MASTERCLASS ARTICLE

The Pedicled Fibula Flap for Lower Limb Reconstruction

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Abstract

The pedicled fibula flap is a reliable technique to treat large defects in the tibia. Despite increasing evidence of its efficacy and good long-term outcomes, a knowledge gap exists in its indications and technique. This instructional article presents a comprehensive overview of the indications, pre-operative planning, step-by-step surgery, and subsequent post-operative management.

Keywords: Critical bone defect, Fibula flap, Limb reconstruction, Orthoplastic, Pedicled flap, Skin island, Surgical technique, Tibia, Vascularised bone flap.

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Indications

The pedicled fibula flap can be used for the management of segmental defects or large partial defects of the tibia. Additionally, the technique is used for hind foot or mid foot defects and as part of salvage arthrodesis after a failed knee arthroplasty.[1–5]

Indications of this technique include the following reconstructive challenges:

- Acute bone loss after trauma or tibial resections in oncology.
- After debridement in osteomyelitis or fracture related infections
- Atrophic non-unions.
- Salvage procedure (arthrodesis) after multiple failed prosthetic knee replacements.

Vascularised bone flaps were introduced in the 19th century when Curtis recognized the importance of maintaining a viable blood supply to enable confident bone healing and reduce resorption rates.[6] Since then, autologous bone transfer techniques have undergone significant advancements and the fibula has emerged as a highly reliable flap for oromandibular, upper, and lower limb reconstructions amongst other indications. The fibula offers several advantageous characteristics including a predictable pedicle, potential for hypertrophy, and a suitable shape and size for grafting purposes. Notably in 1905, Huntington gained prominence for implementing fibula transfers to address non-unions of the tibia ("fibula pro tibia") in patients.[7] This marked a significant milestone in the utilization of the fibula for reconstructive purposes. However, in this original procedure, the fibula was translated without dissection of the vascular pedicle. This may work in some specific situations but a proper dissection of the vascular pedicle offers a larger reach and a more predictable vascular status of the flap.

Variations in the Use of the Pedicled Fibula Flap

Depending on the location of the defect, a proximally or distally pedicled fibula flap can be used. The proximal pedicle is most suitable for proximal and middle tibial defects. Additionally, it can be utilized as vascularised bone stock as part of salvage procedures in failed knee arthrodeses.[5] Alternatively, for distal tibial defects, the distally based pedicled fibula can provide excellent bone stock with its blood supply depending on retrograde flow through the distal anastomosis between the posterior tibial and peroneal artery. In most cases, the distally based pedicled fibula flap can also be utilized for bone defects around the ankle and in the foot. If the (distal) pedicle is not patent or does not have enough length to reach the defect, the fibula flap (ipsilateral or contralateral) can still be used as a free flap; if this strategy is considered, then other free vascularised bone flaps can also be used.

The fibula flap offers the opportunity to include muscle and skin for soft tissue reconstruction.[8,9] The fibula itself can be folded as a double or triple barrel transfer depending on the size and location of the defect thereby increasing the cross-sectional area and strength. Moreover, the vascularised living bone acts as a primary source of osteogenic cells which facilitates union and can be associated with lower infection rates.[10–13]

Contraindications

The use of this technique may be contraindicated in the following cases:

- Vascular damage or peripheral vascular disease affecting the blood supply of the lower leg.
- A history of severe injury to the lower leg, including the fibula, such as crush or multilevel fractures.

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Alternative Techniques

These include bone transport (including shortening and re-lengthening or classic bone transport), the induced membrane (Masquelet) technique, autologous non-vascularised bone grafting, and other vascularised tissue transfer such as iliac or scapula flaps. Bone transport is popular and recommended especially if the fibula cannot be used. It is, however, associated with a lengthy period of external fixation and there are often secondary procedures (docking sites), the risk of pin-site infections, joint stiffness, and bone alignment issues. There is also a need for repeated and regular outpatient follow-up.[14,15]

Pre-op Planning and Work-up

A thorough clinical evaluation of the patient including the characteristics of the defect and the condition of surrounding bone and soft tissues is essential. The surgeon should assess the extent of bone loss, the affected level of the tibia (proximal, middle, or distal), and the associated soft tissue damage. Plain X-rays and CT scans are used to evaluate the location and type of bone defect and possible damage to the adjacent joints. In cases of deep infection, additional investigations may include serum inflammatory markers and other imaging techniques (i.e., MRI or PET-CT scanning) in order to formulate a detailed treatment plan. To evaluate the neurovascular status of the leg, clinical assessment, duplex scanning and CT-Angiogram are used together with other forms of angiography. In our centre, we use the angiogram specifically to verify the patency of the distal pedicle.

Equipment and Other Requirements

Fine instruments (as used for flap procedures by plastic surgeons), loupe magnification or microscope use (depending on surgeon preference and patient characteristics) or both, an oscillating saw, and implants for osteosynthesis.

Consent Issues

Our centre has reported high union rates with low complications, a low risk for amputation and limited donor site morbidity in cases of severe injuries.[16]

The general risks of this procedure include bleeding, infection, scarring, delayed wound healing or inadequate soft-tissue coverage.

