

# Flap Decisions and Options in Soft Tissue Coverage of the Lower Limb

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**Abstract:** The lower extremities of the human body are more commonly known as the human legs, incorporating: the foot, the lower or anatomical leg, the thigh and the hip or gluteal region.

The human lower limb plays a simpler role than that of the upper limb. Whereas the arm allows interaction of the surrounding environment, the legs' primary goals are support and to allow upright ambulation. Essentially, this means that reconstruction of the leg is less complex than that required in restoring functionality of the upper limb. In terms of reconstruction, the primary goals are based on the preservation of life and limb, and the restoration of form and function. This paper aims to review current and past thoughts on reconstruction of the lower limb, discussing in particular the options in terms of soft tissue coverage.

This paper does not aim to review the emergency management of open fractures, or the therapy alternatives to chronic wounds or malignancies of the lower limb, but purely assess the requirements that should be reviewed on reconstructing a defect of the lower limb.

A summary of flap options are considered, with literature support, in regard to donor and recipient region, particularly as flap coverage is regarded as the cornerstone of soft tissue coverage of the lower limb.

**Keywords:** Flap, lower limb, reconstruction.

## 1. THE LOWER LIMB

The leg consists of four main regions before attaching to the pelvis.

Working proximally, these are: the foot, the lower or anatomical leg (from the ankle to knee), the thigh (knee to hip) and the hip or gluteal region. Primarily, the four areas work together to aid balance and support, which, in turn, allow a human to stand and walk.

Evolution has forced the lower limb to gain this distinct feature, and although bipedal gait is not unique to humans, an efficient upright locomotion for long durations is. This adaptation has forced the human leg to become longer and more powerful in comparison with our primate relations, as well as change the way in which the muscles and joints of the leg interact and function [1].

The ability of the legs to offer support and allow upright ambulation has permitted the adaptation of the upper limb, the arm, to allow precise interaction with the surrounding environment.

## 2. RECONSTRUCTION OF THE LOWER LIMB: WHY IS IT NEEDED?

The lower limb may need to be restored for multiple reasons.

Originally lower limb reconstruction was required as an alternative to amputation, which was the principal treatment for war injuries. Amputation allows for the removal of necrotic tissue and infection, with the aim of saving the victim's life, but can sacrifice potential function and rehabilitation. Since World War I, major developments in applied anatomy, fracture management, wound care and sterile techniques, as well as the introduction of antibiotics and anaesthesia, have allowed surgeons to consider the role of limb salvage, a field which has greatly expanded since its introduction.

The field of reconstruction gained a vast number of options following the improvement of vascular techniques in the 1960s, opening the door to the microvascular reconstruction era.

Today, war injuries still make up a proportion of the number of people who require access to advanced techniques in the field of lower limb salvage and reconstruction. However, the scope of injury mechanisms has been added to with an increasing number of blunt trauma, thanks to urbanisation and industry, as well as increased diagnosis of lower limb malignancies and chronic medical conditions, including diabetes and peripheral vascular disease.

Today's goal in lower limb reconstruction has not changed much from those originally cited in the early war victims, with restoration, or maintenance of function becoming the essential goal as these injuries became less life threatening. Function involves the need for a stable skeleton,

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allowing weight bearing status, with adequate soft tissue coverage to nourish and protect the underlying bone. 'Normal' function of the limb is then more reliant on the rehabilitation of the limbs muscles and joints, with proprioception and plantar sensitivity key.

End points of reconstruction are also measured by a return of function to a level required by that individual. Options become dependent on a balance of anatomical, social and psychological factors, which will be discussed later in this paper. This functionality can be reduced by chronic pain and infection, as well as complications with chronic swelling or wound healing. The aesthetic outcome is also important, but this should never take priority over the limb's ability to function.

### **3. RECONSTRUCTION: EASY OPTIONS BUT A DIFFICULT CHOICE?**

The reconstructive ladder should always be addressed when considering closure of wounds. This progresses from secondary healing to primary closure, through the options of grafting to the more complex local, then distant, free tissue flaps.

