BMC Surgery

RESEARCH Open Access

# Vascularized fibular epiphyseal transfer for biological reconstruction of bone defects following resection in children with proximal humeral sarcoma

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## Abstract

**Background** The functional reconstruction of bone defects following resection of proximal humerus tumors in children poses a significant challenge. This study utilized vascularized fibular epiphyseal transfer for proximal humerus reconstruction to evaluate the outcome, complications, and survival rates.

**Methods** In this study, we conducted a retrospective analysis of 13 pediatric patients who underwent vascularized fibular epiphyseal transfer for biological reconstruction following oncologic resection of the proximal humerus between 2019 and 2021. All patients received adequate preoperative preparation and evaluation, and complications were meticulously recorded. Regular functional follow-ups and imaging evaluations were performed.

**Results** A total of 13 patients with an average age of 9.8 years were included in this study. The average length of the humerus defect after surgical resection was 13.7 cm (9.4–17.8 cm). Delayed wound healing was observed in 2 patients, and one patient experienced brief common peroneal nerve palsy. There were 3 cases of graft fracture, all of which occurred within 1 year after operation. These cases were successfully managed through the application of draping plaster or brace fixation. The mean follow-up period was 39.8 months (ranging from 19 to 57 months). The mean Musculoskeletal Tumor Society (MSTS) score was 21.5 (18–24). All patients reported no persistent pain.

**Conclusion** In conclusion, we assert that vascularized fibular epiphyseal transfer provides a reliable and promising option for reconstruction in pediatric patients undergoing proximal humerus tumor resection surgery. Graft fractures were the most prevalent complication, emphasizing the importance of cautionary measures to prevent falls or trauma. However, further validation through increased case numbers and extended follow-up periods is necessary.

**Keywords** Vascularized fibular graft, Proximal humeral, Sarcoma, Biological reconstruction, Children

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## Background

Osteosarcoma and Ewing's sarcoma are the two most prevalent malignant bone tumors in children, posing a significant threat to their health and survival [1, 2]. The proximal humerus ranks as the third most frequently affected site for primary bone sarcomas, following the distal femur and proximal tibia [3]. Resection of malignant tumors in the proximal humerus often results in substantial bone defects and disruption of shoulder joint integrity [4]. Therefore, reconstruction of shoulder function is crucial and a great challenge.

Currently, there are several techniques available for reconstructing the proximal humerus following tumor resection, such as prosthesis replacement, allograft prosthesis composite (APC), and vascularized fibular epiphyseal transfer [5–7]. Prosthesis replacement is the most commonly used for proximal humerus reconstruction. However, it may not be suitable for young children due to the increased risk of prosthetic stem fracture associated with their smaller medullary cavity. Additionally, a critical factor that renders prosthetics unsuitable for children is the need to account for the growth of the humerus during their development [8]. Generally, the proximal humerus contributes approximately 80% to the total growth capacity of the humerus in children [9, 10]. Therefore, biological reconstruction also holds promise for mitigating long-term limb differences [11]. Vascularized fibula grafts demonstrate favorable biological activity and mechanical properties that make them an ideal approach for addressing bone defects in the proximal humerus [12]. Nevertheless, the application of this technique remains limited with few reports on its use specifically for proximal humerus reconstruction.

In this study, we retrospectively analyzed a case series involving pediatric patients who underwent vascularized fibular epiphyseal transfer for biological reconstruction following oncologic resection of the proximal humerus at our institution. Our objective was to evaluate the outcome, complications, and survival rates associated with this surgical procedure and contribute our institutional experience.

## Methods

### Patient information

In this study, we enrolled 13 pediatric patients with primary malignant bone tumors of the proximal humerus who were admitted to our institution from January 2019 to December 2021. The inclusion criteria were as follows: (1) pediatric patients (age < 14 years), (2) diagnosed with osteosarcoma or Ewing sarcoma of the proximal humerus, (3) undergoing Vascularized fibular epiphyseal transfer for biological reconstruction. The exclusion criteria included loss of follow-up or incomplete follow-up data. This study was approved by the Medical Ethics Committee of the Second Xiangya Hospital, and informed consent was obtained from the patients and their legal guardians. All patients underwent standard neoadjuvant chemotherapy after biopsy. Preoperative humerus MRI, humerus CT, lung CT, and bone scanning were performed to assess tumor size and its relationship with important blood vessels and nerves, determine the scope of surgery, and exclude contraindications of limb salvage.