The specific risks are peroneal nerve injury, a great toe contracture, delayed or non-union, graft fracture, graft or skin island failure, leg length discrepancy and malalignment.

Set-up in Theatre

General anaesthesia is used. Antibiotic prophylaxis is administered at the start of the procedure and the choice may depend on cultures taken in cases of infection. The patient is placed in a supine or lateral position with the knee and hip flexed. On the affected side, the hip is elevated slightly with a folded towel to enable better access to the dorsolateral side of the lower leg. A sandbag is used under the sole of the affected leg to keep the knee in flexion. A tourniquet may be used during the dissection of the fibula although we perform the procedure without a tourniquet. This offers several advantages including a reduction of postoperative oedema which then facilitates primary wound closure and subsequent healing. Not using a tourniquet also avoids producing ischaemia in an already traumatised leg.[17] The reduction of blood loss with a tourniquet is relative as bleeding occurs after the release of the tourniquet. With practice, blood loss without a tourniquet is minimal.

Fig. 1: Case example of an open comminuted proximal tibia fracture leading to significant bone loss

Procedural Steps

- Defining the bone defect and developing a reconstructive plan.
- General consideration and skin markings.
- Posterior approach: freeing the fibula of the superficial posterior compartment.
- Freeing the fibula from the lateral compartment.
- Freeing the fibula from the anterior compartment.
- Proximal and distal osteotomies.
- Freeing the membrane and the posterior compartment from the fibula.
- The middle osteotomy, tunnelling and placement in the bone defect.
- Review the result and fixation in the bone defect with plates/screws, closure.

The following instructions outline the surgical technique for reconstructing a bone defect in the proximal third of the tibia (Figs 1 and 2).

The first step is a careful inspection of the soft tissue and bone defect of the tibia after removal of any external fixation and material that might have been used for dead space management. A further debridement is performed if this is required. When a healthy wound bed is created, the plan for reconstruction can be revised and adjusted accordingly (Fig. 3). Careful planning plays a pivotal role; favourable outcomes depend on more than just the correct technical dissection of the fibula flap. In reconstruction using a pedicled fibula flap, the tunnelling technique, adequate positioning and protection of the vascular pedicle, well-located osteotomies, mechanically correct placement of the transferred fibula and its stable fixation are key factors for a successful outcome. We advocate a posterior approach because it allows visualization of the most important structures early in the procedure. This facilitates adjustments to the projection of the skin island to ensure a favourable entry point for the perforators.

The following describes the dissection of the fibula flap. As the skin perforators are septocutaneous perforators, lying just behind the posterolateral septum, we palpate for, identify and mark out

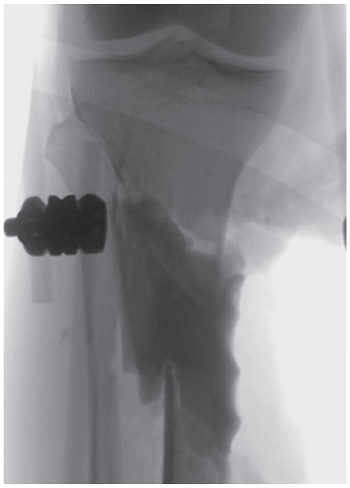

Fig. 2: Debridement of debris and devitalized tissue after which a cement spacer was placed in the defect. Primary stabilisation was achieved through external fixation

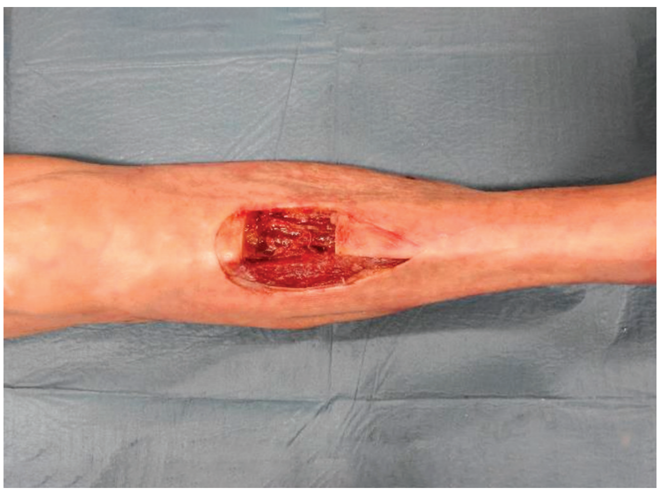

Fig. 3: Cadaver example of a segmental defect of the proximal tibia after debridement

