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Use of Three-Column Reconstruction and Free Vascularized Fibular Grafts for the Repair of Large Tibial Defects after Tumor Resection

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Background: This study aimed to evaluate the clinical outcomes of three-column reconstruction of the lower leg using a single-barrel contralateral vascularized fibular graft (VFG), medial locking plate, and the ipsilateral fibula for the repair of large tibial defects after tumor resection.

Methods: In this retrospective study, we reviewed 12 patients who underwent three-column reconstruction using a single-barrel contralateral VFG, medial locking plate, and the ipsilateral fibula between June 1996 and May 2020. These patients had large tibial bone defects following tumor resection. The mean age of the patients was 26.3 years (range, 11–63 years), and 7 of them were women. The mean follow-up period was 104.8 months (range, 26–284 months). The mean size of the tibial bone defect after tumor resection was 17.8 cm (range, 11–26.8 cm). The clinical and radiological outcomes were evaluated at the final follow-up.

Results: All patients survived beyond the final follow-up without recurrence of the primary bone tumor. The mean time from reconstruction to bony union at both host-graft junctions was 12.9 months (range, 4–36 months). The mean Musculoskeletal Tumor Society score was 82.3% (range, 60%–97%). All tibial defects were reconstructed with adequate bone healing. There were 4 cases of stress fracture and graft failure; these were resolved by using longer plates and more screws. All patients were ambulatory without assistance and showed no permanent complications.

Conclusions: Large tibial defects that occur after tumoral resection can be effectively reconstructed by three-column reconstruction using a medial locking plate, an inlay single-barrel VFG harvested from the contralateral side, and the intact ipsilateral fibula. This technique permits early weight-bearing before fibular hypertrophy and bony union.

Keywords: *Vascularized fibular bone graft, Tibial reconstruction, Tumor reconstruction, Three-column reconstruction*

Reconstruction methods using allografts, autografts, bone transport, and endoprostheses have been introduced to treat large tibial defects after tumor resection.[1] The application of a vascularized fibular graft (VFG) is one of the treatments of choice for reconstructing such defects.[2,3] Because allografts and non-vascularized autografts depend on creeping substitution, which is characterized by slow bony union, the use of VFGs is preferred for large bone defects.[2] VFGs allow for early incorporation and hypertrophy with a length of 26–28 cm and have high mechanical strength and fewer donor site complications compared to other vascularized grafts.[2] Additionally, the size and configuration of the fibula match well with the bones of the forearm, as well as with the medullary canals of the femur and tibia. Thus, VFGs are considered to be ideal

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for extremity reconstruction and are the most widely used vascularized bone grafts for reconstructing large bone defects.[4,5)]

Three-column theory has been used to explain the stability of fractures at various anatomical locations including the spine,[6)] distal humerus,[7)] and proximal tibia.[8)] We applied three-column reconstruction using a medial locking plate, an inlay single-barrel VFG harvested from the contralateral side, and the intact ipsilateral fibula (Fig. 1) for large tibial defects after tumoral resection. In this study, we evaluated the clinical and radiological outcomes of this strategy.

METHODS

This study obtained approval from the Institutional Review Board of Seoul National University Hospital (No. H-2105-160-1221). Informed consent was waived as this study was performed retrospectively.

Patients

This retrospective review included 12 patients (5 men and 7 women; mean age, 26.3 years; range, 11–63 years) diagnosed with primary tumors of the tibia (osteosarcoma, n = 3; osteofibrous dysplasia, n = 3; adamantinoma, n = 3; ossifying fibroma, n = 2; Ewing's sarcoma, n = 1) who underwent wide tumor resection, performed by orthopedic surgeons at the same hospital between June 1996 and May 2020 (Table 1). The authors defined large bone defects as a loss of tibial bone > 6 cm that could not be reconstructed with a simple bone graft and internal fixation.[2)] The mean size of the tibial bone defect after tumor resection was 17.8 cm (range, 11–26.8 cm) The large bone defects were reconstructed using a three-column technique with a medial locking plate, an inlay single-barrel VFG harvested from the contralateral side, and the intact ipsilateral fibula (Figs. 1 and 2). All patients were followed for > 2 years. The mean follow-up period (from the VFG procedure to the last follow-up visit) was 104.8 months (range, 26–284 months).