### Operation

The patient was positioned laterally to enable free mobility of the upper limbs. An anterolateral incision was selected for the complete resection of the tumor. The humerus was resected 2 cm distal to the tumor margin based on the preoperative MRI. The deep brachial artery and vein were separated and utilized as blood supply vessels for the fibular artery and vein. Typically, the ipsilateral fibula with about 6 cm of the biceps femoris tendon bundle was harvested (Fig. 1C). Careful protection of the common peroneal nerve and peroneal vessels during surgery is essential. Then, the harvested fibula end was inserted into the medullary cavity of the humerus stump. If necessary, adjustments could be made by enlarging or trimming the structure to achieve a proper fit. The fibula and humerus were fixed with locking plates. Then, microvascular anastomosis was performed between the peroneal vessels and deep humeral vessels, and the fibula was checked for spontaneous bleeding to ensure successful anastomosis. Fibula graft acquisition and vascular anastomosis were performed by our colleagues from the Department of Bone Microsurgery. The retained biceps femoris aponeurosis was sutured to the remaining rotator cuff to stabilize the shoulder joint.

### Postoperative recovery and follow-up

After the operation, patients were instructed to immobilize the upper limb using an arm sling or functional brace to minimize the risk of graft failure. Subsequently, passive and active functional exercises were gradually introduced based on individual circumstances after 4 weeks. Patients diagnosed with osteosarcoma and Ewing's sarcoma received standard chemotherapy after surgery. The follow-up assessments included regular evaluation of limb function and imaging examination. Follow-up was conducted every 3 months for the first 2 years, semiannually for 2–5 years, and annually after 5 years. Surgical complications, shoulder function, and oncology outcomes were meticulously recorded. Limb function was evaluated using the Musculoskeletal Tumor Society (MSTS) upper limb function score [13].