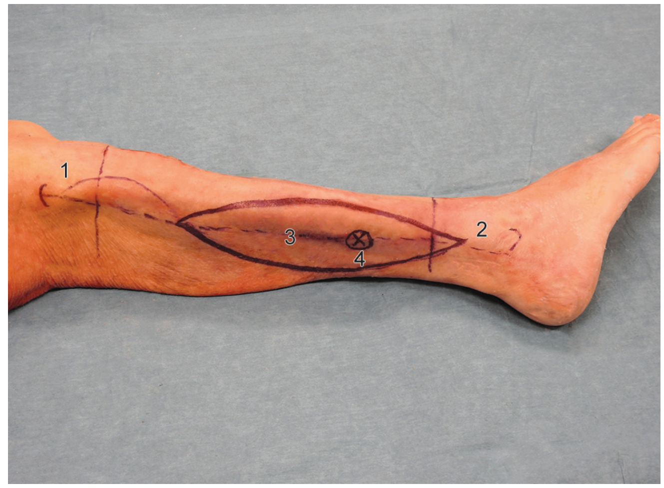

Fig. 4: Lateral view of the lower leg, with a mark 5 cm below the fibular head and 8 cm above the lateral malleolus, indicating the two levels of osteotomies (1, 2). Interrupted line indicating the posterolateral septum (3). Design of a skin island (bold lines) after locating skin perforator(s) (with Doppler) (4)

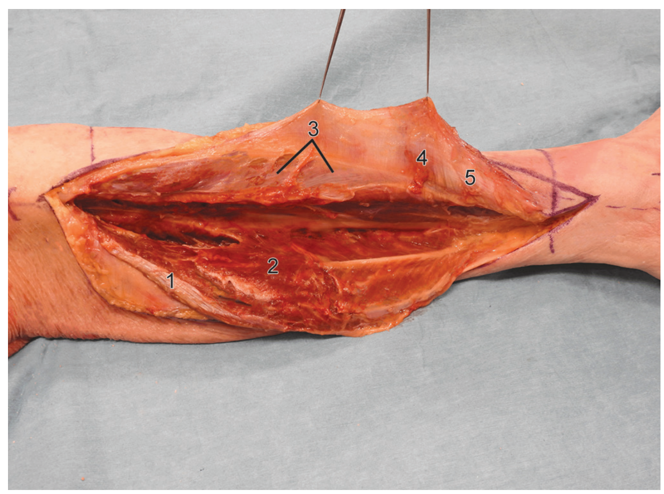

Fig. 5: After releasing the lateral gastrocnemius (1) and the soleus (2) from the posterolateral intermuscular septum (3) and preserving two skin perforators (4, 5)

this septum on the skin. The skin paddle is designed along this line, with 60% of the area posterior to it. It is advisable to be prepared to use a split-thickness skin graft to close the donor site," when primary closure is not feasible". Next, mark out 5 cm below the fibular head and 8 cm above the lateral malleolus indicating the two maximal levels of osteotomies with acceptable donor site morbidity (Fig. 4). If no skin island is needed, a straight line or lazy incision can be used over or just posterior to the posterolateral septum.

Otherwise, a skin incision is made on the posterior border of the skin island. The soleus muscle is reached after proceeding through subcutaneous tissue and incising the fascia. The avascular plane is followed anteriorly, taking note to identify the posterolateral intermuscular septum which contains the skin perforators from the fibular artery that supply the skin island.

The fibula is reached following this plane deeply. Once the posterolateral surface of the fibula is reached, the soleus muscle (with the overlying gastrocnemius) can be freed from the fibula over its full length. At the position of the skin perforators, there will also be muscular branches to the soleus (Fig. 5). In the lower 2/3rd of the leg, these branches to the soleus muscle do not feed into the skin perforators and thus there is no need to dissect them from the muscle; these branches can be clipped or electro-cauterised with bipolar diathermy. Proximal to the origin of the flexor hallucis longus (FHL) muscle, the skin perforators often run through the soleus muscle. Consequently, if a proximal skin island is required, these perforators should be dissected out of the soleus muscle and followed up to their origin which may be proximal to the bifurcation of the fibular and posterior tibial artery. Therefore, a proximal skin island may necessitate a separate anastomosis.

Continue by incising the fascia of the FHL muscle. This will facilitate the dissection in a later stage when the tibialis posterior muscle needs to be transected. If a skin island is required, proceed by making the anterior skin incision and approaching the fibula from the ventral side of the posterior lateral septum (Fig. 6). If a skin island is not required, the posterolateral septum can now

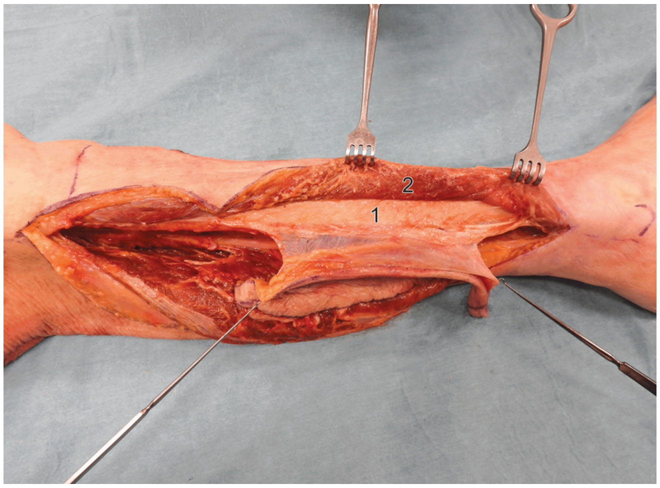

Fig. 6: Anterior approach of the fibula when including the skin island. Release the fibula (1) from the peroneus longus and brevis muscles (2)

