The use of autologous free vascularized fibula grafts in reconstruction of the mobile spine following tumor resection: surgical technique and outcomes

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OBJECTIVE Reconstruction of the mobile spine following total en bloc spondylectomy (TES) of one or multiple vertebral bodies in patients with malignant spinal tumors is a challenging procedure with high failure rates. A common reason for reconstructive failure is nonunion, which becomes more problematic when using local radiation therapy. Radiotherapy is an integral part of the management of primary malignant osseous tumors in the spine. Vascularized grafts may help prevent nonunion in the radiotherapy setting. The authors have utilized free vascularized fibular grafts (FVFGs) for reconstruction of the spine following TES. The purpose of this article is to describe the surgical technique for vascularized reconstruction of defects after TES. Additionally, the outcomes of consecutive cases treated with this technique are reported.

METHODS Thirty-nine patients were treated at the authors' tertiary care institution for malignant tumors in the mobile spine using FVFG following TES between 2010 and 2018. Postoperative union, reoperations, complications, neurological outcome, and survival were reported. The median follow-up duration was 50 months (range 14–109 months).

RESULTS The cohort consisted of 26 males (67%), and the median age was 58 years. Chordoma was the most prevalent tumor (67%), and the lumbar spine was most affected (46%). Complete union was seen in 26 patients (76%), the overall complication rate was 54%, and implant failure was the most common complication, with 13 patients (33%) affected. In 18 patients (46%), one or more reoperations were needed, and the fixation was surgically revised 15 times (42% of reoperations) in 10 patients (26%). A reconstruction below the L1 vertebra had a higher proportion of implant failure (67%; 8 of 12 patients) compared with higher resections (21%; 5 of 24 patients) ($p = 0.011$). Graft length, number of resected vertebrae, and docking the FVFG on the endplate or cancellous bone was not associated with union or implant failure on univariate analysis.

CONCLUSIONS The FVFG is an effective reconstruction technique, particularly in the cervicothoracic spine. However, high implant failure rates in the lumbar spine have been seen, which occurred even in cases in which the graft completely healed. Methods to increase the weight-bearing capacity of the graft in the lumbar spine should be considered in these reconstructions. Overall, the rates of failure and revision surgery for FVFG compare with previous reports on reconstruction after TES.

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KEYWORDS en bloc spondylectomy; mobile spine; primary tumor; reconstruction; vascularized graft; oncology

Negative margins have been linked to improved oncological outcomes for patients with primary malignant osseous tumors in the mobile spine.[1–5] Obtaining negative margins often requires total en bloc spondylectomy (TES). TES has been linked to significant patient morbidity in the perioperative setting. However, reconstructive failure after TES is also associated with morbidity.[6–9] Nonunion of the osseous reconstruction is one reason for reconstructive failure. We have utilized free vascularized fibular grafts (FVFGs) to help prevent

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ABBREVIATIONS ASIA = American Spinal Injury Association; EBL = estimated blood loss; FVFG = free vascularized fibular graft; TES = total en bloc spondylectomy.

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nonunion in the setting of TES while still maintaining adequate structural support.

Our center has combined TES with high-dose proton-based radiation therapy for the treatment of primary malignant tumors of the spine.[10,11] One reason to utilize radiotherapy is that negative margins cannot always be obtained with TES. In the case in which microscopically positive margins are present, we think that the addition of preoperative radiotherapy improves local control. Furthermore, recent studies have shown that, even with negative margins, local failure can occur late, particularly in chordoma, the most common primary malignant tumor of the spine.[12–16] We administer preoperative and postoperative radiation therapy since improved local control has been shown compared with postoperative radiation therapy alone.[17]

Although radiotherapy may be beneficial for improved local control, radiation negatively impacts bone biology, as an acute loss of bone density after preoperative radiation doses of 50 Gy was demonstrated.[18] This, coupled with the loss of osteoblastic activity in the radiation field, leads to a very unfriendly environment for bone healing.[19] To circumvent the problems with preoperative radiotherapy, we have routinely utilized FVFG reconstructions after resection of primary malignant osseous tumors of the spine.

The advantages of vascularized grafts have been demonstrated in previous studies, where the union rates are higher when compared with nonvascularized grafts.[7,8,20–23] Vascularized grafts have the added benefit of being harvested from outside the radiated field and therefore provide optimal biology for healing in the radiated bed. Furthermore, vascularized grafts can be harvested at lengths that would satisfy almost all spondylectomy defects. One of the key aspects of TES involves devascularizing the region of the spine involved with the malignancy. This leads to a large defect without a blood supply. The vascularized graft allows a conduit of healthy blood to be brought into the region.

