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Long-term outcome of free fibula osteocutaneous flap and massive allograft in the reconstruction of long bone defect☆

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Summary Reconstruction of massive bone defects in bone tumors with allografts has been shown to have significant complications including infection, delayed or nonunion of allograft, and allograft fracture. Resection compounded with soft tissue defects requires skin coverage. A composite osteocutaneous free fibula offers an optimal solution where the allografts can be augmented mechanically and achieve biological incorporation. Following resection, the cutaneous component of the free osteocutaneous fibula flaps covers the massive soft tissue defect.

In this retrospective study, the long-term outcome of 12 patients, who underwent single-stage limb reconstruction with massive allograft and free fibula osteocutaneous flaps instead of free fibula osteal flaps only, was evaluated. This study included 12 consecutive patients who had primary bone tumors and had follow-up for a minimum of 24 months.

The mean age at the time of surgery was 19.8 years. A total of eight patients had primary malignant bone tumors (five osteosarcomas, two chondrosarcomas and one synovial sarcoma), and four patients had benign bone tumors (two giant-cell tumors, one aneurysmal bone cyst, and one neurofibromatosis). The mean follow-up for the 12 patients was 63 months (range 24–124 months). Out of the 10 patients, nine underwent lower-limb reconstruction and ambulated with partial weight bearing and full weight bearing at an average of 4.2 months and 8.2 months, respectively.

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In conclusion, augmentation of a massive allograft with free fibula osteocutaneous flap is an excellent alternative for reducing the long-term complication of massive allograft and concurrently addresses the soft tissue coverage.

Introduction

Limb-sparing surgery for patients with primary malignant sarcomas of the extremities has been well established. Osseous defects created by limb-salvage surgical procedures may be reconstructed by a variety of methods including segmental autograft, intercalary endoprosthesis, allografts, or a combination allograft and fibula composite. Various series have documented that reconstructions with allograft are associated with significant rate of complications.[1–5] Isolated free vascularized fibula flaps offer well-integrated tissue and vascularity for reconstruction, but they demonstrate early mechanical weakness in lower-limb reconstruction and the risk of early fracture.

In this study, all cases were reconstructed with a combination of allografts and free fibula osteocutaneous flaps. Previous related studies[6–9] emphasized limb reconstruction with massive allografts and free vascularized fibulas without cutaneous components. The combination reconstruction in our patients offered immediate early mechanical stability. In the long term, vascularized fibular grafts incorporated entire allografts and became complete biological vascularized units. Cutaneous components are beneficial for soft tissue reconstruction and facilitating postoperative monitoring. The cutaneous component also minimizes wound breakdown and reduces infection rate with the allograft.

Methodology

Between 1999 and 2012, 16 consecutive patients underwent either upper- or lower-limb reconstruction post tumor resection with massive allograft and free fibula osteocutaneous flap. This study included patients who were operated for primary bone tumors and followed up for a minimum of 24 months. Four cases were excluded: two of the patients needed early amputation within 12 months secondary to recurrence and histologically malignant change of tumor (final histology were telangiectatic osteosarcoma from aneurysmal bone cysts on biopsy) and two other patients underwent surgeries for secondary bone tumors (metastatic bone disease). The medical records for the remaining 12 patients were reviewed retrospectively with the ethical approval of the Human Research Ethic Committee (USM/JEPeM/15070252) for demographic information, diagnosis, operative technique, imaging study, and postoperative functional status.

According to tumor resection principles, a wide en bloc tumor resection was performed in all cases. All free vascularized fibula flaps were harvested along with skin paddles as osteocutaneous flaps from the contralateral lower limb. To reconstruct the resected bone segment, the free vascularized fibula was inserted in the intramedullary position of the massive allograft-grooved medullary cavity (Figure 3a–d) or open-sandwiched alongside the allograft (Figure 4a–c) and stabilized with plate and screws. The cortical allografts were maintained at three-fourths of the diameter for the comfortable placement of the vascularized fibulas. Distal cancellous allografts were maintained to provide better union and stability. The entire reconstruction was stabilized with a long neutralizing plate in nine patients and an external fixator in three patients. Based on the availability of the recipient vessels and suitability of the vessel, recipient and donor vessels were anastomosed end to end, end to side, or in a flow-through configuration.