Surgical Procedure

The length of the tibial defect after tumor resection was measured preoperatively before harvesting the contralateral fibular graft. The harvested fibular graft was 5–6 cm longer than the tibial defect to enable insertion into both intramedullary ends of the defective tibia. As the ipsilateral fibula was used as the lateral buttress during three-column reconstruction, the VFG was harvested from the contralateral lower leg. The distal and proximal 4–6 cm of the fibula were maintained to preserve ankle and knee joint stability, respectively.[9,10)] All VFGs were harvested as pure bone grafts without osteocutaneous flaps, and primary skin closure was performed at the donor site. Postoperative donor site complications were minimized by careful handling of the nerve and muscle tissue around the fibular graft.

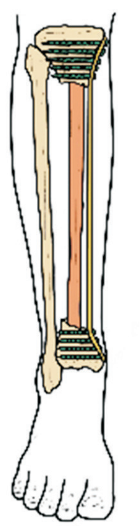

Fig. 1. Schematic illustration of three-column reconstruction of tibial bone defects using the intact ipsilateral fibula, an inlay contralateral vascularized fibular bone graft, and a medial locking plate as the lateral, middle, and medial columns, respectively.

Table 1. Characteristics of the Enrolled Patients

Case no.	Age (yr)/sex	Histology	Bone defect (cm)	Length of VFG (cm)
1	11/F	Osteofibrous dysplasia	12.0	17.8
2	41/F	Ewing sarcoma	16.1	23.8
3	60/M	Adamantinoma	17.8	21.5
4	21/M	Osteofibrous dysplasia	22.6	26.2
5	11/F	Ossifying fibroma	12.1	24.1
6	24/F	Adamantinoma	11.0	15.8
7	17/M	Osteosarcoma	20.3	22.7
8	63/M	Osteosarcoma	13.4	24.0
9	18/F	Adamantinoma	26.8	28.6
10	15/F	Osteosarcoma	18.7	25.6
11	24/M	Ossifying fibroma	23.2	27.4
12	11/F	Osteofibrous dysplasia	19.1	22.9

VFG: vascularized fibular graft.

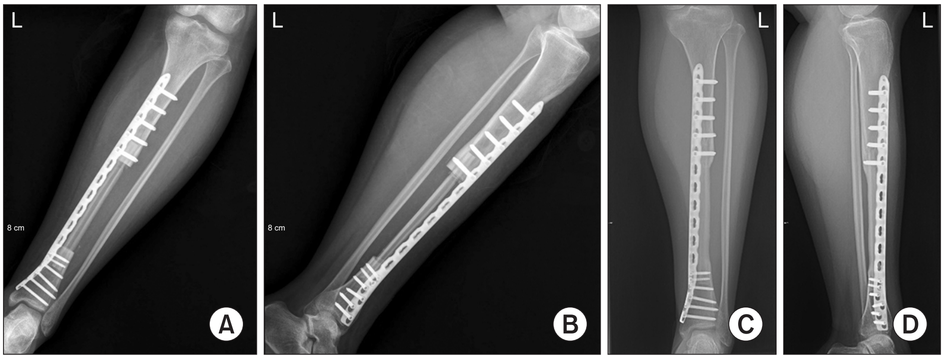

Fig. 2. A 26-year-old woman with an 11-cm-long left tibial defect after tumor resection; the tibial pathology was confirmed as adamantinoma. (A, B) Using a vascularized fibular bone graft, three-column reconstruction of the tibial bone defect was performed after tumor resection by an orthopedic surgeon. (C, D) Plain radiographs of the lower leg obtained 3 years after reconstructive surgery. Bony union was achieved and the patient could perform normal daily activities with full weight-bearing, without the need for walking aids.