The purpose of this article is to describe the surgical technique utilized for vascularized reconstruction of defects after TES. In addition, we report the outcomes of a consecutive series of patients treated with this technique.

Methods

Study Design and Participants

This retrospective study was approved by our institutional review board. We included all patients 18 years or older who underwent anterior spinal reconstruction using an autologous FVFG following TES of the mobile spine at a single tertiary care oncology referral center between January 2010 and July 2018. We identified 978 potentially eligible patients using the *International Classification of Diseases, Tenth Revision* diagnosis codes for any malignant neoplasm of the spine and Current Procedural Terminology codes for vertebral corpectomy or resection. After manually screening medical records of all eligible patients, 930 patients were excluded because they did not undergo TES with reconstruction using FVFG, and 9 patients were excluded because they had less than 12 months of follow-up. Ultimately, 39 patients were included.

Surgical Procedure

In all 39 cases, the FVFG was placed through the anterior approach in the anterior column of the spine. In 35 patients (90%), the surgery was performed in a staged fashion. In the first stage, posterior tumor resection and spinal stabilization were performed. In 4 patients (10%), who had either tumor recurrence or anterior implant failure following previous resections, the procedure was performed solely through the anterior approach. During the posterior stage, incision and dissection of the paraspinal muscles are performed with the patient placed prone, as has been thoroughly explained by Shah et al.[1] A summary of the posterior approach can be viewed in Video 1.

VIDEO 1. Surgical video explaining the posterior approach (stage 1). Copyright Michiel E. R. Bongers. Published with permission. Click here to view.

Tumor resection is sometimes possible from a posterior-only approach. It is often possible to identify and ligate the segmental vessels from the great vessels in the thorax and abdomen. The arterial vessels are typically easier to manage and more readily visualized and palpated as they come off the aorta. One must be particularly attentive to managing the vessels off of the vena cava and/or azygous vein. These vessels are less easily palpated and frequently less easily visualized. When the surgeon is confident that these vessels have been controlled, it is possible to remove the tumor from a posterior approach. However, in revision surgery the tissue is often more difficult to parse, making vascular injury more problematic. We favor a second stage in the revision setting to ensure adequate control of these vessels. When tumors are located in the lower lumbar spine and the segmental nerve roots are spared, the surgeon must contend with them when trying to remove the tumor from a posterior approach. In addition, the psoas muscle makes visualization and control of the vessels more difficult in the lower lumbar spine. For these reasons, we favor a staged approach for most tumors located in this region. It is possible to place an FVFG from a posterior approach. However, we find it safer and technically easier to place the graft from an anterior approach when the revascularization component of the operation is considered. Finding recipient vessels is usually easier from an anterior approach. Furthermore, the working space is more amenable to microvascular work from an anterior approach. In situations in which we want to use a vascular graft from a posterior-only approach, we often use a vascularized rib rotated into position onto the posterior elements rather than placing an FVFG.

A median 4 days later (IQR 2–6 days), the second stage was performed through the anterior approach. Depending on the location of the tumor, the patient is placed in the supine (cervical tumors) or lateral (thoracic and lumbar tumors) position (Fig. 1).

In all cases, the graft was harvested concurrently with the anterior stage, using a tourniquet on the thigh for a median of 90 minutes (IQR 70–104 minutes). For the harvesting of the FVFG, a longitudinal incision of the skin and facia is made on the lateral side of the leg. The peroneal muscles are then sharply elevated to visualize the fibula and the interosseous membrane between the fibula and tibia. The membrane is incised the entire length be-

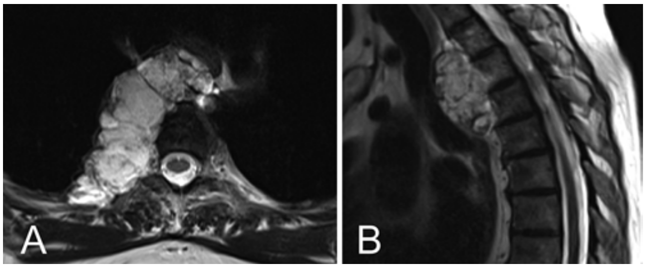

FIG. 1. Axial (**A**) and sagittal (**B**) T2-weighed MR images of a T2–5 chordoma.

tween the planned bone cuts; this should be done a couple of millimeters away from the fibula to protect the peroneal vessels. The distal vascular pedicle of the peroneal vessels can be identified medial to the fibula and posterior to the distal end of the flexor hallucis longus muscle. The proximal vascular pedicle is identified posterolateral to the fibula just proximal to the soleus muscle. After identification of both vascular pedicles, the bone cuts can be made while protecting and visualizing these vessels constantly; also, caution must be taken to protect the superficial peroneal nerve when making the proximal cut. Under continuous irrigation, to prevent thermal osteonecrosis, an oscillating saw is used to resect the fibula approximately 10 cm distal to the head of the fibula and 10 cm proximal to the lateral malleolus, with the peroneal vessel attached and intact.