The skin paddle was monitored postoperatively to ensure the viability of all free fibula flaps. All the patients

Figure 1 (a) Computerized tomography angiogram (CTA) showed flowthrough configuration vessel in a flow- through flap. (b) Full weight wearing postoperative 6 months. (c-d) Five-year follow-up, x-ray and (CT) scan showed hypertrophy and incorporation of the allograft with the fibula.

Figure 2 Eleven months post left femur reconstruction with good functional outcome — MSTS 27. (a) In standing position and weight wearing on left reconstructed limb. (b-c) Knee in flexion and extension without limitation.

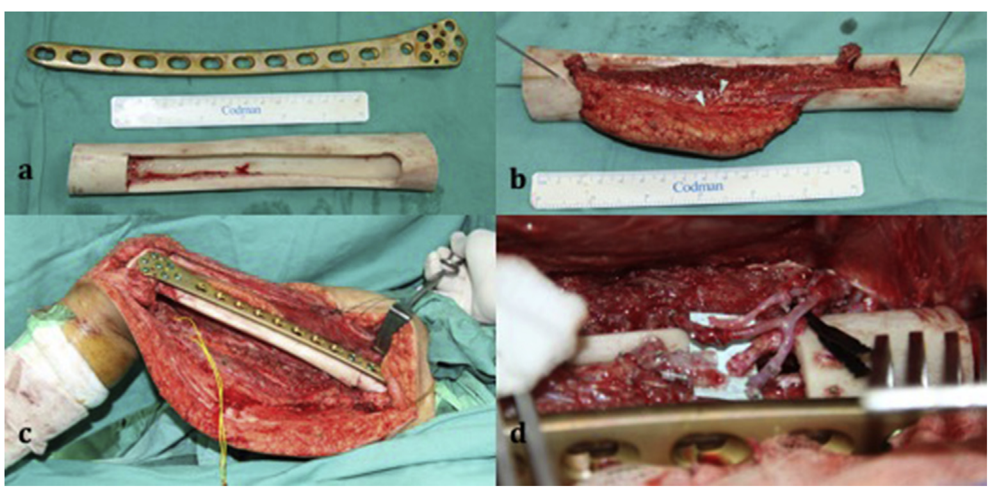

Figure 3 Intramedullary technique. (a) One quarter diameter of the massive allograft discarded with maintaining its continuity. (b) Free fibula osteocutaneous flap was inserted into medullary cavity of massive allograft and stabilization done with two k-wire to avoid compression of the skin paddle perforators (green arrow). (c) Combination of massive allograft and free fibula osteocutaneous flap was inserted to the femur defect and fixation done with long neutralizing plate. (d) Immediate after fixation, the pedicle vessels and recipient vessels were prepared and ready for anastomosis.

were subjected to laser Doppler fluximetry and handheld Doppler monitoring for 72 h. Patients were subsequently followed up for a minimum of 24 months or until death. Postoperative skin paddle viability, early and late complications, and oncological results were evaluated.

After complete wound healing, a thermoplastic splint was placed on the lower limb of the patient with plate stabilization. The external fixator group received a cast made of plaster of Paris once the surgical wounds had healed. To assess the union, radiographic evaluation was performed every 6 weeks for up to 1 year. Partial weight bearing was allowed once union between the host bone and free vascularized fibula at both ends was observed radiographically. Until union was observed, all reconstructed limbs were protected by the thermoplastic splint. Full weight bearing was allowed once radiographic evidence of union of allograft and vascularized fibula had been achieved. At the final follow-up, the functional outcome of patients who underwent lower-limb reconstruction will be assessed according to the Musculoskeletal Tumor Scoring system (MSTS).

