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Are Vascularized Fibula Autografts a Long-lasting Reconstruction After Intercalary Resection of the Humerus for Primary Bone Tumors?

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Abstract

Background A vascularized fibula graft (VFG) is the vascular autograft most frequently used to restore large segmental long bone defects, particularly in the upper limb. Because the use of a vascularized fibula involves an operation in an uninvolved extremity with potential morbidity, it is important to document that this type of reconstruction is successful in restoring function to the humerus. However, the long-term results of VFG after intercalary resection of the humeral diaphysis for bone tumors are still unknown.

Questions/purposes (1) What was the complication rate of reconstruction? (2) What was the functional result after surgical treatment, as assessed by the Musculoskeletal Tumor Society (MSTS) score, the American Shoulder and Elbow Society (ASES) score, and Constant score? (3) What was the survivorship of these grafts free from revision and graft removal at 5, 10, and 15 years?

Methods Between 1987 and 2021, 127 patients were treated at our institution with en bloc resection for a primary malignant or an aggressive benign bone tumor of the humerus; we excluded patients treated with extra-articular resection or amputation. Of those, 14% (18 of 127) were treated with intercalary resection of the humeral diaphysis for primary bone tumors and reconstruction with VFG, with or without a bulk allograft, and were analyzed in this retrospective study. Generally, our indications for reconstruction with VFG are intercalary resection of the humerus for primary malignant or aggressive benign bone tumors in patients with long life expectancy and high functional demands, in whom adequate bone stock of the proximal and distal epiphysis can be preserved. In 13 patients, VFG was used alone, whereas in five patients, a massive allograft was used. Our policy was to use VFG combined with a massive allograft in patients undergoing juxta-articular joint-sparing resections in which proximal osteotomy was performed close to the anatomic neck of the humerus to obtain more stable fixation and better

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tendinous reattachment of the rotator cuff and deltoid. All 18 patients who were treated with a VFG were available for follow-up at a minimum of 2 years (median follow-up 176 months, range 26 to 275 months), and although three have not been seen in the past 5 years and are not known to have died, they had 172, 163, and 236 months of follow-up, and were included. The median age at surgery was 25 years (range 2 to 63 years), the median humeral resection length was 15 cm (range 8 to 21 cm), and the median fibular length was 16 cm (range 12 to 23 cm). Complications and functional scores were ascertained by chart review that was performed by an individual not involved in patient care. Functional results were assessed with the MSTS score (range 0 to 30), the ASES score (range 0 to 100), and the Constant score (range 0% to 100%). Survivorship was estimated using a Kaplan-Meier survivorship estimator, which was suitable because there were few deaths in this series.

Results Seven patients underwent a revision procedure (one radial nerve transient palsy because of screw impingement, four nonunions in three patients with one humeral head avascular necrosis, treatment for screw-related pain in one patient, and two VFG fractures), and one patient underwent VFG removal. Donor site complications were observed in four patients (one ankle valgus deformity and three claw toes—the first toe in two patients and the other toes in the third). At the final clinical control, at a median follow-up of 176 months (range 26 to 275 months), the median MSTS score was 30 of 30 (range 28 to 30), the median ASES score was 98.3 (range 93 to 100), and the median Constant score was 93.5% (range 79% to 100%). Revision-free survival was 71% (95% CI 53% to 96%) at 5 years and 57% (95% CI 37% to 88%) at 10 and 15 years; VFG removal-free survival was 94% (95% CI 83% to 100%) at 5, 10, and 15 years.

Conclusion VFG appears to be an effective reconstructive option after humeral intercalary resection for primary bone tumors. These are complex procedures and should be performed by an experienced team of surgeons who recognize that complications may occur frequently in the first years after the procedure. The frequency of mechanical complications observed in the first 5 years postoperatively may be lessened by using long spanning-plate fixation, and if successful, this reconstruction provides a long-term, durable reconstruction with excellent functional results.

Level of Evidence Level IV, therapeutic study.

Introduction

Humerus reconstruction after bone tumor resection is a challenge for articular and diaphyseal defects. Patients with primary bone tumors are often young with high functional demands; advances in adjuvant treatments have substantially improved their survival. Therefore, long-term, durable reconstruction is preferable for these patients. Most humeral sarcomas occur in the metaepiphyseal area and are treated with articular resection and reconstruction. However, with accurate imaging-based planning and the use of intraoperative guides, joint-sparing intercalary resections can be performed with wide surgical margins, making it possible to preserve the native joints. Several reconstructive options to reconstruct large intercalary defects of the humerus have been reported, such as intercalary prostheses [1, 3, 10, 24, 28, 36], massive allografts [4, 16, 23], bone transport [19], osteoinductive membrane techniques [13], recycled autografts [7, 33, 35], vascularized autografts [2, 8, 15, 18, 27], and a combination of massive allografts and vascularized autografts [20, 21]. Most of these reconstructive options have drawbacks and complications in patients treated for bone sarcoma, considering long-term outcomes.

Intercalary vascularized autografts provide early osteotomy union and healing after fracture, maintaining the ability to hypertrophy under mechanical stress, even in critical soft tissue conditions [6]. Among free vascularized bone transfer, the fibula is the most used in humeral reconstruction. Vascularized fibula graft (VFG) transfer to the humerus is an established reconstructive method for posttraumatic bone loss [2] and nonunion, as well as for large bony defects after tumor resections [8, 15, 26]. After intercalary resection for humeral malignancy, VFG can be used alone or in combination with massive allografts or allogenic cortical struts, as reported in some studies [8, 15, 18, 20, 21, 27].

We therefore asked: (1) What was the complication rate of reconstruction? (2) What was the functional result after surgical treatment, as assessed by the Musculoskeletal Tumor Society (MSTS) score, the American Shoulder and Elbow Society (ASES) score, and Constant score? (3) What was the survivorship of these grafts free from revision and graft removal at 5, 10, and 15 years?

Patients and Methods

Study Design and Setting

This was a retrospective study performed over a 25-year period at a university hospital by experienced orthopaedic oncology and plastic surgery teams.