Simultaneously with the harvest of the FVFG, the anterior part of the spine is exposed. Considering the anatomical challenges of the tumor location with different approaches, an oblique incision anteromedial of the sternocleidomastoid muscle (cervical tumors); thoracotomy, sternotomy, or sternothoracotomy (thoracic tumors); or a flank incision with a retroperitoneal approach to the spine (lumbar tumors) is performed. Using careful dissection, the mass can be mobilized and resected en bloc.[1] The tumor is brought to pathology for careful inspection by our musculoskeletal pathologist. At this moment, intraoperative dural plaque radiation therapy can be applied for patients with dural disease.[10,24]

Sizing the defect is a crucial step. Measuring the specimen is helpful, but the defect remaining after resection is the true dimension that must be filled. It is advisable to cut the FVFG slightly longer than the initial defect size to prevent the graft from being cut too short. When the size of the defect in the spine is determined, the fibula is marked, measuring from the distal to the proximal end. The periosteum with its surrounding vasculature is stripped from the proximal end of the fibula down to the planned osteotomy site, leaving a vascular leash. The oscillating saw is used to cut the fibula at the marked site under continuous irrigation. The proximal peroneal vessel is ligated at the most proximal attainable location to provide sufficient pedicle length for the anastomosis. Then the vessels are copiously injected with heparinized saline to prevent clot formation and to inspect for any major leaks.

It is important to note the quality of the endplate remaining after tumor resection. If the vertebral endplate has been removed, the graft will be positioned into cancellous bone and subsidence may occur if the quality of the bone is structurally insufficient. In some cases, the graft may be "potted" into the cancellous bone. The advantage of this technique is that it provides greater surface contact between the fibula and the vertebrae. In addition, it provides some increased stability of the fibula from lateral translation. However, if the bone quality is poor, as in cases of osteoporosis or if the vertebra has been irradiated, one might consider placing the graft on the closest available vertebral endplate rather than cancellous bone. This implies that a channel is constructed in the osteotomized vertebral segment to allow access to the next available endplate. This also implies that a longer FVFG is needed; thus, an assessment of the bone quality must be made in advance of this procedure. Once the true length of the defect has been determined, one can begin insertion. This can be done using a Penfield no. 1 probe with the angled end inserted between the intended endplate and the FVFG (Fig. 2). Once the graft is engaged on the vertebral endplate, the Penfield no. 1 probe can be removed, and the bone tamp can be used to gently tap the fibula into its final resting position (Fig. 3). It is important to remember that the vascular leash must be in a position to allow anastomosis with the recipient vessels (Fig. 4). Segmental vessels adjacent to the resection often make ideal recipient vessels. However, particularly in the revision setting, these vessels are not always available, and alternative vessels must be sought.

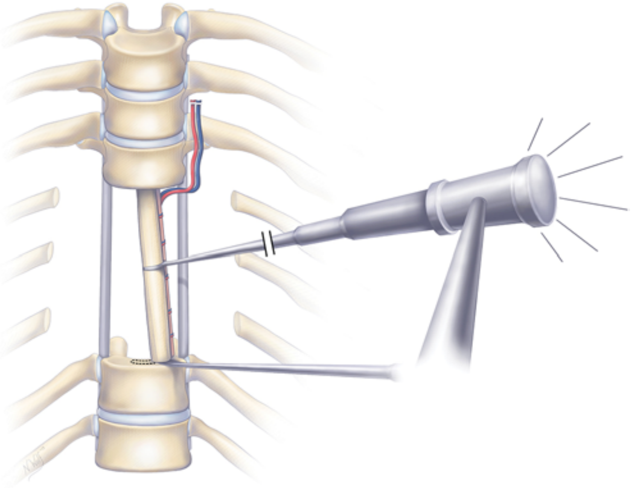

FIG. 2. The graft must be handled carefully with a Verbrugge or Kocher clamp, or by other means that allow control of the fibula, as the vascular supply is attached and must be protected. One end of the graft should be positioned so that the osteotomized end of the FVFG is nearly parallel to the intended vertebral endplate docking point. The other end of the graft will then be at an angle to the intended vertebral endplate docking point. It is this end of the graft that must be carefully maneuvered into position. The graft is secured by the surgeon in one hand. The Penfield no. 1 probe is held in position by the other hand. The assistant will then use a mallet and bone tamp to gently tap the graft as it glides over the curved end of the Penfield no. 1 probe. Illustration by Nicole Wolf, MS, ©2019. Printed with permission. Figure is available in color online only.

