Erciyes Med J 2020; 42(2): 167–73 • DOI: 10.14744/etd.2019.80148
ORIGINAL ARTICLE – OPEN ACCESS

Is Non-Vascularized Fibular Grafting an Effective Choice in the Treatment of the Upper Extremity Pseudarthrosis?

Yakup Ekinci, Kaan Gürbüz

ABSTRACT

Objective: To examine the efficacy of non-vascularized fibular grafts (NVFGs) in cases of isolated upper extremity pseudarthrosis, a subject covered by few publications in the literature.

Materials and Methods: Twelve long bones of 11 patients treated with NVFGs for upper extremity pseudarthrosis between January 2014 and July 2018 in our clinic were included in this study. Demographic data, length of the NVFG, postoperative complications, postoperative recovery period, radiographic bone union, joint range of motion measurements, Quick-Disabilities of the Arm, Shoulder and Hand (Q-DASH) score for functional evaluation, and Lower Extremity Functional Scale (LEFS) or donor site morbidity were recorded.

Results: Of the 11 cases (three females and 8 males; median age 42.5 years; range 11 to 54 years; mean follow up 24.58±9.31 months), five cases involved the humerus, three cases involved the radius, two cases involved the ulna, and two cases involved the clavicle. The mean amount of graft harvested from the donor site was 39.7±8.87 mm, while the graft union time was 6±0.50 months. Satisfactory Q-DASH [median 6.8 (2.28-29.50)] and LEFS scores (mean 76.5±2.81) were obtained

Conclusion: Reconstruction with NVFGs is still an effective method in patients with problematic treatment of upper extremity long bone pseudarthrosis.

Keywords: Upper extremity, pseudarthrosis, fibula, graft

Cite this article as: Ekinci Y, Gürbüz K. Is Non-Vascularized Fibular Grafting an Effective Choice in the Treatment of the Upper Extremity Pseudarthrosis? Erciyes Med J 2020; 42(2): 167-73.

Department of Orthopedics and Traumatology, Kayseri City Hospital, Kayseri, Turkey

Submitted 01.10.2019

Accepted 12.12.2019

Available Online Date 03.04.2020

Correspondence Yakup Ekinci, Kayseri City Hospital, Department of Orthopedics and Traumatology, Kocasinan, Kayseri, Turkey
Phone: +90 352 315 77 00
e-mail: belduya@gmail.com

INTRODUCTION

Bony defects of the upper extremity secondary to osteomyelitis, trauma, tumor resection, or pseudarthrosis may result in significant functional deficits and deformities if left untreated (1). Conventional cancellous bone grafts have commonly served to reconstruct bone defects smaller than 6 cm. However, larger defects and cases of impaired vasculature require biomaterials, endoprostheses, and vascularized bone transfer (2–4).

Theoretically, pseudarthrosis is diagnosed if there is no radiological union sign in the bone six months after the fracture (5). There are several causes of pseudarthrosis, including patient-related factors (aging, osteoporosis, alteration of bone metabolism) (6), fracture types (open fractures, bone defect), and surgical mistakes, which may affect vascularization and lead to unstable synthesis (7).

Non-vascularized fibular grafts (NVFGs), which were introduced at the beginning of the twentieth century, have been used for biological reconstructions for almost 100 years (8). Because of low donor site morbidity, short operation time, and easy surgical technique, it is possible to reconstruct long bone defects of the upper extremity shorter than 6 cm using NVFGs with excellent functional and cosmetic results (9–11).

In the literature, some studies report that NVFGs have disadvantages, such as a high risk of resorption and lack of biological activity, while some other studies state that they have much more advantageous features than other methods (12). Upper extremity pseudarthrosis is more challenging to treat surgically than lower extremity pseudarthrosis. Surgical solutions for lower extremity pseudarthrosis had more efficacy due to load-bearing forces, gravity and weight of the body on the fracture site. On the other hand, upper extremity had not been under any load-bearing forces, which make the upper extremity pseudarthrosis surgical treatment hard to handle. Thus, there is no consensus on the method of choice in pseudarthrosis cases requiring reconstruction with grafting.

In this retrospective study, we aimed to evaluate NVFGs, which are used in the treatment of upper extremity pseudarthrosis but rarely covered in the literature, concerning radiological results and functionality.