Patients

Between 1987 and 2021, 127 patients were treated at our institution with en bloc resection for a primary malignant or aggressive benign bone tumor of the humerus; we excluded patients treated with extraarticular resection or amputation. Of those, 68% (86 of 127) had proximal humeral tumors that were treated with intra-articular resection and

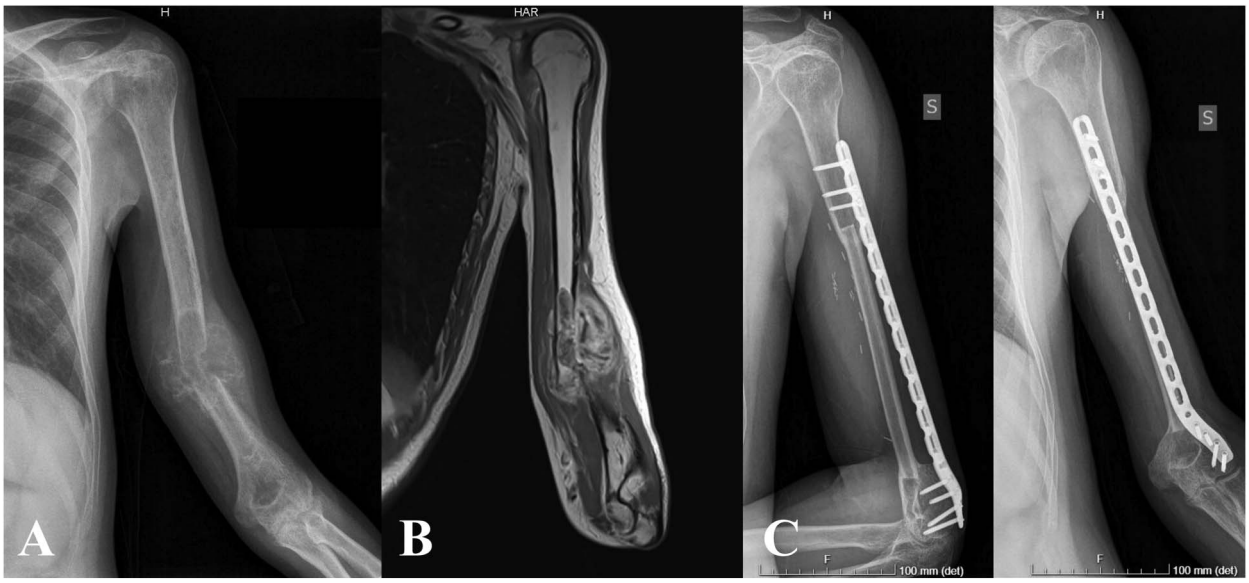

Fig. 1 (**A**) This is a radiograph of a 29-year-old man with a pathologic fracture of the humeral diaphysis because of high-grade osteosarcoma that healed after preoperative chemotherapy. (**B**) This coronal T1-weighted MR image with contrast shows an aggressive bony lesion with an extraosseous mass, without involvement of the proximal and distal part of the humerus. (**C**) This radiograph taken 37 months after intercalary resection and reconstruction with a VFG and a bridging plate shows union of the fibula with slight hypertrophy owing to stress shielding induced by the bridging plate. The plate is fixed on the lateral column of the distal humerus, taking advantage of the scarce residual bone stock.

reconstruction with a growing autologous VFG, osteoarticular allograft, allograft-prosthesis composite, or modular prosthesis; 5% (six) had distal humeral tumors that were treated with intra-articular resection and reconstruction with allograft prosthetic composites, modular prostheses, or a combination of VFG and vascularized iliac crest autologous grafts; 5% (six) underwent total humeral resection for extensive tumoral involvement of the humerus; and 6% (eight) underwent hemicortical resection for tumors of the bone surface.

A total of 17% (21 of 127) had a diaphyseal bone tumor of the humerus and they were treated with intercalary resection. Our indications for reconstruction with VFG are intercalary resection of the humerus for primary malignant or aggressive benign bone tumors in patients with long life expectancy and high functional demands in whom adequate bone stock of the proximal and distal epiphysis can be preserved. We avoid this reconstructive method in patients with humeral bone metastases, older patients, or patients with primary bone tumors in whom postoperative radiation therapy might be indicated. In such patients, alternative reconstructive options are used, such as endoprostheses, intercalary massive allografts, plate and cement, or intramedullary nails with cement augmentation. According to the above-mentioned indications, 2.4% (three) underwent massive allograft reconstruction because these patients had metastases at diagnosis and did not have a long life expectancy, while 14% (18) of patients underwent VFG reconstruction. In 13 patients, VFG was used alone (Fig. 1) and in five patients, it was used in combination with a massive allograft (Fig. 2). Our policy was to use VFG combined with a massive allograft in patients undergoing juxta-articular joint-sparing resections, in which proximal osteotomy was performed close to the anatomic neck of the humerus. In this clinical situation, the allograft and VFG combination allows more stable fixation than VFG alone and it can be used for better tendinous reattachment of the rotator cuff and deltoid. Bone fixation was performed with a bridging plate in 10 patients (Group 1), only screws or K-wires in four patients (Group 2), a distal plate and proximal screws in three patients, and two plates (one proximal and one distal) in one patient (Group 3) (Fig. 3).

All 18 patients who were treated with VFG were available for follow-up at a minimum of 2 years (median follow-up 176 months, range 26 to 275 months), and although three have not been seen in the past 5 years and are not known to have died, they had 172, 163, and 236 months of follow-up, and were included.