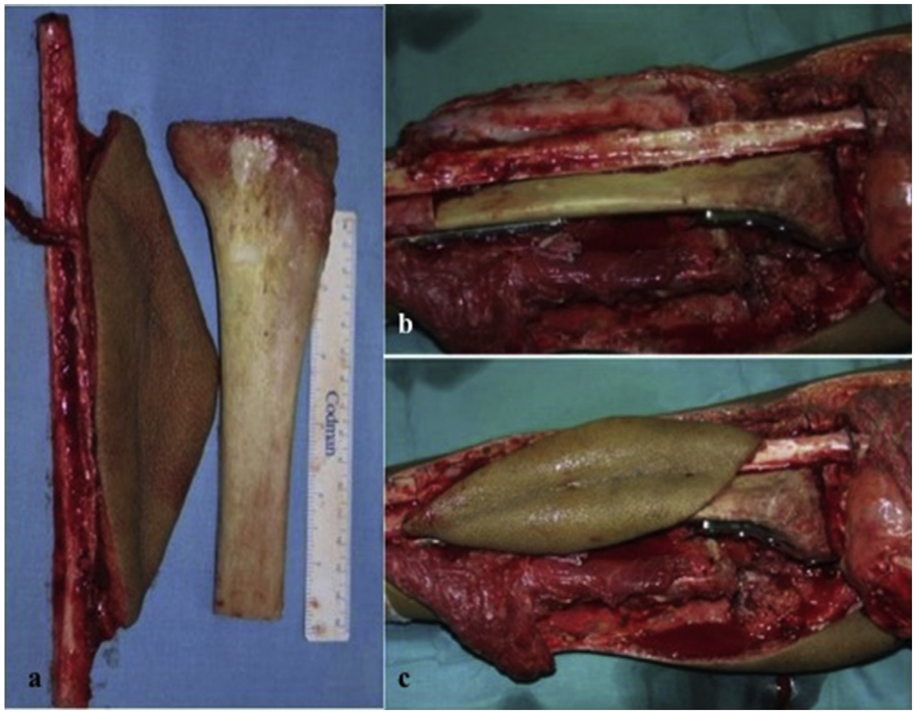

Figure 4 Open sandwich technique. (a) Free fibula osteocutaneous flap and massive allograft were prepared. (b-c) Massive allograft was bridged across the bone defect with plate. Free fibula osteocutaneous flap with its skin paddle was fixed to the side of allograft.

Result

The mean age of the 12 patients at the time of surgery was 19.8 years (range 5–44 years). There were eight male and four female patients. The mean follow-up was 63 months (range 24–124 months). The pathology and its location for 12 cases are shown in Table 1. Six tumors involved the distal one-third of the tibia, followed by three in the femur, two in the humerus, and one in the diaphysis of tibia.

The mean bone defect post tumor resection was 15.5 cm in length, and the mean skin defect was 100.9 cm^2. The mean length of free vascularized fibula bone and allograft were 23 cm and 15.8 cm, respectively. The average size of the skin paddle was 88.8 cm^2 (range 28–140 cm^2). The operative modalities are summarized in Table 2.

Of the 12 patients, three underwent emergency flap exploration due to underlying venous thrombosis, based on skin paddle parameters in terms of reduced venous Doppler signal and congestion of skin paddles. All free fibula osteocutaneous flaps were salvaged, and the skin paddles were viable thereafter. One patient, who underwent humerus reconstruction with free fibula osteocutaneous flap

Table 1 Preoperative data for 12 patients.

Patient	Age (years)	Gender	Pathology	Location	Chemotherapy		Radiotherapy (Postop)
					Neoadjuvant	adjuvant	
1	18	M	OS	Distal 2/3 of Humerus	Yes	Yes	No
2	44	F	CS	Upper 2/3 Humerus	No	No	No
3	8	M	OS	Distal femur	Yes	Yes	No
4	27	F	OS	Distal 1/3 tibia	Yes	Yes	No
5	13	M	SS	Diaphysis of Tibia	Yes	Yes	Yes
6	25	M	CS	Mid shaft Femur	No	No	No
7	21	M	GCT	Distal end of tibia	No	No	No
8	13	F	ABC	Femur	No	No	No
9	5	M	NF with pseudoarthrosis	Distal end Tibia	No	No	No
10	30	M	GCT	Distal 1/3 tibia	No	No	No
11	14	F	OS	Distal end of tibia	Yes	Yes	No
12	19	M	OS	Tibia	No	Yes	No

M: Male; F: Female; OS: Osteosarcoma; CS: Chondrosarcoma; ES: Ewing sarcoma; GCT: Giant-cell tumour; SS: Synovial sarcoma; ABC: Aneurysm bone cyst; NF: Neurofibroma.

