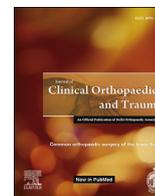




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## Lower extremity flap coverage following trauma

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## ABSTRACT

Lower extremity injuries requiring soft tissue coverage comprises a significant proportion of these injuries worldwide. Reconstruction of the soft tissues overlying fractures is essential for bone union and reduction of infection thus improving function and reducing the rate of limb amputation. A systematic exploration and excision of the wound should be jointly performed by senior surgeons from Orthopaedic and Plastic Surgery. The grading of the injury and subsequent reconstruction of bone and soft tissue should only be planned once a thorough excision of all necrotic tissue has been performed. It is this thorough debridement and early flap coverage that contributes to infection-free bony union. This article explores the options for soft tissue flap coverage for the different zones in the lower limb.

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## 1. Introduction

Lower extremity injuries requiring soft tissue coverage comprises a significant proportion of these injuries worldwide. Reconstruction of the soft tissues overlying fractures is essential for bone union and reduction of infection thus improving function and reducing the rate of limb amputation.<sup>1,19</sup> Guidelines such as those produced jointly by the British Orthopaedic Association and British Association of Plastic, Reconstructive and Aesthetic surgeons recommend a systematic exploration and excision of the wound to be jointly performed by senior surgeons from each of these disciplines. The grading of the injury and subsequent reconstruction of bone and soft tissue should only be planned once a thorough excision of all necrotic tissue has been performed.<sup>1</sup> Meticulous wound debridement removes any non-viable soft tissue including muscle that may serve as a nidus of infection and a source of catabolic myokines to inhibit bone repair.<sup>9</sup> It is this thorough debridement and early flap coverage that contributes to infection-free bony union.

## 2. Lower limb vascular anatomy

The lower limb is supplied by a rich vascular network of vessels provided by the 3 main arteries the anterior tibial, posterior tibial and peroneal arteries. These 3 main arteries and their branches are used as recipients vessels for free flap anastomosis. Local flaps rely

on the rich vascular network provided by these vessels. They can be designed as 'random pattern' where no single vessel is identified or on 'perforator' vessels from these arteries. In particular the posterior tibial and peroneal artery perforators are commonly used for flaps of the lower third of the leg. Perforators from the posterior tibial artery are situated 5, 10 and 15 cm above the medial malleolus (Fig. 1). Care should be taken to preserve these perforators during surgery for debridement or fracture fixation including placement of pins for external fixators.<sup>1</sup> Wound exploration can be safely performed by extending wounds in fasciotomy lines.<sup>1</sup> Random pattern local flaps, which are not based on identifiable perforators rely on the vascular network entering through the base of the flap. Including fascia with these flaps improves vascularity. It is important to understand these principles of flap design so that any inadvertent violation of the base of the flap (incisions, pin placement) is avoided, compromising the vascularity of the flap.

It is essential that any surgeon operating in the lower limb is familiar with the vascular anatomy of this region so as not to damage main vessels or their branches precluding them from being used as recipient vessels or for designing local flaps, thus reducing options for reconstruction. It is also equally important that a thorough vascular assessment of the leg is performed following trauma so that reconstruction can be planned accurately. Extensive damage to the soft tissue vasculature from the initial injury may exclude the use of local flaps. The extent of damage to the main vessels should be investigated before planning a free flap.

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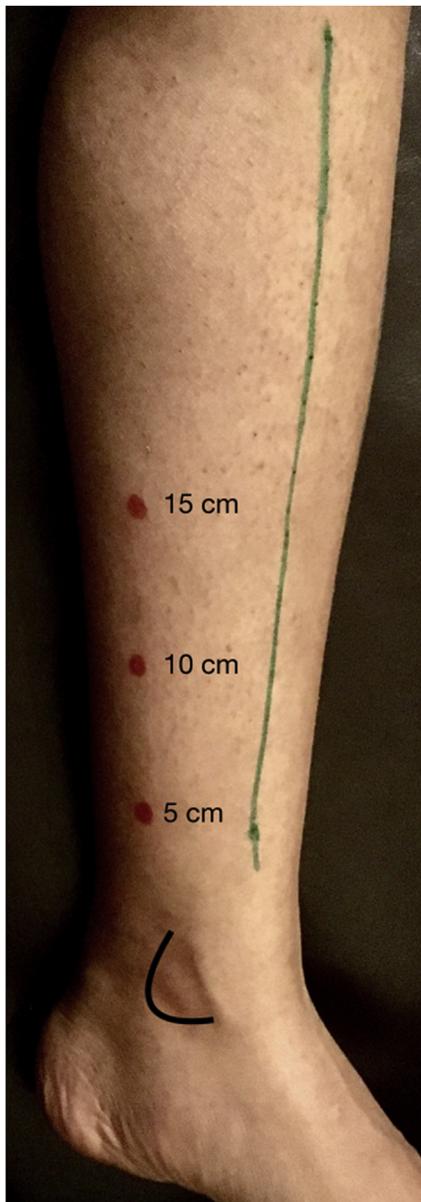