Further anterior implants are used to provide stability to the graft. In the thoracic or lumbar spine, we utilize

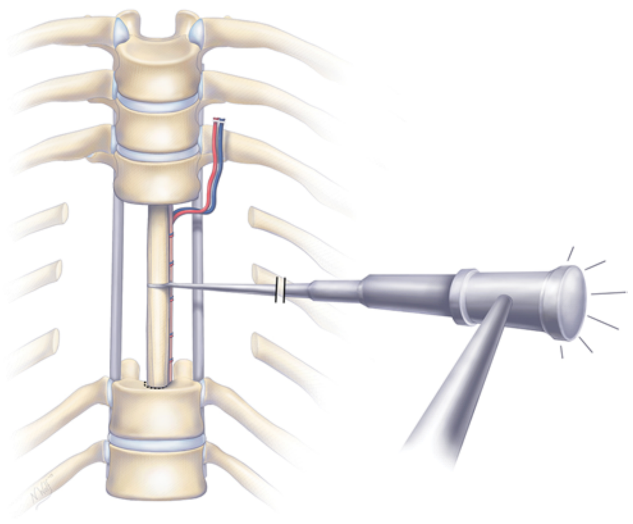

FIG. 3. The Penfield no. 1 probe can be removed, and the bone tamp can be used to gently tap the fibula into its final resting position. Once the graft is in position, it should be secure; one can manually test the stability of the graft to ensure it is indeed stable. Illustration by Nicole Wolf, MS, ©2019. Printed with permission. Figure is available in color online only.

vertebral body screws. We favor dual screw fixation per vertebral level, but single screws may be sufficient. A lateral or anterior plate can also be utilized (Fig. 5). We may or may not use a plate in the cervical spine, depending on the length of the graft and the initial stability of the fibula. A summary of the anterior approach can be viewed in Video 2.

VIDEO 2. Surgical video explaining the anterior approach (stage 2). Copyright Michiel E. R. Bongers. Published with permission. Click here to view.

Outcome Measures and Explanatory Variables

The primary outcome measure was union between the FVFG and the proximal and distal vertebral bodies. Union was defined as an external bridging callus at the proximal and distal ends of the graft, or the absence of osteotomy lines by reviewing 2D CT images; the presence of proximal and/or distal union was noted separately. This was performed blindly and separately by one orthopedic research fellow (M.E.R.B.) and two orthopedic spine surgery fellows (B.R. and A.P.); inconsistencies were checked by a musculoskeletal radiology fellow (K.F.C.). Union was calculated for 34 patients because 3 patients died prior to the 6-month follow-up and imaging was not available for 2 patients. The secondary outcome measure was reoperation, defined as any operation to the surgical site within 90 days following the index surgery due to surgical site infection or iatrogenic damage, or any surgery in the entire follow-up period due to nonunion, graft fracture, implant failure, or recurrence. Reasons for reoperation, complications, and neurological status using the American Spinal Injury Association (ASIA) Impairment Scale (complete palsy [ASIA grade A], incomplete palsy [ASIA grade B, C, or D], and no neurological abnormalities [ASIA grade E])[25] were also reported at the preoperative visit and 6 months after the index surgery. We manually extracted the following explanatory variables: age, sex, indication for the procedure, histological diagnosis, tumor volume (in cm^3), radiotherapy, chemotherapy, previous surgical treatment, length of hospitalization, length of stay in the ICU, spinal region, number of spine levels dissected, graft length (in cm), docking location of the FVFG (endplate or cancellous bone), duration of surgery (in minutes), estimated blood loss (EBL; in mL), and the blood vessels to which the graft's vessels were anastomosed. Patients with a resection involving the cervicothoracic junction (C7–T2) or with a resection in high kyphotic and lordotic stress segments of the spine (T10–L2, and L4 and below) were labeled as high-stress reconstruction patients to establish whether this had an effect on union or implant failure.

