

Principal recommendations

1. A primary amputation is performed as a damage control procedure if there is uncontrollable haemorrhage from the open tibial injury (usually from multiple levels of arterial/venous damage in blast injuries) or for crush injuries exceeding a warm ischaemic period of 6 h.
2. Primary amputation is also needed for incomplete traumatic amputations where the distal remnant is significantly injured.
3. A primary amputation is considered an option where injury characteristics include one or several of the following:
 - (a) Avascular limbs exceeding a 4–6 h hour threshold of warm ischaemia
 - (b) Segmental muscle loss affecting more than two compartments
 - (c) Segmental bone loss greater than one-third of the length of the tibia.
4. Absent or reduced plantar sensation at initial presentation is not an indication for amputation.
5. Amputation levels are preferably transtibial or transfemoral (if salvage of the knee is not possible). Through-knee amputations are not recommended for adults.
6. The decision to amputate primarily should be taken by two consultant surgeons with, if possible, patient and family involvement.
7. Discussion with the nearest specialist centre is advised when there is uncertainty or disagreement between surgeon recommendations and patient/family wishes.

Introduction

A decision to amputate a limb needs to balance the impact of reconstruction and salvage against that of limb removal. The scientific approach, turned to when there are uncertainties in treatment decisions, is unhelpful; a randomized controlled trial is unlikely to get balanced recruitment simply because most patients will not opt to be randomly allocated to amputation if there is a reasonable chance that limb salvage might produce a functional limb.

Modern surgical techniques offer the potential to reconstruct limbs which were thought unsalvageable a few years ago. Vehicle design improvements have also made it more likely that traffic collision victims will survive, albeit with more severe injuries. These factors, combined with occasional episodes of severe blast injuries encountered

in civilian practice, mean a surgeon may encounter severe limb trauma that poses the dilemma: should limb salvage be undertaken? Futile attempts to preserve a limb which should be amputated disrupt a patient's life both physically and psychologically. Early amputation can avoid this eventuality but is not without its own problems.^{1,2}

Assessment in limb-threatening trauma

Even in the presence of limb-threatening injuries, a firm grasp of the 'big picture' is essential. Advanced Trauma Life Support (ATLS)[®] management appropriately emphasizes the primary survey as the starting point. Life-threatening problems are identified and treated in a logical, hierarchical sequence. Assessment of limb-threatening trauma is part of the primary survey in 'C' for circulation and 'D' for disability.

A rapid assessment of perfusion, soft tissue injury, fracture pattern and, wherever possible, sensation and motor function is essential. Multiple levels of injury in the same limb pose a difficult problem in assessment – if there is a vascular or neurological deficit, identifying the level of arterial or nerve injury may not be possible from clinical examination alone. Multiple limb trauma will also pose problems. Neurological examination may, at best, be incomplete or even impossible owing to the likelihood of other injuries affecting major systems and rendering the patient unable to respond clearly. In that event, the inability to assess neurology should be clearly documented.

The decision node for amputation against limb salvage is beset with multiple branches. Each branch carries combinations of injury-, patient-, surgeon- and even family-determined variables. Decisions to perform amputations are usually taken at two points in time:³ (1) immediately, as part of primary treatment or, (2) when either features of the injury or patient recovery declare themselves fully and render any further attempts to save the limb unwise. In the latter group are those cases where initial attempts at salvage fail whilst the patient remains in hospital, as well as those where the family and patient wishes are reflected on.

Immediate amputation is indicated in several open tibial fracture scenarios. These include:

1. Incomplete amputations, where the injury has almost completely severed the limb and the distal portion is itself subject to significant trauma
2. Extensive crush injury, particularly to the foot and distal tibia
3. An avascular limb with a warm ischaemia time in excess of 4 h.

Less certain are scenarios which form the 'grey areas':

1. An ischaemic limb with clinical evidence of nerve dysfunction, particularly absent plantar sensation
2. Segmental muscle loss across more than two compartments, especially if the posterior compartment is involved

3. Segmental bone loss greater than one-third of the length of the tibia
4. Severe open foot injury associated with the tibial fracture.