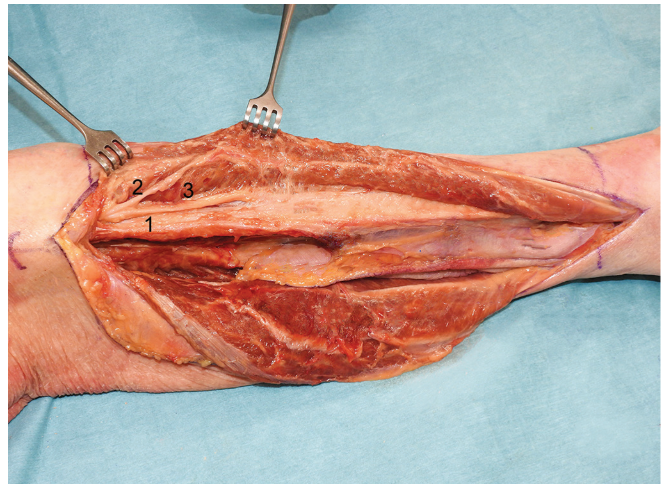

Fig. 7: The proximal fibula (1) exposed with the superficial peroneal nerve (2) and the deep peroneal nerve (3) indicate deep peroneal nerve

be dissected, sacrificing the skin perforators from the fibular and peroneal arteries.

The peroneus longus and brevis muscles are released from the fibula (Fig. 6). Be careful not to damage the muscle branches of the skin perforators that pass through the septum. These should be clipped or ligated and transected. Care is needed not to damage the skin perforators when doing this if the perforators are to be preserved for the skin island. Continue freeing the muscle in the extraperiosteal plane. Note that the periosteum should be preserved over the fibula. Proximally, the neurovascular bundle to the peroneal muscles will be very close to the fibula. Take great care to preserve this (Fig. 7). When freeing the muscles of the anterior compartment from the fibula, transect the anterolateral septum close to the fibula as the anterior tibial artery and peroneal nerve will be near the fibula and will need to be protected carefully (Fig. 8). The interosseous membrane is located only a few millimetres medially from the anterolateral septum as the bony surface of the fibula facing the anterior compartment is small.

When this point is reached, the proximal and distal fibula osteotomies are performed next with care, using retractors to protect the soft tissue while using a cooled oscillating saw (Figs 9 to 11). The interosseous membrane is dissected with scissors from the bone and the fibula is rotated outward using a bone hook placed in the distal intramedullary canal. Next, the distal vascular pedicle is exposed clearly by freeing it from the FHL muscle (Fig. 12). For a proximally pedicled flap, the distal pedicle may be ligated and cut at this stage of the procedure. The vascular pedicle runs between the FHL and the tibialis posterior muscle. The easiest way to free the fibula without damaging the pedicle is to dissect from distal to proximal, following the middle of the V shape in the tibialis posterior muscle, keeping the vascular bundle on the side of the fibula. There will be many muscular vascular branches to coagulate and transect (Fig. 13). The tibial nerve can be seen clearly and marks the medial border of the dissection. The FHL can be dissected with the flap, thereby saving time. The FHL can be released at the level of the distal osteotomy. Nerve branches will run from the tibial nerve to the FHL. These can also be divided. The dissection is continued proximally until the bifurcation of the peroneal artery from the posterior tibial artery is exposed. There will be large muscle branches to the soleus in this area. Depending on the desired pedicle length to accompany

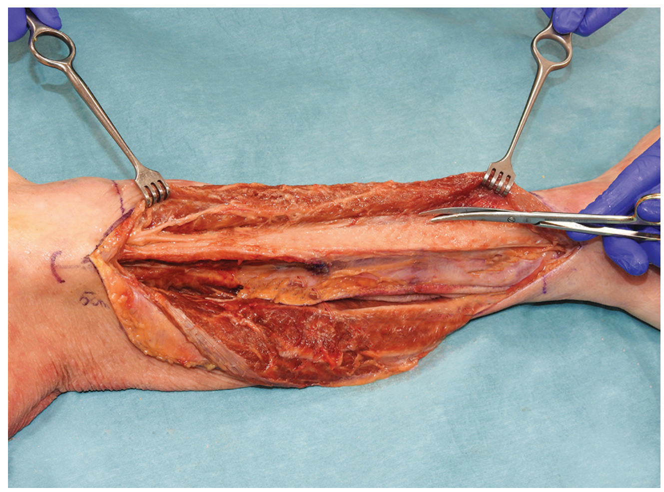

Fig. 8: Opening the anterior compartment with the scissors close to the fibula to avoid damage of the deep peroneal nerve