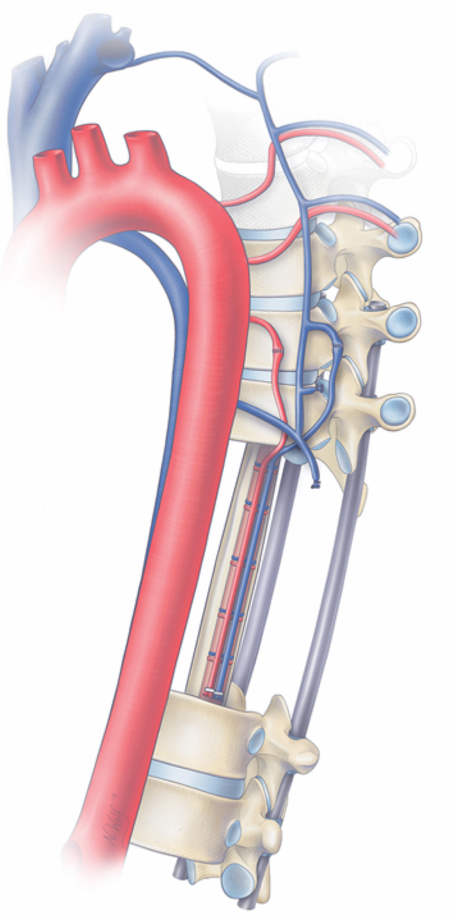

FIG. 4. The graft is securely in position and the vascular leash is in a relaxed position to allow anastomosis with the recipient vessels. Illustration by Nicole Wolf, MS, ©2019. Printed with permission. Figure is available in color online only.

Statistical Analysis

Categorical variables are presented as numbers and frequencies, and continuous variables are presented as medians and IQRs. The Fisher exact test and a univariate logistic regression were used to test the association be-

FIG. 5. Sagittal postoperative CT image of the reconstruction with the fused FVFG 6 months after surgery.

tween explanatory variables and outcomes. We used Stata version 15.1 (StataCorp) for all statistical analyses.

Results

Demographics

The median age was 58 years (IQR 43–63 years), and 26 patients (67%) were male. Chordoma was the most common tumor with 26 patients (67%) affected, followed by chondrosarcoma in 9 patients (23%); 1 patient (3%) underwent surgery for a metastasized stage IIIC (pT2-M1b) nonseminomatous germ cell tumor of the left testicle to the spine (Table 1). The median follow-up duration was 50 months (entire range 14–109 months).

Union

Both proximal and distal union of the FVFG were achieved in 26 of the 35 patients (76%) for whom union was reviewed. Five patients (15%) had union of only one side of the graft, and 3 patients (8.8%) had complete nonunion (Table 2). Univariate logistic regression revealed that there was no association between graft length and bilateral union (OR 0.74, 95% CI 0.55–1.01; p = 0.059). There was no difference in union rates between patients with a resection and reconstruction cranial to the L1 vertebra compared with more caudal resections (p = 0.098). There was no association between union and the number of resected vertebrae (p = 0.894), the reconstruction being in a high-stress spinal segment (p = 0.681), or the graft being docked on cancellous bone or the endplate (p = 0.061).

Reoperations

A total of 35 reoperations were performed in 18 patients (46%). Eight patients (21%) underwent a single reoperation, 5 patients (13%) had 2 reoperations, 3 patients (7.7%) had 3 reoperations, 1 patient (2.6%) had 4 reoperations, and 1 patient (2.6%) had 5 reoperations. In total, 13 patients (33%) experienced failure of the reconstruction: 3 (7.7%) for implant failure alone, 0 for nonunion alone, 3 (7.7%) for graft fracture, and 7 (18%) for a combination of these (Table 2). In 1 patient (2.8%) the posterior instrumentation was removed after union of the FVFG due to instrumentation complaints. Six patients (15%) required one or more reoperations for problems related to wound complication. In 3 patients (7.7%), a CSF leak was repaired in the first 90 days following placement of the FVFG.

Implant Failure

The fixation was surgically revised a total of 15 times (42% of reoperations) in 10 patients (26%). Within this group, revision was required due to a combination of implant failure and nonunion in 8 reoperations (53%), nonunion solely in 1 reoperation (6.7%), and solely due to implant failure in 6 reoperations (40%) (Table 3). On univariate logistic regression, there was no association between graft length and implant failure (OR 1.24, 95% CI 0.96–1.60; p > 0.99). Patients who underwent a resection and reconstruction below the L1 vertebra had a higher proportion of implant failure (67%; 8 of 12 patients) compared with patients with higher resections (21%; 5 of 24 patients) (p = 0.011). No association was found between implant failure and the number of resected vertebrae (p = 0.832) and if the reconstruction was in a high-stress spinal segment (p = 0.054). For the 3 patients with a fractured graft, all of the fractures occurred in the lumbar region, but only 1 patient underwent surgical intervention. One patient had initial pain that passed and does not have any difficulties to date accompanied with a healed graft on CT. The third patient has pain and decreased mobility but opted for conservative treatment of the fracture, where nonunion of the fractured graft is seen on CT scanning.

