3D printing guide plate for accurate hemicortical bone tumor resection in metaphysis of distal femoral: a technical note

Hongwei Wu, Shuo Yang, Jianfan Liu, Linqin Li, Yi Luo, Zixun Dai, Xin Wang, Xinyu Yao, Feng Zhou and Xian’an Li

Abstract

Background: Surgical resection and reconstruction for low-grade bone sarcoma in the metaphysis of the distal femur remain challenging. We hypothesized that 3D printing osteotomy guide plate could assist to accurately resect the tumor lesion and save the joint function.

Methods: From January 2017 to August 2019, five patients diagnosed with low-grade bone sarcoma in the metaphysis of the distal femur were treated with hemicortical resection using 3D printing guide plate. Autologous bone graft was inactivated in a high-temperature water bath and re-implanted in situ fixed with plate and screw. Patients were followed up from 17 to 33 months. The Musculoskeletal Tumor Society Score was used to evaluate the joint function. X-ray was used to evaluate the bone union.

Results: One patient was paracortical osteosarcoma, and four cases had highly differentiated chondrosarcoma. All cases were involved in the metaphysis of the distal femur. Patients were followed up from 13 to 33 months, with an average of 23.6 months. There was neither post-operation infection, internal fixation loosening, nor fracture occurrence in any of the patients. The Musculoskeletal Tumor Society Score averaged at 28.1, while the International Society of Limb Salvage imaging score examination averaged 89.8%.

Conclusions: Here, we demonstrate that the 3D printing osteotomy guide plate-assisted hemicortical bone resection is a beneficial strategy to effectively resect the primary low-grade malignant bone tumors in the metaphysis of the distal femur and retained satisfied joint function.

Keywords: Bone resection, Metaphysis of the distal femur, Reconstruction, Devitalization, 3D guide plate, Hemicortical resection

Background

Paracortical osteosarcoma and highly differentiated chondrosarcoma are the most prevalent low-grade malignant primary bone tumors [1, 2]. Hemiexcision of the tumor bone with inactivated tumor bone replantation is a valuable surgical procedure for low-grade malignant bone tumors [3–5]. However, it has been reported that this procedure has several complications, such as inadequate margins, infection, and fractures of the host bone [6]. Especially in the metaphysis of the long bone, unintended excision margin usually resulted in dysfunction of the adjacent joint [5]. For safe surgical boundaries, the hemiexcision strategy should retain as more normal bone tissue as possible, thus providing favorable conditions for the
reconstruction of the bone defects for the rapid postoperative recovery [6–8].

Recently, 3D printing technology has been extensively used in the medical field [9–12]. For instance, establishing tumor models in vitro helps doctors understand tumor shapes and the adjacent tissues from multiple perspectives and also identify lesion locations and surgical risks. Additionally, the technology has been applied in 3D printing implants through in vivo studies to assist in determining surgical boundaries [13–15]. In this technical note, we describe the technique using 3D printed osteotomy guide plate for accurate hemiexcision. Short-term follow-up results and shortcomings of this technique were also discussed.

Methods

Five patients with tumor mass in the distal metaphysis of the femur were selected to receive this operation from January 2017 to August 2019 (Table 1). There were four cases of posterior femoral tumor and one case of lateral femoral tumor. One patient was diagnosed with paracortical osteosarcoma, and the other four were diagnosed with chondrosarcoma. The diagnosis was taken via biopsy and reported by a specialized pathologist. There were one male and four females. The minimum age of the patients was 11, the maximum 65, and the mean age was 29.8 years old.

X-ray, thin-layer enhanced three-dimensional CT, and MRI were conducted for the tumor site examination upon admission (Fig. 1). The patients were informed of the feasibility of this operation based on the comprehensive assessment of their medical history, clinical signs, and imaging manifestations.

