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Outcomes of Sling Procedure Using a Free Vascularized Fibular Graft After Resection of the Proximal Humerus

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Investigation performed at the National Cancer Center Hospital, Tokyo, Japan.

Background: The proximal humerus is a common site for both primary and metastatic bone tumors. Although various methods have been developed for reconstruction following resection of the proximal humerus, a consensus on which technique is best has not been established. We focused on the sling procedure using a free vascularized fibular graft (FVFG) and conducted what we believe to be the largest retrospective study of patients to undergo this surgery to date.

Methods: We retrospectively reviewed the data of 19 patients who underwent the sling procedure with use of an FVFG at our hospital between 1998 and 2022. The median age was 20 years, and the median follow-up duration was 63.1 months. Surgical data, oncological outcomes, the postoperative course, complications, and functional outcomes as measured with use of the Musculoskeletal Tumor Society (MSTS) score were thoroughly reviewed.

Results: The median operative duration was 555 minutes, and the median blood loss was 374 mL. The median length of the bone defect was 17.0 cm, and the median length of the graft was 20.0 cm. With respect to oncological outcomes, 9 patients were continuously disease-free, 9 patients had no evidence of disease, and 1 patient was alive with disease. Bone union was present in 13 of the 17 patients for whom it was evaluable. The median time to bone union was 4 months. Graft growth was observed in 2 pediatric patients. Postoperative fracture was a major complication at the recipient site. The incidence of pseudarthrosis significantly increased when the FVFG could not be inserted into the remaining humeral bone or was split in half ($p = 0.002$). Although a few patients demonstrated peroneal nerve palsy at the donor site, the symptom was temporary. The overall functional outcome was favorable, with an average MSTS score of 66.9%.

Conclusions: The sling procedure demonstrated a low complication rate and a favorable functional outcome overall. Therefore, we believe that this procedure is a useful reconstruction method for patients in a broad age range who have a wide defect of the proximal humerus.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

The proximal humerus is a common site for primary bone tumors, accounting for 10% to 15% of osteosarcomas and 15% to 20% of chondrosarcomas[1-4]. In addition, metastasis of malignancies to the humeral bone is frequently observed[5,6]. However, surgery that involves the shoulder girdle is challenging for orthopaedic oncologists because of the inherent mobility and need for stability of the glenohumeral joint. Furthermore, the proximity of complex neurovascular structures makes it difficult to obtain wide margins and to maintain function of the upper limb[7].

To achieve a favorable functional prognosis after surgery, various reconstruction methods have been developed, including biological reconstruction utilizing allografts or autografts, prosthetic reconstruction, and allograft-prosthetic composite reconstruction[8-10]. However, each of these techniques has its pros and cons, and there is no consensus on which technique is best.

Among reconstruction techniques, the sling procedure using a free vascularized fibular graft (FVFG) is an attractive method, especially for young patients[11-14]. The sling procedure

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is a representative biological reconstruction method that uses an autograft, and reoperation is fundamentally not required once the transplanted graft has achieved union. Therefore, it is a reconstruction method with permanent results, unlike prosthetic reconstruction, which requires revision surgery in the long term due to aseptic loosening, dislocation, and subluxation of the implant[12,15,16]. Furthermore, the growth of the transplanted graft is an advantage in young patients[12]. However, there have been fewer reports on the sling procedure than on other reconstruction methods, with a maximum of approximately 10 cases per study related to the sling procedure available for review.

Therefore, we retrospectively reviewed the data of 19 patients who underwent the sling procedure and assessed their clinical and functional outcomes.

Materials and Methods

Study Design and Setting

This retrospective observational study was approved by our institutional review board. We reviewed the data of 19 patients (10 males and 9 females) who underwent the sling procedure with use of an FVFG at our hospital between 1998 and 2022 (Table I). The median patient age was 20 years (range, 4 to 70 years), and the median follow-up duration was 63.1 months (range, 2.9 to 231.7 months). A total of 6 of the 19 patients were pediatric patients <15 years old with an epiphyseal growth plate that remained open. A total of 14 patients underwent the procedure as a primary reconstruction following tumor resection, and 5 patients underwent the procedure as a secondary salvage for subluxation or loosening of the implant. The histological diagnosis was osteosarcoma for 11 patients, chondrosarcoma for 3 patients, giant cell tumor of bone for 2 patients, Ewing sarcoma for 1 patient, malignant fibrous histiocytoma of bone for 1 patient, and soft-tissue sarcoma of the upper arm for 1 patient. Tumor sizes were measured macroscopically following surgery, and data were available for 18 patients. The median maximum diameter of the tumor was 10.9 cm (range, 6.2 to 23.0 cm). Malignant tumors were classified on the basis of the 8th edition of the American Joint Committee on Cancer (AJCC) cancer staging system. Three patients had a Stage-IB tumor, 1 had a Stage-IIA tumor, 4 had a Stage-IIB tumor, and 8 had a Stage-IVA tumor.