Operative Time, EBL, and Hospitalization

For the posterior stage of the surgery, which was calculated for the 35 patients who underwent the staged procedure, the median operative duration was 476 minutes (IQR 379–590 minutes), and the median EBL was 2100 mL (IQR 1450–3600 mL). The median duration of the anterior stage (all patients) was 561 minutes (IQR 447–657 minutes), and the median EBL was 2000 mL (IQR 850–3500 mL). The median length of hospitalization was 17

TABLE 1. Patient and treatment characteristics (n = 39)

	Value
Age at op in yrs, median (IQR)	58 (43–63)
Male patients, n (%)	26 (67)
Tumor region, n (%)	
Cervical	8 (21)
Thoracic	13 (33)
Lumbar	18 (46)
Tumor type, n (%)	
Chordoma	26 (67)
Chondrosarcoma	9 (23)
Fibrosarcoma	1 (3.0)
Osteochondroma	1 (3.0)
Low-grade myofibroblastic sarcoma	1 (3.0)
Metastasized nonseminomatous germ cell tumor	1 (3.0)
Indication for surgery, n (%)	
New oncological diagnosis	20 (51)
Oncological recurrence	8 (21)
Hardware or graft failure following previous resection	11 (28)
Spinal levels grafted, n (%)	
2	5 (13)
3	14 (36)
4	10 (26)
5	8 (21)
6	2 (5.0)
Graft length in cm, median (IQR)*	7.5 (6–10)
Duration of posterior stage in mins, median (IQR)†	476 (379–590)
Duration of anterior stage in mins, median (IQR)	561 (447–657)
EBL during posterior stage in mL, median (IQR)*†	2100 (1450–3600)
EBL during anterior stage in mL, median (IQR)*	2000 (850–3500)
Radiotherapy, n (%)	
None	1 (3.0)
Around previous resection	5 (13)
Preop	4 (10)
Pre- & intraop	4 (10)
Only intraop	1 (3.0)
Pre- & postop	10 (26)
Pre-, intra-, & postop	14 (36)
Radiotherapy dose in Gy, median (IQR)‡	68.4 (50.4–70.2)
Chemotherapy, n (%)	5 (13)
Tumor vol in cm^3, median (IQR)*	41.9 (6.2–128.9)
Duration of ischemia in leg in mins, median (IQR)*	90 (70–104)

* Missing values: graft length in 1 patient, EBL in 1 patient, tumor volume in 4 patients, time of ischemia in leg in 3 patients.

† Four patients underwent single-stage anterior surgery.

‡ Total external beam radiation therapy delivered to the mobile spine.

days (IQR 12–33 days), and the median length of stay in the ICU was 8 days (IQR 5–14 days) (Table 2).

Neurological Outcome

Preoperatively, 34 patients (87%) had no neurological deficit (ASIA grade E). Five patients had preoperative neurological deficits, 3 patients (7.7%) were classified as ASIA grade D, and 2 patients (5.1%) were classified as ASIA grade C. Six months after surgery, a neurological examination was performed in the 36 living patients; 33 patients

TABLE 2. Postoperative outcomes (n = 39)

	Value
Union of vascularized fibula graft, n (%)*	
Bilateral union	26 (76)
Unilateral union	5 (15)
Bilateral nonunion	3 (8.8)
No. of complications, n (%)	21 (54)
1	11 (28)
2	8 (20)
≥3	2 (5.1)
Complication type, n (%)	
Failure of reconstruction	
Implant failure solely	3 (7.7)
Nonunion solely*	0 (0)
First implant failure, later nonunion*	5 (15)
First nonunion, later implant failure*	2 (5.9)
Graft fracture†	3 (7.7)
Wound infection (superficial)	7 (18)
Of whom also deep infected	3 (7.7)
With wound dehiscence	3 (7.7)
CSF leak	3 (7.7)
Bacterial meningitis	2 (5.1)
Length of stay, median (IQR)	
Hospitalization	17 (12–33)
ICU‡	8 (5–14)
No. of reops, n (%)	18 (46)
1	8 (21)
2	5 (13)
≥3	5 (13)
Recurrence, n (%)	4 (10)
Postop survival in yrs, n (%)	
1	37 (95)
3	36 (92)
5	34 (87)

* Union was calculated for 34 patients, because 3 patients died prior to the 6-month follow-up and imaging was not available for 2 patients.
† All graft fractures occurred in the lumbar region.
‡ Length of stay in the ICU is missing in 1 patient.