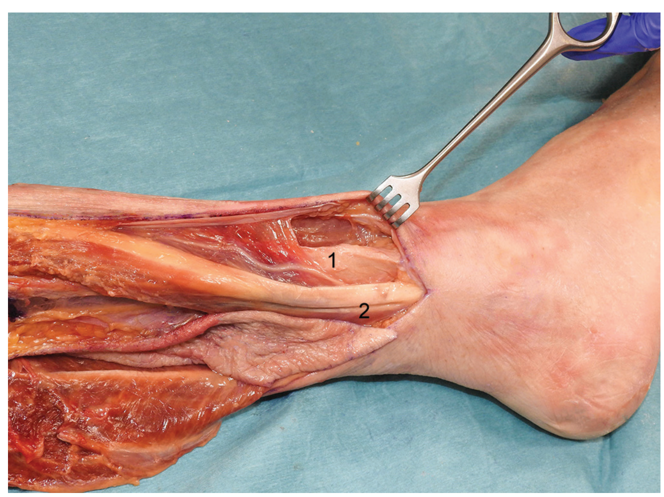

Fig. 9: Anterior approach to the distal osteotomy site with the distal fibula (1) and the peroneal muscles (2)

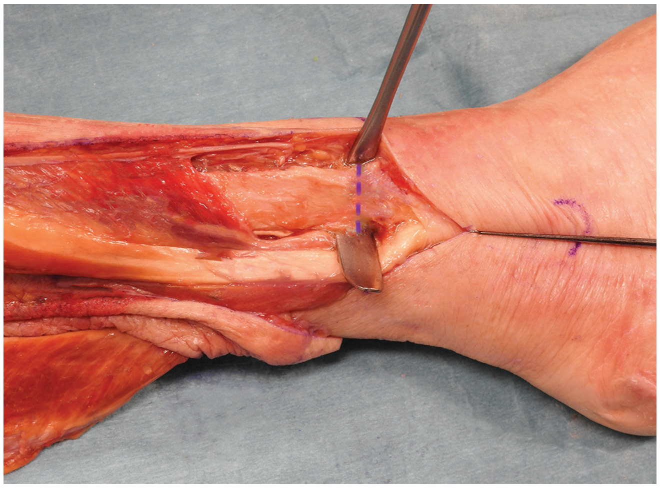

Fig. 10: Distal osteotomy

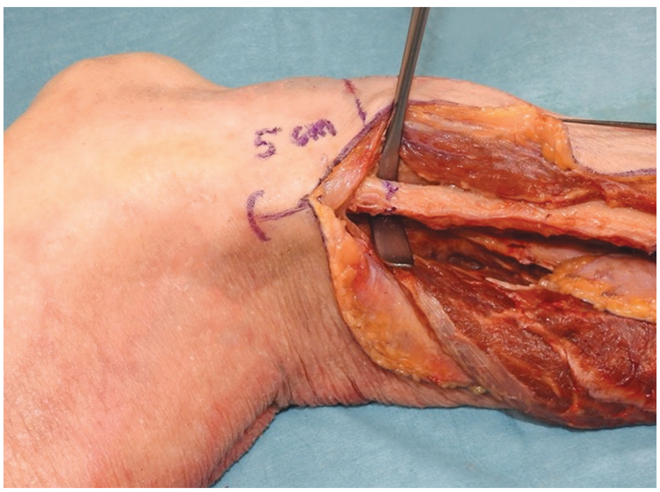

Fig. 11: Proximal osteotomy

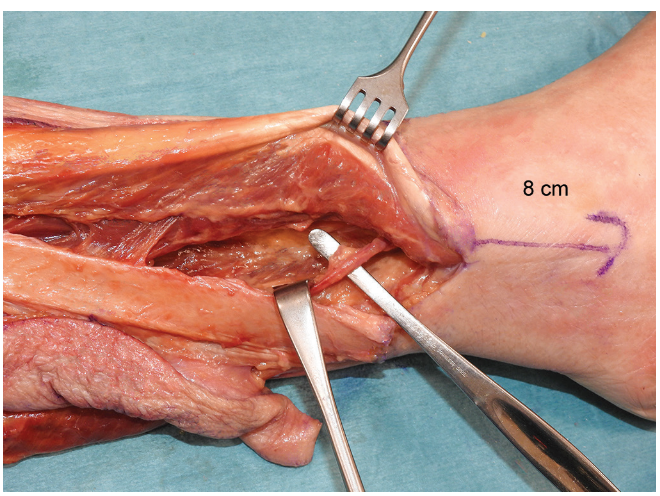

Fig. 12: The distal pedicle may be ligated and released when performing a proximally pedicled flap

the fibula, these branches can be ligated or spared. Sometimes one of the concomitant veins has a more distal anastomosis with