MATERIALS and METHODS

Ethics approval was obtained from Erciyes University Clinical Research Ethics Committee on 08/05/2019 (num-

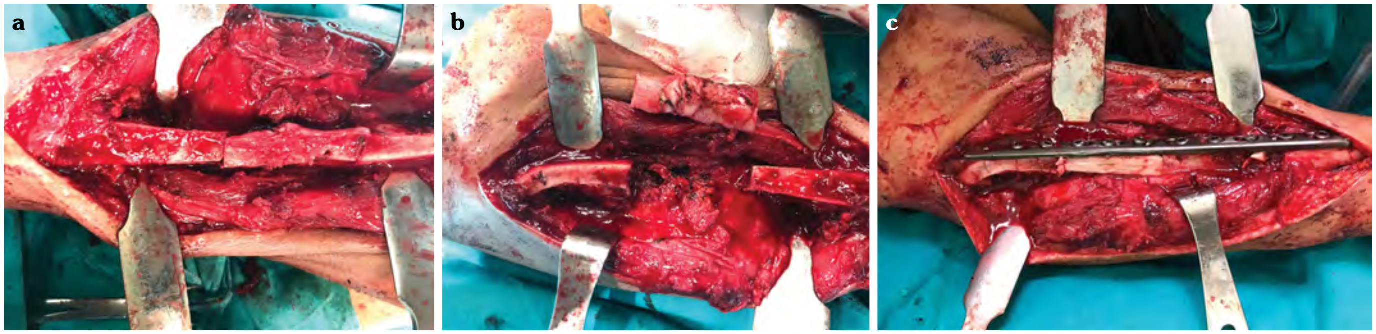

Figure 1. Intraoperative view of the surgical technique. (a) Determination and preparation of the pseudarthrosis bone. (b) Resection of the non-union part of the bone. (c) Final view of the pseudarthrosis reconstruction with NVFGs internal fixed by plate plus

bered 2019/304). A retrospective review of prospectively collected data was performed for all cases of pseudarthrosis of the upper extremity treated surgically by the authors in our clinic from January 2014 to July 2018. All patients provided informed consent before the study entry, and this study was conducted in accordance with the principles of the Declaration of Helsinki.

The inclusion criteria for this study were as follows: a diagnosis of aseptic pseudarthrosis in the upper extremity long bone (no radiological or clinical evidence of union in the bone tissue after a minimum of 6 months) was established for surgical intervention, a ≤6 cm non-vascularized fibula autograft was applied for surgical intervention, a plate plus screw was applied for fixation, and follow-up lasted at least one year. The exclusion criterion was missing data and/or loss to follow-up.

The patients were given a follow-up number by which the following data were recorded: name, age, sex, file number, dominant hand, operated side, history (etiology of the fracture, number of operations and operative techniques that were performed), location (humerus, radius, ulna, and clavicle) and dates of surgeries, follow-up time, the length of resection of the pseudarthrosis bone and length of the NVFG that was re-augmented, postoperative complications, the postoperative recovery period, as well as estimated time for radiographic bone union, measurements of the joint range of motion (ROM) at the last follow-up, and Quick-Disabilities of the Arm, Shoulder and Hand (Q-DASH) scores (13). In addition, the Lower Extremity Functional Scale (LEFS) was used to evaluate donor site morbidity (14).

Surgical Procedures

The method by which the patients were anesthetized was chosen by the same anesthesiologist. The pseudarthrosis site on the long bone was excised from the proximal part and distal to the vascularized bone with the help of a saw under continuous physiological saline washing of the blade. The amount of defect formed was measured and dissected for use as a graft. A fibular autograft as large as the defect was obtained with the help of a saw. The fibular graft was fixed to the defect site using a plate plus screw (Fig. 1 and Fig. 2). The patients were followed up throughout the course. A triangular arm sling was used in postoperative, clavicular pseudarthrosis cases, and a long arm splint was used in the other cases. The passive motion was started at three weeks, and the active motion was started at six weeks and the splint was removed.

Statistical analyses were performed using SPSS 22.0 for Mac (SPSS Inc., Chicago, IL, USA). The data were analyzed for normal distribution using the Shapiro–Wilk test. Mean±standard deviation was used for normally distributed data, while the median (min-max) was used for non-normally distributed data.

RESULTS

In the 11 patients (three females (27.3%), eight males (72.7%); median age 42.5 years, range 11 to 54 years; mean follow up 24.58±9.31 months) who underwent surgery due to pseudarthrosis, 12 bones were treated with NVFGs (Table 1).

The right hand was dominant in 83.3% of the patients, while the pseudarthrosis side was the right side in only 58.3% of the patients (Table 1).