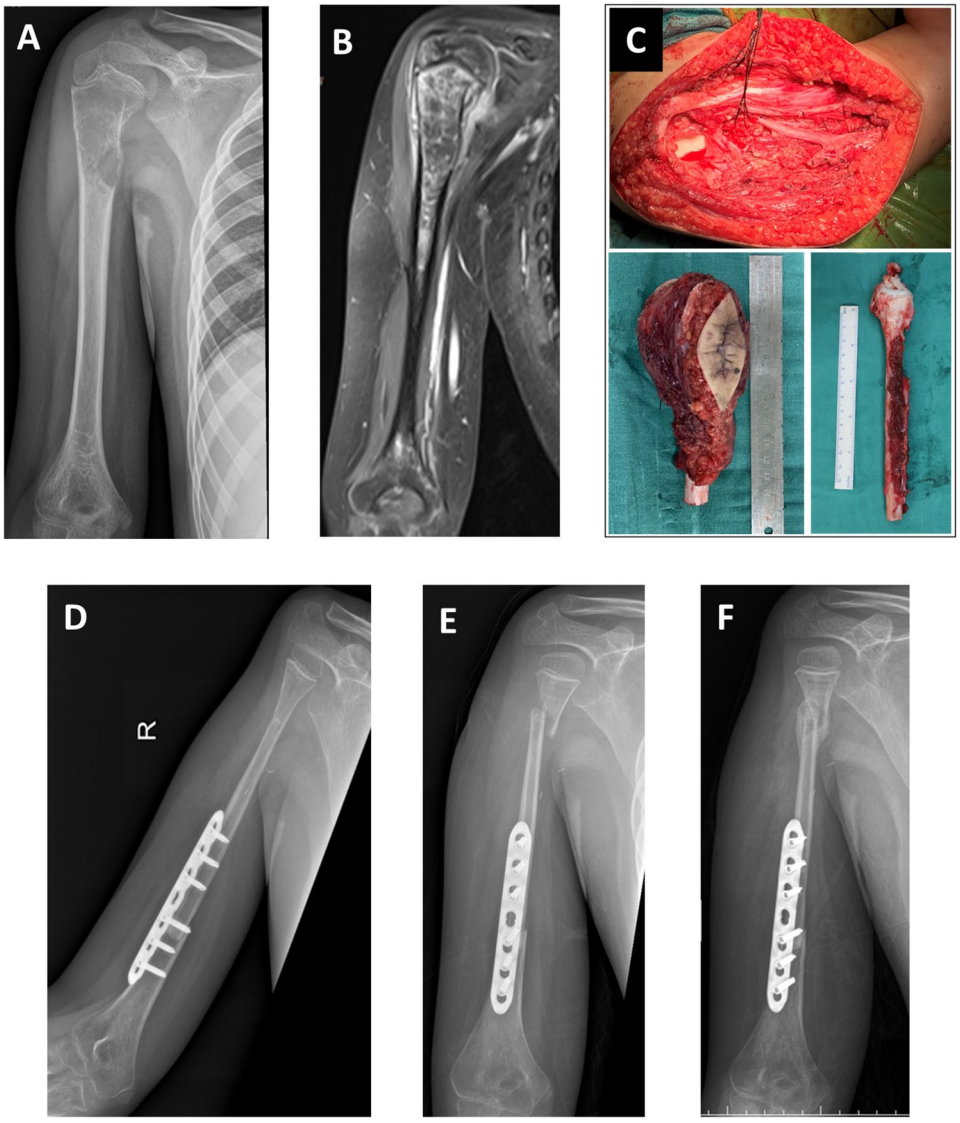


**Fig. 1** A case of graft fracture. Preoperative X-ray(**A**), MRI(**B**), and intraoperative photographs(**C**) of a 11-year-old male patient diagnosed with osteosarcoma in the right proximal humerus. This patient underwent resection of proximal humerus tumors and subsequent reconstruction using a vascularized fibula graft(**D**). Four months after surgery, the graft was fractured due to a fall(**E**). The graft fracture healed successfully after plaster fixation (**F**). (Case 3 in Table 1)

### Statistical analysis

We used Kaplan-Meier survival methods to analyze the overall survival (OS). Statistical analysis and plotting were performed using the SPSS version 17.0 and Graphpad-Prsm version 9.5 software. A p-value of less than 0.05 was considered statistically significant.

## Result

A total of 13 patients were included in this study, including 9 males and 4 females, with a mean age of 9.8 years (range: 7–12 years). Preoperative biopsies were performed to determine the pathological types of tumors, including 8 cases of osteosarcoma and 5 cases of Ewing's sarcoma. The Enneking system was used for tumor staging, including 5 cases of stage IIA and 8 cases of stage IIB. The tumor necrosis rate after chemotherapy was > 90% in a total of 11 out of the 13 enrolled patients (84.6%). The average length of the humerus defect following surgical resection was 13.7 cm (9.4–17.8 cm). The general information and characteristics of 13 patients are shown in Table 1.

Delayed wound healing occurred in 2 patients and healed following dressing changes and infrared light irradiation. No instances of infection or necrosis were reported. One patient experienced common peroneal nerve palsy (manifesting as foot drop and sensory loss of the dorsum of the foot), which gradually recovered after 9 months, leaving no residual functional impairments.

**Table 1** Characteristics and outcomes of the 13 patients

| Case | Gender | Age | Pathological diagnosis | Enneking stage | Defect length (cm) | Complications | Follow-up (months) | Patient status | MSTS Score |
|---|---|---|---|---|---|---|---|---|---|
| 1 | M | 9y | EWS | 2B | 13.8 | - | 38 | NED | 19 |
| 2 | F | 10y | OS | 2B | 17.8 | Peroneal nerve palsy | 19 | DOD | - |
| 3 | M | 11y | OS | 2B | 14.3 | Fracture | 32 | NED | 21 |
| 4 | M | 8y | EWS | 2 A | 9.4 | - | 57 | NED | 20 |
| 5 | F | 11y | OS | 2B | 14.6 | Fracture | 36 | NED | 21 |
| 6 | F | 9y | EWS | 2 A | 11.6 | - | 28 | NED | 24 |
| 7 | M | 10y | OS | 2B | 13.2 | - | 48 | NED | 22 |
| 8 | M | 12y | OS | 2B | 16.5 | Fracture / Delayed wound healing | 45 | NED | 18 |
| 9 | M | 10y | OS | 2 A | 11.2 | - | 42 | NED | 22 |
| 10 | M | 11y | OS | 2B | 17.4 | Delayed wound healing | 30 | DOD | - |
| 11 | M | 9y | OS | 2B | 15.2 | - | 39 | NED | 23 |
| 12 | F | 7y | EWS | 2 A | 10.6 | - | 49 | NED | 22 |
| 13 | M | 10y | EWS | 2 A | 12.5 | - | 54 | NED | 24 |