Today there are options to supplement the reconstructive ladder, with the use of negative pressure wound therapy, as well as tissue expansion or prefabrication of tissue, before a definitive surgery. In the future, it is hoped that adjuncts in the form of pharmacological therapies and the use of engineered materials for wound coverage will become more significant.

Wound coverage requires many aspects of the patient's background and present state to be assessed before making a decision on the most suitable option.

The bed bound patient in their later years with an infected diabetic foot and chronic leg ulcer offers a different challenge to that of the 28 year old with an open fracture, massive skin loss and vascular damage following a road traffic incident. Potentially, the latter has a life-time of earning and dependants as opposed to the former, who may require purely symptomatic relief. The difficult choice then becomes whether you offer both, or either, salvage or amputation. It may seem obvious that amputation in the younger patient is not preferable, but who says that a 'simple' amputation and prosthesis, allowing a quicker return to work and normality, is worse than the potential long term rehabilitation required with a complex bone and skin coverage procedure?

This highlights the need for lower limb reconstruction to be made on an individual basis and involve a multidisciplinary team, who will consider the following points;

#### **3.1. Physical Examination of the Wound**

This will involve inspecting the wound size and noting the amount of damage and loss to both the skeletal and soft tissue envelope. In addition, the vascular supply to both the area and distal regions needs to be assessed and may require the input of orthopaedic, reconstructive and vascular professions.

The location of the wound also plays a large role in the feasibility of reconstruction options. The surrounding tissue

also becomes important in terms of concurrent injuries, such as those in crush injuries, radiotherapy fields in malignancy, chronic infection or oedema related changes.

Once the decision of surgical closure of a wound has been made, appropriate debridement must be undertaken before a final coverage option is chosen.

#### **3.2. Patient Assessment [2, 3]**

This incorporates the morbidity and mortality risk of undertaking the procedure in the elective patient. Patient age, body mass index, their smoking status and previous injuries to the limb involved should be noted. Scars crossing regions involving local and distant flaps options may rule out these choices out. Comorbidities involving cardiac and respiratory disease may discourage a long general anaesthetic and potential intensive care stay, as well as having an impact on rehabilitation. Diabetes and peripheral vascular disease, particularly stenosis and arteriosclerotic vasculature, will again rule out both donor and wound coverage options. Angiography is often required, particularly in the chronic wound as opposed to the blunt trauma scenario, as a chronic lower limb wound will often heal adequately as long as the area is reasonably perfused, and a non-healing area due to poor perfusion is unlikely to be successfully grafted. Likewise, nutritional state is strongly influential on both chronic wounds and the healing of the wound coverage options. This will involve dietician support. Pre injury dementia and ambulation should also be reviewed to determine rehabilitation and compliance with reconstruction.

For the emergency patient, life threatening injuries take precedence over everything and the patient will require assessment in a structured way, as defined by the Advanced Trauma Life Support (ATLS) principles [4].

Soft tissue coverage is needed to aid an infection free fracture union. This should ultimately be completed at the same time as bony fixation if simple or local flap closure is achievable. Free flap reconstruction should be performed on a scheduled trauma list by an experienced, dedicated senior surgical team in a specialist centre, preferably within a week of injury [5].

#### **3.3. Rehabilitation and Functional End Point**

As suggested by the scenario above, the rehabilitation of the bed bound, chronic wound against the active, acute trauma patient will have a strong influence on what options are used for reconstruction. Is the procedure for symptom relief, functional restoration or functional improvement? Social status pre-injury and potential rehabilitation options must be assessed. Occupational therapist and physiotherapist inputs emphasise the need for a multi-disciplinary team approach to determine the most suitable reconstruction option. Good progress during early rehabilitation can also determine the successful return of normality for the patient.