Almost half of the cases involved the humerus (41.7%), while two involved the clavicle (16.7%), three the radius (25%) and two the ulna (16.7%) (Fig. 3). The mean time to diagnose pseudarthrosis at the time of surgical intervention was 12±3.39 months (range from 8 to 17 months). Seven adult patients were smokers, consuming 279.4 packets/year.

The mean length of the fibula graft, 39.7±8.87 mm, taken from the donor site to fill the defect obtained by resecting until viable bone tissue was achieved. The longest grafts were used for the humerus and the shortest for the clavicle (Table 1). Radiologically, the graft union time was 6±0.50 months, while the fastest union was observed in the radius, and the delayed union was observed in the clavicle (Table 1). In almost all cases, radiological remodeling was observed in the donor site of fibula during follow-up (Fig. 2).

The Q-DASH score, by which functionality was assessed, was median 6.8 (2.28 to 29.50). Although satisfactory results were obtained in general (4, 10, 11), the patients stated that they had difficulty in washing their backs mostly. According to the LEFS score (mean 76.5±2.81) in which the lower extremity was used as a donor, all subjects regained their lower extremity functions almost completely at the end of the follow-up. The patients had pain complaints at the operation side and limited pain during walking at the donor side of the fibular graft in the early postoperative period.

Although a patient was treated for radius and ulna pseudarthrosis, 10° wrist dorsoflexion limitation was observed, but joint ROM an-