Simultaneously, we retrieved the enhanced CT scan data of the bone tumor sites and used the Mimics software (Materialise’s interactive medical image control system, USA) to extract and reconstruct the 3D CT scan data, to highlight the location and size of the tumor lesions, and to print the 3D tumor bone model. We used the Mimics software to mark the tumor resection scope and the osteotomy model (Fig. 2a–c). Afterward, the doctor determined the safe boundary of tumor resection. For low-grade malignant tumors, 2 cm outside the tumor was generally selected as the safe boundary of resection. The osteotomy guide plate was then developed to facilitate the determination of the resection boundary and efficacy of accurate osteotomy during the operation (Fig. 2d, e). The tumor bone model and the guide plate were both printed with poly-l-lactide acid (PLLA) using the melting extrusion method.

During the operation, we adopted general anesthesia and optimal surgical approaches based on the different tumor sites. For the posterior femoral tumor, dual medial and lateral incisions were adopted to completely expose the operative field [4]. The surface of the mass was generally covered with a fibrous capsule. The capsule was not cut directly, while the normal tissue outside the capsule was separated to the cortical surface of the bone. The vessels close to the tumor were separated apart from the mass and protected carefully. The periosteum stripper stripped the adjacent soft tissue attached to the bone about 3–5 cm up and down. The osteotomy guide plate was then covered on the surface of the tumor bone and fixed by two K-wires (Fig. 3a, b), and the pendulum sawing osteotomy along the guiding plate was applied to remove the whole tumor bone. During the process of osteotomy, the saw should be maintained accurately along the groove to prevent the breakage of the guide plate. We scraped the visible tumor bone tissue using the curettage and retained the cutting edge for routine disease examination. We treated the remaining bone tissue using normal saline at 70 °C for 30 min to inactivate the tumor cells in the bone tissue (Fig. 3c, d). Subsequently, the inactivated bone tissue was transplanted back to the bone defect site, and the appropriate length of the screw and bone plate was selected to fix the inactivated bone and the adjacent normal bone tissue (Fig. 3e, f).

At 3, 6, 12, and 24 months after the operation, we performed regular follow-up for X-ray to check the bone graft situation and the abdominal B-ultrasound and chest CT to assess whether there was distant metastasis. We adopted the American Society for bone tumors (Musculoskeletal Tumor Society (MSTS)) function scoring system to score [16] the limb function after the reconstructive surgery. We also used the international limb-salvage association (International Society of Limb Salvage (ISOLS)) imaging scoring system for the evaluation of the patients with postoperative radiographic

| No | Age/gender | Diagnosis       | Site     | Resected bone (cm) | % of cortical circumference | Fixation |
|----|------------|-----------------|----------|--------------------|----------------------------|----------|
| 1  | 11/F       | PO              | Femur    | 11                 | 40                         | P+S      |
| 2  | 37/M       | CS              | Femur    | 9                  | 40                         | P+S      |
| 3  | 17/F       | CS              | Femur    | 5                  | 30                         | P+S      |
| 4  | 65/F       | CS              | Femur    | 15                 | 50                         | P+S      |
| 5  | 19/F       | CS              | Femur    | 13                 | 30                         | P+S      |

PO paracortical osteosarcoma, CS chondrosarcoma, P+S plate and screw
images regarding the bone healing at the cutting surface, the graft bone changes, the stability of the internal fixation, and the joint mobility. Lastly, the percentage evaluation result was obtained by dividing the sum of the integral of each item by the full score.

**Results**
All patients received a complete resection of the bone tumor. In particular, the longest inactivated bone tumor after resection was 17 cm, while the shortest bone tumor was 9 cm, with an average of 13.8 cm. The excised bone accounted for 30–50% of the diameter of the diaphysis, with an average of 38%. Notably, postoperative pathological analysis was consistent with the biopsy pathology results.