Table 2 Operative modalities.

Patient	Length (cm)			Skin defect (cm^2)	Skin paddle (cm^2)	Perforator at skin paddle	Reconstruction technique	Method of fixation	Anastomosis	
	Defect	FVF	Allograft						Arterial	Venous
1	12.5	25	14	175	138	1	Open sandwich	Cable plate	Brachial (E—S)	Basilic (E—S) VC(E—E)
2	23	23	24	280	28	3	Open sandwich with shoulder fusion	Plate and screw	anterior Circumflex humeral (E—E)	Brachial A. VC (E—E)
3	20	29	25	54	56	1	Open sandwich with knee fusion	Screw and DCP plate	Femoral (E—S)	Femoral VC (E—E)
4	12	20.5	12.5	68	140	2	Intramedullary approach with ankle fusion	Screw and plate	Anterior tibial (FL)	Anterior Tibial VC (E—E)
5	14	20	9	70	133	2	Intramedullary approach	Screw and sherman plate	Peroneal (E—E)	Peroneal VC (E—E)
6	22	26.5	22	58	52	2	Intramedullary approach with joint preservation	Locking compression plate	Profunda Femoral (E—S with AG)	Profunda femoral VC (E—E)
7	12	25	12	80	90	1	Intramedullary approach	Screw	Anterior tibial (E—E)	Anterior tibial VC (E—E)
8	12	22	13	84	64	1	Intramedullary approach	Plate and screw	Profunda Femoris (E—E)	Saphenous V (E—E)
9	10	13.5	10.5	25	39	3	Intramedullary approach	Plate and screw	Anterior tibial (E—E)	Anterior tibial VC (E—E) Long saphenous V (E—E)
10	14	24	14	138	140	3	Intramedullary approach with ankle fusion	7-hole plate and cancellous screw	Anterior tibial (FL)	Anterior tibial VC (FL)
11	18	24	17.5	49	90	1	Intramedullary approach with ankle fusion	Screw EF	Anterior tibial (E—E)	LSV (E—E)
12	16	24	16	130	96	2	Intramedullary approach with ankle fusion	Screw and external fixator	Peroneal (E—E)	Peroneal VC (E—E) LSV (E—E)
Mean	15.5	23	15.8	100.9	88.8					

FVF: Free vascularized fibula; E—S: End to side; E—E: End to end; FT: Flow through; VC: Venae commitantes; AG: Arterial graft.

with concomitant pedicle latissimus dorsi flap, sustained wound breakdown due to skin flap necrosis at the tip of the latissimus dorsi flap. After debridement, secondary wound closure was performed with a local rhomboid flap.

Of the 12 patients, 11 achieved primary solid bony union upon follow-up. For lower-limb reconstruction, partial weight bearing (with thermoplastic splint) was achieved at an average of 4.2 months (range 3.5—7 months). Full weight bearing without splint was achieved at 7.2 months (range 6—12 months) postoperatively (Table 3).

For long-term follow-up, one patient was treated for infected allograft with resection of allograft and spacer replacement 6 months postoperatively. This patient's thigh tumor recurred after 18 months. At 12 months post surgery, two of the 12 patients sustained fractures at the host—allograft junction. One of the patients had undergone postoperative radiotherapy; therefore, fracture replating was needed to achieve union. Another patient who had congenital pseudoarthrosis sustained a fracture at the distal host—allograft junction and implant failure. Implant removal, Rush rod insertion, and bone autograft were performed to achieve union. To improve the gait of one pediatric patient noted to have lower-limb discrepancy by approximately 3 cm, epiphysiodesis of the contralateral limb was performed.

