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REVIEW ARTICLE

Free vascularised fibular grafts in orthopaedics

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Abstract Bony defects caused by trauma, tumors, infection or congenital anomalies can present a significant surgical challenge. Free vascularised fibular bone grafts (FVFGs) have proven to be extremely effective in managing larger defects (longer than 6 cm) where other conventional grafts have failed. FVFGs also have a role in the treatment of avascular necrosis (AVN) of the femoral head, failed spinal fusions and complex arthrodeses. Due to the fact that they have their own blood supply, FVFGs are effective even in cases where there is poor vascularity at the recipient site, such as in infection and following radiotherapy. This article discusses the versatility of the FVFG and its successful application to a variety of different pathologies. It also covers the applied anatomy, indications, operative techniques, complications and donor-site morbidity. Though technically challenging and demanding, the FVFG is an extremely useful salvage option and can facilitate limb reconstruction in the most complex of cases.

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Introduction

Bony defects caused by trauma, tumors, infection or congenital anomalies present a significant clinical challenge and can often result in significant patient disability or limb amputation. The same could be said of failed spinal fusions, complex arthrodeses and femoral-head avascular necrosis (AVN). Free vascularised fibular bone grafts (FVFGs) are extremely effective in managing all these conditions [1–3].

The first known bone transplants took place in the seventeenth century (Job van Meekeren, according to DeBoer) [4]. Despite the development of bone substitutes, growth factors, endoprostheses and distraction osteogenesis, bone grafts are still the most biological solution and remain the workhorse in most complex cases [5, 6]. Bone grafts can broadly be divided into nonvascularised (conventional) and vascularised grafts [1, 5, 7]. The key to the success of conventional bone grafting lies with the blood supply of the recipient bone and surrounding tissues. Without an adequate blood supply, nonvascularised grafts are incapable of remodeling, and the transplanted bone can fail to unite with the recipient bone [3]; only very few live osteocytes are able to survive beneath the periosteum, and most are subject to necrosis [5]. This is not the case with vascularised grafts, in which most cells remain alive, preserving bone remodeling, and the bone is able to integrate and even hypertrophy [5]. In these instances, the graft and recipient bone almost always unite and often show similar healing characteristics to those of a simple fracture [6, 8].

Vascularised bone grafts

A number of potential vascularised bone grafts can be harvested, including the fibula, iliac crest, rib, radius, ulna, scapula, femur, humerus, pubis and metatarsal. These grafts are based around their vascular supply and can be pedicled or free. The revascularised segments of bone then remain live and dynamic tissues at their recipient sites [5]. FVFGs have become the most commonly used free vascularised bone grafts and account for >600 published articles cited on PubMed. Although a pedicled fibula transfer was first used to fill an ipsilateral tibial defect (without microvascular anastomosis) in 1905 [9], the concept of performing a FVFG was only realised 70 years later [10]. FVFGs were initially used to treat posttraumatic bony defects; however, the indication rapidly broadened to include bony defects resulting from congenital anomalies, infections and tumors [1, 2], as well as salvage scenarios including problematic arthrodeses and the treatment of femoral head AVN [11–13]. They are currently the mainstay for extreme reconstructions largely because of their particular anatomical characteristics, reliability and versatility.