Fig. 1. Posterior artery perforators - 5, 10 and 15 cm proximal to the medial malleolus.

### 3. Types of flaps

Soft tissue coverage of lower limb defects overlying fractures and or/metalwork usually consists of flap reconstruction. The role of soft tissue reconstruction in open fractures is not just limited to wound coverage to prevent wound desiccation and infection. Soft tissues also contribute to fracture repair by serving as a local source of stem or osteoprogenitor cells, growth factors and vascular supply. Thus, vascular tissue, ie a flap, is essential for the healing of fractures.<sup>16–18</sup> Skin graft alone is not appropriate to cover such defects as grafts are not vascularised. It is worth noting the use of a negative pressure dressing, although a good temporising measure, is not a definitive reconstruction and should not be used as such.<sup>1,13</sup> Attempts to use them to reduce the need for microsurgical free tissue transfer may be accompanied by unacceptably high infection rates.<sup>14,15</sup>

**Local versus free flaps:** Traditionally, flap reconstruction involved movement of local skin around pivot points to cover

defects. These 'local flaps' are designed using tissue local to the wound and are reliant on having an intact blood supply. Proximally based large local transposition/rotation fasciocutaneous flaps were described by Ponten<sup>11</sup> to reconstruct defects below the knee. These have been found to have a significant necrosis rate, especially when used in the lower third of the leg.<sup>10</sup> With greater understanding of lower limb vascular local flaps based on perforators, in particular from the posterior tibial and peroneal arteries have gained popularity.<sup>31</sup>

However with the emergence of microsurgical techniques, local flaps have fallen out of favour and replaced with 'free flaps' in many parts of the world for reconstructing lower limb defects following trauma. These flaps involve detaching a known vascular pedicle based tissue composite unit and transferring it to the defect and micro surgically reconnecting the blood supply at the recipient site. Free flaps have largely taken over the reconstruction of such defects in big centres and institutions where the facilities and expertise is available. However, in many places worldwide specialist reconstructive surgical expertise is not available and local flap techniques are still widely practised. Even in large centres, local flaps maybe employed if there are reasons that preclude the use of free flap techniques, e. g patient fitness for a long procedure.

There are no randomised controlled studies comparing local flaps to free flaps. The literature however suggests that there are fewer complications with free flaps when performed by experienced surgeons in centres that are specifically set up for such procedures.<sup>1</sup>

Local flaps offer the advantages of simplicity, availability, shorter operations and not requiring specialist expertise or equipment.<sup>9,10</sup> The main criticism of local flaps is that it is raised within the zone of injury and thus its vascularity could be compromised. Local skin flaps can also interrupt superficial veins, the lymphatic vessels and cutaneous nerves, leading to oedema and neuromata.<sup>10</sup> The use of such flaps is limited by the orientation of the wound and availability of uninjured soft tissue, which is limited in high velocity injuries.