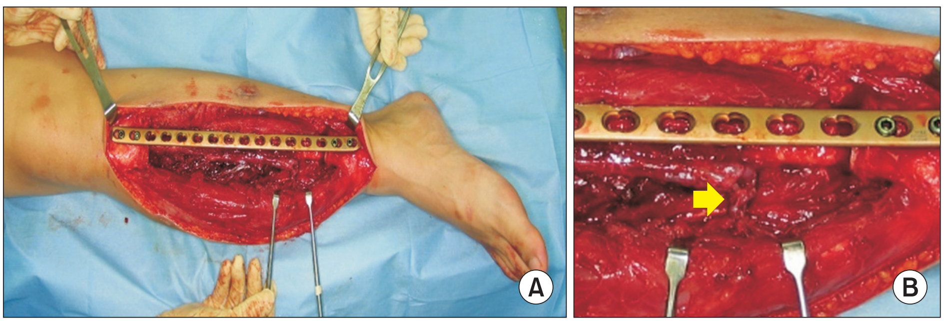

Fig. 3. (A) The contralateral vascularized fibular bone graft was inserted into the tibial defect as an inlay. (B) The medial locking plate was firmly fixed, and the graft vessels were anastomosed with the posterior tibial artery and adjacent vein (yellow arrow).

To ensure that the procedure was safe and secure, preoperative computed tomography angiograms were obtained for all patients. After aligning the tibia and fixing it with a medial locking plate (DePuy-Synthes, West Chester, PA, USA), the VFG was inserted into the medullary ends of the tibia. If the canal was tight, it was widened using a burr. A groove was cut at each end of the tibia to facilitate the insertion of the graft into the canal. The fibular graft was placed in the tibial defect in the form of an inlay bone graft and engaged in the medullary cavity of the tibia. A long locking plate was used to fix the column construct on the medial cortex of the tibia to protect the VFG (Fig. 3). Proximal and distal graft-host junctions were fixed with locking screws to improve the stability of the construct (Fig. 2A and B). During this process, the intact ipsilateral fibula was useful for maintaining alignment and stabilizing the construct.

The graft-feeding vessels were anastomosed with the recipient vessels using a microsurgical technique. The recipient vessels were either the posterior or anterior tibial vessels according to their availability. End-to-side arterial anastomoses were performed when utilizing the posterior tibial artery, and end-to-end arterial anastomoses were performed in cases where other recipient vessels were used (Fig. 3). In some cases, autologous iliac bone was packed around the graft-host junctions. The skin was closed after inserting a suction drain. The limb was immobilized with a long leg splint for 3–4 days. Partial weight-bearing ambulation with walking aids was permitted and full weight-bearing was subsequently allowed according to the patient's condition.

Outcome Evaluation

Graft healing and hypertrophy were assessed in plain radiographs at each follow-up visit. Bone scans were used to evaluate graft perfusion,[4] local recurrence, and bone metastasis in all cases. Clinical outcomes were assessed using the Musculoskeletal Tumor Society (MSTS) score, which evaluates pain, functional activity, emotional acceptance, the need for external support, walking ability, and gait.[11] Postoperative complications related to the procedure were also assessed.

Successful bony union was defined as the consolidation of at least three of the four cortices on each side of the proximal and distal graft-host bone junctions in anteroposterior and lateral plain radiographs (Fig. 2C and

D). If the bony union site was not visible in the lateral radiograph because of obstruction by the medial plate, an oblique radiograph was used to evaluate the consolidation of the medial cortex.