EWS: Ewing's sarcoma, OS: Osteosarcoma, NED: no evidence of disease, DOD: died of disease, MSTS: Musculoskeletal Tumor Society

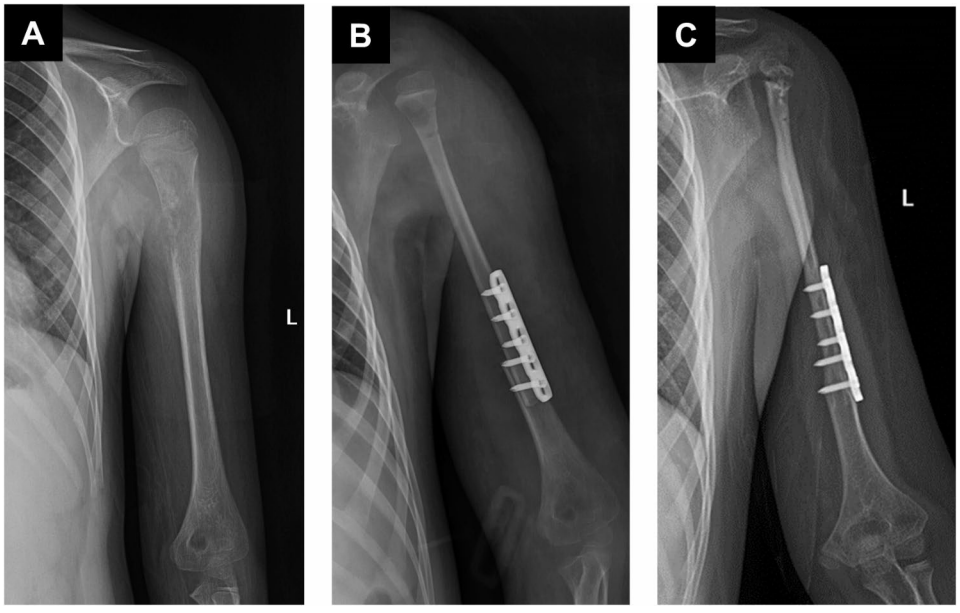


**Fig. 2** A typical case without any complications. **A**: Preoperative X-ray (**A**) of a 9-year-old male patient diagnosed with osteosarcoma in the left proximal humerus. **B**: X-ray at one week after surgery. **C**: X-ray at the last follow-up. (Case 11 in Table 1)

Throughout the follow-up period, none of the patients exhibited ankle valgus deformity or pain at the fibular graft donor site. The average healing time was 4.1 months (ranging from 3 to 6 months), with no cases of nonunion reported. The average growth of grafts was 3.5 mm per annum (2.2–4.7 mm), and no obvious hypertrophy was observed. The mean arm discrepancy at the last follow-up was 3.2 cm (2.0–4.5 cm). There were 3 cases of graft fracture, all of which occurred within 1 year after operation. These cases were successfully managed through the application of draping plaster or brace fixation. Figure 1 shows a case of graft fracture and Fig. 2 shows a typical case without any complications.

The mean follow-up was 39.8 months (19–57 months). Among them, 2 patients with OS died of lung metastasis at 19 months and 30 months after operation, respectively. The overall survival rate was 84.6% (Fig. 3). At the last follow-up, shoulder abduction ranged from 25° to 90° (mean abduction 56.8°), forward flexion ranged from 15 ° to 75° (mean flexion 38.6°), and external rotation ranged from 10 ° to 45° (mean external rotation 26.4°). The mean MSTS score was 21.5 (18–24). All patients reported no persistent pain.