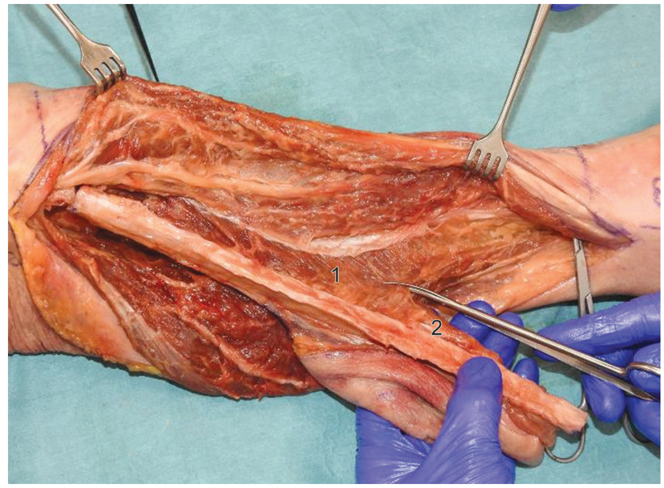

Fig. 13: Freeing the fibula upwards dissecting the tibialis posterior muscle following the middle of the V pattern of the muscle fibres (1), keeping the peroneal artery and the FHL muscle cuff (2) with the fibula

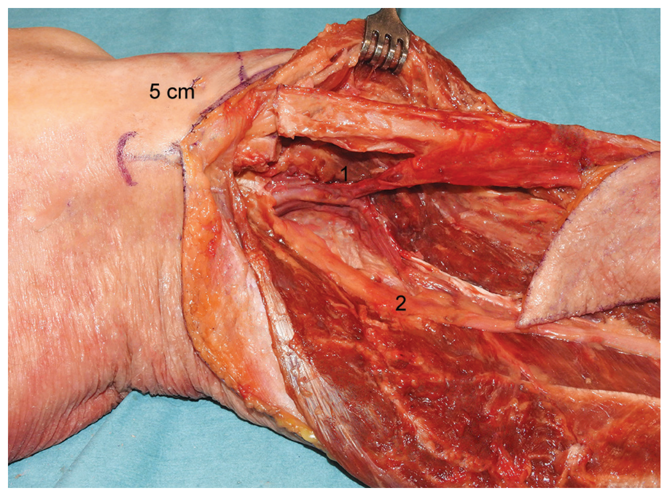

Fig. 14: Reaching the end of the pedicle, the bifurcation of the peroneal artery and the posterior tibial artery (1). The tibial nerve is visible posteriorly (2)

one of the posterior tibial veins (Fig. 14). In these cases, one of the concomitant veins of the flap can be ligated to obtain more length of the pedicle.

The anterolateral muscles of the leg have their own neurovascular bundle (anterior tibial vessels and deep peroneal nerve) that enters proximally. This allows us to free these muscles circumferentially over a substantial length without interfering with their vitality or function. This is done by freeing them from the interosseous membrane. The fibula flap is now fully dissected (Fig. 15).

We now need to fashion the fibula flap to the appropriate size, starting distally to preserve the maximum pedicle length (Fig. 16). When creating a double barrel graft, perform the osteotomy after a limited subperiosteal exposure of the fibula surface at the osteotomy site only and take care to maintain the vascular supply to the distal segment (Fig. 17). At the proximal end of the flap, there is often a bone segment that is not needed. This can be discarded but this segment must be removed subperiosteally so as not to damage the vascular pedicle.

Fig. 15: The fibula and flap fully dissected and only connected by the proximal pedicle

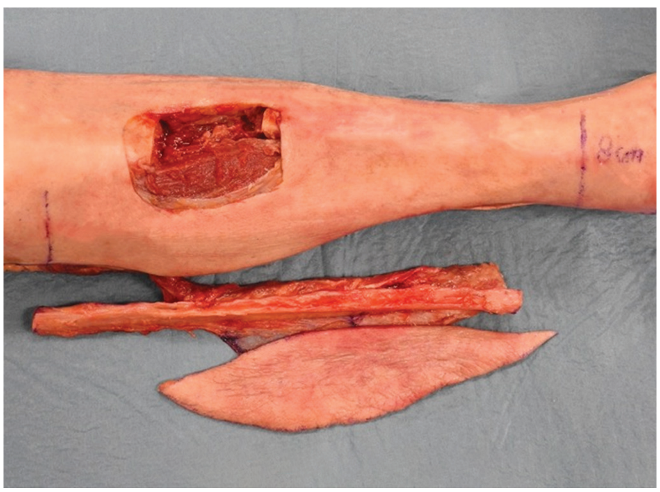

Fig. 16: Measuring the defect size before planning the osteotomy

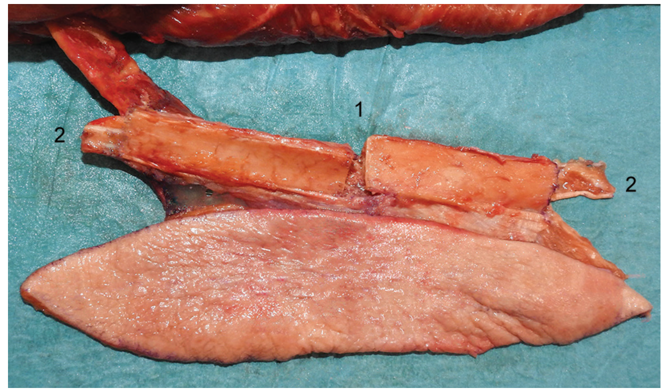

Fig. 17: The fibula segment and skin island after the osteotomy for creating a double barrel (1), including distal and proximal periosteal flaps (2)