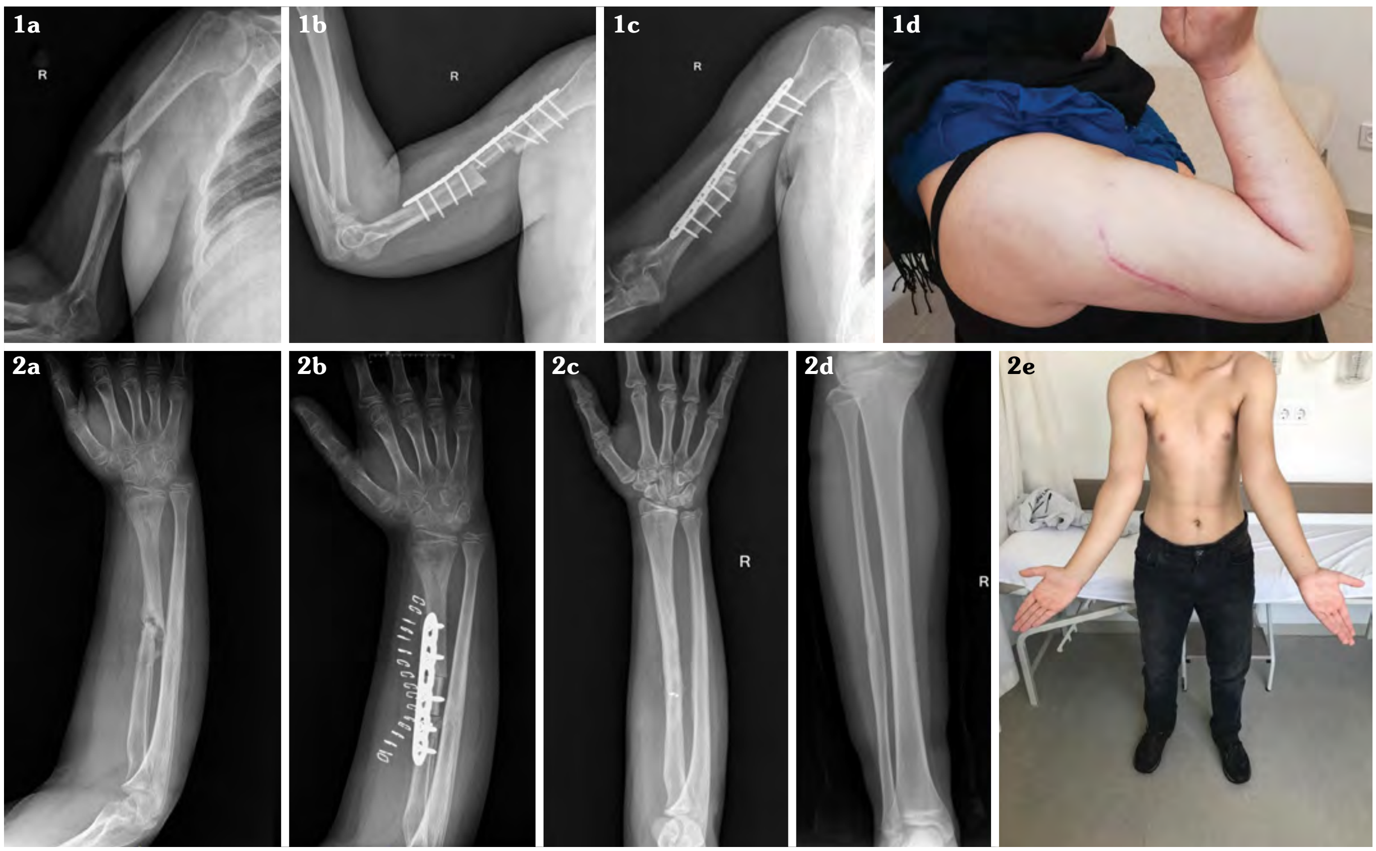

Figure 2. **Sequence of two selected patients in our series. (1a) Preoperative radiological view of the pseudarthrosis at humerus shaft. (1b) Early postoperative radiological view of the pseudarthrosis at humerus shaft which was reconstructed by NVFG. (1c) Late postoperative radiological view of the reconstructed humerus shaft which showed bone union. (1d) Final clinical appearance of the patient's upper extremity without any complication. (2a) Preoperative radiological view of the pseudarthrosis at radius shaft which results in radial deviation of the wrist. (2b) Early postoperative radiological view of the pseudarthrosis at radius shaft which was reconstructed by NVFG. (2c) Late postoperative radiological view of the reconstructed humerus shaft which showed bone union after removal of the plate. (2d) Full regeneration of donor bone graft side at fibula. (2e) Final clinical appearance of the patient's upper extremity without any complication**

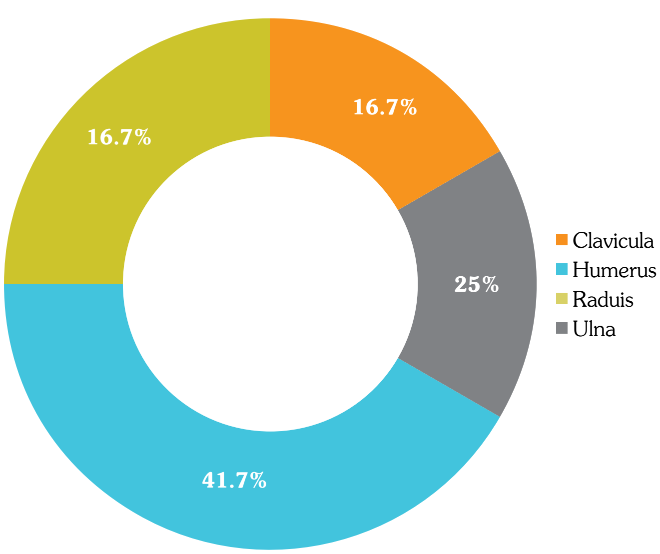

Figure 3. **Distribution of the pseudoarthrosis of the long bones**

gles measured according to the contralateral upper extremity were satisfactory in all patients (Table 2).

Two patients with superficial infection of the suture line were treated with oral antibiotics after debridement. There were no other complications.

DISCUSSION

Pseudarthrosis of the long bones of the upper extremity is often a problem both for the patient and the surgeon, and it requires patience to achieve successful treatment. It is a good option to keep in mind in appropriate patients because it is possible to solve this complex problem with one-session surgery using an NVFG.

Different methods can be used in primary pseudarthrosis surgery, but it should not be forgotten that each surgical intervention for nonunion is itself a cause of nonunion (5, 7). Each of the graft options that can be used has its own advantages and disadvantages. The formation of callus cannot be expected in the bone tissue without blood supply.

Table 1. Demographic data of the patients

#	Sex	Age (y)	Side	Dominant hand	Location	Preoperative follow-up (mo)	Before NVFG surgery*	Fibular graft (mm)	Postoperative follow-up (mo)	Union time (mo)	Q-DASH (p)	LEFS (p)
1	F	47	Left	Right	Radius	8	2 (ORIF)	33	13	6	6.8	76
			Left	Right	Ulna	8	2 (ORIF)	29	13	6	6.8	76
2	M	43	Right	Right	Humerus	13	4 (CREF, ORIF)	41	18	8	6.8	78
3	F	41	Right	Right	Humerus	14	3 (CREF, ORIF)	53	16	4	2.3	80
4	M	54	Left	Left	Clavicula	9	2 (ORIF)	28	22	7	20.4	74
5	M	51	Right	Right	Clavicula	17	1 (ORIF)	30	21	9	29.5	72
6	M	34	Right	Right	Humerus	16	2 (CREF, ORIF)	49	27	5	20.4	77
7	M	11	Left	Left	Ulna	13	3 (CREF, CRPF)	35	21	5	25	72
8	M	13	Right	Right	Radius	15	3 (CREF, CRPF)	38	38	8	6.8	77
9	M	39	Right	Right	Humerus	14	3 (CREF, ORIF)	51	35	5	6.8	80
10	F	42	Left	Right	Humerus	8	3 (CREF, ORIF)	46	37	6	4.5	76
11	M	54	Right	Right	Radius	9	1 (ORIF)	44	34	3	4.5	80