Generally, we used intra-articular resection and reconstruction for proximal humerus tumors with modular prostheses in adults with primary bone tumors or metastatic lesions or in patients in whom postoperative radiation therapy could be used, while generally, we use

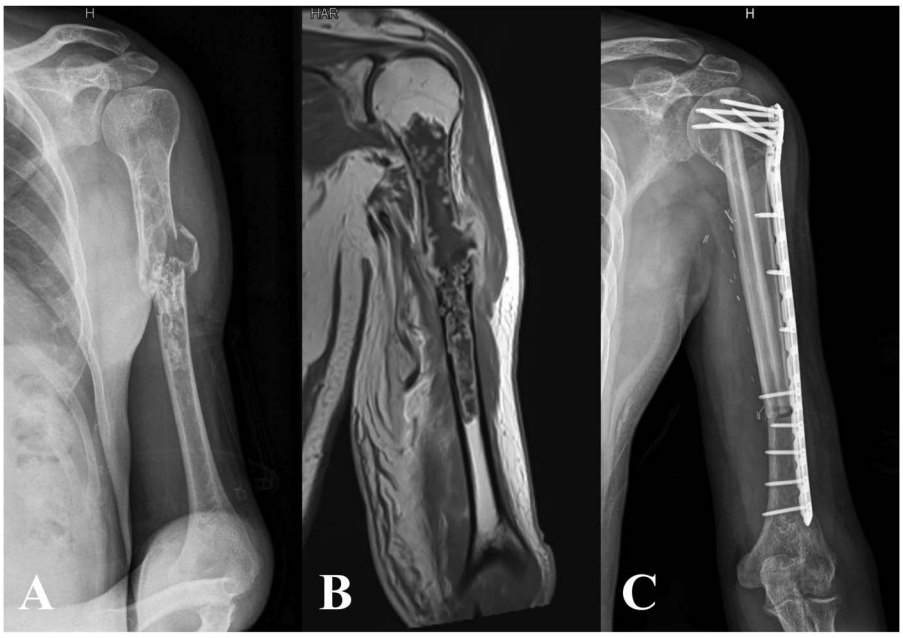

Fig. 2 (**A**) This is a radiograph of a 51-year-old man with pathologic fracture of the humeral diaphysis because of Grade 2 chondrosarcoma. (**B**) A coronal T1-weighted MR image with contrast shows proximal metaphyseal extension of the tumor to the neck of the humerus. (**C**) This postoperative radiograph shows reconstruction with VFG combined with a massive allograft and bridging plate to achieve more stable proximal fixation.

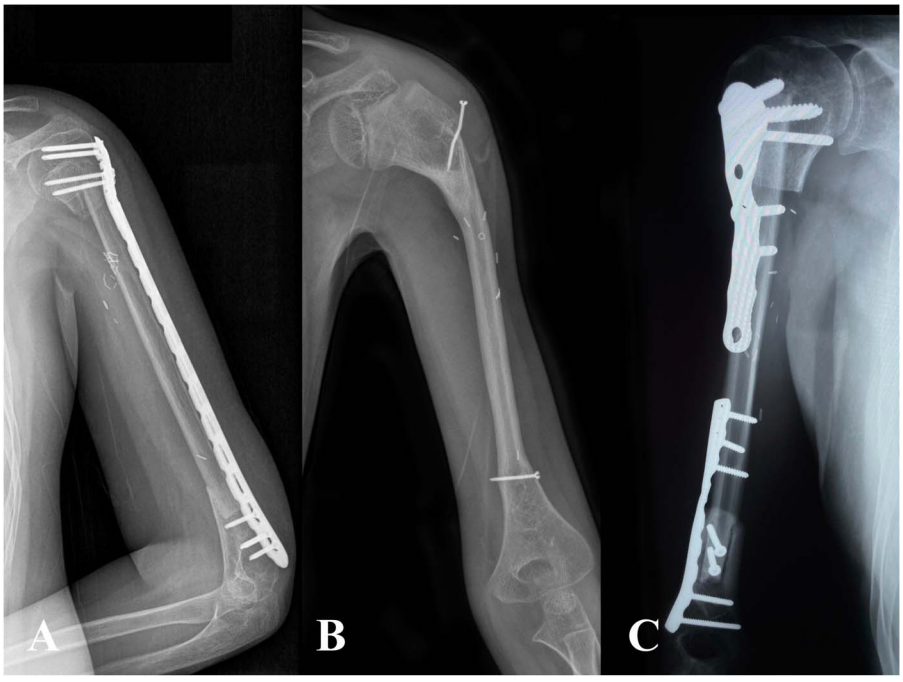

Fig. 3 This figure shows the types of fixation we used in this study. (**A**) Group 1 had fixation with a bridging plate. (**B**) In Group 2, screws were used only for fixation. (**C**) In Group 3, fixation with two plates was used. A distal plate and proximal screws are another option.

Table 1. Patient characteristics

Patient	Age in years	Gender	Diagnosis	Resection length in cm	Type of fixation
1	12	Woman	Ewing sarcoma	10	1
2	17	Man	Osteosarcoma	21	3
3	11	Man	Ewing sarcoma	13	2
4	63	Man	Grade 2 chondrosarcoma	17	3
5	25	Man	Grade 2 chondrosarcoma	15.5	3
6	16	Woman	Ewing sarcoma	12	3
7	2	Man	Ewing sarcoma	14	2
8	28	Woman	Grade 2 chondrosarcoma	12	1
9	31	Man	Low-grade fibromixoid sarcoma	11	2
10	39	Woman	Radiation-induced sarcoma	14	1
11	41	Woman	Grade 2 chondrosarcoma	8	1
12	15	Man	Ewing sarcoma	16	1
13	25	Man	Osteosarcoma	15	1
14	4	Man	Ewing sarcoma	12	2
15	51	Man	Grade 2 chondrosarcoma	20	1
16	27	Man	Parostal grade 1 osteosarcoma	16	1
17	29	Man	Osteosarcoma	15	1
18	13	Man	Ewing sarcoma	18	1

Type of fixation: 1 = bridging plate; 2 = screws-only fixation; 3 = fixation with two plates or one distal plate and proximal screws.

osteoarticular allografts or allograft prosthesis composites in young patients. Finally, we generally use growing VFG reconstruction in children younger than 10 years in whom an allograft reconstruction would result in significant limb length discrepancy and bulkier reconstruction.