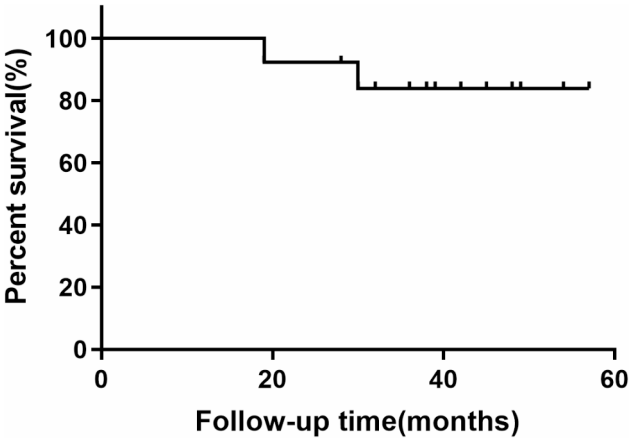


**Fig. 3** The overall survival rates among 13 patients

## Discussion

The functional reconstruction of bone defects following resection of proximal humerus tumors poses a considerable challenge for orthopedic surgeons. This complexity is particularly pronounced in young children who have not yet achieved skeletal maturity, wherein biological reconstruction techniques are prioritized to ensure optimal healing and development. Among various reconstruction strategies, vascularized fibular grafts have emerged as a prominent option due to their excellent biological activity and favorable mechanical properties, which are crucial for the repair of long bone defects [14].

In this study, we employed vascularized fibular epiphyseal transfer as a method for reconstructing bone defects following the oncological resection of malignant bone tumors in the proximal humerus of children. The results observed in the early and mid-term follow-up periods were promising, indicating that this technique not only supports effective bone regeneration but also facilitates functional recovery. Our findings contribute to the growing body of evidence that supports the use of vascularized fibular epiphyseal transfer for biological reconstruction in pediatric orthopedic oncology, ultimately improving outcomes for young patients facing such complex surgical interventions.

Biological reconstruction techniques for proximal humerus include allografts, clavicula pro humero, and vascularized fibular epiphyseal transfer [15, 16]. However, no single technique is universally accepted as optimal, as each presents its advantages and disadvantages. Allografts are noted for their favorable mechanical properties, yet they carry a significant risk of complications, including infection and bone nonunion [16]. Clavicula pro humero can provide shoulder stability for children with shoulder joint reconstruction without local recurrence; however, it is associated with a high incidence of nonunion. In the study of Calvert et al., 5 of 7 patients experienced nonunion [17]. The vascularized fibula graft was first described by Weiland in 1977 for the reconstruction of bone defects following tumor resection [18]. The utilization of free vascularized fibular grafting offers a reliable biological reconstruction method with commendable success rates. Additionally, it facilitates long-term hypertrophy and axial growth while effectively preserving limb functionality.

The most prevalent complication observed in this study was graft fracture (3/13), primarily attributed to the relatively thin fibula and poor adherence to immobilization protocols among pediatric patients. The reported incidence of graft fracture in other similar studies varies considerably, ranging from 0 to 64% [19–22]. Notably, we believe that the probability of graft fracture was highest in the first year, and all the fractures we observed occurred in the first year. Therefore, it is recommended to avoid falls or trauma to mitigate the risk of fracture, especially in the first year. The size of the grafted fibula gradually increased with age, exhibiting an average hypertrophy index of about 65% and an average annual growth of 4.6 mm [19]. However, in our study, the average growth of grafts was only 3.5 mm per annum, and no obvious hypertrophy was observed. This discrepancy may be related to the insufficient follow-up time and the relatively inadequate stress stimulation of the upper limbs. Additionally, previous studies utilizing the Capanna technique, which combines allograft bone with vascularized fibular grafts, have demonstrated improved mechanical strength during the healing process; however, these approaches also present a heightened risk of infection and nonunion [23].

The vascularized fibular graft is widely utilized for the reconstruction of large bone defects such as femur, tibia, humerus, and pelvis caused by various etiologies [24]. However, harvesting the fibular graft can lead to donor site complications, including common peroneal nerve injury, lateral malleolus pain, and ankle valgus [25]. The incidence of these complications is closely associated with the surgical skills of the operating surgeon. In close collaboration with our colleagues who specialized in bone microsurgery, we meticulously dissected and protected the common peroneal nerve during surgery. None of our patients experienced permanent common peroneal nerve damage. Another complication worth mentioning is ankle valgus. To mitigate the risk of postoperative ankle instability in skeletally immature children, it is recommended to preserve a minimum length of 5 to 8 cm at the distal end of the fibula during transplantation. Given the long learning curve of fibular graft surgery, we advocate collaborating with specialized bone microsurgeons to ensure a successful harvest and transplantation.