#### **3.4. Patient Expectation: their Desires and Need**

Encompassing the above, exploring the patient's psychological state is equally important. A complication free free-flap that saves a patient's foot is almost wasted if the patient automatically rejects the rehabilitation phase. The patient's motivation and compliance is critical in the functional end point. The appearance of the reconstruction

alongside post-operative pain and swelling is interpreted differently by each individual, and will need individual assessment. Likewise, it is important to ensure the patient has a close support system. Offering counselling to those closely involved may aid the patient's recovery.

It has been reported that, when offered, a high percentage of patients (93%) would prefer a limb salvage procedure in the traumatic scenario to avoid undergoing amputation [6], and as an option in the chronic wound, reconstruction provides a chance for the patient to remain socially independent and maintain or improve their ambulatory status [7].

This supports patient choice in the reconstructive options, and all options should be discussed in detail by a trained expert to the patient to aid end compliance and balance expectations.

Other factors to be aware of in lower limb reconstruction include, but are not limited by:

- Cost of care
- Surgeon's experience
- Donor site disability
- Potential complications

Once these areas have been appropriately assessed and individually tailored to the patient, a list of potential surgical options will be made and offered to them.

#### **4. RECONSTRUCTION OPTIONS: THE RECONSTRUCTION**

The reconstructive ladder offers a list of options in terms in surgical closure of the wound. However, the simplest option is not always the best option. On top of the above pre-operative assessment requirements, a failed technique in lower limb reconstruction can have a devastating effect on the patient resulting in further tissue and bone loss, deterioration of comorbidities and functional deficit with an end point involving amputation. For this reason, the best reconstructive option is often not the easiest choice, but the choice that has the highest chance of success. For this reason free flap tissue transfer is often regarded as the cornerstone of lower limb reconstruction.

##### **4.1. Direct Closure and Local Alternatives**

Primary and delayed closure, as well as grafting of a wound are well documented options and should be attempted in both the simple wound, those where expedited recovery is required, or where more complex reconstructive failure would be disastrous [8].

Both of these options require an adequate blood supply to the wound area and relatively reliable surrounding tissue. Where the blood supply is poor, involves periosteum stripped bone or where there is a requirement of soft tissue depth, the use of reconstructive flaps is generally required.

Another option using the nearby soft tissue envelope includes tissue expansion, a choice which negates variance in tissue thickness, texture and colour and offers provision of specialist skin to a region (hair bearing for instance). This technique is limited by the reliability of the surrounding

tissue, but may offer a potential donor site for both direct closure and local flap coverage.

##### **4.2. Flap Reconstruction**

Flap reconstruction options can be broken down to local and free flap descriptions. In general flaps can be described based on the blood supply to the flap, the location of the donor site and the type of tissue being transferred.

The first uses of flap reconstruction initially involved movement of skin around pivot points, with these 'local flaps' designed using tissue local to the wound. They will require their blood supply to be intact from the injury, whereas free flaps are based along a distant donor site.

Flaps utilise composite tissue blocks and may include skin, muscle, bone, fascia and combinations of these.

Local cutaneous flaps can be based along random pattern or axial vascular circulations using the subdermal blood supply. Random pattern cutaneous flaps are limited by the arc of rotation and decreased bacterial resistance, as well as a general rule of a 2: 1 ratio between the length and base of the flap used in the lower limb. The discovery of axial pattern flaps, where the flap is perfused by a defined vessel or angiosome, has permitted the use of longer flaps.

Other options for local flaps to aid take have included delayed transfer. An example of this is 'the arm carrier' technique, involving abdominal flaps being transferred to a donor site on the arm before final transfer to the leg. This technique is still dependant on the final location wound environment for the take to be successful.

The discovery of random pattern skin flaps led to an investigation into vascular anatomy and consequently it was found that local flaps could involve muscle, with transposition of either the muscle or a musculocutaneous block supplied by the muscle's dominant vascular pedicle. This finding was further supplemented by the discovery regarding fascial vascular supply and that the deep fascia, with or without skin, also allowed reliable flap creation. In 1981, Ponten [9] noted skin survival in a patient correlated with a single perfused vessel shown on angiography. This led him to raise a calf based flap including the fascia and sural vessels, prompting a variety of new discoveries in flap options [10].