Often the flap has a limited arc of rotation and does not reach the most crucial part of the defect, ie the fracture site, thus failing to achieve the aim of the operation. Some studies,<sup>7,11,20</sup> including a multi-centre prospective study<sup>7</sup> report significantly higher complications such as infection, necrosis and flap loss rates with local flaps which can be attributed to the flaps being located within the zone of injury. This study also found that patients were 4.3x more likely to require a subsequent surgical intervention if they had a local flap. In addition the contour of local transposition or rotational flaps and their associated grafted donor sites have been reported as aesthetically unappealing and hard to camouflage.<sup>12</sup> The recommendation is to use these flaps for relatively low energy tibial fractures providing the vascularity has not been compromised locally.<sup>1</sup>

Free flaps on the other hand can be more easily planned and contoured to match the defect, is not limited in its reach, thus can be placed exactly where required. Free flaps are designed according to the needs of the defect and patient preferences rather than around the availability of local tissue. The donor site is often directly closed and less conspicuous. In addition, the flap provides healthy tissue from outside the zone of injury and thus is thought to be providing cellular and humoral elements for healing. However these flaps are much longer procedures, require specialist surgical and anaesthetic expertise and equipment and a surgical centre that is equipped with staff that are specifically trained to look after such patients.

**Free Muscle versus fasciocutaneous flaps:** There is little data to suggest the use of one type of free flap over another. The debate

continues regarding the use of free muscle free versus free fasciocutaneous flaps.

There are multiple clinical case series data supporting the effective and safe use of both muscle and fasciocutaneous flaps for acute open lower limb injuries as well as late complications including chronic osteomyelitis.<sup>5,6</sup> Arguments both for and against exist for both types of flaps.

Muscle tissue has greater malleability allowing better conformation to defects for elimination of dead space and hence reduce complications relating to seroma/haematoma formation.<sup>8</sup> In addition some muscle flaps such as a gracilis flap have more consistent and predictable vascular anatomy compared to an anterolateral thigh flap allowing ease of harvest. Therefore this flap is easier and quicker to teach new surgeons. Experimental models provide good evidence of improved bone blood flow, better fracture union rates and improved quality bone formation with muscle flap coverage compared to fasciocutaneous flaps.<sup>2–4</sup> However there are no robust clinical studies that confirm this.

In contrast the better colour match and contour of fasciocutaneous flaps to surrounding skin is an argument in favour of free fasciocutaneous flaps. Also, the greater elasticity of such flaps allows easier re-exploration and closure following secondary procedures such as bone grafting.

Ultimately, in the absence of definitive Level I evidence, the choice of flap is often dependent on the preference and expertise of the operating surgeon. The main principle is thorough wound debridement and early flap coverage of open fractures achieves infection-free union. Some authors recommend that the biological contribution of the constituent tissues should also be taken into consideration during flap selection.<sup>9</sup>

The UK open lower limb fracture guidelines suggest fasciocutaneous flaps such as the anterolateral thigh flap may be superior for treating metaphyseal fractures such as around the ankle.<sup>1</sup> A flap such as this can also be raised in a chimeric manner with a portion of vastus lateralis muscle and thus maybe optimal to use for tibial shaft fractures, by combining the benefits of both types of flaps.

### 3.1. Flap coverage by zone

Soft tissue flap coverage can be considered in 3 zones - upper, middle and lower third of the lower limb (Fig. 2).

## 4. Upper third

Defects around the upper third of the tibia often relate to fractures around the knee joint including tibial plateau fractures.

**Pedicled gastrocnemius muscle flap:** A pedicled gastrocnemius muscle flap is the flap of choice for most defects in this region. Either one or both gastrocnemii muscle can be used, depending on the site and size of the defect. The medial gastrocnemius muscle is often bigger and has a longer reach than the lateral. Harvest of the lateral can also risks injury to the common peroneal nerve around the head of the fibula, hence the medial is a safer option and used more commonly.

The muscle is harvested via a posterior or postero-lateral or postero-medial longitudinal incision. Once the muscle is identified it is dissected free from over lying skin and fascia and the underlying soleus muscle. Care must be taken to preserve the plantaris tendon and emerging sural nerve. The muscle is detached distally with the Achilles tendon preserved and is dissected towards its midline raphe where fibres interdigitate with those of the other side. This midline raphe can often be indistinct thus care must be taken to identify it - a longitudinal band of fat can often be seen

indicating the midline. The muscle is then dissected free in the midline from the other side, taking care to control the multiple small vein that cross the midline. Once sufficient length has been achieved the muscle is transposed to the defect directly into the defect of via a subcutaneous tunnel. Care must be taken to preserve its vascular pedicle, the sural artery (arises from the popliteal artery at or just above the joint line) which enters the muscle proximally. Extra gains can be made in the arc of rotation by detaching the muscle from its proximal insertion whilst protecting its vascular pedicle. The muscle is covered with a thin split skin graft taken from the thigh (Fig. 3). If a subcutaneous tunnel has been used for muscle transfer this must be made wide and checked for any constrictions. The muscle is likely to swell postoperatively therefore the tunnel needs to be as spacious as possible to avoid compression of the vascular pedicle. It is also worth noting that the gastrocnemius muscle can also be used to reconstruct the extensor mechanism at the same time if this is required.