Surgical Procedure

We evaluated the extent of resection according to the classification system proposed by Malawer et al.[17]. During surgery, the orthopaedic surgery team performed the tumor resection or prosthesis removal and the plastic surgery team harvested the FVFG. The FVFG was harvested to be greater in length than the bone defect and was harvested with the biceps femoris tendon attached to the fibular head. The FVFG was slung by threading the biceps femoris tendon through the hole drilled at the acromion in cases in which the acromion was preserved (Malawer Type I) or at the distal part of the clavicle in cases in which the acromion was resected (Malawer Types IV and V). The tendon was folded back through the hole and then a tendon-to-tendon running suture was applied tightly with use of FiberWire (Arthrex). Furthermore, the FVFG was shaped by tapering the distal end or by splitting the distal end in half and inserted into the enlarged medullary cavity of the remaining humerus. The FVFG and remaining humerus were then fixed with use of a screw or plate. In cases in which insertion of the FVFG into the medullary cavity was difficult, end-to-end plate fixation was performed. Vascular anastomosis was performed by anastomosing the peroneal artery with the brachial artery or surrounding arteries. Venous anastomosis was also performed. A monitoring flap was made to evaluate the blood supply in all cases. Preoperatively, contrast-enhanced computed tomography and ultrasonography were performed to evaluate blood flow, and the area fed by perforating branches around the FVFG was utilized for the flap. For patients with large soft-tissue defects, a latissimus dorsi rotation flap was also utilized, and the resected deltoid muscle and rotator cuff were sutured to the flap. The skin

TABLE I Patient Characteristics (N = 19)*

Median age *(yr)*	20 (4-70)
Age, in years	
<15 (pediatric patients)	6 (31.6%)
15-40	7 (36.8%)
>40	6 (31.6%)
Sex	
Male	10 (52.6%)
Female	9 (47.4%)
Follow-up duration *(mo)*	63.1 (2.9-231.7)
Timing of reconstruction	
Primary	14 (73.7%)
Secondary	5 (26.3%)
Diagnosis	
Osteosarcoma	11 (57.9%)
Chondrosarcoma	3 (15.8%)
Giant cell tumor of bone	2 (10.5%)
Ewing sarcoma	1 (5.3%)
Malignant fibrous histiocytoma of bone	1 (5.3%)
Soft-tissue sarcoma of the upper arm	1 (5.3%)
Tumor size *(cm)*	10.9 (6.2-23.0)
Stage†	
IB	3 (15.8%)
IIA	1 (5.3%)
IIB	4 (21.1%)
IVA	8 (42.1%)
Intermediate	2 (10.5%)
Not available	1 (5.3%)

*Values are given as the median, with the range in parentheses, or as the number of patients, with the percentage in parentheses. †Tumors were classified according to the AJCC cancer staging system, 8th edition.