The use of cutaneous, musculocutaneous and fasciocutaneous flaps based along specific dominant vascular pedicles have allowed the direct transfer of tissue which is less dependent on the wound bed blood supply. They also introduce new circulation to the area and offer a more reliable and larger wound coverage option. As our understanding continues to develop, it has been noted that both true and 'choke' anastomoses exist between the perforator angiosomes allowing longer flaps to be more successful [11].

As noted, the pedicled flaps are restricted by their arc of rotation, something which was greatly increased compared to random pattern skin flaps. The advancement of microscopy, micro-instruments and sutures has allowed the development of free flap surgery, which essentially involves detaching a known pedicle based tissue composite unit and transplanting

it to the wound area and anastomosing it to a suitable receptor artery and vein in proximity to the wound.

Microsurgery has allowed the direct transfer of large tissue units from distant donor sites, allowing wounds to be covered and reconstructed based on flap suitability rather than wound proximity.

Free flap coverage has helped reduce the often bulky pedicled flap seen, particularly in muscle flaps. It also allows direct closure in the majority of the donor regions. A skin graft to this site should only be used if the donor flap is of special significance (superiority in function/shape etc).

Igari *et al.* report end to side and end to end anastomosis of latissimus dorsi free flaps to the vascular graft on these wounds with 85% flap survival and 100% limb salvage rate. This technique helps with the problem of exposed functional tissues when the wound is debrided [12].

Free flap reconstruction offers wound coverage but does not improve the distal circulation. However, there are reports of revascularisation of critical limb ischaemic wounds with free flap coverage being offered as a single procedure with reasonable results [13, 14].

In the traumatic scenario, all open fractures require a vascularised soft tissue envelope free of infection to allow appropriate bone healing.

The use of Negative Pressure Wound Therapy (NWPT) can temporarily be used as a substitute for definitive flap coverage [5].

With the improvement of microvascular techniques, replantation of amputated lower limbs is feasible and may become a reliable option with improved results in the future [15].

#### 4.2.1. Flap Vascular Anatomy

The blood supply of the raised flap is key to its survival. The classification of flaps can be described by the vascular source. As noted random pattern flaps have no specific named vessels supplying them, whilst a recognised artery or group of arteries forms an axial based flap. The variation in axial blood flow into different muscles is complex and Mathes and Nahai attempted to subclassify this form of flap vasculature [16]. This classification is well described in reconstructive literature and summarised in Table 1.

**Table 1. Muscle/musculocutaneous flap classification [16].**

Type	Pedicle	Example
I	One vascular pedicle	Tensor fascia lata Gastrocnemius
II	One dominant pedicle and minor pedicles	Gracilis Soleus
III	Two dominant pedicles	Gluteus maximus Serratus anterior
IV	Segmental pedicles	Sartorius Extensor hallucis longus
V	One dominant and secondary segmental pedicles	Latissimus dorsi Pectoralis major

The blood supply to fascial based flaps has also been classified in Table 2.

**Table 2. Fascia/fasciocutaneous flap classification [17].**

Type	A	B	C
	Direct cutaneous pedicle	Septocutaneous pedicle	Musculocutaneous pedicle

#### 4.2.2. Flap Failure and Complications

Flap complications can be wound specific, vary from reconstructive unit to unit and are dependent on the flap used. They include: failure of the flap, involving partial or total necrosis; haematoma and seroma collections (for which the use of post-operative drains is not uncommon) and wound dehiscence and infection. Donor site morbidity should be negligible but could involve a reduction in function, particularly in flaps involving muscle components.