### 4.1. Other options in this region include

- **a distally based pedicled anterolateral thigh flap:** This is a fasciocutaneous flap based harvested from the thigh. It is based on the descending branch of the lateral circumflex artery a branch to the femoral artery and can be used as a proximally based or a distally based flap. For upper third defects of the leg this flap can be used as a distally based flap where the pedicle is divided proximally and the flap is rotated inferiorly into the required defect. The vascular pedicle commonly requires dissection through the vastus lateralis muscle for harvest.
- **free flaps:** A free flap can be considered for this zone (see below). The genicular arteries are often used as recipient vessels for the free flap. Other branches of the femoral or popliteal vessels can also be considered.

## 5. Middle third

This zone of the lower leg is deficient in suitable local flaps for reconstruction. A gastrocnemius muscle flap may be used for the proximal part of a defect in this region but often the arc of rotation is limited for most defects in this zone. For reasons stated earlier in the article the flap of choice for this region is a free flap. Commonly used free muscle flaps for this region include gracilis muscle and latissimus dorsi (for larger defects) muscles. Free fasciocutaneous choices include the anterolateral, radial forearm, scapula and parascapula flaps. The anterior and posterior tibial vessels are used as recipient vessels.

**Gracilis muscle flap:** The gracilis is a long thin uni-pennate muscle in the medial compartment of the thigh<sup>21</sup> and is a reliable workhorse flap. The muscle is accessed via a longitudinal incision on the medial side of the thigh, posterior to the adductor longus (the palpable tendon lateral to the pubis symphysis identified with the leg in abduction). It is detached from its distal insertion on the medial aspect of the proximal tibia and origin on the ischio-pubic ramus<sup>21</sup> whilst protecting its vascular pedicle under the adductor longus. There are smaller vascular pedicles found more distally, these are ligated when the muscle is harvested. The muscle is supplied by the medial femoral circumflex artery which is traced under adductor longus. Once harvested and flap transferred, the donor site is directly closed with a drain in situ. This flap leaves a longitudinal donor scar in the medial thigh. Most open tibial fractures of the middle third can be covered using this flap, which is much wider in men. It can also be used to eliminate dead space in the wound. There is very little noticeable functional deficit with harvest of this muscle.