Immediately postoperatively and at the final follow-up, the mean anteroposterior and lateral diameters of the graft and recipient bone were determined in plain radiographs at the midpoint of the graft (F) and the point nearest to the proximal graft-host junction (R), respectively. Graft hypertrophy was determined using the formula of de Boer and Wood:[12)]

$$\text{Hypertrophy \%} = \frac{\frac{F2}{R2} - \frac{F1}{R1}}{\frac{F1}{R1}} \times 100$$

RESULTS

There were no cases of local recurrence or tumor metastasis during follow-up and all fibular grafts survived without avascular resorption. The surgical outcomes are summarized in Table 2. Graft hypertrophy occurred in all patients; the mean percentage of hypertrophy was 33.5% (range, 5%–74%) and the mean MSTS score was 82.3% (range, 60%–97%). The mean MSTS functional score was 82.3% (range, 60%–97%). Bony union at the proximal and distal graft-host bone junctions occurred in all patients after a mean of 12.9 months (range, 4–36 months). There were no serious donor site complications, and any donor site discomfort was resolved during follow-up. Eight patients complained of transient weakness of the foot evertors and greater toe flexor muscles during the early postoperative phase, but their strength was restored through weight-bearing exercise and physiotherapy. Six patients experienced paresthesia or hypoesthesia of the dorsum of the foot or calf during the early postoperative period, but these conditions resolved within 6 months in all cases. Regarding recipient site complications, 3 cases of stress frac-

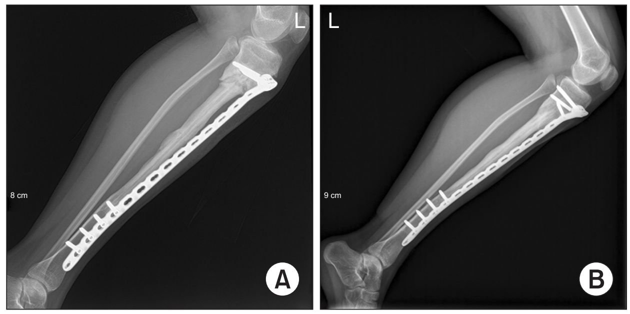

Fig. 4. (A) Metal failure and stress fracture of the vascularized fibular bone graft at 18 months after reconstructive surgery. The locking screws in the proximal tibia are broken and stress fracture can be seen in the proximal host-graft junction. The distal end of the construct is intact. The deformity seen in the ipsilateral fibular bone is due to the mass effect of the tibial bone tumor. (B) Bony union was achieved using additional locking screws with different trajectories. There were no other complications.

Table 2. Clinical and Radiologic Outcomes

Case no.	FU period (mo)	Bony union (mo)	Weight-bearing (mo)	MSTS score (%)	Graft hypertrophy (%)	Complications of recipient site
1	54	6	3	87	19	Stress fracture with plate breakage
2	140	4	6	60	29	None
3	26	6	5	77	32	None
4	222	36	36	97	41	Stress fracture with proximal screw breakage
5	59	8	2	90	68	None
6	30	5	1	90	27	None
7	59	5	2	83	43	None
8	284	32	7	60	5	Distal screw breakage
9	31	14	1	63	74	Skin irritation
10	58	8	5	97	5	None
11	242	11	5	93	23	None
12	53	20	20	90	36	Stress fracture with proximal screw breakage

FU: follow-up, MSTS: Musculoskeletal Tumor Society.

ture (cases 1, 4, and 12) occurred due to breakage of the metal plate or locking screw (Fig. 4). Because displacement was minimal in all cases, bony union could be achieved by replacing the metal plate with a longer plate or using more screws for fixation. One patient (case 9) had an uneventful course but complained of discomfort in the medial malleolar area due to irritation caused by the implanted locking plate. Because bony union was achieved at that time, the medial implant was removed 21 months postoperatively. However, a stress fracture occurred after implant removal, and 3 months of partial weight-bearing with walking aids and a long leg cast were prescribed. Bony union subsequently progressed and the patient started full weight-bearing ambulation 5 months after sustaining the stress fracture.

DISCUSSION

Large tibial bone defects were reconstructed using three-column reconstruction involving a medial locking plate, an inlay single-barrel VFG harvested from the contralateral side, and the intact ipsilateral fibula; satisfactory clinical and radiologic outcomes were obtained in all cases. Although favorable clinical outcomes after reconstruction of tibial defects with contralateral VFGs and locking plates have been reported,[5,13,14] our study is the first to conceptualize this as a three-column reconstruction (Fig. 1).