TABLE 3. Reason for reoperations (n = 35)

	No. of Reops (%)
Implant failure or nonunion	
Combination of implant failure & nonunion	8 (23)
Implant failure	6 (17)
Nonunion	1 (2.9)
Wound infection/dehiscence	8 (23)
Recurrence	8 (23)
CSF leak	3 (8.6)
Instrumentation complaints	1 (2.9)

(92%) had no deficit (ASIA grade E), and 3 patients (8.3%) had ASIA grade D neurological deficit. The ASIA score for all 5 patients who had neurological deficit prior to surgery improved by 1 grade 6 months after surgery. One patient (2.8%) did have a lower ASIA score 6 months after surgery. Past the 6-month follow-up, the neurological status of 2 patients (5.6%) deteriorated to full paraplegia (ASIA grade A) due to recurrence and they died shortly after.

Survival

Six patients (15%) in this cohort died of disease during the course of the follow-up, and 2 patients died of cardiac arrest 10 and 21 days after surgery. Another patient died 5 months after surgery, and 3 patients died of disease 2.1, 3.5, and 3.5 years after surgery, respectively (Table 2).

Discussion

Numerous techniques exist for reconstruction of spinal defects after tumor resection. Potential advantages of FVFG over nonvascularized reconstruction techniques are tolerance to therapeutic levels of the postoperative radiation therapy, rapid consolidation, resistance to infection, and hypertrophic reaction.[7,22,26] The purpose of this study was to determine the postoperative outcome and complication rates in patients who underwent resection of a tumor in the mobile spine with a reconstruction using an FVFG.

Partial or complete nonunion was seen in 8 patients; however, 3 patients were without complaint and therefore no intervention was needed. Furthermore, there was implant failure in 33% of the patients, but fewer patients (26%) required revision surgery. Also, 10 patients underwent a reoperation for implant revision, even though in 3 patients the graft was completely fused. One patient experienced nonunion of the screws at nonresected caudal levels, but 2 patients had broken rods only without screw loosening or nonunion elsewhere. This probably indicates that the rods were carrying too much load, as the FVFG could not sufficiently unload enough of these forces, which we did see in 1 case (Fig. 6). Hence, the question arises as to how much union contributes to the structural support of the entire spinal reconstruction if failure can occur in the absence of nonunion. Possible explanations that graft length, the number of resected vertebrae, a high-stress spinal segment resection, and the graft being docked on cancellous bone or the endplate had no association with both union and implant failure on univariate analysis might be that 1) the load carried by the fibula is insufficient to fully unload the strain from the remaining implants, and over time it fatigues to failure; or 2) the number of patients is insufficient to show a significant difference.

Multiple reconstruction techniques other than FVFGs can be used for spinal reconstruction after tumor resection, such as nonvascularized autografts, allografts, and various types of cage implants.[27–34] Overall union rates vary between 36% and 100%, and implant failure rates between 0% and 51% have been reported following TES for both benign and malignant tumors.[35–38] Nonvascularized bone grafts have implant failure rates between 37% and 51%,

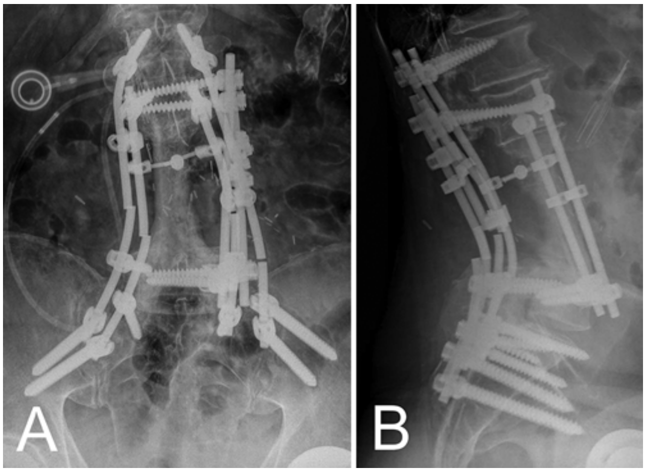

FIG. 6. Anteroposterior (**A**) and lateral (**B**) radiographs obtained in a patient with union of the FVFG, showing hypertrophy at docking sites; however, implant failure occurred 3 years after primary resection of the L2–5 vertebrae for chordoma, with multiple broken rods without screw loosening.