Particularly, there were four cases with a giant lesion very close to the posterior tibial vessels and femur condyles (see supplemental materials). Besides the vessels were delicately separated from the lesion, the lesion was resected intactly using this method (Fig. 3c, d). The inactivated bone was then re-implanted into the defect site. The fixation was stable, and the bone graft was well fixed (Fig. 3e, f). Additionally, no residual tumor at the postoperative incision edge was noted in any patient based on the pathological examination. Overall, the pain score at 3 months after surgery was 1–4 points, averaging 2.2 points. All patients were followed up after surgery for 17–33 months, and the median follow-up time was 23.6 months. The highest percentage of the resected bone was 50% of the cortical circumference, and the lowest one was 30%. Importantly, none of the patients developed loosening or fracture of the internal fixation and femur fracture from the post-operation X-ray examination. The case in this technical note exhibited bone union 24 months post-operation (Fig. 4c, d).

Patients were suggested to walk cautiously with the aid of crutches 3 months after surgery. During the last follow-up, all patients exhibited satisfactory limb function and good joint activity. Representative images and videos were shown in supplementary materials. The MSTS score averaged at 28.1, while the ISOLS imaging score examination averaged 89.8%. Of note, there was no postoperative recurrence, internal fixation loosening and fracture, bone mass displacement, and metastasis in all patients (Table 2).

**Discussion**
In this technical note, we introduced an effective method to resect the low-grade bone tumor in the metaphysis of distal femur intactly. Conventional hemicortical excision or piece meal resection usually resulted in residual tumor or fracture. The resection plane could not be controlled delicately. Especially in the posterior part of the
distal femur, the vessels usually interfere with the exposure of the surgical field, making it more difficult to operate. Furthermore, excision of large segments of the joint requires extensive joint reconstruction. Allogenic bone graft or cement for this reconstruction leads to reduced joint function and a similar risk of infection to other internal plants [17, 18]. Therefore, despite its limited indications, hemicortical resection followed by inactivation and replantation is recognized and applied by many scholars [6–8, 19]. Campanacci et al. were the first to report the application of hemiectomy in bone tumor surgery [20]. Also, some scholars have used hemiexcision for the surgical treatment of high-grade osteosarcoma. It has been noted that it is suitable for eccentric bone tumors, but its long-term effects remain elusive [19]. In particular, hemiexcision is more predominantly used for low-grade malignant tumors [3, 4, 7, 21, 22]. In this study, all the patients were of low-grade malignant tumors. The benefits of hemiexcision include tumor resection can be expanded, preserves the stability and integrity of adjacent joints, enhances the residual normal bone mechanics using autologous or allogeneic bone grafting, matches the size of the original bone defect accurately, and has no risk of disease transmission. Of note, the initial safety margin of tumor resection is crucial to the treatment effect. Factors such as tumor location, shape, and size pose challenges to the effective application of hemibone resection. Due to the irregular shape of the tumor, and the restriction of the surgical field of view, surgeons may have to make certain plan changes during the osteotomy procedure. This may lead to the unsafe tumor resection border and the recurrence
of residual tumor. For malignant bone tumors at the distal end of the posterior femur, it is difficult to preserve the blood vessels as well as joint function [4].

In the past, no method was available to make three-dimensional measurements on the tumor before surgical resection. However, computer technology has enabled this measurement to be made, thus achieving a higher matching degree between the tumor defect removed and the bone graft reconstructed [23, 24]. Another method used to accurately remove a tumor from the bone is the surgical navigation robot, but this tool is expensive and not readily available in ordinary hospitals. Recently, 3D digital reconstruction and 3D printing of osteotomy guide plate technology have improved osteotomy for hemibonectomy of bone tumors. The 3D reconstruction of the bone tumor is achieved using a three-dimensional
CT scan which transmits the data into a 3D reconstruction software to establish a 3-dimensional model. This technique reveals the tumor after printing, thus allowing doctors to make a plan for the resection border. The corresponding resection guide plate can be fabricated according to the plan [23]. Theoretically, the safe boundary of osteotomy for this method is more reliable, and the chances of postoperative recurrence are lower. Moreover, with the assistance of the osteotomy guide plate, the time needed for osteotomy localization is relatively shorter, which reduces the operation time and in turn decreases blood loss, thus making it more effective in the rehabilitation of patients. Using the osteotomy guide plate, most of the bone tumor can be removed as a whole, rather than unplanned lumps. After inactivation treatment, the original shape of most of the bone tumor is maintained which creates a very high matching degree with the bone defect site. This ensures good fixation of bone blocks and also shortens the operation time. Overall, this method results in good postoperative recovery and functional recovery.