Descriptive Data

The median age at the time of surgery was 25 years (range 2 to 63 years), the median humeral resection length was 15 cm (range 8 to 21 cm), and the median fibular length was 16 cm (range 12 to 23 cm) (Table 1). Seventeen patients had malignant bone tumors (seven had Ewing sarcoma, five had Grade 2 chondrosarcoma, three had high-grade osteosarcoma, one had radiation-induced sarcoma, and one had periosteal low-grade osteosarcoma), and one patient had a low-grade fibromyxoid sarcoma involving the humeral diaphysis. Diagnosis was made by experienced pathologists after biopsy in all patients. At diagnosis, four patients had pathologic fractures, and according to the MSTS staging system [12], two tumors were Stage IB, two were Stage IIA, 13 were Stage IIB, and one was Stage IIIB.

Surgical Technique, Aftercare, and Cancer Treatment

All operations were performed through an extended deltopectoral approach, with the patient in the supine position. The median length of humeral intercalary resection was 15 cm (range 8 to 21 cm). Histologic examination of the resected tumors showed the surgical margins were wide in 15 patients, marginal in two, and wide-contaminated in one.

The VFG was harvested from the contralateral leg by a microsurgical team using separate instruments, who took care to avoid contamination between the two surgical fields. The median length of the fibular graft was 16 cm (range 12 to 23 cm). The harvested fibula was at least 2 cm longer than the humeral resection to allow a minimum overlap of 1 cm for each osteotomy. No primary syndesmotic screw fixation was undertaken at the ankle of the donor side; we routinely do not use primary syndesmotic fixation in patients with more than 7 cm of residual distal fibula. The vascular pedicle of the flap, including the peroneal artery and two vena comitans, was anastomized in all patients with the collateral branch of the profunda brachial artery and vein.

The median operative time was 8 hours (range 6.5 to 9.5 hours).

All patients received perioperative antibiotic prophylaxis with intravenous vancomycin (1 g every 12 hours) and piperacillin and tazobactam (4.5 g every 8 hours) following the protocol of our institution, which was continued until drain removal. After surgery, the patient wore a brace with moderate shoulder abduction (15° to 30°) to prevent compression of the microvascular anastomosis on the medial side of the arm. Controlled passive movements of

Table 2. Functional and oncologic outcomes

Patient	MSTS score	ASES score	Constant score, %	Oncologic outcome	Follow-up, months
1	30	98.3	98	CDF	172
2	29			NED	163
3	29			CDF	236
4	28	95	81	CDF	275
5	30	96	83	CDF	253
6	29			DOD	73
7	30	100	95	CDF	245
8	30	100	100	CDF	229
9	30	100	100	CDF	216
10				CDF	204
11	30	100	100	CDF	196
12	29	98.3	98	CDF	179
13	28	93	87	CDF	161
14	30	98.3	83	CDF	132
15	30	100	98	CDF	127
16	30	98.3	92	CDF	112
17	28	94.9	79	CDF	37
18	30	94.9	83	CDF	26

MSTS = Musculoskeletal Tumor Society; ASES = American Shoulder and Elbow Surgeons; CDF = continuously disease-free; NED = no evidence of disease; DOD = dead of disease.

the shoulder and elbow were then allowed. The donor leg was left free postoperatively, encouraging active and passive movements of the knee, ankle, and toes. Full weight-bearing on the donor side was allowed after 3 weeks postoperatively. After 1 month, the abduction brace was replaced with a shoulder immobilizer, which the patient wore as protection until there was radiographic evidence of VFG union.

Eleven patients with a diagnosis of high-grade osteosarcoma, Ewing sarcoma, and radiation-induced sarcoma received preoperative and postoperative chemotherapy. One patient with Ewing sarcoma underwent autologous bone marrow transplantation with high-dose chemotherapy. No patients underwent preoperative or postoperative radiation therapy. In patients treated with preoperative chemotherapy, the surgery was planned 3 weeks after the last drug administration, not differently from other reconstructive options.

Data Sources and Variables

All patients were periodically reviewed according to oncologic follow-up, and they underwent clinical and radiologic examinations. After surgery, we reviewed patients with malignancy every 3 months during the first 2 years, every 4 months during the third year, every 6 months during the fourth and fifth year, and then annually until the tenth year after the index surgery. Data extracted from medical records were registered in our database.

At the last clinical follow-up, at a median follow-up of 176 months (range 26 to 275 months), 16 of 18 patients were continuously disease-free. One patient with Ewing sarcoma experienced a lung metastasis 6 months after the index surgery and died at 73 months. Another patient with high-grade osteosarcoma experienced lung metastasis 103 months after the primary surgery; he was treated with metastasectomy and chemotherapy, and remained disease-free at the last follow-up 60 months later (Table 2). No local recurrence was observed.

Primary and Secondary Study Outcomes

The functional outcome was evaluated using the MSTS score [11], ASES score [26], and the Constant score [9]. The MSTS score is an established system to assess functional outcomes in patients treated for bone tumors; in upper limb reconstructions, it evaluates six parameters: pain, function, emotional acceptance, hand positioning, manual dexterity, and lifting ability, giving a value ranging from 0 to 5 according to specific criteria. The sum of the individual scores defines the overall functional score with a possible maximum of 30 points [11]. The ASES and Constant scores are both nononcologic 100-point scales that evaluate performance in activities of daily living and

Table 3. Donor-site and recipient-site complications and treatment of complications

Patient	Donor-site complications	Treatment of donor-site complication	Recipient-site complications	Treatment of recipient-site complication
1				
2			Fracture	Nonoperative
3			Fracture	Nonoperative
4			Nonunion of both osteotomies	Iliac crest autograft augmentation and new fixation
5			Fracture	Nonoperative
6			Fracture	Nonoperative
7	Valgus ankle	Syndesmotic screw	Fracture; radial nerve neuroprassia	Nonoperative; screw removal
8				
9			Fracture with radial nerve deficit	ORIF and splint
10			Recalcitrant nonunion	Total humerus resection and reconstruction with prosthesis
11				
12	First claw toe	Surgical tendon release		
13			Nonunion with humeral head necrosis	Autograft augmentation, new fixation, and shoulder hemiarthroplasty
14	Claw toes	Surgical tendon release	Fracture	ORIF
15				
16			Pain related to a screw	Screw removal
17				
18	First claw toe	Nonoperative		