but no clear union rates have been reported.[20,39] Titanium and carbon mesh cages, or plates in combination with iliac crest bone autograft have been proven to be a viable method for reconstruction of the cervicothoracic spine disorders with reported union rates of 77% and implant failures of 27% and 40%, although the literature reports high complication rates in patients with malignant disease (78%).[36,38,40] The union and implant failure results in this study are comparable to those of other studies. However, we have seen that patients with lumbar spine resections were affected more by implant failure than those with cervical and thoracic resections, with no difference in union rates. We therefore have recently augmented the FVFG with an allograft sleeve for resections and reconstructions in the lumbar spine at our institution to provide extra stability and support but maintain the vascular component of the FVFG as has previously been described for extremity reconstructions.[41,42] A double-barrel FVFG is another technique that can increase the weight-bearing load of the reconstruction.

The overall complication rate in this study (54%) is comparable to that in studies using nonvascularized bone grafts (42.8%–65.2%).[20,29,43,44] In our cohort, 7 patients (18%) had wound-related complications, which is lower than the rate of other techniques (23.7%–26.1%).[44,45] Larger, probably multicenter, studies are needed to reestablish favorability of the FVFG as a reconstruction method following TES for malignant spinal disease.

The harvesting, and especially placement and vascular anastomosis of an FVFG procedure, is known to increase operative time by approximately 3–4 hours.[20,21,46] Unfortunately, no other study has reported the operative time for anteriorly placed nonvascularized fibula grafts or mesh cage placement in patients with spinal tumors, making a comparison impossible. Due to the fact that the harvesting of the FVFG is done during tourniquet compression of the thigh, the additional blood loss from this subprocedure is negligible.[21]

Although no patients had a complication at the donor site of the FVFG, late donor-site morbidity, such as chronic pain, gait abnormality, ankle instability, and sensory deficit, have been described,[47,48] all of which can potentially decrease quality of life. Therefore, larger multiinstitutional studies are needed to assess donor-site morbidity and its effects on the quality of life.

This study has several limitations. First, diagnostic codes were used to identify eligible patients. Patients may have been lost due to miscoding. Therefore, we intentionally used a broad search and manually reviewed all electronical medical records for eligibility. Second, due to the limited use of FVFG in the spine after tumor resection,[7,21–23] it is difficult to perform a prospective study or use a control group. Because of the retrospective nature of this study, limited data were available for collection, and, in some cases, variables were missing. Nonetheless, our primary outcome variables were all present, and no patients were lost to follow-up. Third, this is a single-center study, which may not be reflective of the experiences of other hospitals. Fourth, despite the minimum of 12 months of follow-up, recurrence and complications may have been underestimated for patients with a shorter follow-up. Fifth, due to the low number of included patients in this study, no multivariate analysis could be performed. The univariate analysis may not have reached significance for this reason.

Conclusions

The FVFG is an effective reconstruction technique, particularly in the cervicothoracic spine. However, high implant failure rates have been seen in the lumbar spine, which occurred even in cases in which the graft completely healed. Methods to increase the weight-bearing capacity of the graft in the lumbar spine should be considered in these reconstructions. Overall, the rates of failure and revision surgery for FVFG compare with those in previous reports on reconstruction after TES. Nonetheless, further studies are required to determine advantages over other reconstructive techniques and to assess which additional stabilizing constructions are most favorable.

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Disclosures

Dr. Hornicek: consultant for Stryker Medical, direct stock ownership in Bone Solutions, Inc., and board member of ISOLS.

Author Contributions

Conception and design: Bongers, Ogink, Lee, Hornicek, Schwab. Acquisition of data: Bongers, Chu, Patel, Rosenthal, Shin, Hornicek, Schwab. Analysis and interpretation of data: Bongers, Ogink, Chu, Patel, Rosenthal, Shin, Schwab. Drafting the article: Bongers, Shin, Lee. Critically revising the article: Ogink, Chu, Patel, Rosenthal, Shin, Lee, Hornicek, Schwab. Reviewed submitted version of manuscript: Bongers, Shin, Hornicek, Schwab. Approved the final version of the manuscript on behalf of all authors: Bongers. Statistical analysis: Bongers, Lee, Schwab. Administrative/technical/material support: Bongers, Hornicek, Schwab. Study supervision: Hornicek, Schwab.

Supplemental Information

Videos

Video 1. https://vimeo.com/442000092.
Video 2. https://vimeo.com/442000172.

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