Based on oncologic evaluation, five patients received neoadjuvant chemotherapy before surgical intervention and three courses of adjuvant therapy. Postoperative radiotherapy was considered necessary for only one patient. A hip disarticulation was performed on a patient with tumor recurrence 18 months after the secondary operation for infected allograft. The pathological diagnosis changed from an aneurysmal bone cyst to telangiectatic osteosarcoma in this case.

Functional outcomes were evaluated using the MSTS scoring system at the final follow-up averaging 52 months (range 24—122 months). The mean score for nine patients who had undergone lower-limb reconstruction after exclusion of patients with tumor recurrence was 24 (range 18—27). Two patients who underwent humeral reconstruction reported to have good hand function. Two case reports are presented in this series.

Case 1

A 24-year-old man presented with left ankle pain for 9 months and subsequently noted to have a bony swelling that was progressively increasing in size. He had to use crutches due to intolerable pain. X-ray revealed lytic lesion at the distal end of the left tibia. Incision biopsy established the diagnosis of giant-cell tumor of the left distal tibia. Wide resection and left tibial reconstruction with free vascularized fibula flap and allograft were performed. Intraoperatively, the bone defect was 14 cm after the resection, and the harvested free vascularized fibula was 24 cm in length. Reconstruction was performed using the intramedullary technique with the fibula placed inside the medullary cavity of the massive allograft. Distal circulation was established with flow-through anastomosis between

Table 3 Clinical outcome of 12 patients.

Patient	PWB (Month(s))	FWB (Month(s))	Complication (month)	Management	Follow-up (months)	Long-term outcome
1			No	No	124	Good upper limb function-limited shoulder function
2			Superficial wound dehiscence	wound closure with local Rhomberg's flap	122	Good upper limb function with shoulder fusion
3	4	7 (crutches)	Limb-length discrepancy 3 cm (12)	Epiphysiodesis of contralateral distal femur and proximal tibia	24	MSTS 18
4	4	7	No	No	29	MSTS 26
5	3.5	8	Fracture prox junction allograft and hostl prox 1/3 of tibia (12)	Locking plate and BG -achieve union	46	MSTS 20
6	4	7	No	No	24	MSTS 27
7	3	7	No	No	25	MSTS25
8		Amp	Infected allograft (6) Recurrence with malignant change - osteosarcoma (24)	Removal of implant, allograft resection, spacer replacement and Hip disarticulation	24	—
9	7	21	Implant failure and fracture at host -allograft (distal segment) (12)	Implant removal, rush rod and bone graft	122	MSTS 26
10	4	6	No	No	108	MSTS 25
11	6	11	No	No	24	MSTS 25
12	3	7	No	No	84	MSTS27
Mean	4.2	8.2			63	MSTS 24

PWB: Partial weight bearing; FWB: Full weight bearing; MSTS: Musculoskeletal tumour scoring.

peroneal vessels of the free fibula flap and the anterior tibial vessel (Figure 1a). The patient achieved partial weight bearing and full weight bearing at 4 months and 6 months, respectively, without complication (Figure 1b). Computer tomography and X-ray revealed hypertrophy and incorporation of the fibula with the allograft (Figure 1c–d) 5 years after surgery.

Case 2

A 25-year-old man was referred to our center for further management of recurrent left thigh swelling for 3 years with no functional impairment. He was diagnosed with chondroma of the left femur with a history of two excisions done prior to the current presentation. Magnetic resonance imaging (MRI) revealed malignant transformation of the lesion, which suggested chondrosarcoma. Wide resection and reconstruction of the femur was performed with free vascularized fibula and allograft. The bone defect was 22 cm long, involving the diaphysis of the femur. The intramedullary technique was applied. Fixation of the free vascularized fibula and allograft was accomplished with locking compression plate and screw. The patient recovered well postoperatively. He was allowed partial weight bearing at 4 months and full weight bearing at 7 months (Figure 2a–c). After 1 year, the patient presented with good functional status with normal gait and was satisfied with the aesthetic outcome. Due to logistic problems, he was subsequently followed up at another tertiary center.