Previous studies have reported that fractures, infections, and incomplete resection contribute to the development complications of hemiexcision. Specifically, fracture is one of the leading cause (10–18%) [3, 25]. In 2014, some scholars used computer-assisted surgery to design an allograft bone graft to repair the bone defect of hemibonec- tomy. They noted that the method achieved resection and reconstruction precisely with less time-consuming and also reduced the incidence of fracture [23]. Therefore, a 3D-printed osteotomy guide plate can be used to perform accurate osteotomy based on the preoperative surgical plan, without any intraoperative or postoperative fractures. Herein, the inactivated bone tissue was transplanted back into the patient perfectly matched with the original bone defect, shortening the time taken to reconstruct the bone defect and adjust the bone mass. Besides, our short-term postoperative follow-up results enumerated no recurrence in all 5 patients. This implies a safe tumor resection boundary. We also achieved accurate R0 resection and successful reconstruction even for adjacent joint lesions, and this perhaps may have contributed to the highly preserved joint function. Functional scores of the affected limbs after surgery were above 24 points in all patients, while patient satisfaction was very high. This finding is consistent with the recent reports by Japanese scholars [26] and also exceeds scores reported in a review by Dutch scholars [6]. Therefore, this surgical approach is effective for the removal of bone tumors and bone reconstruction. High short-term efficacy following inactivation and re- plantation of hemibone resection for highly malignant bone tumors has been reported [19]. This indicates that it is possible to achieve an effective safe boundary for tumor control. However, the long-term efficacy of our method should be investigated further to confirm these intriguing findings, especially in follow-up studies.

In summary, digital three-dimensional reconstruction is a valuable technique for formulating osteotomy boundary and osteotomy guide plate-assisted osteotomy, which makes hemibone resection more convenient, faster, and reduces the risk of postoperative complications, and lowers the recurrence rate. Furthermore, the method used herein is cheap, reliable, and results in quick recovery. Notably, this is important for reserving the joint function regarding the tumor adjacent to the joint. Despite these benefits, we acknowledge that hemiexcision has its inherent limitations. Among them is the risk of postoperative recurrence and insecure surgical boundaries. The follow-up period for patients in this study is relatively short, and thus, a longer follow-up duration is needed to test the long-term effect of this surgical method. Also, the current digital three-dimensional reconstruction does not accurately identify the tumor tissue, making it difficult to achieve intelligent grasp recognition. Therefore, manual intervention is required to determine the tumor boundary. We believe that with further advancements in imaging, digital technology, and artificial intelligence, these problems will be gradually solved, and hemibonecctomy will yield better therapeutic effects.

Conclusions
The 3D printing guiding plate offered a useful approach for completely resecting low malignant metaphyseal
bone tumors. The joint function is excellent, and the re-
currence rate is low for short-term follow-up. The tech-
nique saves time and decreases bleeding during the 
operation. The cost of this technic is affordable and 
worthy to be applied to this kind of disease.

Abbreviations
FWB: Full weight-bearing; MSTS: Musculoskeletal Tumor Society; 
ISOLS: International Society of Limb Salvage; N: Negative; PO: Paracortical 
osteosarcoma; CS: Chondrosarcoma; P+s: Plate and screw

Supplementary Information
The online version contains supplementary material available at https://doi. 
one.org/10.1186/s13018-021-02374-w.

Acknowledgements
The authors thank Dr. Jerry for the language editing and revision.

Authors’ contributions
HW wrote the manuscript and analyzed the data. XL conceived the study 
and revised the manuscript. Other authors contributed to the patient 
information collection and operations. All authors read and approved the 
final manuscript and agreed to be accountable for all aspects of the work.

Funding
The study was supported by the Project of Natural Science Foundation of 
Hunan Province (No.2018JJ2243), Hunan Provincial Health Commission.

Availability of data and materials
All the data and materials are available from the corresponding author upon 
reasonable request.