Fig. 1-A

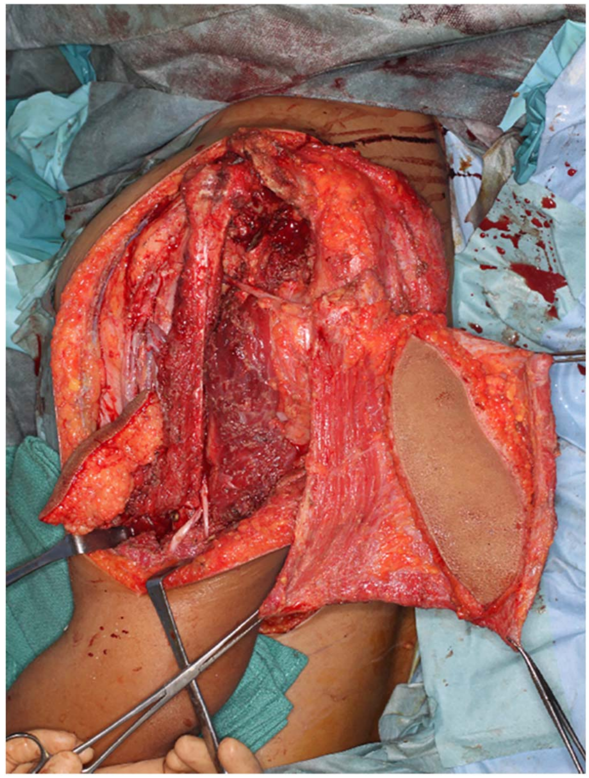

Fig. 1-B

Fig. 1-C

Fig. 1-D

Figs. 1-A through 1-D The surgical procedure. **Fig. 1-A** An FVFG was harvested with the biceps femoris tendon attached to the fibular head. In this case, a monitoring flap was also created to observe the blood flow. **Fig. 1-B** The graft was slung from the acromion. In addition, a latissimus dorsi rotation was performed to cover the soft-tissue defects. **Fig. 1-C** Postoperative radiograph showing the FVFG inserted into the remaining humeral bone and fixed with screws. **Fig. 1-D** Radiograph at the final follow-up (7 years postoperatively). Bone union was observed.

TABLE II Surgical Information and Oncological Outcomes (N = 19)*

Malawer classification	
IA	3 (15.8%)
IB	9 (47.4%)
IVB	1 (5.3%)
VB	5 (26.3%)
Not available	1 (5.3%)
Operative duration *(min)*	555 (374-775)
Blood loss *(mL)*	374 (100-885)
Latissimus dorsi rotation	
Performed	11 (57.9%)
Not performed	8 (42.1%)
Bone defect length *(cm)*	17.0 (11-25)
Graft length *(cm)*	20.0 (10-25)
Graft insertion	
Performed	14 (73.7%)
Performed with the graft edge split in half	3 (15.8%)
Not performed	2 (10.5%)
Graft fixation type	
Screw	14 (73.7%)
Plate	5 (26.3%)
Oncological outcome	
Continuously disease-free	9 (47.4%)
No evidence of disease	9 (47.4%)
Alive with disease	1 (5.3%)

*Values are given as the median, with the range in parentheses, or as the number of patients, with the percentage in parentheses.

above the latissimus dorsi muscle was also harvested and utilized for the monitoring flap as needed (Figs. 1-A through 1-D). Postoperatively, the forearm remained in a sling until callus was observed. Range-of-motion exercises distal to the elbow were permitted for rehabilitation early in the postoperative period.

Functional Evaluations

Postoperative function was evaluated with use of the Musculoskeletal Tumor Society (MSTS) score[18], which utilizes a scale of 0 to 5 points to evaluate each of the following 6 categories: pain, function, emotional acceptance, positioning of the hand, manual dexterity, and lifting ability. The score was determined by occupational therapists at 5 months postoperatively.

Statistical Analysis

We performed Fisher exact tests for categorical variables with use of GraphPad Prism (version 8.4.1; GraphPad). Significance was set to $p < 0.05$.

Source of Funding

No funding was received for this study.

Results

Surgical Information and Oncological Outcomes

The extent of resection was classified as Type IA for 3 patients, Type IB for 9 patients, Type IVB for 1 patient, and Type VB for 5 patients, according to the Malawer classification system. The median operative duration was 555 minutes (range, 374 to 775 minutes), and the median blood loss was 374 mL (range, 100 to 885 mL). A latissimus dorsi rotation was performed in 11 patients. The median length of the humeral bone defect was 17.0 cm (range, 11 to 25 cm). The median length of the FVFG was 20.0 cm (range, 10 to 25 cm). FVFG insertion into the remaining humeral bone was performed in 14 patients; FVFG insertion after half-splitting the graft edge, in 3 patients; and no FVFG insertion, in 2 patients. The graft was fixed with screws in 14 patients and with a plate in 5 patients. At the time of the latest follow-up, 9 patients were continuously disease-free, 9 had no evidence of disease, and 1 was alive with disease (Table II).