Discussion

In this study, we reviewed 12 consecutive patients who underwent reconstruction of the upper or lower extremity with a combination of a massive allograft and a free fibula osteocutaneous flap. Capanna R et al.[10] first introduced combined graft reconstruction mainly with a free fibula osteal flap. In comparison with the published studies by Capanna R et al.,[6] Chang et al.,[7] Moran SL et al.,[8] and Inocenti et al.,[9] this study not only emphasized the good long-term outcome of combination graft reconstruction but also highlighted the advantages of using the cutaneous component of the free fibula osteocutaneous flap.

The use of a cutaneous component of free fibula osteocutaneous flap posed its challenges and advantages. Before harvesting the flap, the skin paddle had to be designed precisely as it affects the inset of skin paddle into the defect site. Harvesting the free fibula osteocutaneous flap includes the skin perforators. Careful placement and fixation of the fibula into the massive allograft was essential for preventing compression of the perforators. The skin paddle provided the soft tissue component at the initial reconstruction, which allowed good oncological margin of the soft tissue resection to include the biopsy site and area with suspicious tumor invasion. In addition, skin paddles allowed closure of the skin defect without tension and compression to reduce the risk of compromising microvascular anastomosis, especially as the resection site such as the distal tibia had limited soft tissue coverage. Postoperatively, skin paddle parameters have shown to be a reliable means for monitoring the vascularized fibula viability and allow early detection of a failing flap. As in our series, three free vascularized fibula flaps were fully salvaged with early detection and intervention of underlying vascular failure.

Biological limb reconstruction post tumor ablation is a preferred method, especially in younger patients to achieve a long-term favorable outcome. Reconstruction with a combination of allograft and a free vascularized fibula improved the outcome in comparison to the reconstruction with isolated allograft or free vascularized fibula graft. Free vascularized fibula flap is a well-recognized source of vascularized bone with high cortical density and predictable anatomy. Reconstruction with isolated free vascularized fibula graft offers high union rate (82–90%),[11,12] and has the ability to achieve hypertrophy (80% at 2 years).[13] However, it may provide insufficient length, stability, and initial strength, which might lead to a high rate of fatigue fracture. The availability of massive allograft facilitated the limb reconstruction, especially in cases with extensive defects. It not only offers immediate structural support but also is reported to have high complication rates including infection (5–30%),[1–4] nonunion (22–57%),[2–4] and allograft fracture (7–19%).[2–5] Therefore, a combination of allograft and a free vascularized fibula is an ideal biological reconstruction because it combines the advantages of a strong bone stock of allograft and the biological potentials of a free vascularized fibula flap. This technique was introduced in the late 1980s[14] and reported to have good long-term results with excellent functional status.[6–8] The use of allograft improved the initial stability and allowed patients to have early functional recovery without increased risk of stress fractures during the first postoperative year. A free vascularized fibula enhanced the union of host–allograft junction and decreased the time of bony union.[7]

Limb reconstruction with a combination of graft allowed surgeons to have different configurations of the reconstruction depending on the site of defect, site of recipient vessels, orientation of the pedicle vessels, length of harvested fibula, and massive allograft in relation with the defect. Free vascularized fibula could be segmentally osteotomized and slotted into the medullary cavity of the allograft or by using the open-sandwich approach. Initial design of skin paddle and choice of combine graft reconstruction configuration are essential to avoid tension and compression to perforators of skin paddle and anastomotic vessels. The cutaneous component of the free fibula osteocutaneous flap played a significant role in the refinement of the limb reconstruction. Another advantage was flow-through reconstruction of vessels to ensure the limb perfusion post tumour resection as in some of the cases. To the best of our knowledge, this is the first consecutive series with all cases using a cutaneous component with a vascularized fibula flap and massive allograft.

Conclusion

The use of allograft and free fibula osteocutaneous flap in limb reconstruction post tumor resection offers a good long-term functional outcome and has a low complication rate. The cutaneous component further enhances the clinical benefits of this procedure. Limb salvage and reconstruction surgery for bone tumors help to preserve functions without compromising the overall disease survival.

Ethical approval

Human Research Ethic Committee (USM /JEPem/ 15070252).

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Conflict of interest

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