In addition to the anatomical and functional deficits (which imply the extent of reconstruction or repair needed as well as the likely outcome), there needs to be an appreciation of the patient's reserve – physiological, psychological, social and economic. A patient with a 'grey area' scenario with continued haemodynamic instability may shift the decision towards amputation. A patient with a substance abuse history, including alcohol, may struggle to cope with the rigours of protracted limb salvage. Similarly, an individual who is self-employed and a bread-winner needs a predictable and assured period of recovery and may be better served with an amputation. To compound matters, the acceptance of limb loss varies greatly between societies of North America and Western Europe, in contrast to the Middle and Far East.

Attempts have been made to produce clinically useful scoring systems to assist in making decisions about limb salvage in these difficult circumstances. However, none has proven useful.⁴ Data from the North American Lower Extremity Assessment Project (LEAP) have yielded differences in the priority of limb-threatening variables to amputation, even amongst experienced trauma surgeons and general trauma surgeons.^{3,5,6} A systematic review of the literature⁷ showed similar outcomes when comparing amputation and salvage for grade IIIB and IIIC fractures.

Some idea of the time scale, surgical stages and likely outcome of reconstruction of these scenarios may assist in decision-making. At times, the decision not to amputate immediately is taken in order to gain more information – from the patient and family, or to allow a more complete assessment of the extent of limb injury.

Impact of limb-threatening variables

Limb ischaemia

Warm ischaemia time serves as a threshold as do the extent and levels of associated non-vascular injury in the open fracture (see Chapter 14). The greater the ischaemic time, the more likely it is that there is significant muscle loss from necrosis, no-reflow and reperfusion injury.⁸ Salvage of an ischaemic limb in association with an open tibial injury needs to be achieved within 4–6 h if it is to be successful. The 4–6 h warm ischaemia threshold is reduced if the patient is hypotensive throughout most of this time.⁹ The use of temporary intravascular shunts can be extremely effective in reducing warm ischaemia time and allows prompt fracture stabilization to proceed before definitive arterial repair.¹⁰ Major deep venous injuries proximal to the trifurcation should also be repaired.^{11,12} In the event that the warm ischaemia threshold is approached and the limb is unlikely to receive temporary intravascular shunts immediately, due consideration should be given to amputation. Delayed revascularization may not only induce greater local damage but may also produce systemic effects through the circulation of breakdown products of reperfused muscle.

Absent plantar sensation

It is not uncommon for this clinical finding to exist with evidence of vascular disruption as both nerve and artery course the lower limb together. Absent plantar sensation at initial presentation should not be regarded as an absolute indication for amputation. Recovery of normal plantar sensation is possible in over half the patients and may suggest the initial loss is due to neuropraxia and cannot be assumed to arise from nerve disruption.⁵ If structural disruption of the nerve is confirmed during wound assessment, the outcome is less certain, even if the integrity of the nerve is restored by microsurgical repair. Long-term outcomes for patients with permanent absent plantar sensation are unknown, although analogies are made with other non-traumatic conditions which also produce neuropathic feet, e.g. diabetes and spinal cord pathology. An important difference between the insensate traumatic and non-traumatic groups may be the extent of muscle loss and scarring in the former that may influence pain and functional levels; these two groups are not exactly comparable.

Altered plantar sensation requires exploration of the tibial nerve at the time of debridement in open tibial fractures. Structural continuity of the nerve should prompt an expectant approach and not weigh towards a decision for amputation. Conversely, early amputation should be considered if the nerve is found to be divided together with extensive muscle loss across two or more compartments (particularly if the posterior compartment is involved) and a warm ischaemia time greater than 4–6 h. A neuropathic sole with an abnormal, poorly functional foot and ankle are likely outcomes if limb salvage is contemplated in this scenario.