**Latissimus Dorsi muscle flap:** The Latissimus Dorsi muscle is

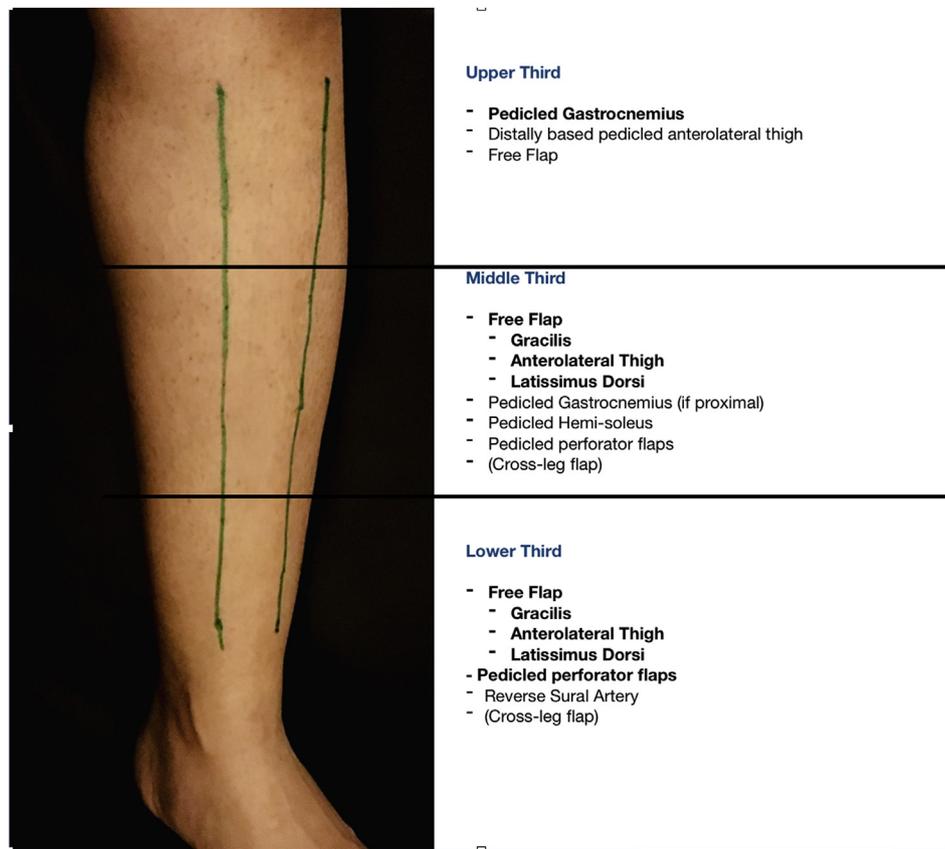


Fig. 2. Options for lower limb reconstruction.

another workhorse flap used for larger defects. It is a flat, triangular muscle that covers the posterior trunk.<sup>22</sup> Supplied by the thoraco-dorsal artery this large muscle flap can be based on this single artery and can be harvested with skin or in combination with other flaps such as the scapular/parascapular or ribs. The muscle is accessed via an incision in the posterior axillary fold extending inferiorly or over the muscle depending on the specific flap design. It is detached from its origins on the iliac crest inferiorly and thoracolumbar fascia in the posterior midline. Perforators from thoracic intercostal and lumbar arteries are that supply the muscle are ligated at this point, as are other communicating branches, such as at the angle of the scapula. The main thoraco-dorsal pedicle is protected in the axilla whilst the muscle is detached from its humeral insertion. This large flap has a long pedicle allowing microsurgical anastomoses to take place outside of the zone of injury. It can also be harvested partially thus reducing any associated morbidity that can be noticed in certain sporting activities such as cross-country skiing. The donor site is directly closed over drains.

**Antero lateral thigh flap:** Supplied by the descending branch of the lateral femoral circumflex artery, this flap is harvested from the anterolateral aspect of the thigh. It can be taken as a cutaneous flap (skin and subcutaneous tissue) or fasciocutaneous flap based on either a septocutaneous vessel or musculocutaneous perforator.<sup>30</sup> The anatomy of the perforator vessels is variable and quite often requires careful and often long dissection through muscle. Infrequently the perforator is septo-cutaneous thus making the dissection easier. The perforators are followed through to the descending branch of the lateral femoral circumflex artery between the rectus femoris and vastus lateralis muscles. It is a commonly used flap amongst microsurgeons and leaves an acceptable donor site as most donor sites are closed directly. Wider flaps can be taken if the

patient is agreeable to having a skin graft at the donor site. It can be harvested as a composite flap including muscle (vastus lateralis myocutaneous anterolateral thigh flap) or a combined flap to include other tissues (including rectus femoris muscle, tensor fascia lata, anteromedial thigh flap).

It is worth noting both the anterolateral thigh flap and latissimus dorsi flap can be used as a 'flow through' flap in which both the proximal and the distal ends of the vascular pedicle of a free flap are anastomosed to provide blood flow to distal tissues, thus allowing a one stage reconstruction of both soft tissue and vascular defects of the lower limb.<sup>29</sup>

## 6. Other flap options

**Radial forearm Free Flap:** Although this is a relative easier flap to harvest compared to the anterolateral thigh flap due to its needs for donor site grafting and visibility of the donor site, this flap is used less commonly.

**Local flaps:** For low velocity injuries where local vascularity has not been compromised, especially in those patients with comorbidities and not suitable for long procedures, local options can be considered.

These include:

**Pedicled Gastrocnemius flap:** For proximal wounds only (see above).

**Pedicled hemi-soleus muscle flap -** a pedicled muscle flap that can be used for lower limb defects.<sup>23</sup> The soleus muscle sits deep to the gastrocnemius muscle and hence can be transposed in a similar way if required. It can be raised as a hemisoleus flap due to its dual blood supply. However it is more prone to venous congestion, and is not suitable for defects too proximal due to limited arc of rotation.