Fibular graft anatomy and structure

The fibula is extremely well suited as a graft and is considered to be a long-bone flap. It is long and straight, has good bone mass, a tricortical profile and can be up to 3 cm x 40 cm in size [14]. Its dimensions allow it to anatomically match forearm defects, and it can be fitted into the medullary canals of the larger long bones (humerus, femur and tibia) as a single- or a double-barrelled construct [2]. The fibular flap has a direct arterial supply from the peroneal artery. The length of artery required for microsurgical anastomosis is ~4–6 cm. The fibular diaphyseal bone has an endosteal and periosteal blood supply, and its endosteal vascularity usually comes from a single nutrient artery considered to be the dominant pedicle [5]. The entry point for the nutrient vessels (nutrient foramen) must be included when harvesting the graft and commonly lies posterior to the interosseous membrane in the middle third of the fibula at a mean of 17 cm (14–19 cm) below the styloid process. The periosteal circulation is a profuse and net-like structure supplying the outer third of the fibular bone and is considered to be the minor pedicle. It also originates from the peroneal artery and vein. The epiphyseal vascularity is derived from its surrounding vessels and predominantly from the anterior tibial artery. The overlying skin can also be raised with the fibular graft as a composite flap, and it is supplied by four to eight cutaneous perforators from the peroneal artery [2, 7].

FVFG versatility

The FVFG is a true composite graft and can be modified to suit many clinical situations. FVFG size can vary and include skin, fascia and muscle to add soft-tissue cover to any reconstruction [6]. Skin islands/pedicles can measure up to 10 cm x 20 cm and make it possible to directly monitor the viability of the pedicle anastomosis. The fibular graft can be transversely divided to create double-barrelled cortical struts on a single vascular pedicle, which can be helpful in addressing the cross-sectional mismatches between fibula and tibia/femur [7, 15]. Similarly, bilateral simultaneous FVFGs can be carried out to bridge longer femoral defects, avoiding the need to wait for graft hypertrophy to take place (and thus addressing the cross-sectional mismatch). The inclusion of an open proximal epiphysis in the FVFG can also enable/support the longitudinal growth of the graft in children [16].

Surgical technique

Preoperative planning for FVFGs begins with the exclusion of patients with peripheral vascular disease, deep venous thrombosis or previous damage to their blood vessels. One should be aware that 8 % of the population have hypoplasia or an absence of one or both of the anterior and posterior tibial arteries, a condition called peronea arteria magna, and FVFG harvesting in these patients can compromise their crural circulation [2, 7, 8].

The flap design depends on the requirements of the pathology one is treating and whether other tissues are needed as well as bone. In each case, it must be borne in mind that the peroneal artery should not be divided from the fibular bone during harvesting. It must also be noted that the main nutrient artery enters the fibula in the middle third of the bone, and sometimes in its proximal part, and the FVFG must therefore include this section of bone [2]. The size of the defect will determine the length of bone required; however, at least 6 cm of proximal and 4 cm of distal fibula should be left behind at the donor site. A lateral surgical approach is most commonly used for the osseous flap: Gilbert's modification of Taylor's original posterior approach [10, 17]. Modifications of this surgical approach are needed when raising an osteomuscular, osteocutaneous or proximal epiphyseal flap [9, 15, 16, 18–20].

Indications for FVFGs

FVFGs can be used in the management of bony defects (such as salvage after trauma, infection or tumor), in the treatment of congenital anomalies, for AVN, in arthrodeses and in special situations (such as an epiphyseal FVFG for paediatric pathology).

FVFG in trauma, infection and tumor

FVFGs are often used to the treat large posttraumatic defects caused by high-energy trauma (Fig. 1), as well large