Severe soft tissue damage and loss

The extent and level of muscle loss influence the functional potential in the limb. Muscle damage may occur as a direct consequence of trauma or through effects of ischaemia and reperfusion injury.

Loss of dorsiflexion from anterior compartment loss can be offset by transfer of a functioning tibialis posterior through the interosseous membrane. Loss of peroneal muscle action can be offset by transfer of tibialis posterior to the peroneal tendons behind the tibia. When there is loss of muscle action spanning several compartments, it increases the likelihood of dependence on orthotics to support the foot and ankle. Whilst this alone is not an indication for amputation, other variables often present with the severe soft tissue damage and need to be considered. For example, the presence of extensive muscle damage in the posterior compartment usually is associated with segmental bone loss and disruption of posterior tibial vessels and nerve. Such a combination is seen most frequently after a crush injury and may be an indication for amputation.

Severe bone loss

Bone loss is managed through several strategies: autogenous bone grafts (usually of iliac crest origin), bone substitutes, free vascularized bone or composite tissue transfer

and bone regeneration through distraction osteogenesis. A threshold for amputation set by the amount of bone loss is difficult to quantify – cuneiform patterns of bone loss (typically from extrusion of butterfly fragments), even when large, are easily treated with simple autogenous grafts in comparison to segmental patterns of bone loss. Thus, variations exist, not only in the size and type of bone defect, but also in host tissue conditions and the patient's general health.

Guidelines can be obtained by a comparison of the scale and time needed for recovery following salvage when compared to recovery from amputation. In the adult tibia, autogenous bone grafting of segmental defects less than 2 cm in length will consolidate in approximately 5 months, provided the recipient site is well vascularized and the patient is a non-smoker. Larger defects, if treated by distraction osteogenesis, usually consolidate at approximately 45 days per centimetre of tibia replaced. Therefore, a 5 cm defect can be successfully reconstructed using this method in about 7–8 months. However, limb reconstruction using distraction osteogenesis is time consuming and may involve more than one surgical procedure in the period. When segmental bone defects approach 10–15 cm, reconstruction by bone transport will take in excess of 12 months. Only well-motivated patients with appropriate domestic and financial support will be suitable to undertake this magnitude of limb salvage. Free vascularized transfer of bone into the defect (usually the fibula) may shorten the reconstruction time and prove a better alternative, but protection of the transferred bone until suitable hypertrophy occurs is needed in the after-care period.^{13,14} In contrast, a transtibial amputee will take approximately 5–6 months to rehabilitate to independent walking if there are no other injuries. In general, bone loss in excess of one-third the length of the tibia will take more than 12 months to reconstruct using distraction osteogenesis. In this situation, amputation should be considered as a viable alternative solution, particularly if the patient has need for early return to independent ambulation and work.

Open foot injuries (in association with open tibial fracture)

This is a segmental injury to the lower limb with special significance: hind-foot injuries are usually complex, and vary from open calcaneal injuries to talar body and neck fractures. In very severe examples, there is extrusion of part of the talus (see Chapter 15).

Whilst the principles of management to both levels of injury are similar, some projection of the likely functional outcome after salvage is needed. Severe hind-foot injuries end up with joint stiffness. Loss of plantar skin is very difficult to reconstruct, even with reinnervated flaps. Salvage of early post-traumatic joint degeneration will need arthrodesis. This sequence of reconstruction and further salvage procedures, should complications within the joints supervene, may leave the patient with the functional equivalent of a below-knee prosthesis. In this event, an early recommendation for a transtibial amputation could provide a functionally equivalent outcome with a shorter rehabilitation period.

Damage control over primary limb salvage

Amputation as damage control

Amputation may serve as the only means for haemorrhage control and resuscitation. Another scenario is a limb that has been crushed for several hours (exceeding the warm ischaemic threshold) and reperfusion may induce severe systemic upset through circulating breakdown products of muscle.