Pressure ulcer coverage is particularly complicated, usually due to issues regarding the continuation of pressure at the reconstructed site. One paper quotes flap complications involving ischial, sacral and trochanteric wounds of 87 complications in 421 (21%), with suture line dehiscence (31%), infection (22%), haematoma (19.5%), partial necrosis (13.7%) and total necrosis (10.3%) noted [18].

#### 4.3. Choice of Reconstruction: The Flap Options [19]

Traditionally the use of local muscle flaps proximally and free flaps distally in the lower limb have been used, although improvement in local flap reliability have allowed their use throughout the limb [20].

##### 4.3.1. Local Flap Reconstruction

Random pattern cutaneous flaps can be limited by their vascular input. There are suggestions that the detection of perforators can be made by using thermal imaging to improve the sensitivity of current Doppler and anatomical landmark techniques [21]. In particular, thermal imaging may help locate the 'choke' anastomoses which help aid flap perfusion and drainage [22].

The propeller flap, a pedicle based perforator flap, is well documented as an option for the majority of coverage in the lower limb, particularly below the knee, with the peroneal and posterior tibial artery perforators being commonly used [23-27].

It provides good form and function for elective and traumatic defects, offering an option in forefoot cover [28]. However, a recent literature review reports up to 16% of flaps suffering partial necrosis, with a third of them involving the whole flap [29].

V-Y flaps, as described by Blasius in 1848 [30], are another option, particularly around the ankle and lower leg and can provide a sensate flap to the region [31].

Bi-pedicle flaps are random pattern flaps but, due to two pedicles, their continued viability is improved. They are a flap gaining popularity for closure of lower limb wounds, as is the keystone flap [32-34].

For open fractures of the lower limb, local fasciocutaneous flaps should be used in low energy tibial fractures. As long as there is no vascular compromise by the initial injury, these can be used, along with free fasciocutaneous flaps, in metaphyseal injuries (particularly around the ankle) [15]. Muscle flaps would be suggested by experimental data in open tibial shaft fractures or where the blood supply is compromised, possibly helping to reduce both the healing time and risk of deep infection [15].

### 4.3.2. Fasciocutaneous Flaps

#### 4.3.2.1. Groin

One of the earliest axial based fasciocutaneous flaps, the groin flap, has been used as both a free and pedicled flap [35] providing a substantial amount of both tissue and skin. Often needing subsequent debulking and due to the fact it is a hair bearing area this flap can be a poorer aesthetic match compared to other options. The short venous supply to the region also causes an increased risk of flap failure.

Often taken using a pedicle from the superficial circumflex iliac artery, the groin flap allows up to 20 x 10cm flaps to be harvested alongside direct closure, and twice this with grafting of the donor site.

#### 4.3.2.2. Medial Thigh

Typically using the anterior septocutaneous artery and the venae comitantes from the superficial femoral vessels, this flap can be also be raised more anteriorly by using the lateral femoral circumflex artery, where it is more commonly referred to as the antero-medial thigh flap. The saphenous vein can be utilised to aid venous drainage as well as keeping a sensate flap when the medial anterior cutaneous nerve of the thigh is raised, the medial thigh flap is useful both as a free and pedicled flap. The latter will help cover wounds involving the perineum, groin and thigh up to 10 x 20cm in size.

#### 4.3.2.3. Lateral Thigh

This flap and the antero-lateral thigh flap, exploit the profunda femoris perforating branches. Of the three, the first is used for proximal regions including the trochanteric and ischial areas, and the third, thanks to an extended pedicle, is typically used as a free flap. A 7 x 20cm skin paddle can be raised with a tight closure of the donor site.

#### 4.3.2.4. Sural

The sural artery allows probably the longest pedicled fasciocutaneous or fascial flap. Also, with the ability of being reversed, this flap can cover defects around the knee, anterior and posterior and upper third of the leg, as well as proximal foot defects. A type A fasciocutaneous flap skin flaps of up to 12 x 20cm can be raised.