The vascularized fibula graft transfer is a crucial technique for the biological reconstruction of bone defects. However, the influence of the number of vascular

pedicles on the healing process of the graft remains a matter of debate within the surgical community. Conversely, the non-vascularized fibular graft presents several advantages, including greater operational simplicity and a reduced duration of the surgical procedure. Despite the prevailing recommendation for the use of vascularized fibular grafts in addressing bone defects that exceed 6 cm in length, a comprehensive meta-analysis has indicated that this guideline may lack robust scientific support [24, 26]. Therefore, it is imperative to undertake more meticulously designed scientific studies, accompanied by thorough follow-up assessments, to elucidate the true benefits and appropriate indications for the utilization of vascularized fibula grafts. Our research provides compelling evidence that satisfactory graft healing can be achieved using a vascularized fibular epiphyseal transfer in cases with an average humeral defect of 13.7 cm. This finding suggests that vascularized fibula transfer may be a viable alternative in specific clinical scenarios, potentially broadening the treatment options available for patients with significant bone defects.

Limitations: Firstly, the size of the patient cohort in this study was relatively small. This limitation primarily arises from the inherent difficulty in obtaining a significant number of cases from a single institution, particularly considering the notably low incidence rate of proximal humerus malignancies in the pediatric population. Secondly, the study did not include a comparative analysis with alternative techniques for humeral reconstruction, which could have provided valuable insights into the relative effectiveness and outcomes of different approaches. Nevertheless, we believe that the use of vascularized fibular epiphyseal transfer represents an optimal biological option for proximal humerus reconstruction in young children. Thirdly, the follow-up period in our study was limited, and it is important to note that not all patients had reached developmental maturity at the time of follow-up. Therefore, future research should aim to include a larger patient population and extend the duration of follow-up to obtain more comprehensive data regarding outcomes and the long-term efficacy of this technique.

## Conclusion

The utilization of vascularized fibular epiphyseal transfer for the reconstruction of proximal humerus bone defects in children has demonstrated favorable functional outcomes in this study. Graft fractures were the most prevalent complication, emphasizing the importance of cautionary measures against falls or trauma. In conclusion, we believe that vascularized fibular epiphyseal transfer is a reliable and promising option for reconstruction. However, further validation through increased case numbers and extended follow-up periods is necessary.

**Acknowledgements**
None.

**Author contributions**
TL and LW designed this study and wrote the draft; JL and XZT collected and analyzed the data and helped to write the manuscript. All authors read and approved the final manuscript.

**Funding**
This study was funded by the National Natural Science Foundation of China (No. 82072441), Central South University Research Programme of Advanced Interdisciplinary Studies (No. 2023QYJC026), and Hunan Provincial Natural Science Foundation of China (No. 2024JJ7346).

**Data availability**
All the data and materials are available in the manuscript. The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Ethics approval and consent to participate**
This retrospective study was approved by the Medical Ethics Committee of the Second Xiangya Hospital, Central South University. Meanwhile, all the patients signed written informed consents. This study was conducted in accordance with Declaration of Helsinki.

**Consent for publication**
The case information used in this study does not involve patients' private information, and all case information is obtained from the electronic medical record system and kept strictly confidential.

**Competing interests**
The authors declare no competing interests.

Received: 21 October 2024 / Accepted: 3 March 2025
Published online: 11 March 2025

**References**

1. Beird HC, Bielack SS, Flanagan AM, Gill J, Heymann D, Janeway KA, Livingston JA, Roberts RD, Strauss SJ, Gorlick R. Osteosarcoma. Nat Reviews Disease Primers. 2022;8(1):77.
2. Balamuth NJ, Womer RB. Ewing's sarcoma. Lancet Oncol. 2010;11(2):184–92.
3. Barbier D, De Billy B, Gicquel P, Bourelle S, Journeau P. Is the clavicula pro humero technique of value for reconstruction after resection of the proximal humerus in children?? Clin Orthop Relat Res. 2017;475(10):2550–61.
4. Grimer RJ. Surgical options for children with osteosarcoma. Lancet Oncol. 2005;6(2):85–92.
5. Teunis T, Nota SP, Hornicek FJ, Schwab JH, Lozano-Calderón SA. Outcome after reconstruction of the proximal humerus for tumor resection: a systematic review. Clin Orthop Relat Res. 2014;472(7):2245–53.
6. Nota S, Teunis T, Kortlever J, Ferrone M, Ready J, Gebhardt M, Raskin K, Hornicek F, Schwab J, Lozano Calderon S. Functional outcomes and complications after oncologic reconstruction of the proximal humerus. J Am Acad Orthop Surg. 2018;26(11):403–9.
7. Dubina A, Shiu B, Gilotra M, Hasan SA, Lerman D, Ng VY. What is the optimal reconstruction option after the resection of proximal humeral tumors?? A systematic review. Open Orthop J. 2017;11:203–11.
8. Abed R, Grimer R. Surgical modalities in the treatment of bone sarcoma in children. Cancer Treat Rev. 2010;36(4):342–7.
9. Lu Y, Xiao X, Li M, Chen G, Huang M, Ji C, Wang Z, Li J. Use of vascularized fibular epiphyseal transfer with massive bone allograft for proximal humeral reconstruction in children with bone sarcoma. Ann Surg Oncol. 2021;28(12):7834–41.
10. Pritchett JW. Growth plate activity in the upper extremity. Clin Orthop Relat Res. 1991;268:235–42.
11. Lewis VO. Limb salvage in the skeletally immature patient. Curr Oncol Rep. 2005;7(4):285–92.