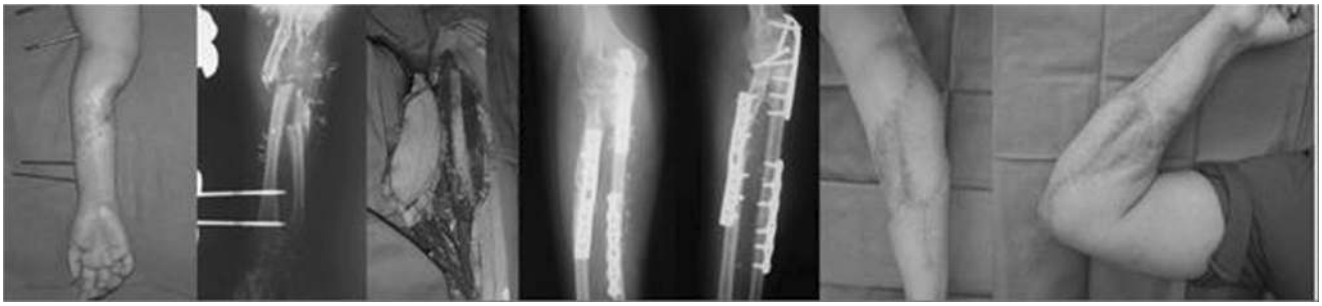

Fig. 1 A patient who suffered high-energy trauma to the right forearm treated initially with external fixation. The large ulna and soft-tissue defect has been reconstructed with an osteoseptocutaneous free vascularised fibular bone graft (FVFG) following debridement, with a good aesthetic and functional outcome

posttraumatic nonunions [21–25]. These injuries usually require combined soft-tissue and bony reconstructions, and other treatment options such as bone transport with/without muscle flaps can also be effective. The approach to these injuries is in the standard manner, with tetanus and antibiotic prophylaxis, copious irrigation and radical wound debridement. Immediate bony stabilisation is usually achieved with an external fixator [26, 27]. In the context of large injury zones with significant irreversible tissue damage/loss and bone defects >6 cm, FVFGs can facilitate a complete one-stage reconstruction (such as with an osteocutaneous graft) and can be performed in the early biological healing stages of these injuries [28, 29].

Bone defects that follow a radical debridement of infected tissues require a staged approach and are rarely managed at a single sitting [1, 2, 28–31]. Once the infection has subsided and the fracture stabilised, one should plan a second-stage reconstruction to resolve the bone defect. Various techniques have been used, including Ilizarov distraction osteogenesis; however, this often requires prolonged hospital stays and is fraught with numerous potential complications. These patients often have poor-quality, poorly vascularised, scarred-down, immobile tissues, and a single-stage osteocutaneous, osteomuscular or osteomusculocutaneous FVFG reconstruction may be preferable (for both the surgeon and the patient) if one can successfully secure a microvascular anastomosis. In cases of osteomyelitis, tumors and even higher-energy trauma, appropriate blood vessels may not be available for a microsurgical tissue transfer [32–40], and an arteriovenous (AV) fistula may be required to improve the success of any microvascular anastomosis [6].

In the past, malignant tumors were often treated with limb amputation; however, with current chemotherapy/radiotherapy and surgical techniques, survival rates of these sarcoma patients are similar to those undergoing limb reconstruction. These aggressive tumors often cause significant intercalary bony destruction, and reconstruction of the residual defects is necessary following their radical excision [32–40]. Larger defects can be bridged with large/massive allografts, endoprostheses, bone-transport osteogenesis techniques and the use of nonvascularised bone grafts. However, these techniques can be plagued by infection and bony nonunion, and the best biological option is probably a well-vascularised bone graft [1, 39]. FVFGs have very high bony union rates and can improve regional circulation, particularly when the surrounding tissues have been additionally damaged by chemotherapy and irradiation [39]. The biggest downside to using FVFGs in this context is their smaller cross-sectional diameter, particularly when reconstructing the femur, tibia and humerus; hence, there are usually delays in patient weightbearing. Graft hypertrophy takes time, which may be unacceptable in sarcoma patients who may have a shorter life expectancy, and it is sometimes necessary to use a double-barrel transplant or a combined FVFG and allograft in these cases [40, 41].

FVFG and congenital anomalies

Though successful in the treatment of many congenital anomalies, FVFGs are currently most commonly used to treat congenital pseudoarthrosis of the tibia (CPT), with the first reported case in 1978 [42–44]. CPT is notoriously difficult to treat, and many of these children end up with amputations. Most are now treated with radical resections and Ilizarov distraction osteogenesis; however, the apparatus can be cumbersome, and these small children and their families can struggle with the aftercare. FVFGs present a good alternative as a single-stage corrective procedure, with 78 % of patients achieving bony union and avoiding further surgery [43, 44] (Fig. 2). Recovery is also rapid in this patient group, with bony union and graft hypertrophy at a mean of four months [2]. FVFG is usually indicated in cases with defects >3 cm or in cases of failed previous surgery [4].