y: Year; mo: Month; mm: Milimeter; p: Points; F: Female; M: Male; NGFG: Non-vascularized fibular graft; ORIF: Open reduction internal fixtion; CREF: Closed reduction external fixation; CRPF: Closed reduction percutaneous fixation; *Number of operations before NVFG surgery and the techniques were used

Although so many different surgical techniques and materials have been used in the treatment of non-union fracture treatment, autologous bone grafting is the gold standard. Autologous bone grafts are the only biological material that has the both osteogenic, osteoinductive and osteoconductive effect on bone fracture healing. These unique properties make the autologous bone grafts ideal choice to compare the alternative biological and/or artificial materials (15, 16).

These biological and/or artificial materials are bone marrow aspirate, allograft bone, demineralized bone matrix, ceramics, platelet-rich plasma (PRP), and recombinant bone morphogenic proteins (BMPs) which have been widely used (16).

Although the graft volume is limited for the iliac crest bone grafting (ICBG), ICBG is the most preferred source of autologous bone graft in the literature for its rich source of progenitor stem cells, growth factors and also relatively easy harvesting technique (16, 17). Although it does not provide sufficient mechanical stability, it quickly adapts to the host site (18).

Progenitor stem cells in autologous bone grafts quickly respond to local stimuli and accelerate angiogenesis and bone formation. On the other hand, re-vascularization is slower and bone remodeling takes longer in cortical bone grafts. The use of vascularized cortical bone grafts can accelerate this process but is significantly more complex and time-consuming with more complication to perform.

In their study, Kessler et al. (19) reported that the average ICGB amount obtained from subjects with a mean age of 44 years was 9 cm^3 (range, 5–12 cm^3) from the anterior and 25.5 cm^3 (range, 17–29 cm^3) from the posterior. Although the amount of graft taken is higher than the posterior, it is possible to come across reports of more blood loss (1).

There are very few studies comparing the amount of growth factors and viable cells contained in the grafts. One of these few studies was published by Schmidmaier et al. (20) which compared the quantity of BMPs in the crest graft versus the intramedullary graft. Although they report that femoral intramedullary graft quality sounds more meaningful, further studies are needed to see clinical outcomes.

Although ICBG is known to provide cortical support by taking tricortical, it is insufficient in volume in large defects. In addition, as in our case, recurrent ICBG harvest despite avascular pseudarthrosis in cases developing NVFG with much more successful results can be achieved.

Pseudarthrosis surgery requires resection of the unviable bone. This requirement can be achieved by compression-distraction osteogenesis in the lower extremity. However, in the upper extremity, there are difficulties in using this technique and morbidity problems due to high complication rates. Therefore, the use of the Masquelet and Ilizarov techniques in upper-extremity bone defects is quite low (21, 22). However, there is evidence in the literature that NVFGs may be integrating and remodeling into the host bone (10, 11). For these cases, reconstruction with NVFGs can be performed successfully after short (<6 cm) segment resection (10, 11).

In a series of 12 cases involving two forearms and two humerus with posttraumatic bone defect treated with NVFGs, El-Sayed et al. (11) found that the mean radiological duration of the union was four months.