Postoperative Course and Complications

The postoperative course and complications are summarized in Table III. Of the 17 patients for whom bone union between the transplanted graft and remaining humeral bone was evaluable, bone union was observed in 13. The median time to bone union was 4 months (range, 2 to 10 months). Patients who were <15 years old demonstrated earlier bone union than those who were ≥15 years old (median time to bone union, 3 versus 6 months). In

TABLE III Postoperative Course and Complications (N = 19)*

Bone union status	
Union	13 (68.4%)
Pseudarthrosis	4 (21.1%)
Not available	2 (10.5%)
Time to bone union *(mo)*	4 (2-10)
Patients <15 years old (n = 6)	3 (2-4)
Patients ≥15 years old (n = 7)	6 (3-10)
Fibular head absorption	7 (36.8%)
Recipient-site complications	
Fracture	4 (21.1%)
Infection	2 (10.5%)
Monitoring flap trouble (necrosis or venous congestion)	2 (10.5%)
Donor-site complications	
Transient peroneal nerve palsy	2 (10.5%)
Infection	1 (5.3%)
Weakness of the EHL muscle	1 (5.3%)
Reoperation due to complications	2 (10.5%)

*Values are given as the median, with the range in parentheses, or as the number of patients, with the percentage in parentheses. EHL = extensor hallucis longus.

Fig. 2
Radiograph showing pseudarthrosis following end-to-end plate fixation.

contrast, 4 patients did not demonstrate bone union, indicating pseudarthrosis. Fibular head absorption was observed in 7 patients (median age, 14 years; range, 8 to 20 years), although the patients did not report any particular symptoms.

Recipient-site complications consisted of fracture in 4 patients, infection in 2 patients, and monitoring flap trouble (i.e., necrosis or venous congestion) in 2 patients. All 4 patients with a fracture eventually demonstrated pseudarthrosis. Donor-site complications consisted of transient peroneal nerve palsy in 2 patients, infection in 1 patient, and extensor hallucis longus muscle weakness in 1 patient. Both patients with peroneal nerve palsy recovered completely within 2 months. Finally, 2 patients with recipient-site complications underwent reoperation. There were no patients with knee instability or laxity.

Bone union was achieved in all 13 patients for whom insertion of the FVFG into the remaining humeral bone had been possible. In contrast, the incidence of pseudarthrosis significantly increased when insertion of the FVFG into the remaining humeral bone had not been possible or when the graft had been split in half ($p = 0.002$) (Fig. 2).

Growth of the Transplanted Graft

We evaluated the growth of the transplanted graft among pediatric patients who were <15 years old. Graft growth was observed in 2 of 6 patients. A 4-year-old boy demonstrated 5 cm of graft growth at 14 years postoperatively (Figs. 3-A and 3-B),

Fig. 3-A

Fig. 3-B

Figs. 3-A and 3-B Radiographs showing the growth of the transplanted graft in a single patient. **Fig. 3-A** Radiograph when the sling surgery was performed at 4 years old. **Fig. 3-B** Radiograph at 18 years old. The fibular graft grew 5 cm in 14 years.

and an 11-year-old boy demonstrated 1 cm of growth at 2 years postoperatively.

Functional Outcomes

A functional evaluation utilizing the MSTS score was performed for 15 patients (the remaining 4 patients had a short follow-up period and were excluded). The average scores for pain (4.87) and manual dexterity (5.0) were excellent. Function (average score, 3.2), emotional acceptance (3.07), and positioning of the hand (3.07) were satisfactory, with an average score of >3.0. In contrast, the average score for lifting ability (0.87) was poor. Consequently, the average overall rating was 66.9%. When excluding lifting ability, the rating was 76.8% (Fig. 4).

Discussion

The proximal humerus is frequently affected by both primary bone tumors and metastatic malignancies[1-6]. Although various reconstruction methods, such as allografts, autografts, and prostheses, have been developed, a consensus concerning which technique is best has not yet been established[8-10]. The sling procedure using an autograft is an attractive method, especially for young patients; however, reports of its clinical and functional outcomes have been limited[11-13]. Therefore, we conducted what is, to our knowledge, the largest retrospective study to date concerning the sling procedure.