Shunt and span as damage control

When the patient's condition demands a damage control strategy, prolonged surgery to salvage a limb-threatening injury is unhelpful. Damage control orthopaedics in a physiologically unstable patient avoids tipping the patient's inflammatory response into adult respiratory distress syndrome (ARDS), disseminated intravascular coagulation (DIC) and multiple organ failure.¹⁵ A decision has to be made either to amputate the limb or do the minimum to salvage, with a plan to return later for more definitive surgery. The level of temporizing can vary; at its most fundamental, intravascular shunts can be placed for ischaemic limbs and the fracture spanned by external fixation⁸ (see Chapter 14). Wound debridement may have to be limited to removal of gross contamination, thereby avoiding extensive exposure and dissection in a coagulopathic patient. The shunts can be left *in situ* whilst the patient remains in the intensive care unit. Shunts with a 'dwell' time averaging 23.5 h have been reported, with a thrombosis rate of 5%.¹⁰ A return for definitive arterial or venous repair coupled to more definitive debridement, should the patient's general condition improve, has to be undertaken at the earliest opportunity or a decision made to amputate. The timing of a return to surgery must be decided upon jointly by the intensive care specialists, plastic and orthopaedic surgical teams.

Amputation levels

The level of amputation is an important consideration with implications for future mobility and employment prospects.^{2,16–18} The physical effort of walking is lower and the quality of life superior with a transtibial (below knee) as compared to a transfemoral (above knee) amputation. Energy expenditure for a transtibial amputee is 10–30%^{19–21} greater as compared to a 40–67%²⁰ increase in transfemoral cases. Bilateral transtibial amputees incur an extra energy cost of over 40%, whereas those with bilateral amputations where one level is transfemoral may have to double their energy costs simply to ambulate.¹⁹ The impact of this increased energy cost will vary between patients; in younger, more-able individuals the penalty may not translate into functional significance, but in others both ambulation speed and walking capacity are limited.²⁰ Similarly, amputees resulting from trauma have lower energy costs compared to those resulting from peripheral vascular disease.²⁰ Even so, function with modern transtibial prostheses can be excellent and many young patients return to work and sporting activities.

Amputations through the ankle or knee are not recommended for adults. The theoretical advantage of a longer lever arm is not supported by clinical outcomes. Furthermore, patients dislike the pronounced knee level asymmetry (especially when seated) with through-knee amputations. The functional outcome of a through-knee amputation is also poorer to an above-knee equivalent.²

Every effort must be made to preserve the knee, including vascular repair or flap coverage, even if the distal limb is hopelessly injured and needs amputating. Very short below-knee amputation stumps can be avoided if, in the presence of a reasonable foot remnant, a pedicled flap of plantar skin and attached os calcis is transferred and fixed to the end of the divided tibia.²² Such ‘partial salvage’ can make an enormous difference to ultimate function.

Conclusion

Medium-term studies show comparable outcomes in terms of function, return to work and quality of life for those with successful reconstruction or amputation.^{5,23,24} Long-term follow-up of US Army Veterans with lower limb amputations indicate that many people are capable of successful adaptation to their circumstances and lead lives with comparable health-related quality of life to their peers, at least for below-knee amputees.^{16–18} Those with transfemoral amputations tended to abandon their prostheses after 10 years or more, opting for mobility in a wheelchair.

Limb salvage is complex and demanding for both patient and surgical team. An amputation should always be considered as an option for open tibial fractures where the severity of injury and patient characteristics shift the balance away from limb salvage. Financial considerations are always quoted as a reason for amputation over limb reconstruction but the sum incurred in a lifetime of prosthesis supply and adjustments can be higher compared to reconstruction in Western societies.^{25,26} Furthermore, the ageing amputee can encounter additional problems with mobility that are avoided with successful limb salvage.^{27,28}

Wherever possible the decision to amputate should be taken by two consultant surgeons. This serves a dual purpose: reassurance for the patient and their family that a second opinion has been sought, and confirmation (and to some extent protection) for the operating surgeon that such a momentous decision is unavoidable.

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