#### 4.3.2.5. Saphenous

Coverage of the knee can be achieved by raising this flap using the saphenous artery and venae comitantes. A more difficult dissection than those listed above due to increased vascular anatomy variance, this flap can also be reversed and includes an osseofasciocutaneous option (from the medial femoral condyle) using the articular branches of the genicular artery [36]. Skin paddles 7 x 20cm are typical, with

a section of sartorius occasionally taken with the raised tissue to aid flap survival rates.

#### 4.3.2.6. Posterior thigh

The posterior thigh flap, based on the profunda femoris artery, has been described as an alternative free flap option [37].

### 4.3.3. Muscle and Musculocutaneous Flaps

#### 4.3.3.1. Gluteus Maximus

Being the largest muscle of the body and having both two dominant and two minor pedicles this allows for a high degree of versatility. Reliable coverage of the buttock, hip, perineal and upper thigh regions is achievable. Raised either from the lateral femoral circumflex artery to allow posterior thigh coverage in a reversed technique or off of one of the gluteal arteries (superior or inferior) with the muscle split preserving function [38] and tissue to cover either anterior or posterior defects. These can incorporate either only muscle or muscle and skin coverage options.

#### 4.3.3.2. Tensor Fascia Lata

Useful as a pedicled or free flap, the thin muscle belly and long fascial extension allows this flap to be used in a multitude of scenarios, as well as it being an expendable muscle unit in the majority. Able to reach the umbilical region, perineum, ischium and groin it can incorporate skin to cover defects in the proximal lower limb, as well as iliac bone for osteomusculocutaneous coverage.

#### 4.3.3.3. Gracilis

A pedicled and innervated gracilis flap is useful in perineal and ischial coverage but its relative lack of functional deficit on removal means its use as a free flap for the lower leg cannot be underestimated. It allows purely lower limb anaesthesia and its small size does not cause gross contour changes in its final location. It is raised from its main pedicle, the terminal branch of the medial circumflex femoral artery.

#### 4.3.3.4. Soleus

Used for defects of the middle third of the lower leg [39], soleus can be split to form a hemisoleus flap thanks to its dual pedicle supply and bipennate morphology [40]. Due to an increased risk of substantial ankle flexion weakness alongside loss of lower limb venous return through the muscle, its use has been criticised [41].

#### 4.3.3.5. Gastrocnemius

The two origins of this muscle allow separate muscle or musculocutaneous flaps to be raised on separate pedicles, along the lateral or medial sural arteries. Useful for distal femur, proximal tibia and knee coverage, it may be advanced minimally to allow coverage over the Achilles tendon or rotated to the mid tibia thanks to anastomosis across the muscular raphe. The gastrocnemius flap can only be employed in scenarios where soleus is intact as rehabilitation and walking are dependant on ankle plantar flexion.

The *vastus lateralis* muscle provides a musculocutaneous flap which offers no great deficit in ambulation which is not afforded by flaps raised using the *rectus femoris muscle* for hip and proximal thigh defects.

#### 4.3.4. Other Flap Choices

**Free osteocutaneous flaps** options include, but are not limited to:

- Iliac osteocutaneous flap
- Vascularised rib transfer +/- serratus anterior and/or latissimus dorsi
- Fibula osteocutaneous flap
- Radial osteocutaneous flap

#### 4.4. Choice of Reconstruction: By Anatomical Location of Injury

Anatomical zone of injury is a key determinant of introducing a more reliable pedicled flap to a wound bed. Many papers have stated success with varying options:

The gluteal and the thigh regions, due to their option as free flap choice, allow great versatility in regard to local flaps. V-Y, bipedicled and keystone flaps are all utilised with good outcomes [42].

Due to the unique anatomy of the knee, reconstruction of the soft tissues has been attempted with both local and free flaps, the choice being more dependent on surrounding tissue availability and the amount of bony and soft tissue injury [43].

The knee and popliteal region, as commented on, can be covered by pedicled gastrocnemius, or proximally based hemi-soleus, flaps [44-46].

