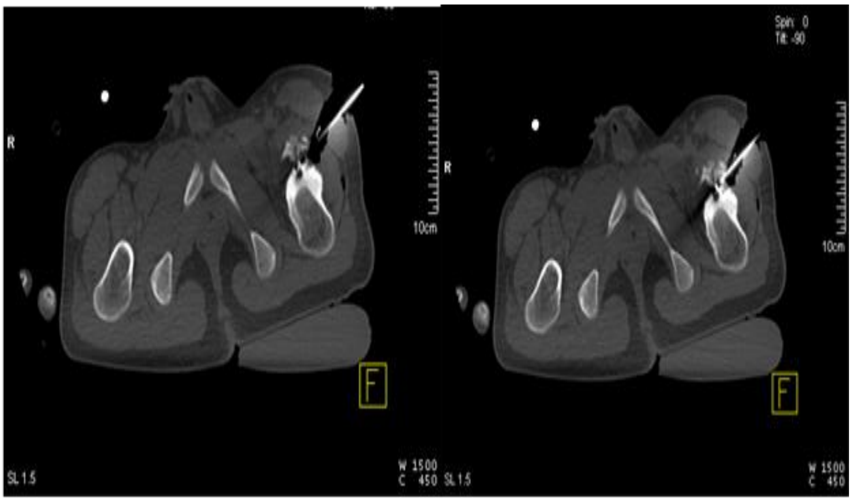

Figure 5: Case 1 Male, 16 years old, recurrence osteoid osteoma of proximal femur after operation, 2018-10-18, intraoperative CT localization image.

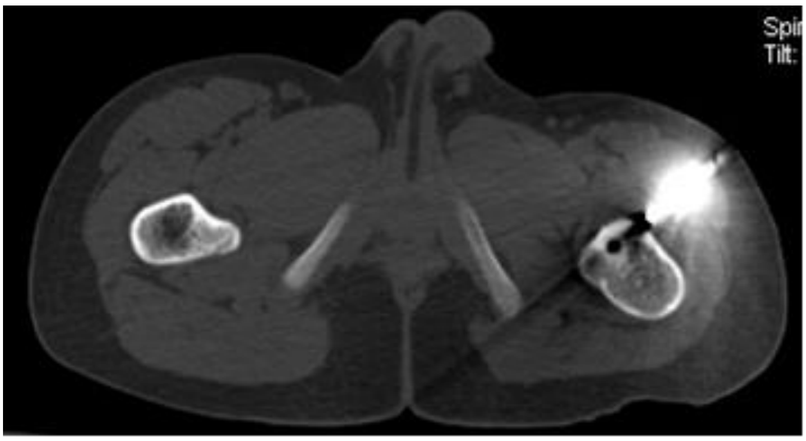

Figure 6: Case 2 Male, 14 years old, osteoid osteoma of proximal femur, 2014-9-2, intraoperative CT localization

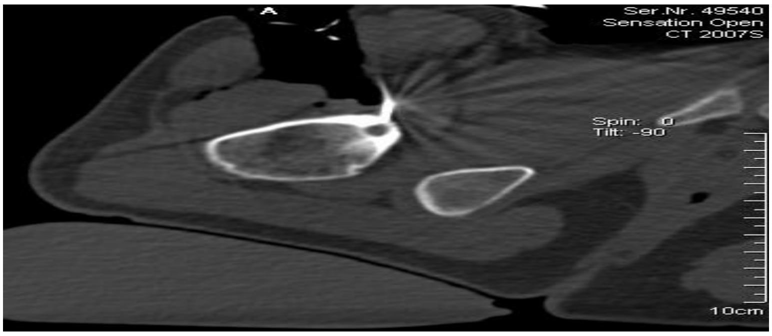

Figure 7: Case 3 Male, 18 years old, osteoid osteoma of proximal femur, 2017-2-21, intraoperative CT localization