FVFG in avascular necrosis

Vascularised grafts can be used in the treatment of AVN at a variety of anatomical sites, though FVFGs are most

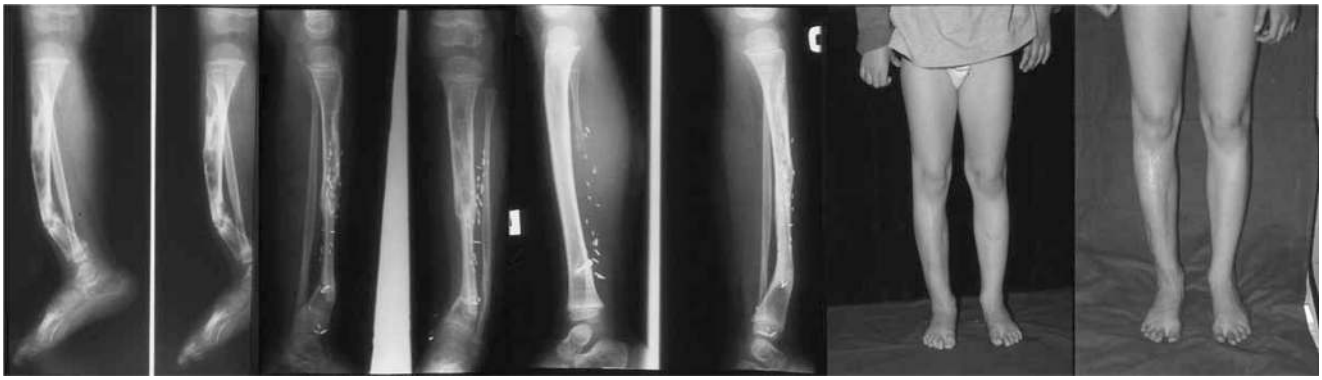

Fig. 2 A congenital pseudoarthrosis of the right tibia (CPT) following debridement and free vascularised fibular bone graft (FVFG) reconstruction. There is good hypertrophy at the end of the fibular graft and solid bony union at the proximal and distal graft sites

commonly used in young patients with hip AVN [2] (Fig. 3). Hip AVN has a tendency to progress rapidly and culminates in degenerative arthritis of the hip. A large number of surgical techniques have been devised in order to reverse the process and regain a painless mobile hip. However, treatment outcomes are highly unpredictable, particularly in the latter Ficat stages of the disease. The concept behind the use of FVFGs is to reduce the intraosseous pressure by removing necrotic tissue, preventing subchondral collapse and revascularising the femoral head. Some authors have also suggested packing the defect with allograft bone chips or calcium sulphate crystals prior to implanting the FVFG [45]. Since its introduction in 1979, this technique has shown superiority over nonvascularised grafts [11–13, 46, 47] and to significantly reduce the need for hip replacement surgery. Only 8 % of patients needed joint replacement in one study [48], and surgery was postponed by up to seven years in 70 % of patients in another report [9]. FVFGs have also been successful in treating teenagers with posttraumatic AVN [48, 49], improving Harris hip scores (HHS) from 60.4 to 94.2, and appear to give more successful outcomes than other joint-preserving procedures [48–50]. Ultimately, the success of FVFGs depends on AVN aetiology, stage and size [13].

FVFG and arthrodesis

FVFGs can be used for joint arthrodesis following tumor resections, in cases plagued by infection or when the soft-tissue envelope is poor following radiotherapy and chemotherapy. They are also effective in a variety of spinal pathologies, including large segmental defects and where spinal fusions have failed using other conventional methods, such as nonvascularised bone grafts [51, 52].