A unique feature of our cohort was that patients were of a wider age range than those in previous studies of the sling procedure (Table IV). Whereas previous studies mainly consisted of pediatric patients and young adults (patients ≤40 years old), our cohort included patients >40 years old, in addition to younger patients. The sling procedure has typically been utilized for younger patients, whereas prosthetic reconstruction has tended to be performed for elderly patients[8-10]. In the present study, bone union was observed early after surgery, even in elderly patients, and the postoperative complication rate was low. In contrast, prosthetic reconstruction has been shown to frequently result in aseptic loosening, dislocation, and subluxation[12,15,16]. Furthermore, as a result of the limited durability of the prosthesis, implant failure is inevitable in the long term, with researchers having reported a reintervention rate as high as 35%[8,9]. Considering the complications of prosthetic reconstruction, the sling procedure using an FVFG may be an attractive surgical option, even for elderly patients.

One of the advantages of utilizing an FVFG is the capability to harvest long grafts. An FVFG of up to 26 cm can be harvested, allowing for the treatment of a wide range of bone defect sizes[19,20]. We actually achieved reconstruction with a graft that was 25 cm in length. Allografts may not be available in appropriate sizes, and the clavicula pro humero procedure, which is a different type of reconstruction method that utilizes a clavicle autograft, is limited in the graft length that can be harvested[7,21,22]. Furthermore, the sling procedure can be performed in patients who undergo extra-articular resection (Malawer Types IV and V) by suspension of the graft from the distal clavicle, whereas the clavicula pro humero procedure is not feasible in such cases. We therefore believe that the sling procedure has a positive effect on the oncological outcome, as reconstruction can be achieved even if extensive resection is performed with sufficient margins.

Although the sling procedure has been shown to have a lower complication rate than other reconstruction methods, complications such as postoperative fracture, pseudarthrosis, and infection have been reported[11-13] (Table IV). These complications were also observed in the present study. However, a

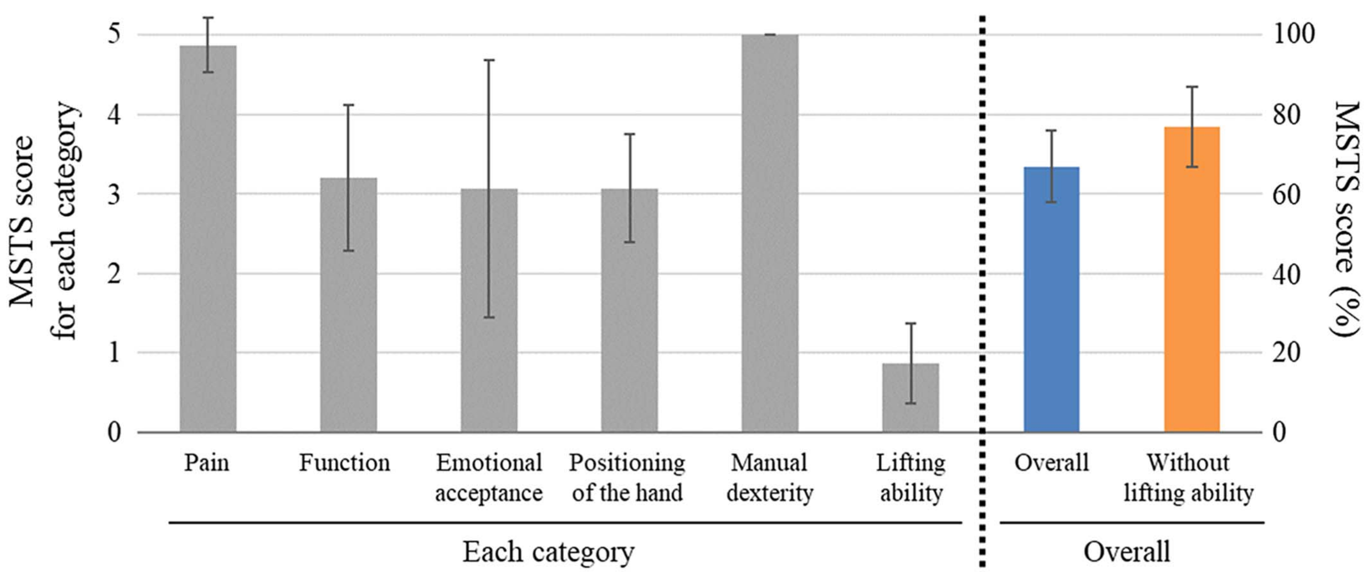

Fig. 4

Bar graphs showing the MSTS score for each category and overall. The average MSTS score was 66.9%. When excluding lifting ability, the MSTS score was 76.8%. The error bars indicate the standard deviation. The manual dexterity score was the same for all patients.