Significant tissue coverage here is important as loss of the extensor mechanism of the knee is seen to have long term functional consequences [47]. Improved microsurgery has allowed the use of the genicular arteries as recipient vessels, minimising trauma to the popliteal and femoral vessels [48].

Sarcomas involving the tibial bone are not uncommon. A combination gastrocnemius and soleus flap has been described for proximal tibia defects. This unit's results state 25% of these required either a bipedicled flap or sural flap reconstruction later with a 10% amputation rate. Nineteen of twenty-one patients were ambulatory at follow up (median 2.8 years) [49].

The mid tibia defect can also be covered using a combination medial hemisoleus and gastrocnemius flap, with an aim of maintaining the Achilles tendon and posterior tibial vessels to allow ankle plantar flexion post reconstruction [50] with the author also describing his use of the medial hemisoleus [51] and the reversed hemisoleus flap for distal tibia defects [52].

The middle and distal tibia defect has also been salvaged using the osteocutaneous fibula flap with good results, both as a pedicled and free flap [53-57].

The lower third of the lower leg, heel and hindfoot are technically challenging areas to cover. Options include the saphenous and sural flaps. The saphenous flap provides a reliable and versatile option for the medial and anterior lower leg, as well as the hind foot and malleolar region [58]. The sural fasciocutaneous flap has successfully been used to reconstruct tissue loss in these areas. The distally based sural

flap is safe, reliable and operatively quick to perform negating free flap reconstruction. However, this flap may be limited by the size of the defect, reasonably covering an area up to 10cm square [59, 60].

Heel defects in particular present a difficult area to reconstruct being a weight bearing zone. Delayed reverse sural flaps have been used successfully in cases of distal tibial and calcaneal fracture with neurofasciocutaneous coverage, improving long term function and rehabilitation [61-63]. The perforator supply to the sural based flap allows numerous options, allowing reduced donor morbidity [64, 65].

The dorsal foot and ankle are likewise difficult to reconstruct due to a functional lack of tissue around this site. Distal based lateral supramalleolar adipofascial flaps have been described, providing less bulky flaps although requiring grafting of the transposed flap and covering only small defects [66, 67]. They may also reduce long term ulcer formation due to some retained sensation compared to free flaps [68].

The anterior tibial artery provides an adipofascial flap suitable for coverage over the malleolar regions [69].

Foot coverage has been successfully performed using sural artery-, lateral calcaneal artery based-, extensor digitorum brevis muscle rotation-, and abductor hallucis muscle rotation- flaps [70-72]. Dorsalis pedis based flaps are also often considered in the foot [73].

Medial plantar flaps, both described as free or pedicled, have also been reported as successful in plantar forefoot repair, giving a sensate region which is preferential in this weight bearing region [74].

Free flaps, as commented are generally a reliable and with a specialist team, reliable option for both traumatic and non-traumatic defects. The serratus anterior [75], latissimus dorsi, radial forearm, lateral arm, rectus abdominis [76] and parascapular free flaps can be added to those described above, with results in both adult and child populations [77-80].

It has been noted that the latissimus dorsi and rectus abdominis flaps offer a more reliable flap option with the less microsurgically experienced team than the antero-lateral thigh flap [81].

In scenarios where a large defect is unable to be covered by a pedicled flap and there is contraindication to a free flap (included only one intact vascular axis), particularly in the heel region, the cross leg flap has been used with reasonable results, using the medial saphenous flap with a mean division time of 27 days [82].

Free flap cross leg flaps have also been described [83], as well as scenarios where free flaps have been taken from one amputated limb to cover severe tissue loss of an intact lower limb [84].

## 5. CHOICE OF RECONSTRUCTION; ALTERNATIVES AND ADJUNCTS TO A FLAP

### 5.1. Amputation

Amputation is an option for both traumatic and chronic wounds of the lower limb. These are generally taken at

transmetatarsal below knee or above knee levels. It has been shown that there is a failure for elective elderly patients to regain baseline function after 6 months, particularly in patients having a higher amputation level, poor baseline cognitive function and high co-morbidity [85].