The application of ipsilateral VFGs, which is also known as the Huntington procedure, has yielded favorable clinical outcomes in cases of massive tibial defects.[15,16] However, this was not performed in the present study for the following reasons. First, the ipsilateral fibula provided some biomechanical advantage as a component of three-column reconstruction, enabling early weight-bearing (3–4 days after surgery). Second, an intact fibula can serve as a marker for accurate alignment of the affected tibia, thereby ensuring anatomical integrity of the ipsilateral knee and ankle joints. Third, there were no concerns about additional damage to the operated lower leg after tumor resection surgery.

Although a systematic review found no significant difference in clinical outcomes between cases in which ipsilateral and contralateral VFGs were used for tibial reconstruction, only 25.9% of the studies used the former type of VFG.[17] We believe that a lack of confidence in the biomechanical stability of ipsilateral VFGs accounts for their limited use, despite the benefits of reduced donor site morbidity and no requirement for microsurgical techniques. When using ipsilateral VFGs for tibial reconstruction, long-term immobilization and non-weight-bearing periods have typically been required;[18,19] leading to some experienced authors to prefer contralateral VFGs, which have certain biomechanical advantages and wider indications.[20,21]

Donor site morbidity is the primary concern when considering the use of a contralateral VFG.[17] A systematic review revealed that 10.7% of all complications were donor site-related, including hallux contracture, paresthesia, foot drop, ankle valgus deformity, and ankle instability.[17] However, the vast majority of these complications resolved without the need for additional surgical interventions, and patient complaints tended to resolve over time;[17,22] this is probably because these patients are usually prepared to make significant sacrifices to achieve complete tumoral resection and satisfactory reconstruction.[22] Therefore, most studies have reported limited donor site morbidity, as we found.[17]

A serious complication that can arise after fibular harvest is ankle valgus deformity and instability.[17,23] Previous studies have generally recommended preserving 6–8 cm of the fibula.[23] Pacelli et al.[24] reported biomechanical instability only when the residual fibular length was < 10% of the total length (equivalent to an average residual length of 3.9 cm). Numerous clinical studies have shown that leaving an adequate fibular length can prevent ankle valgus deformity and instability; our findings support this suggestion.[10,25]

Stress fractures are a well-known disadvantage of VFGs, as the fibular graft's cross-sectional area is significantly smaller than that of the tibia, making stress fractures more likely.[17,25] Beris et al.[26] identified crucial factors for preventing stress fractures, such as ensuring anatomical graft alignment during the initial procedure and maintaining protective weight-bearing until adequate hypertrophy is achieved. However, it takes a long time to attain sufficient fibular hypertrophy with considerable variation and increased patient discomfort.[27]

Although attempts have been made to reduce stress, mainly by enhancing mechanical stability by applying double-barrel VFGs or stable fixation using a locking plate, stress fracture remains a possibility.[5,13,23] Fortunately, despite the high prevalence of stress fractures when using VFGs, only 2.8% of patients ultimately required amputation.[17] In addition, stress fractures may play a key role in fibular hypertrophy.[27,28] Therefore, we believe that it is more important to prevent a stress fracture leading to catastrophic results even if it occurs. In our study, early ambulation was allowed with walking aids after three-column reconstruction, even before sufficient fibular hypertrophy had been achieved. Although 3 cases of stress fracture occurred, they were resolved through nonsurgical interventions or a relatively simple procedure, such as implant change. In cases with no ipsilateral fibula, simultaneous implant breakage and stress fractures can lead to more serious consequences (Fig. 4). We believe that retaining the ipsilateral fibula as an element of three-column reconstruction promotes early weight-bearing, prevents reliance on hypertrophy of the fibula for mechanical strength, and reduces the likelihood of a catastrophic result after a stress fracture.