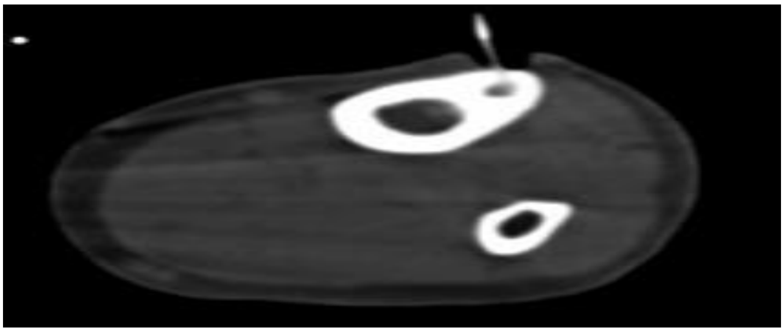

Figure 8: Case 4 Male, 32 years old, osteoid osteoma of proximal tibia, 2016-4-20, intraoperative CT localization.

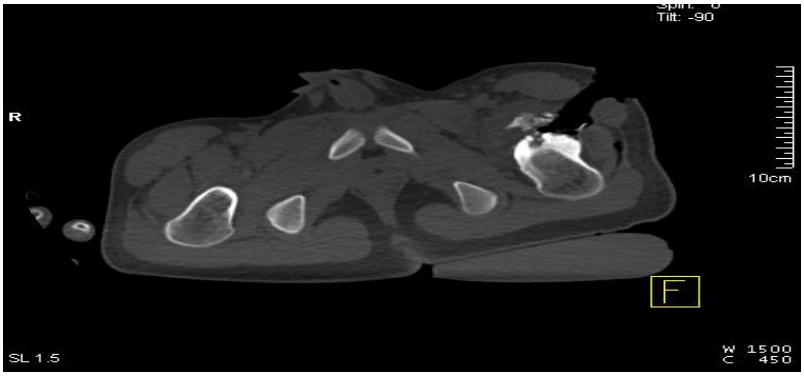

Figure 9: Case 1 Male, 16 years old, recurrence osteoid osteoma of proximal femur after operation, 2018-10-18, intraoperative thoroughly resection of tumor.

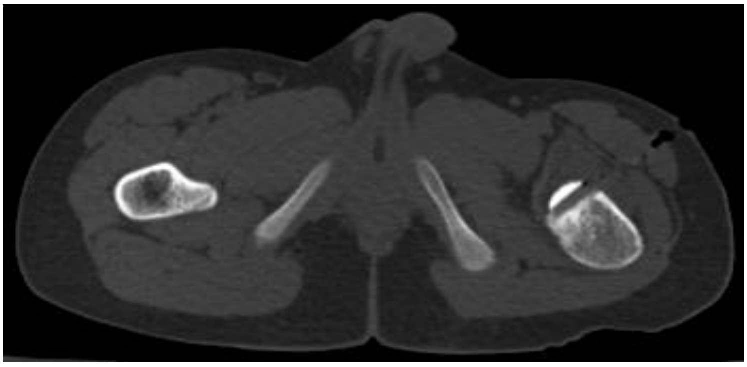

Figure 10. Case 2 Male,14 years old, osteoid osteoma of proximal femur, 2014-9-2, intraoperative thoroughly resection of tumor.

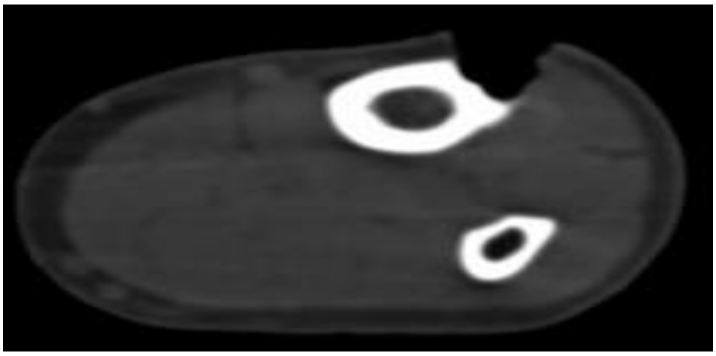

Figure 11. Case 4 Male, 32 years old, osteoid osteoma of proximal tibia, 2016-4-20, intraoperative thoroughly resection of tumor.