**Fig. 3.** A pedicled gastrocnemius muscle flap covered with a split skin graft from the medial thigh for a defect around the knee.

The soleus muscle itself however maybe injured and not suitable as a flap if close to the fracture site. It can be used in combination with a lateral or medial gastrocnemius flap. It is not usually a flap of choice for many due to increased risk of compromising plantar flexion, as well as decreased venous return of the lower limb.

- Pedicled perforator flaps (see below)
- Proximally based fasciocutaneous flaps: Proximally based local transposition/rotation fasciocutaneous flaps were described by Ponten<sup>11</sup> who introduced the concept of improving flap vascularity by including fascia. These flaps are prone to higher rates of complications as discussed above.

## 7. Lower third

This zone is particularly difficult to reconstruct due to very limited mobility of soft tissues, poor circulation and functional needs of the ankle such as shoe fitting and protection against trauma. Free fasciocutaneous flaps such as the anterolateral flap have been used effectively in this regions. Many surgeons will thin such flap to allow for better contouring either on table or as a secondary procedure, thus problems with footwear. Muscle flaps

such gracilis flaps have also been used with good success for the lower third area of the lower limb. Although they may appear bulky to start with, these muscle flaps will partly atrophy from disuse and thus contour better. Use of specialist bandaging techniques over the flap can also be used over time to reduce bulk and improve contour.

## 8. Local options

- **Pedicled perforator flaps:** A perforator is a vessel that enters the suprafascial plane through a defined fenestration in the deep fascia.<sup>12</sup> These flaps are divided into direct, indirect septocutaneous, and indirect musculocutaneous based on the type of perforator vessel used. Flaps can be designed based on known perforators or 'free style' by identifying a perforator near the defect to be reconstructed via through surgical exploration or Doppler mapping. Perforators from the peroneal and posterior tibial artery perforators are commonly used to design local fasciocutaneous flaps (Fig. 4). The location can be confirmed using a hand-held doppler. Perforators from the posterior tibial artery are found at 5, 10 and 15 cm above the medial malleolus - flaps can be designed around these known perforators and safely islanded on one perforator and its venae comitantes (Fig. 1). The propeller flap,<sup>27</sup> a pedicled island flap that reaches the recipient site through an axial rotation<sup>28</sup> is a variation on this type of flap where the perforator is isolated and the flap rotated up to 180° if required. The VY advancement and adipofascial perforator flaps are examples of other types of perforator flaps. It is worth noting there is a learning curve with these flaps and must be planned with extreme care.



**Fig. 4.** A flap based on a posterior tibial artery perforator for a defect in the lower third of the lower leg.

**Reverse Sural Artery flap:** This is a distally based flap, which is perfused by reverse flow through the anastomosis between the superficial sural artery and the lowermost perforator of the peroneal artery (5 cm above the lateral malleolus).<sup>24</sup> It is often used for coverage of the heel, the middle and distal one-third of the leg. One advantage of this flap is a constant blood supply that does not require sacrifice of a major artery to the lower limb.<sup>25</sup> It is, however prone to congestion<sup>26</sup> and likely to have more complications in patients with co-morbidities.

- **Cross leg-flap:** In certain circumstances free or local flaps may not be an option. A pedicled cross-leg flap can be considered in these situations. Although fallen out of favour with the advent of microsurgical techniques, this flap has the advantage of transferring tissue from the uninjured leg, ie good quality tissue from out of the zone of injury where microsurgery is not available. It has the disadvantage of difficulties with stable immobilisation and positioning of the extremities. Some authors propose the use of external fixators to overcome this.<sup>32</sup> It also leaves a visible donor site on the uninjured leg.

## 9. Conclusion

Lower extremity wounds from trauma need meticulous planning according to the requirements of the wound and patient, patient preferences, degree of injuries, availability of donor tissue and bony reconstruction. Flaps should be planned jointly with the orthopaedic surgery, plastic surgery and anaesthetic teams. A full discussion about risks, benefits, long term effects, donor site scars, functional and aesthetic losses should be undertaken with the patient.

## Conflicts of interest

None.

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