The amount of hypertrophy after tibial reconstruction significantly varies when using VFGs. Based on simple radiographs, Toros et al.[27] classified fibular hypertrophy as follows: Type 1 is characterized by uniform but limited thickening of the fibula, with an average hypertrophy of 9.2% (range, 3.2%–19%). Although new bone formation is achieved, the average increase in fibular diameter does not exceed 20%. Patients in this group are usually supported by permanent fixation, for example using a locking plate. Type 2 is characterized by abundant bone production triggered by stress fractures; in these cases, support is usually provided by temporary external fixation. Type 2 cases can be further divided into two subgroups based on the degree of bone response. In type 2a, new bone formation primarily occurs at the fracture site and the average hypertrophy is 56.7% (range, 52%–64%). In type 2b, bone production is triggered by stress fracture and the average hypertrophy is 104.6% (range, 80%–154%). Finally, in type 3 cases, an enlarged fibula surrounded by peripheral new bone formation is seen, with an average hypertrophy of 170% (range, 77%–214%). In our study, the mean fibular hypertrophy was 33.5% (range, 5%–74%), which can be classified as type 1 or 2a. Although significant fibular hypertrophy may be seen in type 2b and 3 cases after multiple stress fractures, there were gradual malalignment in some cases after several stress fractures. We believe that the main reason for using VFGs for tibial reconstruction is not to achieve massive fibular hypertrophy but rather to enable early functional gait while also maintaining good lower extremity alignment and mechanical stability.

This study has some limitations, including its retrospective design and the small number of patients; this was due to the low incidence of tibial bone tumors. Second, because this was not a comparative study, it cannot be concluded that the method described herein is superior to methods based on ipsilateral VFGs, bone transport, or allograft reconstruction. Nevertheless, satisfactory clinical outcomes were obtained in all patients with early partial weight-bearing (3–4 days after surgery) despite the relatively limited fibular hypertrophy; we believe that the mechanical stability provided by the ipsilateral fibula and long locking plate largely explains the favorable outcomes.

Large tibial defects that occur after tumoral resection can be effectively reconstructed by three-column reconstruction using a medial locking plate, an inlay single-barrel VFG harvested from the contralateral side, and the intact ipsilateral fibula. This technique permits early weight-bearing before fibular hypertrophy and bony union.

CONFLICT OF INTEREST

Young Ho Lee is an editorial board member of the journal but was not involved in the peer reviewer selection, evaluation, or decision process of this article. No other potential conflict of interest relevant to this article was reported.

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REFERENCES

1. Malawer MM, Sugarbaker PH. Musculoskeletal cancer surgery: treatment of sarcomas and allied diseases. Berlin: Springer Science & Business Media; 2001.
2. Mauffrey C, Barlow BT, Smith W. Management of segmental bone defects. J Am Acad Orthop Surg. 2015;23(3):143-53.
3. Eward WC, Kontogeorgakos V, Levin LS, Brigman BE. Free vascularized fibular graft reconstruction of large skeletal defects after tumor resection. Clin Orthop Relat Res. 2010;468(2):590-8.
4. Bos KE. Bone scintigraphy of experimental composite bone grafts revascularized by microvascular anastomoses. Plast Reconstr Surg. 1979;64(3):353-60.
5. Sun Y, Zhang C, Jin D, Sheng J, Cheng X, Zeng B. Treatment

for large skeletal defects by free vascularized fibular graft combined with locking plate. Arch Orthop Trauma Surg. 2010;130(4):473-9.

6. Denis F. The three column spine and its significance in the classification of acute thoracolumbar spinal injuries. Spine (Phila Pa 1976). 1983;8(8):817-31.

7. Beazley JC, Baraza N, Jordan R, Modi CS. Distal humeral fractures-current concepts. Open Orthop J. 2017;11:1353-63.

8. Luo CF, Sun H, Zhang B, Zeng BF. Three-column fixation for complex tibial plateau fractures. J Orthop Trauma. 2010;24(11):683-92.