Table 2. ROM values of the operated and non-operated sides

#	Sex	Age(y)	Side	Location	Operated side ROM*		Non-operated side ROM*	
1	F	47	Left	Radius	Wrist	Flex/Ext: 65°/60°	Wrist	Flex/Ext: 68°/52°
						U/R Dev: 25°/15°		U/R Dev: 27°/14°
					Elbow	Flex/Ext: 132°/0	Elbow	Flex/Ext: 140°/0
						Pro/Sup: 75°/80°		Pro/Sup: 78°/84°
			Left	Ulna	Wrist	Flex/Ext: 65°/60°	Wrist	Flex/Ext: 68°/52°
						U/R Dev: 25°/15°		U/R Dev: 27°/14°
					Elbow	Flex/Ext: 132°/0	Elbow	Flex/Ext: 140°/0
						Pro/Sup: 75°/80°		Pro/Sup: 78°/84°
2	M	43	Right	Humerus	Shoulder	Flex/Ext: 135°/35°	Shoulder	Flex/Ext: 180°/45°
						Abd/Add: 145°/40°		Abd/Add: 180°/45°
						In/Ex Rot: 70°/85°		In/Ex Rot: 90°/90°
					Elbow	Flex/Ext: 135°/0	Elbow	Flex/Ext: 135°/0
						Pro/Sup: 85°/85°		Pro/Sup: 90°/90°
3	F	41	Right	Humerus	Shoulder	Flex/Ext: 154°/40°	Shoulder	Flex/Ext: 180°/45°
						Abd/Add: 170°/40°		Abd/Add: 180°/45°
						In/Ex Rot: 80°/75°		In/Ex Rot: 90°/90°
					Elbow	Flex/Ext: 135°/0	Elbow	Flex/Ext: 135°/0
						Pro/Sup: 90°/85°		Pro/Sup: 90°/90°
4	M	54	Left	Clavicula	Shoulder	Flex/Ext: 174°/42°	Shoulder	Flex/Ext: 172°/40°
						Abd/Add: 165°/35°		Abd/Add: 170°/42°
						In/Ex Rot: 85°/85°		In/Ex Rot: 80°/85°
5	M	51	Right	Clavicula	Shoulder	Flex/Ext: 170°/35°	Shoulder	Flex/Ext: 174°/40°
						Abd/Add: 150°/35°		Abd/Add: 154°/40°
						In/Ex Rot: 70°/80°		In/Ex Rot: 78°/84°
6	M	34	Right	Humerus	Shoulder	Flex/Ext: 170°/40°	Shoulder	Flex/Ext: 180°/45°
						Abd/Add: 175°/40°		Abd/Add: 180°/45°
						In/Ex Rot: 85°/85°		In/Ex Rot: 90°/90°
					Elbow	Flex/Ext: 130°/0	Elbow	Flex/Ext: 135°/0
						Pro/Sup: 87°/90°		Pro/Sup: 90°/90°
7	M	11	Left	Ulna	Wrist	Flex/Ext: 78°/70°	Wrist	Flex/Ext: 80°/70°
						U/R Dev: 30°/20°		U/R Dev: 30°/20°
					Elbow	Flex/Ext: 130°/0	Elbow	Flex/Ext: 135°/0
						Pro/Sup: 86°/85°		Pro/Sup: 90°/90°
8	M	13	Right	Radius	Wrist	Flex/Ext: 80°/65°	Wrist	Flex/Ext: 80°/70°
						U/R Dev: 30°/17°		U/R Dev: 30°/20°
					Elbow	Flex/Ext: 130°/0	Elbow	Flex/Ext: 135°/0
						Pro/Sup: 90°/82°		Pro/Sup: 90°/90°
9	M	39	Right	Humerus	Shoulder	Flex/Ext: 172°/37°	Shoulder	Flex/Ext: 180°/45°
						Abd/Add: 170°/40°		Abd/Add: 180°/45°
						In/Ex Rot: 85°/80°		In/Ex Rot: 90°/90°
					Elbow	Flex/Ext: 105°/22°	Elbow	Flex/Ext: 135°/0
						Pro/Sup: 68°/72°		Pro/Sup: 90°/90°
10	F	42	Left	Humerus	Shoulder	Flex/Ext: 175°/40°	Shoulder	Flex/Ext: 180°/45°
						Abd/Add: 175°/40°		Abd/Add: 180°/45°
						In/Ex Rot: 87°/75°		In/Ex Rot: 90°/90°
					Elbow	Flex/Ext: 124°/0	Elbow	Flex/Ext: 135°/0
						Pro/Sup: 80°/85°		Pro/Sup: 90°/90°
11	M	54	Right	Radius	Wrist	Flex/Ext: 78°/65°	Wrist	Flex/Ext: 80°/70°
						U/R Dev: 28°/20°		U/R Dev: 30°/20°
					Elbow	Flex/Ext: 113°/12°	Elbow	Flex/Ext: 120°/17°
						Pro/Sup: 75°/70°		Pro/Sup: 80°/78°

ROM: Range of motion; Flex/Ext: Flexion/Extension; Abd/Add: Abduction/Adduction; In/Ex Rot: Internal/External rotation; U/R Dev: Ulnar/Radial deviation; Pro/Sup: Pronation/Supination; *All values are active ROM

Lenze et al. (10) reported that the union time of nine upper extremity cases that they reconstructed with NVFGs because of a tumor was an average of 22 weeks. In addition, they achieved 86% functional success.