Declarations
Ethics approval and consent to participate
Ethics approval was not applicable in this study. Written informed consent 
for participation was obtained from all patients before the start of the 
therapy.

Consent for publication
Written informed consent was required from patients in case 9 for the 
publication of this manuscript. Copies of the written consent are available for 
review by the Editor-in-Chief of the journal.

Competing interests
The authors declare that they have no competing interests.

Received: 31 January 2021 Accepted: 21 March 2021
Published online: 28 May 2021

References
1. Harper K, Sathiadoss P, Saifuddin A, Sheikh A. A review of imaging of 
surface sarcomas of bone. Skelet Radiol. 2020.
2. Liu S, Zhou X, Song A, Hua Z, Wang Y, Liu Y. Surgical treatment of 
chondrosarcoma of the sacrum with cement augmentation: a case report. 
Medicine. 2019;98(50):e18413. https://doi.org/10.1097/MD.0000000000018413.
3. Dejkers RL, Bloem RW, Hogendoorn PC, Verlaan J, Knoorn HM, Taminiau AH. 
Hemicortical allograft reconstruction after resection of low-grade malignant 
bone tumours. J Bone Joint Surg Br. 2002;84(7):1009–14. https://doi.org/10. 
13031/0301-620X.84B7.0841009.
4. Lewis VO, Gebhardt MC, Springfield DS. Parosteal osteosarcoma of the 
posterior aspect of the distal part of the femur. Oncological and 
functional results following a new resection technique. J Bone Joint 
Surg Am. 2000;82(2):1083–8. https://doi.org/10.2106/00004623-2 
0000800-00003.
5. Pizzillo F, Maccauro G, Niazegolzadeh T, Rossi B, Goshgari G. Resection of parosteal 
osteosarcoma of the distal part of the femur: an original reconstruction technique 
with cement and plate. Sarcoma. 2008;2008:76056.
6. Bus MP, Branner JA, Schlaep GR, Schreuder HW, Jutte PC, van der Geest IC, 
et al. Hemicortical resection and inlay allograft reconstruction for primary 
bone tumors: a retrospective evaluation in the Netherlands and review of 
the literature. J Bone Joint Surg Am. 2015;97(9):738–50. https://doi.org/10.21 
06/JBJS.N.00948.
7. Liu T, Liu ZY, Zhang Q, Zhang X-S. Hemorticcal resection and reconstruction 
using pasteurized autograft for parosteal osteosarcoma of the distal femur. 
Bone Joint J. 2013;95-B(8):1275–9. https://doi.org/10.1302/0301-620X. 
95B9.13433.
8. Lenze U, Kasal S, Hefti F, Krieg AH. Non-vascularised fibula grafts for 
reconstruction of segmental and hemorticcal bone defects following meta-
diaphyseal tumour resection at the extremities. BMC Musculoskel 
Disord. 2017;18(1):289. https://doi.org/10.1186/s12891-017-1640-z.
9. Maini L, Sharma A, Jha S, Tiwari A. Three-dimensional printing and patient- 
specific pre-contoured plate: future of acetabulum fracture fixation? Eur J 
Trauma Emerg Surg. 2018;44(2):215–24.
10. Liang H, Ji T, Zhang Y, Wang Y, Guo W. Reconstruction with 3D-printed 
pelvic endoprosthesis after resection of a pelvic tumour. Bone Joint J. 2017; 
99-B(2):267–75. https://doi.org/10.1302/0301-620X.99B2.BJ01-2016-0654.R1.
11. Ma L, Zhou Y, Zhu Y, Lin Z, Chen L, Zhang Y, et al. 3D printed personalized 
titanium plates improve clinical outcome in microwave ablation of bone 
tumors around the knee. Sci Rep. 2017;7(1):7626. https://doi.org/10.1038/s41 
598-017-0243-3.
12. Lador R, Regev G, Salame K, Khashan M, Lidar Z. Use of 3-dimensional 