ORIF = open reduction and internal fixation.

shoulder ROM respectively [9, 26]. The MSTS score was assessed in patients in whom the VFG was retained at the final clinical control; furthermore, the ASES and Constant scores were evaluated in patients who have been seen in the past 5 years. In all patients, union and hypertrophy of the VFG were radiographically assessed, and complications and graft removal were recorded during follow-up. We do not routinely use any method of monitoring fibular vitality, such as VFG with skin flap based on perforator vessels, bone scan, or SPECT. We evaluated graft union and hypertrophy as signs of persistent vascular supply. We defined union on radiographs as cortical fusion of the VFG on AP and lateral views, while we defined hypertrophy as dimensional increase of the graft in width, although we did not measure it in detail. Simultaneously, donor site morbidity was evaluated.

Ethical Approval

Ethical approval for this study was waived by our local institutional review board.

Statistical Analysis

Survival of the reconstruction was determined according to the Kaplan-Meier method, including revision surgery for any complications and removal of the VFG as endpoints indicating failure. Kaplan-Meier curves and survival probabilities were computed using R version 4.1.2 via the package Survival version 3.5. A gender analysis was not performed because the numbers available were too small for statistical assessment.

Results

Complications and Reoperations

Donor site complications were observed in four of 18 patients (Table 3). One child experienced an ankle valgus deformity 10 years after the index surgery that was performed at 2 years old, despite an 8-cm residual distal fibula that spontaneously corrected after syndesmotic screw fixation. Three patients had claw toes: the first toe in two

patients and the other toes in the other patient. Two patients underwent surgical tendon release, and one asymptomatic patient with first claw toe had no treatment. During follow-up, 13 complications occurred at the recipient site in 11 of 18 patients after a median of 16 months (range 3 to 112 months) after the primary surgery (Table 3). Seven patients underwent surgical revision after a median of 28 months (range 10 to 112 months), and one patient underwent VFG removal 58 months after the primary surgery. Two patients had radial nerve neurapraxia: The first occurred 112 months after the index surgery because of nerve impingement from a loose screw, which was surgically removed; the second occurred 6 months after the primary surgery because of a VFG fracture treated with new fixation. Both nerve palsies completely and uneventfully recovered. One patient had screw-related pain and underwent screw removal 16 months after the index surgery. There were four nonunions in three patients. We defined nounion as the lack of evidence of osteotomy healing on radiographs 9 months after the index surgery, with or without loosening of fixation. Nonunions occurred in two of five patients who underwent reconstruction with a VFG combined with an allograft and in one of 13 patients with only VFG. One patient had nonunion of the distal osteotomy 10 months after primary surgery and of the proximal osteotomy 22 months after the primary surgery; both healed after autologous iliac crest graft augmentation and new fixation. Another patient had proximal nonunion and hardware breakage, and after three consecutive attempts at biologic reconstruction, underwent total humerus resection and reconstruction with a megaprosthesis 8 years after the primary surgery. One patient was treated with joint-sparing intercalary reconstruction with a VFG and allograft for a high-grade osteosarcoma, leaving only 2 cm of the native proximal humerus; this patient experienced avascular necrosis of the humeral head and nonunion of the distal osteotomy with screw breakage 28 months after the primary surgery. The patient underwent resurfacing hemiarthroplasty of the proximal humerus, retaining the VFG and new fixation with autologous iliac crest graft augmentation, obtaining complete healing and excellent functional results at 161 months of follow-up. Nonunions occurred in two of five patients who underwent reconstruction with a VFG combined with an allograft and in one of 13 patients with VFG alone. Likewise, nonunions occurred in two of 10 patients in Group 1 and one of four patients in Group 3.

Six of 18 patients had a fracture at a median of 12.5 months (range 3 to 77 months) after the primary surgery. Three fractures occurred in patients with two plates or a distal plate and proximal screw fixation, and the other three fractures occurred in patients with only screw osteosynthesis. No fractures occurred in patients with a bridging plate or in patients with a VFG combined with an allograft. All fractures occurred after a fall. In four of six patients, the fracture healed spontaneously with bracing, whereas in two patients, operative repair was performed. Both patients had screw-only reconstructions, and a new fixation was performed with a long bridging plate in one patient and a short plate in the other. No deep infection at either the donor or recipient sites was observed.

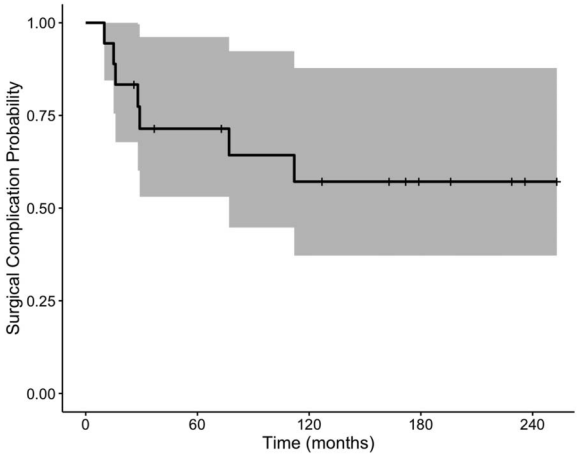

Fig. 4 This graph shows revision-free survival, with surgical revision for any complication as the endpoint. The survival was 71% (95% CI 53% to 96%) at 5 years and 57% (95% CI 37% to 88%) at 10 and 15 years. The gray area represents the CIs.