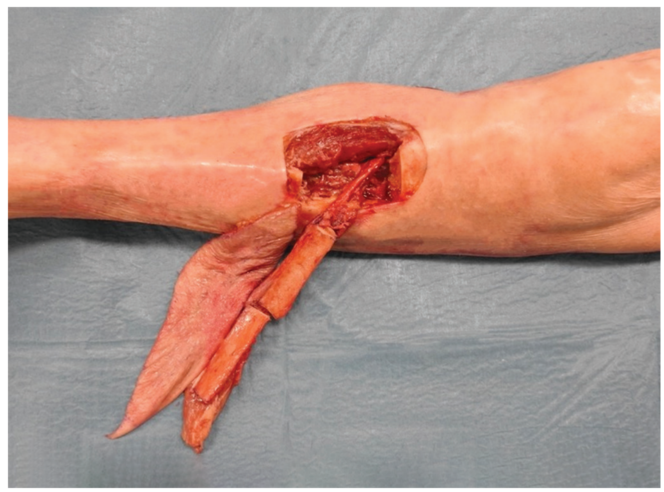

Fig. 18: Tunnelling of the fibula flap after creating a tunnel underneath the lateral and anterior compartments

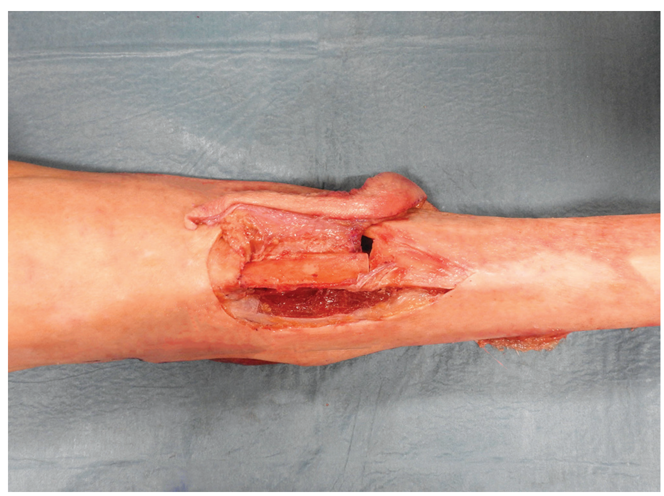

Fig.19: Placement of the double-barrel fibula into the defect, ensuring cortex-to-cortex contact and fit

To reach the defect in the tibia, the fibula has to be passed gently underneath the lateral and anterior compartments of the leg. This long aperture may need to be widened by careful dissection so that the fibula can then be pulled through this wide 'tunnel' to reach the recipient site in the tibia. When bringing the fibula to its new position, avoid rotation, kinking, coiling and compression of the pedicle (Fig. 18).

Before the vascularised fibula segment(s) are placed in the defect (Fig. 19), size adjustments need to be made to ensure that the segments are positioned with good cortex-to-cortex contact with the host bone and without compression to the vessels and (if applicable) the perforators of the skin island. The fibula strut grafts are aligned in a V-shaped configuration for this proximal tibia defect to stabilize and support the tibia plateau optimally (Fig. 20). It is important to achieve tension-free positioning of the skin island in the soft tissue defect (Fig. 21). Checks for viability by assessing the colour and capillary refill of the skin island should be performed.

Next, the fibula strut grafts are fixed to the tibia using appropriately-sized internal fixation devices, usually plates and screws, to secure the fibula in its new position (Fig. 22). The goal is to obtain a stable fixation which allows healing but does not jeopardise the integrity of the vascularity.

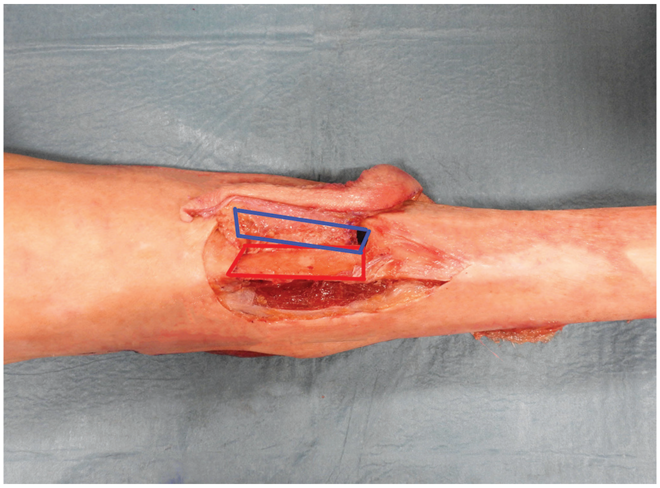

Fig. 20: Configuration of the double-barrel fibula

Fig. 21: Result after suturing in the skin island and closing the donor site primarily