9. Bumbasirevic M, Stevanovic M, Bumbasirevic V, Lesic A, Atkinson HD. Free vascularised fibular grafts in orthopaedics. Int Orthop. 2014;38:1277-82.

10. Li P, Fang Q, Qi J, Luo R, Sun C. Risk factors for early and late donor-site morbidity after free fibula flap harvest. J Oral Maxillofac Surg. 2015;73(8):1637-40.

11. 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.

12. de Boer HH, Wood MB. Bone changes in the vascularised fibular graft. J Bone Joint Surg Br. 1989;71(3):374-8.

13. Jia WT, Zhang CQ, Sheng JG, et al. Free vascularized fibular grafting in combination with a locking plate for the reconstruction of a large tibial defect secondary to osteomyelitis in a child: a case report and literature review. J Pediatr Orthop B. 2010;19(1):66-70.

14. Gao YS, Ai ZS, Yu XW, et al. Free vascularised fibular grafting combined with a locking plate for massive bone defects in the lower limbs: a retrospective analysis of fibular hypertrophy in 18 cases. Injury. 2012;43(7):1090-5.

15. Yin P, Zhang L, Li T, et al. Ipsilateral fibula transport for the treatment of massive tibial bone defects. Injury. 2015;46(11):2273-7.

16. Manfrini M, Bindiganavile S, Say F, et al. Is there benefit to free over pedicled vascularized grafts in augmenting tibial intercalary allograft constructs? Clin Orthop Relat Res. 2017;475(5):1322-37.

17. Feltri P, Solaro L, Errani C, Schiavon G, Candrian C, Filardo G. Vascularized fibular grafts for the treatment of long bone defects: pros and cons: a systematic review and meta-analysis. Arch Orthop Trauma Surg. 2023;143(1):29-48.

18. Puri A, Subin BS, Agarwal MG. Fibular centralisation for the reconstruction of defects of the tibial diaphysis and distal metaphysis after excision of bone tumours. J Bone Joint Surg Br. 2009;91(2):234-9.

19. Khira YM, Badawy HA. Pedicled vascularized fibular graft with Ilizarov external fixator for reconstructing a large bone defect of the tibia after tumor resection. J Orthop Traumatol. 2013;14(2):91-100.

20. Wood MB. Free vascularized fibular grafting-25 years' experience: tips, techniques, and pearls. Orthop Clin North Am. 2007;38(1):1-12.

21. Pederson WC, Person DW. Long bone reconstruction with vascularized bone grafts. Orthop Clin North Am. 2007;38(1):23-35.

22. Farhadi J, Valderrabano V, Kunz C, Kern R, Hinterman B, Pierer G. Free fibula donor-site morbidity: clinical and biomechanical analysis. Ann Plast Surg. 2007;58(4):405-10.

23. 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.

24. Pacelli LL, Gillard J, McLoughlin SW, Buehler MJ. A biomechanical analysis of donor-site ankle instability following free fibular graft harvest. J Bone Joint Surg Am. 2003;85(4):597-603.

25. Arai K, Toh S, Tsubo K, Nishikawa S, Narita S, Miura H. Complications of vascularized fibula graft for reconstruction of long bones. Plast Reconstr Surg. 2002;109(7):2301-6.

26. Beris AE, Lykissas MG, Korompilias AV, et al. Vascularized fibula transfer for lower limb reconstruction. Microsurgery. 2011;31(3):205-11.

27. Toros T, Kayalar M, Ozaksar K, Sugun TS, Gurbuz Y. Classification of vascularized fibular flap hypertrophy based on X-ray evaluation. Acta Orthop Traumatol Turc. 2021;55(6):541-6.

28. Qi Y, Sun HT, Fan YG, Li FM, Lin ZS. Do stress fractures induce hypertrophy of the grafted fibula?: a report of three cases received free vascularized fibular graft treatment for tibial defects. Chin J Traumatol. 2016;19(3):179-81.