TABLE IV Comparison with Previous Reports*

Study	No. of Patients	Median Age (Range) *(yr)*	Median Follow-up Duration *(mo)*	Complications	Reoperation Rate Due to Complications	Graft Growth in Patients <15 Years Old	Average MSTS Score	Average MSTS Score without Lifting Ability
Wada et al.[11]	8	25 (10-47)	76	Fracture, delayed union, fibular head absorption	0%	N/A	79%	80%
Manfrini et al.[12]	11	5 (NA)†	110†	Fracture, infection	36%	At least 1 patient	76.3%	NA
Ejiri et al.[13]	3	12 (12-76)	118	Fibular head absorption	NA	NA	77.8%	78.7%
Present study	19	20 (4-70)	63.1	Fracture, infection, monitoring flap trouble, fibular head absorption, transient peroneal nerve palsy, EHL muscle weakness	10.5%	2 of 6 patients	66.9%	76.8%

*NA = not available, EHL = extensor hallucis longus. †Given as the mean.

fracture only occurred in patients who underwent end-to-end plate fixation, and bone union with only screws for fixation was achieved in all patients for whom it was possible to insert the FVFG into the remaining humeral bone. As evident by the significant differences in the rate of bone union between patients for whom the FVFG was successfully inserted into the medullary cavity and patients for whom the graft had to first be split in half or for whom graft insertion was impossible, appropriate shaping of the graft and the remaining humerus is necessary for intramedullary insertion of the graft. We believe that this process is key to reducing the risk of postoperative fracture and pseudarthrosis associated with the sling procedure. A problem specific to this reconstruction method is the effect on the donor site[8]. However, the peroneal nerve palsy and wound infection observed in our cohort were transient and relieved with conservative treatment. Thus, donor-site complications are not likely to be problems in the long term. Another complication frequently observed in the present study was fibular head absorption, but, consistent with the findings of Wada et al., it did not involve any clinical symptoms[11].

In the present study, growth of the transplanted graft was demonstrated in 2 of the 6 pediatric patients with an epiphyseal growth plate that remained open. A previous report emphasized the advantage of utilizing the anterior tibial artery as the vascular pedicle for graft growth since the blood flow to the fibular head and to the proximal two-thirds of the fibula is supplied by the anterior tibial artery[12,23]. However, graft growth was observed at a higher rate in our study than in previous reports, even though we utilized the peroneal artery as the vascular pedicle. Therefore, bone growth may occur regardless of the anastomotic artery. Interestingly, while this manuscript was in the publication process, Azoury et al. reported a high rate of bone growth following pediatric proximal humeral reconstruction using an FVFG with the anterior tibial artery[24]. However, there is still a lack of evidence in this regard, and further research is needed.

The overall functional outcome observed in our study was generally favorable and comparable with that in previous studies of the sling procedure and of other reconstruction methods, especially when excluding lifting ability (Table IV). In the sling procedure, the articular surface of the fibular head does not adequately match the glenoid, and the deltoid muscle and rotator cuff are extensively resected, thereby reducing lifting ability. In this context, the lifting ability in our study ranged from 0 to 2, but the score was lower than that reported in previous studies[11,13]. We scored upper-limb lifting ability that was based on elbow flexion as 0 or 1, whereas previous studies may have overestimated it, resulting in a higher score.

The present retrospective study had limitations. Although this study assessing sling surgery using an FVFG is, to our knowledge, the largest one of its kind, the number of patients in our cohort was still limited relative to that in studies of other reconstruction methods. Among studies involving prosthetic reconstruction, for example, 1 study included more than 80 patients at a single institute[25]. Therefore, further studies are required to confirm the clinical and functional outcomes of the sling procedure.

In conclusion, we retrospectively reviewed the largest number of patients to date to undergo the sling procedure using an FVFG. This reconstruction method demonstrated a low complication rate and a favorable functional outcome overall. We therefore conclude that the sling procedure is beneficial for patients in a broad age range who have a wide defect of the proximal humerus. ■

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