Krieg et al. (23) reported that six of 46 patients who underwent reconstruction with NVFGs had upper extremity pseudarthrosis, and the union rate of these was 89% in 12 months and the median union time was 24 weeks. They also reported that the incidence of complications in these cases was 33%.

In our study, we achieved satisfactory results in all cases concerning upper extremity functionality, while the radiological union was seen in six months, consistent with the literature.

Lenze et al. (10) reported a direct proportional relationship between union time and defect size. Furthermore, Lenze et al. (10) also reported that the rate of mechanical complications was increased in NVFGs above 12 cm and Schuh et al. (24) reported 10 cm. Thus, the use of vascularized grafts became more advantageous. We determined 6 cm as the upper limit in our cases, and we did not encounter any mechanical complications.

Complication rates of vascularized fibula grafts have been reported to be 7%–35% and 3.3%–23.1% in several cases (23, 25). Although no serious complication was seen in our patients, two of them were treated early due to superficial infection.

Complications, such as peroneal nerve injury, compartment syndrome, localized muscle problems, and ankle instability, can be encountered during fibular grafting. Pacelli et al. (26) stated that after biomechanical analysis studies, there would be no negative reflection in the foot and ankle by removing the graft to leave at least 6–8 cm length distal to the fibula. To reduce the risk of nerve damage proximally, 4 cm of fibula should be preserved (26).

In our cases, we did not encounter donor site morbidity and/or lower extremity problems. This can be attributed to the use of the fibula graft according to the principles stated by Pacelli et al.

Krieg et al. (23) reported that the average duration of fibula remodeling was 3.6 years in 69% of cases in their study of NVFGs for lower and upper extremity defects. The mean age of the patients with remodeling was 16 years, while the mean age of those without remodeling was 38 years. Partial remodeling was observed radiologically at the last follow-up of the two patients in our study, but we think that longer follow-up periods are needed for this evaluation.

The most important limitation of our study is the number of patients. The most important reason for this is the low number of defects specific to the upper extremity and because the number of cases operated on with a diagnosis of pseudarthrosis is very low in our clinic. We think that more specific cases and bone-specific studies can provide more accurate results.

CONCLUSION

Although free vascularized bone grafts are a more popular and sophisticated method, NVFGs is still an effective method in short segment upper extremity defects, especially because of the shorter surgical time, lower complication rate, and simplicity in addition to lower morbidity at the graft donor site.

Ethics Committee Approval: This research was approved by the ethics board of Erciyes University Medical School, Melikgazi/Kayseri, Turkey (date: 08.052019, number: 2019/304).

Informed Consent: Written informed consent was obtained from patients who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – YE; Design – KG; Supervision – YE; Resource – YE, KG; Materials – YE, KG; Data Collection and/or Processing – YE, KG; Analysis and/or Interpretation – YE; Literature Search – KG; Writing – YE; Critical Reviews – KG.

Conflict of Interest: The authors have no conflict of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