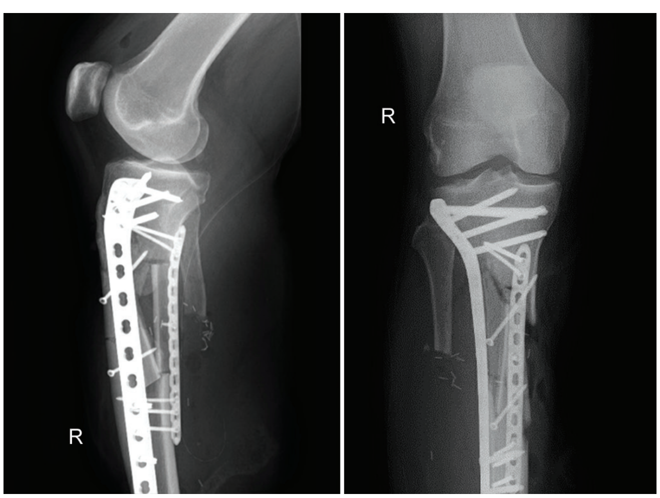

Fig. 22: Post-operative X-ray with plate fixation in the comparable case example (same patient as Figs 1 and 2)

The donor site of the fibula flap will be closed primarily over a drain or covered with a split skin graft if primary closure is not feasible. Care is taken not to close the skin with too much tension, a compartment syndrome can occur even without closure of the fascia.

Reconstruction of a Lower Tibial Defect with Distally Pedicled Fibula Flap

In the reconstruction of a defect in the distal half of the tibia or foot, a few adaptations are required. For a defect in the distal half of the tibia, the distal pedicle of the fibula should be preserved. After exposure of the distal vascular pedicle by freeing it from the FHL, the pedicle then needs to be released proximally. Retrograde flow should be checked prior to definitive ligation of the proximal pedicle. If there is insufficient blood flow, conversion to a free fibula with anastomosis to one of the other arteries in the lower leg is then indicated.

Post-op Plan

The patient should be given prophylactic low-molecular-weight heparin and pain management. Inspection of the dressing is required early to recognize any post-operative bleeding.

The viability of this osteocutaneous graft can be monitored by careful clinical examination and the use of a Doppler ultrasound on the skin island or on the vascular pedicle if this runs close enough to the surface. Several methods have been described to monitor buried flaps. It is beyond the scope of this paper to discuss this in depth.

Active tests should be performed to assess the function of the ankle and toes. Extreme pain and loss of function can be indicative of compartment syndrome.

The leg should remain elevated for the first five days. Subsequent reviews by the orthoplastic team should occur at two weeks, six weeks, three months, six months and 1 year for the follow-up of functional outcomes.

Tip

Include the flexor hallucis muscle in the flap. The incorporation of the flexor hallucis muscle in the fibula flap is advocated for several reasons. Firstly, it facilitates an easier and quicker dissection. Secondly, the muscle serves for dead space management, promoting better wound closure and reducing the risk of postoperative complications. Thirdly, retaining the flexor hallucis muscle in the transplant results in diminished blood loss during the surgical intervention. Furthermore, we believe that including the FHL leads to an augmented vascular flow in the flap, potentially leading to better flap survival. It should be noted that sparing the muscle does not confer any additional functional advantages because its blood supply comes from the peroneal artery. In a recent study, we reported patients experience limited functional deficits (namely reduced force of flexion in the big toe and a shortened stride), regardless if the muscle is spared or incorporated as part of the graft.[18]

Extend the biological augmentation provided by the fibula graft by using vascularised periosteal flaps to cover the osteotomy sites to enhance bone union (Fig. 18). Stem cells from the inner periosteal lining and the inherent vascularity provide osteogenic properties that promote bone healing. This, in turn, can decrease union time and the rate of nonunion. Including this vascularised periosteal tissue does not increase donor site morbidity.[19–21]

Pitfall

Inadequate treatment of deep infections may lead to recurrence and ultimately produce failure of the graft. In infected cases, a multidisciplinary treatment plan is essential; part of the strategy will include a wide excision of the infected and poorly vascularised bone so as to optimize good outcomes.

Too much tension, kinking and torsion of the vascular pedicle must be avoided as this may lead to mechanical obstruction of the vascular pedicle. This is a critical aspect and is the main reason for flap failure.

Controversy

Placing the fibula graft and ensuring good cortex-to-cortex contact to the tibia allows for the transmission of beneficial axial micromovements in weight-bearing. This stimulation promotes early healing and can avoid constructing failure if healing is delayed.[22] These axial stresses also lead to hypertrophy and more effective integration.[23] We, therefore, recommend a stable construct optimised for the individual patient and, preferably, with double segments and fixation with double plating to reduce the size mismatch in cross-sectional area.

Alternatively, the fibula graft can be placed in an intramedullary position. This technique may be more appropriate for nonunion treatment where there can be smaller segmental defects and the fibula is then used as a biological 'intramedullary nail'.[24]

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