On the first day after operation, the athletic patients were encouraged to take full-weight bearing and daily activities. Due to the increased risk of pathological fracture associated with damaged bone cortex, athletic patients, whose ranges of lesion were wide or particular anatomic sites such as middle femur or tibia, were told to avoid long-distance running and other intense activities within one month.

2.4 Follow-Up

In the first year after surgery, the radiograph was conducted every 3 months to check the osseous union and local tumor recurrence, then every 6 months in the next 2 to 3 years. VAS scores were also obtained and any complications documented. If the pain recurred, CT was performed to identify whether there was recurrence of tumor. The treatment success may be defined as both the absence of OO related pain, the disappearance of the nidus and osseous union radiologically.

2.5 Statistical Analysis

Data processing and statistical analyses were performed using SPSS Statistics 21.0 (IBM Corp., Armonk, New York). The quantitative variables were expressed as the mean ± standard deviation (SD), using the Variance test. *P*-value < 0.05 was considered statistically significant.

3. Results

In all, there were 14 athletic patients included in our study, with 12 males and 2 females. The average age was 21 years old (range, 12 to 35 years old). No patients were lost to follow-up. The mean follow-up time was 37.9 ± 13.9 months (range: 22 to 63 months). The mean operation time was 27.8 ± 14.2 minutes (range: 11 to 55 minutes), and there was a statistically significant difference in the operation time between the femoral trochanter and other parts of the lower limb (43.2 ± 8.76 vs. 19.33 ± 7.76 minutes, $p < 0.01$).

The mean blood loss was 31.1 ± 21.8 ml (range: 5 to 80 ml) and the mean incision length was 3.6 ± 1.5 cm (range: 2 to 6 cm). No complications, including infection, fracture and neurovascular injury, were observed during the perioperative period. All patients suffered from serious night pain (mean VAS score: 7.6 points) before operation. To our great delight, pain was greatly relieved with a mean VAS score of 3.1 points on the first day after operation. Thereafter, the mean VAS score was 0.4 and 0 points one month and one year after operation, respectively (Table 1). Early recovery to their daily activities or social life was achieved in all patients. All athletic patients achieved tumor-free survival, with none showing recurrence and metastases during the mean follow-up at 37.9 months (range: 22 to 63 months). No late complications were detected by the last follow-up.

Table 1(a): Patient Demographics and Clinical Data

GENDER	AGE (Y)	FOLLOW UP (M)	VAS Score				LOCATION	BLOOD LOSS (ML)	INCISION LENGTH (CM)	OPERATION TIME (MIN)
			PRE-OPERATION	1ST DAY AFTER OPERATION	1ST MONTH AFTER OPERATION	MORE THAN 1 YEAR AFTER OPERATION				
MALE	14	63	8	4	2	0	Left Femoral trochanter	20	6	35
MALE	21	59	7	4	0	0	Left Proximal tibia	5	3	15
MALE	30	54	7	4	1	0	Left Femoral trochanter	30	5	38
MALE	16	48	8	3	0	0	Right Proximal femur	20	4	23
MALE	18	44	8	3	0	0	Left Proximal femur	20	4	28
MALE	35	38	7	2	0	0	Left Distal femur	50	2	11
MALE	19	37	8	4	0	0	Right Femoral trochanter	50	5	38