Outcomes Scores for Pain and Function

At the final follow-up after a median of 176 months (range 26 to 275 months), the median MSTS score was 30 (range 28 to 30). The three patients lost to follow-up and the patient who died of disease were evaluated only with the MSTS score. Function scores ranged between 3 and 5 points; pain, emotional acceptance, hand position, and manual dexterity scored 5 points in all patients, whereas lifting ability was 4 to 5 points. Regarding shoulder function, the median active flexion was 175° (range 100° to 180°), median active abduction was 175° (range 100° to 180°), median active internal rotation was to T7 (range T7 to T12), and median active external rotation was 90° (range 70° to 90°). For elbow function, median active flexion was 140° (range 100° to 140°), and two patients had an extension lag of 5° and 10°; pronosupination was complete in all patients. Functional outcomes were also evaluated using nononcologic scoring systems, giving a more detailed estimate of the impact of reconstruction on daily living activities and shoulder function. Moreover, ASES and Constant scores allowed us to assess the recovery of abduction strength, which cannot be analyzed in detail using the MSTS score. The median ASES score was 98.3 (range 93 to 100), and the median Constant score was 93.5% (range 79% to 100%) (Table 2).

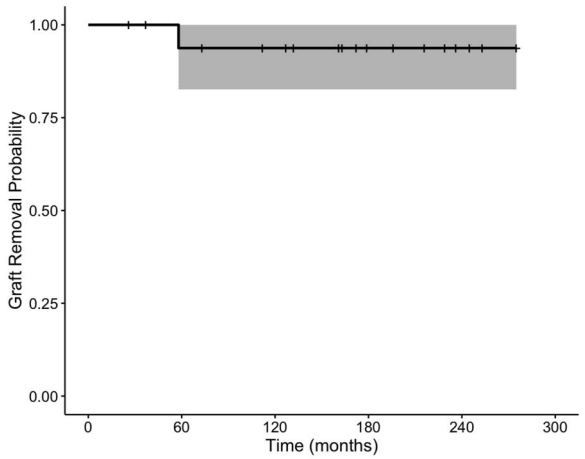

Fig. 5 This graph shows VFG removal-free survival, with graft removal for any complication as the endpoint. The survival was 94% (95% CI 83% to 100%) at 5, 10, and 15 years. The gray area represents the CIs.

Survivorship of Vascularized Fibular Grafts

The revision-free survival of the reconstructions, with revision surgery for any complication as the endpoint, was 71% (95% CI 53% to 96%) at 5 years and 57% (95% CI 37% to 88%) at 10 and 15 years (Fig. 4). The overall survival of the reconstructions, with removal of VFG as the failure endpoint, was 94% (95% CI 83% to 100%) at 5, 10, and 15 years. (Fig. 5).

Discussion

After intercalary resection of the humerus for primary bone tumors, the objective of reconstruction is to restore upper limb function and have a reconstruction with a low long-term risk of reoperation or graft removal. Autologous VFG is one of the reconstructive methods available. The fibula has become the vascular autograft most frequently used to restore large segmental long bone defects, particularly in the upper limb, because of the length of its vascular pedicle and ease of access for harvesting [2, 15, 18, 29, 31]. The advantages of using VFG for humeral intercalary reconstructions are adequate anatomic matching (similar shape and size), early osteotomy fusion, healing potential after fracture, and the ability to hypertrophy under mechanical stress, even in patient with loss of or compromised soft tissue that might not support a metal implant or an allograft [6]. The Capanna technique of combining an allograft with a vascularized fibula [5] is a well-established reconstructive option for the long bones. This technique aims to associate the mechanical strength of the allograft with the biological activity of the VFG to improve allograft union and internal repair. Moreover, the allograft enhances fixation stability even in patients with juxta-articular joint-sparing resections. Some authors have successfully used this technique for humeral intercalary defects with few complications, but with only short-term follow-up [15, 20, 21]. In the present study, we aimed to investigate the long-term results of this technique, which resulted in a functional long-lasting joint-sparing biological reconstruction. In spite of a consistent risk of mechanical complications in the first 5 years after implantation, all but one patient were able to retain the VFG at the time of the most recent follow-up. The risk of fracture may be lessened by using long-spanning plate fixation.

Limitations

First, there might have been a selection bias regarding the indication for joint-sparing biologic intercalary reconstruction instead of prosthetic replacement, but we aim to preserve native joints, when feasible, in patients with primary bone tumors. Second, three patients were not seen recently, and they could have undergone revision for complications elsewhere. However, all three patients were seen at long-term follow-up, confirming functional and survival results. Third, no control group with an alternative osteoarticular reconstructive method was analyzed, although the functional advantage of preserving the native joint with tendinous insertions appears to us to be advantageous. Fourth, both pediatric and adult patients were included, with consequent possible bias because of different biologic potential; nonunions were not observed in pediatric patients. Fifth, we did not have sufficient numbers to compare our results by gender. Men and women might differ in the proportion of complications or long-term longevity of the graft. A larger study is necessary to address this issue.

Complications and Reoperations

Complications were common in this series; 7 of our 18 patients underwent revision for complications. Most complications occurred during the first 30 months after the index surgery, and all but one of our patients retained their VFG in the long term. Nonunion and fracture were the most frequent complications in our series. Nonunion was more frequent in patients with VFG combined with an allograft, but it did not seem to be related to patient age or chemotherapy, as reported by other authors [17]. Except for one patient who underwent VFG removal and total humerus reconstruction after many surgical procedures, the other two nonunions healed after autologous iliac crest augmentation. To reduce the risk of nonunion, we recommend overlapping the VFG and host bone by at least 1 cm and, as