REFERENCES

1. Myeroff C, Archdeacon M. Autogenous bone graft: donor sites and techniques. J Bone Joint Surg Am 2011; 93(23): 2227–36. [CrossRef]
2. Erol B, Basci O, Topkar MO, Caypinar B, Basar H, Tetik C. Mid-term radiological and functional results of biological reconstructions of extremity-located bone sarcomas in children and young adults. J Pediatr Orthop B 2015; 24(5): 469–48. [CrossRef]
3. Repo JP, Sommarhem A, Roine RP, Sintonen H, Halonen T, Tukiainen E. Free Vascularized Fibular Graft is Reliable in Upper Extremity Long-Bone Reconstruction with Good Long-Term Outcomes. J Reconstr Microsurg 2016; 32(7): 513–9. [CrossRef]
4. 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. [CrossRef]
5. Bernard de Dompsure R, Peter R, Hoffmeyer P. Uninfected nonunion of the humeral diaphyses: review of 21 patients treated with shingling, compression plate, and autologous bone graft. Orthop Traumatol Surg Res 2010; 96(2): 139–46. [CrossRef]
6. Jupiter JB, von Deck M. Ununited humeral diaphyses. J Shoulder Elbow Surg 1998; 7(6): 644–53. [CrossRef]
7. Loi F, Córdova LA, Pajarinen J, Lin TH, Yao Z, Goodman SB. Inflammation, fracture and bone repair. Bone 2016; 86: 119–30. [CrossRef]
8. Agarwal A, Kumar A. Fibula regeneration following non-vascularized graft harvest in children. Int Orthop 2016; 40(10): 2191–7. [CrossRef]
9. Hilven PH, Bayliss L, Cosker T, Dijkstra PD, Jutte PC, Lahoda LU, et al. The vascularised fibular graft for limb salvage after bone tumour surgery: a multicentre study. Bone Joint J 2015; 97-B(6): 853–61.
10. Lenze U, Kasal S, Hefti F, Krieg AH. Non-vascularised fibula grafts for reconstruction of segmental and hemicortical bone defects following meta- /diaphyseal tumour resection at the extremities. BMC Musculoskelet Disord 2017; 18(1): 289. [CrossRef]
11. El-Sayed M, El-Hadidi M, El-Adl W. Free non-vascularised fibular graft for treatment of post-traumatic bone defects. Acta Orthop Belg 2007; 73(1): 70–6.
12. Nataraj B, Singh V, Pathak AC, Jain M, Khapane V. Non-vascularized fibula and corticocancellous bone grafting for gap nonunion of lower limb-retrospective study of 18 cases-an age old technique revisited. Eur Orthop Traumatol 2014; 5(3): 277–83. [CrossRef]
13. Kennedy CA, Beaton DE, Smith P, Van Eerd D, Tang K, Inrig T, et al. Measurement properties of the QuickDASH (disabilities of the arm, shoulder and hand) outcome measure and cross-cultural adaptations of the QuickDASH: a systematic review. Qual Life Res 2013; 22(9): 2509–47. [CrossRef]
14. Çankaya M, Çıtak Karakaya İ, Karakaya MG. Reliability and validity of

the Turkish version of the Lower Extremity Functional Scale in patients with different lower limb musculoskeletal dysfunctions. Int J Ther Rehabil 2019; 26(9): 1–4. [CrossRef]

15. Sultan AA, Khlopas A, Surace P, Samuel LT, Faour M, Sodhi N, et al. The use of non-vascularized bone grafts to treat osteonecrosis of the femoral head: indications, techniques, and outcomes. Int Orthop 2019; 43(6): 1315–20. [CrossRef]
16. Sen MK, Miclau T. Autologous iliac crest bone graft: should it still be the gold standard for treating nonunions?. Injury 2007; 38 Suppl 1: S75–S80. [CrossRef]
17. Conway JD. Autograft and nonunions: morbidity with intramedullary bone graft versus iliac crest bone graft. Orthop Clin North Am 2010; 41(1): 75–84. [CrossRef]
18. Khan SN, Cammisa FP Jr, Sandhu HS, Diwan AD, Girardi FP, Lane JM. The biology of bone grafting. J Am Acad Orthop Surg 2005; 13(1): 77–86. [CrossRef]
19. Kessler P, Thorwarth M, Bloch-Birkholz A, Nkenke E, Neukam FW. Harvesting of bone from the iliac crest--comparison of the anterior and posterior sites. Br J Oral Maxillofac Surg 2005; 43(1): 51–6. [CrossRef]
20. Schmidmaier G, Herrmann S, Green J, Weber T, Scharfenberger A, Haas NP, et al. Quantitative assessment of growth factors in reaming aspirate, iliac crest, and platelet preparation. Bone 2006; 39(5): 1156–63. [CrossRef]
21. Micev AJ, Kalainov DM, Soneru AP. Masquelet technique for treatment of segmental bone loss in the upper extremity. J Hand Surg Am 2015; 40(3): 593–8. [CrossRef]
22. McCoy TH Jr, Kim HJ, Cross MB, Fragomen AT, Healey JH, Athanasian EA, et al. Bone tumor reconstruction with the Ilizarov method. J Surg Oncol 2013; 107(4): 343–52. [CrossRef]
23. Krieg AH, Hefti F. Reconstruction with non-vascularised fibular grafts after resection of bone tumours. J Bone Joint Surg Br 2007; 89(2): 215–21. [CrossRef]
24. Schuh R, Panotopoulos J, Puchner SE, Willegger M, Hobusch GM, Windhager R, et al. Vascularised or non-vascularised autologous fibular grafting for the reconstruction of a diaphyseal bone defect after resection of a musculoskeletal tumour. Bone Joint J 2014; 96-B(9): 1258–63. [CrossRef]
25. Landau MJ, Badash I, Yin C, Alluri RK, Patel KM. Free vascularized fibula grafting in the operative treatment of malignant bone tumors of the upper extremity: A systematic review of outcomes and complications. J Surg Oncol 2018; 117(7): 1432–9. [CrossRef]
26. 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. [CrossRef]