12. Onoda S, Sakuraba M, Asano T, Miyamoto S, Beppu Y, Chuman H, Kawai A, Nakatani F, Kimata Y. Use of vascularized free fibular head grafts for upper limb oncologic reconstruction. Plast Reconstr Surg. 2011;127(3):1244–53.
13. 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.
14. Pederson WC, Person DW. Long bone reconstruction with vascularized bone grafts. Qld Gov Min J. 2007;38(1):23–35. v.
15. D'Arienzo A, Ipponi E, Ruinato AD, De Franco S, Colangeli S, Andreani L, Capanna R. Proximal Humerus Reconstruction after Tumor Resection: An Overview of Surgical Management. Advances in orthopedics. 2021:5559377.
16. Errani C, Aiba H, Atherley A, Palmas M, Kimura H, Donati DM, Manfrini M. What is the Revision-free survival of resurfaced Allograft-prosthesis composites for proximal humerus reconstruction in children with bone tumors? Clin Orthop Relat Res. 2024.
17. Calvert GT, Wright J, Agarwal J, Jones KB, Randall RL. Is claviculo pro humeri of value for limb salvage of pediatric proximal humerus sarcomas? Clin Orthop Relat Res. 2015;473(3):877–82.
18. Weiland AJ, Daniel RK, Riley LH Jr. Application of the free vascularized bone graft in the treatment of malignant or aggressive bone tumors. Johns Hopkins Med J. 1977;140(3):85–96.
19. Stevenson JD, Doxey R, Abudu A, Parry M, Evans S, Peart F, Jeys L. Vascularized fibular epiphyseal transfer for proximal humeral reconstruction in children with a primary sarcoma of bone. Bone Joint J. 2018;100–b(4):535–541.
20. Azoury SC, Shammas RL, Othman S, Sergesketter A, Brigman BE, Nguyen JC, Arkader A, Weber KL, Erdmann D, Levin LS, et al. Outcomes following free fibula physeal transfer for pediatric proximal humerus reconstruction: an international Multi-Institutional study. Plast Reconstr Surg. 2023;151(4):805–13.
21. Rose PS, Shin AY, Bishop AT, Moran SL, Sim FH. Vascularized free fibula transfer for oncologic reconstruction of the humerus. Clin Orthop Relat Res. 2005;438:80–4.
22. Wada T, Usui M, Isu K, Yamawakii S, Ishii S. Reconstruction and limb salvage after resection for malignant bone tumour of the proximal humerus. A sling procedure using a free vascularised fibular graft. J Bone Joint Surg Br. 1999;81(5):808–13.
23. Campanacci DA, Scanferla R, Innocenti M, Muratori F, Puccini S, Scoccianti G, Beltrami G, Capanna R, Innocenti M. Are vascularized fibula autografts a Long-lasting reconstruction after intercalary resection of the humerus for primary bone tumors?? Clin Orthop Relat Res. 2023;481(11):2185–97.
24. Bumbasirevic M, Stevanovic M, Bumbasirevic V, Lesic A, Atkinson HD. Free vascularised fibular grafts in orthopaedics. Int Orthop. 2014;38(6):1277–82.
25. Ou Q, Wu P, Zhou Z, Pan D, Tang JY. Complication of osteo reconstruction by utilizing free vascularized fibular bone graft. BMC Surg. 2020;20(1):216.
26. Allsopp BJ, Hunter-Smith DJ, Rozen WM. Vascularized versus nonvascularized bone grafts: what is the evidence?? Clin Orthop Relat Res. 2016;474(5):1319–27.

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