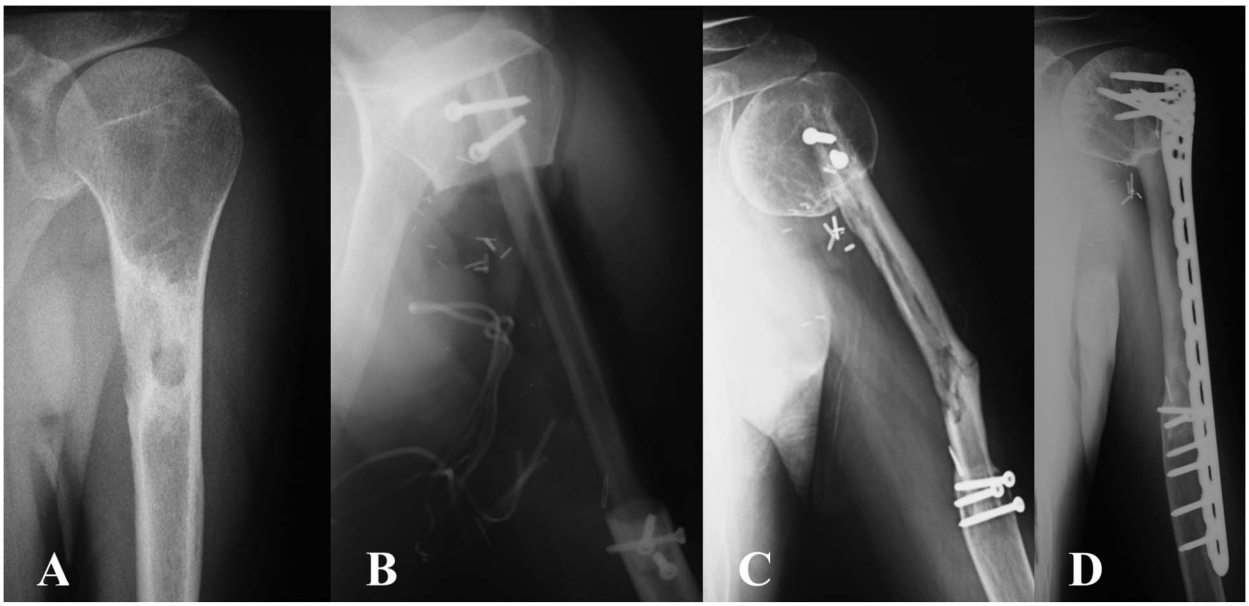

Fig. 6 (**A**) This radiograph of a 31-year-old man shows humeral diaphysis involvement of a low-grade fibromixoid sarcoma. (**B**) The patient underwent intercalary resection of the humerus and reconstruction with VFG and only screw fixation. (**C**) The patient had graft fracture because of a fall 15 months after the index surgery. (**D**) This radiograph shows fracture healing after surgical revision with bridging plate fixation.

advocated by Zelenski et al. [34], using a bridging dynamic compression plate. Six of 18 patients had traumatic fractures; two patients underwent open reduction and internal fixation, and in the other four patients, the fractures healed spontaneously with nonoperative treatment. Fractures occurred only in patients with two separate plates, distal plate and proximal screws, or screw-only fixation. One drawback of intercalary VFG reconstruction is the low mechanical strength of a single fibula. To improve mechanical strength, it is important to combine a VFG with bridging plate fixation or an allograft, as suggested by other authors [20, 21, 27]. Most complications, mainly fractures and nonunions, were related to using two plates or screw-only fixation to improve fibular hypertrophy. We observed fractures and nonunions in seven of eight patients; however, using bridging plate fixation, we observed nonunions in two of 10 patients, while none had fractures. The use of a single long-spanning plate with screw fixation of at least six cortices is recommended, from our experience, in adolescents and adults, to reduce the fracture risk (Fig. 6). However, stress shielding induced by the bridging plate may eventually inhibit VFG hypertrophy [34]. Conversely, in very young children, screw fixation only may be preferred to obtain appropriate fibular hypertrophy and remodeling and avoid growth plate fixation (Fig. 7). Moreover, in our experience, the combination of VFG and a massive allograft is recommended to obtain more stable fixation in joint-sparing resection performed in the proximal metaphysis of the humerus. In reports about VFG reconstruction in the upper limb [8, 14, 25, 31, 34], only a few papers focused on the long-term results of VFG after intercalary resection of the humeral diaphysis for bone tumors [15, 18, 20, 21, 27]. In these small series, the authors observed a low nonunion proportion (0% to 20%) but a high fracture risk (28% to 50%). These findings support the use of a long bridging plate for fixation with a minimum of three screws at each end of the construct, which avoids disrupting the graft's periosteal blood supply and minimizes the risk of failure at the plate-screw interface [15, 18, 27]. Reconstruction of intercalary defects of the humerus with VFG has some drawbacks—such as donor site morbidity, which in our series was 22%—that do not affect patient quality of life, the operative complexity of VFG harvesting and anastomosis, or long surgical time, which can be reduced through the simultaneous work of orthopaedic and microsurgical teams.

Outcomes Scores for Pain and Function

The median MSTS score was 30, ranging between 28 and 30 points, with excellent active ROM of the shoulder and elbow, while the median ASES and Constant scores were 98.3 (range 93 to 100) and 93.5% (range 79% to 100%), respectively. Such excellent functional results were probably related to retention of the native shoulder and elbow and tendinous insertions. Joint-sparing reconstruction was successful, as confirmed by ASES and Constant score