printing technology in complex spine surgeries. World Neurosurgery. 2020; 
133:e327–e41. https://doi.org/10.1016/j.wneu.2019.09.002.
13. Park JW, Kang HG, Kim JH, Kim HS. The application of 3D-printing 
technology in pelvic bone tumor surgery. J Orthop Sci. 2021;26(6):276–83.
14. Ma L, Zhou Y, Zhu Y, Lin Z, Wang Y, Zhang Y, et al. 3D-printed guiding 
templates for improved osteosarcoma resection. Sci Rep. 2016;6(1):23335. 
https://doi.org/10.1038/srep23335.
15. Wang F, Zhu J, Peng X, Su J. The application of 3D printed surgical guides 
in resection and reconstruction of malignant bone tumour. Oncol Lett. 2017; 
14(4):4581–4. https://doi.org/10.3892/ol.2017.7649.
16. Enneking WF, Dunham W, Gebhardt MC, Malawar M, Pritchard DJ. A system 
for the functional evaluation of reconstructive procedures after surgical 
treatment of tumors of the musculoskeletal system. Clin Orthop Relat Res. 
1993;286:241–6.
17. Oliva MS, Vetello R, Cauteruccio M, Pesare E, Rovere G, Meschini C, et al. 
Cemented versus cementless megaprostheses in proximal femur metastatic 
failure: a systematic review. Orthop Rev (Pavia). 2020;12(Suppl 1):18695.
18. Ziranu A, Lillo M, Fantoni M, Maffulli N, Maccauro G. Single dose cefazolin is 
safe and effective for pre-operative prophylaxis in orthopaedic oncology. J 
Biol Regul Homeost Agents. 2017;31(4 suppl 1):51 
–75. https://doi.org/10.1302/0301-620X.99B2.BJJ-2016-0654.R1.
19. Campanacci M, Capanna R, Still S. Posterior hemiresection of the distal 
femur in parosteal osteosarcoma. Ital J Orthop Traumatol. 1982;8(1):23 
–41. https://doi.org/10.4103/0019-5413.132518.
20. Zhang Q, Liu T, Guo X, Ling L. Salvage therapy by hemicortical excision 
and reconstruction for low-grade malignant bone tumour. Zhong Nan Da Xue 
Xue Bao Yi Xue Ban. 2013;38(7):691–4.
21. Guilla A, Puri A, Pruthi M, Desai S. Oncological and functional outcome of 
periosteal osteosarcoma. Indiat J Orthop. 2014;48(4):279–84. https://doi.org/ 
10.4103/0019-5413.132518.
22. Gulati M, Apolito R, De Ieso C, Magarelli N, Maccauro G, et al. Evaluation of accuracy of bone cuts and implant positioning in total 
joint arthroplasty using patient specific instrumentation. J Biol Regul 
Homeost Agents. 2017;31(4 suppl 1):51–60.
23. Agarwal M, Puri A, Anchan C, Shah M, Jambhekar N. Hemicortical excision 
for low-grade selected surface sarcomas of bone. Clin Orthop Relat Res. 
2007;459:161–6. https://doi.org/10.1097/BLO.0b013e318059f8eb.
24. De Santis V, Burrofato A, D'Apolito R, De Ieso C, Magarelli N, Maccauro G, 
et al. Accuracy of bone cuts and implant positioning in total knee arthroplasty 
using patient specific instrumentation. J Biol Regul Homeost Agents. 2017;31(4 suppl) 1:51–60.
25. Agarwal M, Puri A, Anchan C, Shah M, Jambhekar N. Hemicortical excision 
for low-grade selected surface sarcomas of bone. Clin Orthop Relat Res. 
2007;459:161–6. https://doi.org/10.1097/BLO.0b013e318059f8eb.
26. Nakamura T, Fujiwara T, Tsuda Y, Abudu A, Nomoto Y, Takada A, et al. The clinical outcomes of hemicortical extracorporeal irradiated autologous bone graft after tumor resection of bone and soft tissue sarcoma. Anticancer Res. 2019;39(10):5605–10. https://doi.org/10.21873/anticanres.13755.

Publisher’s Note
Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.