Table 1(b): Patient Demographics and Clinical Data

GENDER	AGE (Y)	FOLLOW UP (M)	VAS Score				LOCATION	BLOOD LOSS (ML)	INCISION LENGTH (CM)	OPERATION TIME (MIN)
			PRE-OPERATION	1ST DAY AFTER OPERATION	1ST MONTH AFTER OPERATION	MORE THAN 1 YEAR AFTER OPERATION				
FEMALE	24	35	7	2	0	0	Right Proximal tibia	10	2	12
MALE	32	34	8	3	0	0	Left Middle tibia	10	2	13
MALE	15	27	8	3	1	0	Right Proximal tibia	50	2	23
MALE	12	25	7	4	0	0	Left Femoral trochanter	50	5	50
FEMALE	25	23	8	2	0	0	Left Middle tibia	10	2	16
MALE	19	22	8	2	0	0	Right Proximal femur	30	3	33
MALE	15	22	8	4	2	0	Right Femoral trochanter	80	6	55

4. Discussion

Traditionally, the main treatment for osteoid osteoma (OO) was open surgery, which could completely remove the tumor nidus and achieve satisfactory therapeutic results(Shu & Ke, 2022). Rizzoli Institute of Orthopedics reported 100 cases of open surgery using curettage of lesions under direct vision and no local recurrences were observed(Campanacci & Campanacci, 1999). In the 1990s, with the progress of imaging, increasing orthopedic oncologists achieved accurate localization of the nidus before operation(Bianchi et al., 2022). Consequently, OO including the nidus and reactive bone sclerosis could be removed by using a drill(Mazoyer, Kohler, & Bossard, 1991; Susa et al., 2016). However, open surgery had the unneglectable disadvantages of great operative trauma, delayed full weight-bearing and more risks of fracture.