Similarly, above knee amputation has been seen to have a larger impact on war victims compared with below knee and through knee amputation and requires greater energy expenditure to later mobilise [5, 86].

Early distal amputation may also help minimise the need for major limb amputation as a definitive therapy [87], particularly after misguided reconstruction attempts which include significant morbidity [88, 89].

Hertel *et al.* [90] compared amputation versus patients undergoing complex microvascular reconstruction. They found an increased number of interventions (8 vs 3.5,  $p < 0.009$ ) and rehabilitation time (30 vs 12 months,  $p < 0.009$ ) in the reconstructed group, although this group retained their profession (81 vs 46%,  $p < 0.025$ ) and required a less costly and lifelong invalidity pension (16 vs 54%,  $p < 0.02$ ). There was no great difference in the cost of different interventions. Indications for amputation remain those having a fully severed limb or posterior tibial nerve (loss of foot plantar sensation), with a poor pre-injury health history,  $> 8$ cm segmental tibial loss or a limb ischaemia time greater than 6 hours [5, 90].

There have been multiple attempts at guiding the choice of salvage and reconstruction versus primary amputation with the use of injury severity scoring systems. These include: the Mangled Extremity Severity Score (MESS) [91], the Predictive Salvage Index (PSI) [92], the Hanover Fracture Scale 1998 (HFS-98) [93], the Limb Salvage Index (LSI) [94] and the Nerve injury, Ischaemia, Soft tissue injury, Skeletal injury, Shock, Age system (NISSSA) [95]. These have all been evaluated in their use to describe a recommended threshold for primary amputation in the adult trauma population.

## 5.2. Negative Pressure Wound Therapy

This has been documented for its use in wound coverage until definitive therapy is decided or indicated [5], as well as helping to reduce the size of wound, allowing free flap reconstruction of the massive lower limb wound [96, 97], or the passage down the reconstructive ladder to the point of foregoing the need of even a local flap, something improving investigations and surgical technique is also allowing [98].

Also, improving investigations and surgical technique can limit the need for free flap reconstruction.

NPWT is also of benefit in its use after amputation and wound line dehiscence for healing the wound [80] and in aiding flap success [99], particularly with exposed metalwork [100].

## 5.3. Other Options

Dermal substitutes are gaining popularity in aiding soft tissue coverage with good results reported. Usually in association with skin grafting, these templates are used to help cover areas where, otherwise, skin grafts would fail (lack of paratenon and periosteum) [101-105] and in conjunction with NPWT [106].

They are also becoming useful as a wound closure option in the emergency situation, particularly in war injuries, both allowing delayed, or negating, flap reconstruction [107, 108].

Platelet rich plasma has been trialled in the treatment of chronic diabetic foot wounds of the lower limb [109]. Although only a case report, the use of autologous growth factors in this case could predict a strong future for pharmaceutical therapies.

## CONCLUSION

Lower limb surgery, in particular reconstruction, is important to restore and maintain both balance and ambulation. Loss of the lower limb is a possible outcome in trauma, malignancy treatment, diabetic, peripheral vascular disease and neuropathy. After appropriate debridement, reconstruction of any wound has a significant impact on the patient and their family. The salvage of the limb is preferred to amputation, reportedly being more cost-effective over the patient's lifetime [110].

Soft tissue coverage must be wound and area specific, involving the patient and a multidisciplinary approach as the unmotivated, poor pre-injury ambulatory patient with multiple co-morbidities is likely to have poorer outcomes.

The reconstruction ladder offers options and the improvement in both pedicled and free flap microsurgery has made these the mainstay of therapy options. The choice of coverage should be determined by reliability, rather than ease of a procedure and should be the least disabling with the future likely to provide pharmaceutical and engineered adjuncts to help reach these aims.

## CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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