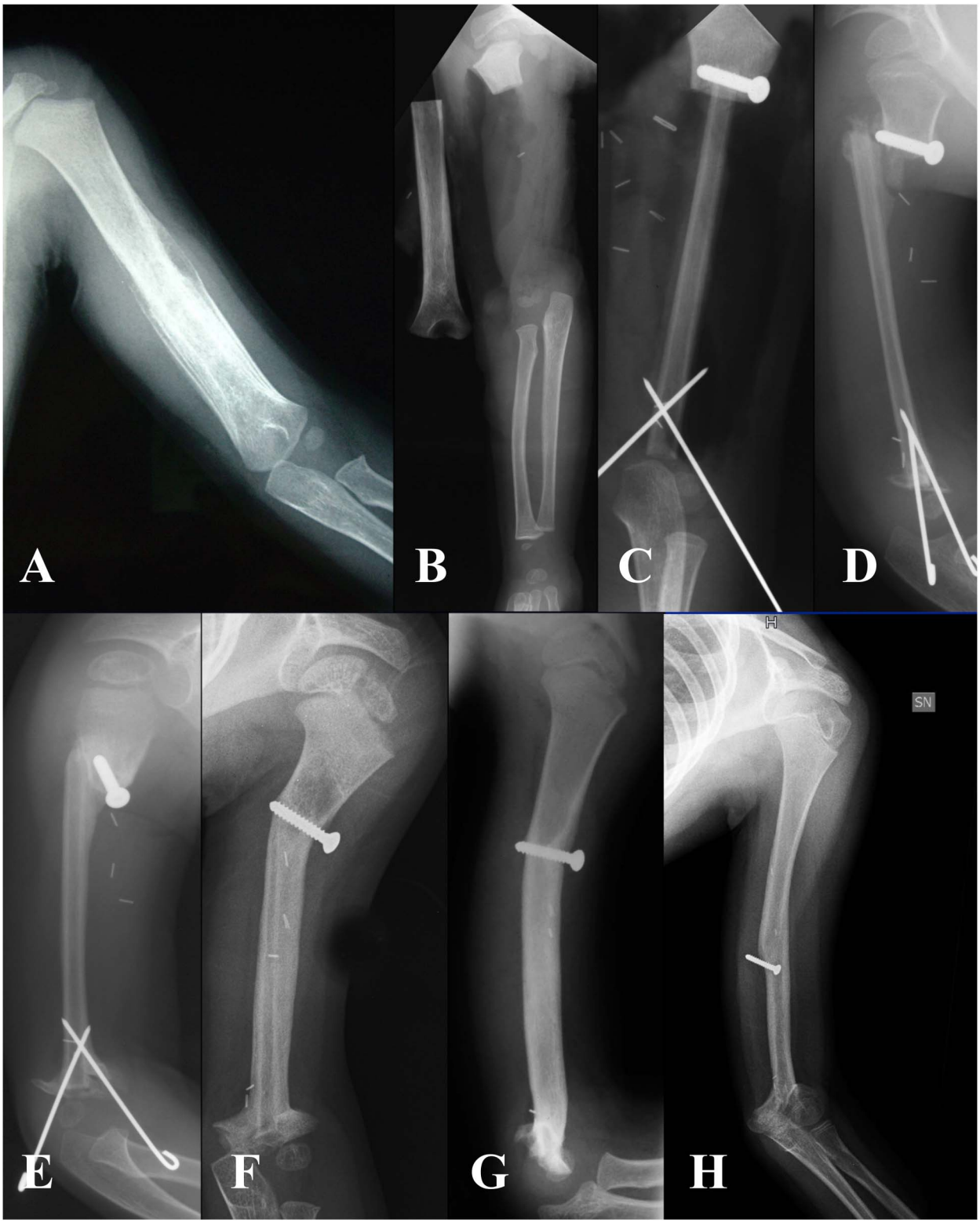

Fig. 7 (**A**) This radiograph of a 2-year-old boy shows Ewing sarcoma of the humeral diaphysis. (**B**) The patient was treated with intercalary resection to preserve the distal epiphysis and (**C**) reconstruction with VFG and fixation with a proximal screw and distal K-wires. These radiographs show that (**D**) a VFG fracture occurred 1 month after the index surgery (**E**) that was managed nonoperatively and (**F**) healed spontaneously. (**G**) This radiograph shows progressive hypertrophy of the fibula. (**H**) The patient had loosening of the proximal screw that was removed because of radial nerve impingement 112 months after the primary surgery.

evaluation, particularly regarding return to activities of daily living and muscular strength recovery. Compared with MSTS scores after prosthetic reconstructions, the average MSTS score reported with intercalary joint-sparing humeral prostheses was 22 to 28.6 points after a mean of 14 to 29 months of follow-up [1, 3, 10, 24, 28, 36]. A comparison of long-term results between biologic and prosthetic intercalary reconstructions of the humerus could be an interesting subject for future research.

Survivorship of Vascularized Fibular Grafts

The revision-free survival was 71% (95% CI 53% to 96%) at 5 years and 57% (95% CI 37% to 88%) at 10 and 15 years. The overall survival of the reconstructions, with removal of VFG as the failure endpoint, was 94% (95% CI 83% to 100%) at 5, 10, and 15 years. Intercalary humeral prostheses are burdened by a high loosening proportion ranging from 0% to 27.3%, considering patients with metastases with not more than a mean of 2 years of follow-up [3, 10, 24, 28, 36]. The aseptic loosening rate reached 100% within 18 months in a series of two intercalary custom-made prostheses implanted for primary bone tumors [1]. Considering the complications of shoulder modular prostheses, an implant survival ranging between 38% and 100% at 5 years has been reported [30], with a failure rate per year of 0.064, considering long-term follow-up [22]. Future research should compare long-term survival free from failure between biologic and prosthetic joint-sparing reconstructions of the humerus.

Reconstruction of intercalary defects of the humerus with VFG is challenging and requires a well-trained microsurgical team, but in our experience, the biological potential of a vascularized fibula is a major advantage in intercalary reconstructions of the humerus after bone tumor resection. In our series, although surgical revision was performed in almost 40% of patients, 94% were able to retain their graft at the last clinical follow-up; this is the main aspect to highlight, in our opinion. Most of the failures were fractures, which healed without surgical intervention in most patients, and nonunions, which healed after autologous iliac crest augmentation in all but one patient. Moreover, most of these occurred in the first postoperative years. Once union of the fibula was achieved, the complication rate was very low, confirming that biologic reconstruction with a viable graft can be a long-lasting solution after intercalary resections of the humerus.

Conclusion

We found that VFG was an effective reconstructive option after humeral intercalary resections for primary bone tumors, and it can be recommended for active patients with long life expectancy. VFG offers many advantages such as biological graft healing after fracture and long-term implant durability. Mechanical complications frequently observed in the first 5 postoperative years might be lessened by using long-spanning plate fixation, providing a long-lasting durable reconstruction with excellent functional results. Larger studies comparing VGF with other reconstruction options such as an allograft alone, intercalary endoprostheses, and sterilized autografts are needed to assess the potential benefits of one technique over the other. However, we believe that VFGs, alone or combined with allografts, are an effective method to reconstruct a functional upper extremity after intercalary resections of the humerus for patients with destructive tumors.

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