Special considerations

Due to the great versatility of FVFGs, there are many reports of their use in difficult and salvage situations [53]. One of these is their use for osteoarticular defects in children. It is possible to substitute these defects and retain/preserve longitudinal growth by using a vascularised proximal epiphyseal section of the fibula. This technique was used successfully in reconstruction of the distal radius in a series of children in whom the transplanted fibula grew at the same rate as the host bone (resulting in no ulnar discrepancy), the articular surface remodeled and hand and wrist function were thereby preserved [35].

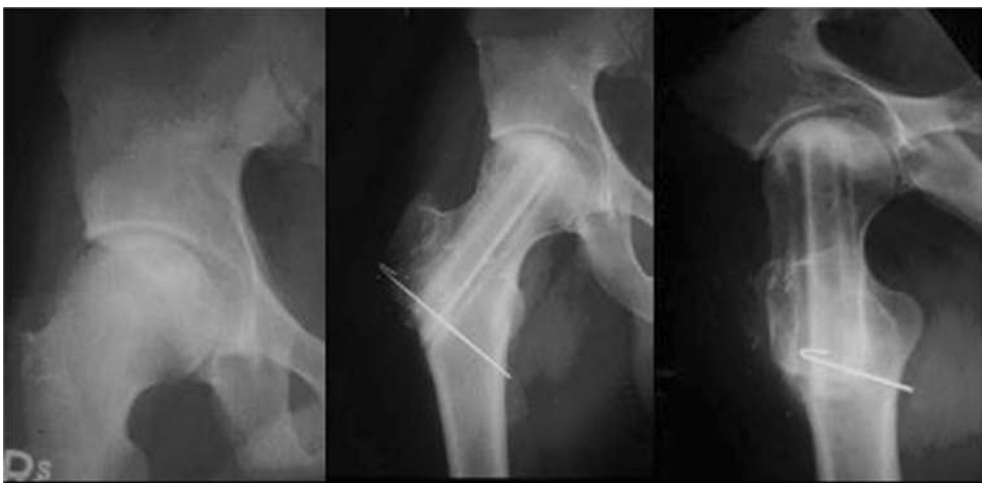

Fig. 3 Avascular necrosis (AVN) of the femoral head treated with a free vascularised fibular graft (FVFG). A good result was achieved, with no evidence of AVN progression at 6 years of follow-up

FVFG contraindication

FVFG is contraindicated if there is absence of vessels at the donor or recipient site.

FVFG complications

Acute, subacute and delayed complications can occur at both the donor and recipient sites. Early complications include uncontrolled bleeding at the site of a technically poorly performed microvascular anastomosis or following failure of adequate hemostasis. Thrombosis of the anastomosis can also result from poor surgical technique, poor choice of recipient vessels (restricted arterial flow and/or slow venous drainage), inadequate peroneal pedicle length and torsion of the vascular pedicle. Subacute vessel thrombosis can also occur at the recipient site for the same reasons, and the donor site can suffer compartment syndrome following poor haemostasis or if the deep fascia is closed too tightly (particularly with osteocutaneous flaps).

Late complications include nonunion and inadequate graft hypertrophy, which often reflect insufficient vascularisation. Infection can also occur later (as well as subacutely) due to poor vascularity of the FVFG and soft-tissue envelope, and sometimes due to inadequate initial debridement/resection of infected bone foci. Graft fractures can also occur, and some studies have reported tibial stress fractures in 35 % and femoral stress fractures in 32 % of patients [54]. There are many reports of donor-site morbidity, muscle weakness, foot pain and valgus ankle deformity, particularly where there has been no fibular transfixion or where too little residual fibular bone has been left [55–58].

Conclusion

This review demonstrates the great versatility of the FVFG as applied to a wide variety of different pathologies. Though technically challenging, it is an extremely useful salvage option and can facilitate limb reconstruction in the most complex of cases.

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