In the mid-1990s, people began to use various physical methods to achieve tumor nidus ablation, such as radiofrequency ablation (RFA), interstitial laser ablation (ILA), microwave ablation (MWA), cryoablation, etc. High rates of success have been reported with all of these modalities, with similar recurrence rates but shorter hospital stays reported for percutaneous techniques. Although RFA for osteoid osteomas has gained favor as a relatively reliable and less invasive procedure, RFA is contraindicated for OO close to the skin or crucial neurovascular structures due to its possible complications[7]. Similarly, ILA has been preferred since it is less invasive and does not require a period of non-weight-bearing in lesions involving the lower limbs. ILA was selected rather than radiofrequency due to its availability, simplicity of use (no internal current) and lower cost of the laser fibers compared to the radiofrequency probes. However, the failure of ILA was more frequent in patients under 18 years old or with a nidus size of 12 mm or larger(Parisot et al., 2022; Roqueplan et al., 2010). MWA, initially performed in the liver to treat hepatocellular carcinoma, is a recent therapeutic option for osteoid osteoma. Only a large diameter of lesion (about 3.5 cm) would be suitable for the application of MWA. Or MWA would possibly increase the risks of the damage on non-targeting surrounding soft tissue and pathological fracture(Le Corroller et al., 2022). Cryoablation can avoid thermal injuries and be usually used in spinal osteoid osteoma. However, cryoablation has the longest ablation time but similar clinical success rate compared with other treatments(Chaudhry et al., 2019). Till now, the standard treatments for OO are controversial. Rizzoli Institute of Orthopedics reported that the success rate of percutaneous ablation was only 83% while that of curettage under direct vision was 100%[11]. The main reason is an issue called center point of treatment(Niazi, Basha, Elsharkawi, & Zaitoun, 2021). Since there is a "radiation zone" for the damage of nerves and blood vessels caused by physical therapy, the dose and area of physical therapy are strictly limited to avoid undesired injury(Neyisci & Erdem, 2019; Oc et al., 2019). Consequently, insufficient physical therapy doses will always result in tumor recurrences and incomplete pain relief. In addition, another major problem is that definite pathological diagnoses are often not made with minimally invasive surgery; however, confirmation of diagnosis is necessary in our country. Therefore, there are still some indications for open surgery in the management of OO(May et al., 2019). Regardless of treatment modalities, accurate localization of the OO nidus is crucial for achieving favorable clinical outcomes(Garnon et al., 2017; Koch et al., 2018). The typical image of OO presents a characteristic oval radiolucent lesion representing the nidus as well as a surrounding area of reactive osseous sclerosis. CT has been generally considered as the first choice for definitive diagnosis for OO. Because of concerns regarding radiation exposure, magnetic resonance imaging (MRI) has emerged an alternative for diagnosis and image guidance, with potential advantages, such as better visualization of structures at risk and real-time temperature monitoring during thermal procedures(Seemann et al., 2022). And because of the greater capacity to visualize soft tissue structures and cartilage surfaces, MRI has become increasingly important for the evaluation of OO about the hip. However, identification of an OO nidus on MRI is not as accurate as doing so on CT scans. Davies et al. reported that as many as 35% of lesions would be missed if MRI alone was utilized (Davies, Cassar-Pullicino, Davies, McCall, & Tyrrell, 2002). Accordingly, it has been proposed that CT must be used in all patients with suspected OO. Intraoperative localization and navigation of OO can be facilitated using CT guidance, which can provide us a shortest anatomical path to the target and complete resection scope with minimal bone destruction (de Berg et al., 1995). Inspired by the respective advantage, our department chose CT-guided open surgery with minimal invasion as the treatment modality of OO. We hoped that the application of intraoperative CT examination helped accurately define the operation scope, thus achieving the effect of complete tumor resection under minimally invasive conditions, with less surgical trauma and definite efficacy at same time. First of all, in the present study, a diagnostic radiolucent nidus was present in all 14 patients. No missed or mistaken pathological examination was made due to high-quality specimens. Moreover, no recurrence was found, and the postoperative VAS scores were all reduced to 0, with an average follow-up of 37.9 months. The curative effect was better than that reported by Professor Gangi (Gangi et al., 2007) and Whitmore (Whitmore et al., 2016). This result demonstrated the accurate and complete excision of the whole lesion. Secondly, there were no requirements for internal fixation and no complications of pathological fracture, which were the main concerns for the traditional open surgery. We achieved the goal of complete resection with minimal bone destruction. Thirdly, although operation time reported in the literature is quite different, ranging from 10 to 50 minutes (Basappa, Rabang, Anderson, Richardson, & Scott, 2019; Wu et al., 2019), the total duration for physical therapy is approximate 30 min even under general or epidural anesthesia. The number of ablation cycles, overall ablation time and the number of the needles may be all responsible for both the surgical time and efficacy. In our study, the valid operation time excluding anesthesia time was 27.8 minutes. What’s more, the average incision length was about 3.6 cm, which is slightly longer than that in some studies. This may be attributed to the reason that we included five patients with OO in the femoral lesser trochanter. The incision of Smith-Peterson approach would be slightly longer than that in other parts, which may be mainly related to the depth of the anatomical site, the range required for exposure and resection and the obesity degree of the patients. All the results above clearly showed the advantages of minimally invasive open surgery under intraoperative CT guidance, which was associated with the adept operative technique and accurate nidus localization.

5. Conclusion

The study on CT-guided precise resection for the treatment of osteoid osteoma (OO) in athletes provides compelling evidence for the clinical efficacy and safety of this minimally invasive procedure. This surgical approach not only facilitates the precise removal of the tumor with minimal impact on surrounding healthy tissues but also significantly reduces recovery times, allowing athletes to resume training and competition sooner. The findings confirm that CT-guided surgery is a viable alternative to traditional methods, offering substantial benefits in terms of reduced operative risks and enhanced recovery profiles. Our research underscores the importance of integrating advanced imaging technologies like CT in surgical practices, particularly in sports medicine where preserving optimal physical function is crucial. The successful outcomes observed in athlete patients highlight the potential of CT-guided precise resection to become a standard treatment for OO, offering a pathway to quick recovery and minimal disruption to athletes' competitive trajectories. Future studies should aim to expand on these findings with larger sample sizes and longer follow-up periods to fully establish the long-term benefits and potential risks associated with this technique. Additionally, comparative studies between CT-guided and other minimally invasive techniques could further delineate the most effective surgical approaches for athletes facing similar musculoskeletal challenges. Ultimately, this study contributes to a broader understanding of how targeted, technology-driven treatments can significantly impact sports health management and athlete care.

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