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The orthoplastic approach in the mangled lower limb

Bruno Battiston[1], Maria Cristina Castrogiovanni[1], Chiara Beltramo[2]

[1] UOC Ortopedia a Traumatologia e Chirurgia della Mano, CTO Hospital, Turin, Italy;
[2] UOC Ortopedia a Traumatologia e Ortopedia Oncologica, CTO Hospital, Turin, Italy

Summary

The recommended treatment of a subamputation or amputation of the lower limb (with a severe combined osteo-articular, vascular and nerve lesions) is a combined orthopedic and plastic approach with revascularization/replantation/reconstruction of the segment. The indications for reconstruction of mangled lower limbs are more selective than for the upper limb due to the possibilities to return to satisfactory walking given by prosthesis. For this reason, some scoring systems have been created to aid in decision making. If a reconstruction is decided, timing is crucial as we have to consider if all structures will be reconstructed immediately (all-in-one approach) or to apply the rules of damage control, and delay the reconstruction. In few cases, loss of tissues may be resolved on emergency.
Secondary reconstructions need the expertise of using sophisticated flaps (simple fasciocutaneous up to complex combined free flaps) and/or well-established orthopedic techniques (bone transport with Ilizarov technique, massive free grafts according to Masquelet, etc.).
The choice of the technique and timing (one stage – two stages) needs a clear plan which will not exclude traditional techniques, but has to take into account the possibility to use microsurgical reconstructions.

Key words: lower limb, replantation, indications, score system, microsurgical repair, complications, results

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Correspondence
Bruno Battiston
UOC Ortopedia a Traumatologia e Chirurgia della Mano, CTO Hospital, via Zuretti 29, 10126 Turin, Italy. Fax. +39 011 6963662
E-mail: bbattiston@cittadellasalute.to.it

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Introduction

Nowadays, the need for reconstruction of lower limb subamputations and amputations is increasing due to high energy traumas in road accidents or work injuries. Indications for lower extremity replantations are more selective than for the upper limb [1-3]. Although the evolution of sophisticated microsurgical techniques has made successful limb salvage possible, the frequency of severe post-operative complications either general (cardiac or renal failure) or local (necrosis, compartimental syndromes, infections) may lead to delayed amputation. The poor functional outcome with several secondary procedures discourages many surgeons from replantation/reconstruction of these severely damaged segments. Moreover, primary amputation, especially at leg level, often provides excellent recovery possibilities thanks to the modern prosthetic replacements. According to some studies, primary amputation is associated with a 50% reduction in costs compared with lower limb reconstruction [4]. In contrast, Battiston et al. [1] believe that, in selected cases (clear lesions, bilateral amputations that impair good ambulation even with a good prosthesis, young patients) reimplantation of a severed lower limb should be attempted. In addition, amputation causes psychological trauma for the patient and the social costs, in the case of functionally replanted segments, are lower (lower rate of disability, no cost for new prosthetic devices).

The purpose of this article is to provide the elements to recognize selected cases in which to perform a reimplantation or a complex reconstruction, avoiding complications and obtaining a vital segment with satisfactory functional and aesthetic results. Flap surgery is evolving: many reconstructions rely more and more on simultaneous and early treatment of bone and soft tissue loss with a strategy combining orthopedic and plastic competence: the "orthoplastic" approach.

Indications and contraindications for replantation

According to the literature [5,6], the main criteria to decide for replantation of an amputated lower limb are:

Patient's age

People over the age of 50 generally have more complications and the worst results.

Patient's general conditions

Associated lesions (head trauma, internal organs injuries, etc.), state of shock, cardiac issues, or general diseases (diabetes, etc.), contraindicate lower extremity replantations.

Ischemia time

Even in the case of good preservation of the distal segment (cold ischemia), revascularization time must not exceed 6 hours, not only to guarantee limb survival but especially to avoid severe postoperative complications such as cardiac or renal failure.

Type and extent of tissue damage

Double level lesions are contraindications for replantation. On occasion, crush injuries jeopardize the possibility of reconstruction. However, crushed margins may be changed into neat lesions by radical debridement. A segmental resection with good primary reconstruction, even with a shortened leg, and the secondary use of limb lengthening techniques, may solve this problem (two-stage procedures) [7,8]. Secondary limb lengthening allows replantations even in the presence of large bone loss, but we think that loss of substance greater than 10 cm is not a good indication as reconstruction will give rise to a poor functional outcome.

Bilateral amputations

Bilateral prosthetic fittings lead to worse results compared to replantation on one side and an under-knee prosthetic device on the other.

Even if these criteria guide decision making, in case of severe post-traumatic ischemic lesions of the lower limbs needing replantation or revascularization, the question of salvage *versus* primary amputation is still based on subjective clinical parameters rather than objective ones.

Scoring systems

After a review of our cases to evaluate not only limb survival, but also functional outcomes [1], we developed a simple objective scoring system to be used in emergency before proceeding with replantation or amputation. This system considers amputations proximal to the ankle level. In fact, to replant an amputation at the foot level is useful only in the case of very clean and neat lesions, otherwise the final functional result will not justify the surgical efforts even because amputation of a small segment will not cause severe walking problems for patients.

Several scoring systems have been proposed for the decision to amputate or salvage the lesioned limbs (Mangled Extremity Severity Score, MESS [9] / Hannover scale [2]/ Predictive Salvage Index, PSI [10]), but, as already stated [11], they have problems in correctly predicting the possibility of a functional reconstruction. This was the reason to modify the MESS system, giving the right weight to age, general conditions, ischemia time, and tissue problems (distinguishing bone from soft tissue problems) (Tab. I).

Patients over 50 years are given 2 points, those between 30 and 50 1 point, and those younger than 30 years 0 points.

For general conditions, patients with hemodynamic problems (shock) are given 4 points, while poor previous health status (systemic diseases as diabetes or hypertension and heart problems) is given 2. Patients in good general health score 0 points.

As ischemia time is critical, we give 4 points to lesions with more than 6 hours of cold ischemia or 4 hours of warm ischemia. Amputated segments with 3 to 6 hours of cold ischemia are given 2 points. Patients with cold ischemia time of less than 3 hours are given 0 points.

We decided to evaluate the problem of local conditions not on the basis of the kinetics of the injury itself (MESS system) but on the extent of the damage, differentiating bone from soft tissue lesions. Therefore, we attribute 2 points to severe bone contamination with comminution and bone loss; 1 point to complex fractures without severe contamination; 0 points to neat lesions without bone loss and almost no contamination. In the category reserved to soft tissue problems, 4 points are given to severe lesions of the posterior tibial nerve with difficult reconstruction; 3 points are attributed to a large amount of skin and muscular and/or tendon loss; patients with severe skin problems (defects or degloving) but with good muscles are scored 2; in the case of partial skin necrosis 1 point is given and only in the case of good soft tissue conditions, patients receive 0 points.

This way the division of problems into 5 categories allow us to postulate that lesions scoring 8 points or more have to be amputated. In cases with 6 or 7 points we may replant an amputated limb, but we also expect a functionally impaired lower extremity. All the cases scored 5 or less may give good functional results.

Table I. Scoring system for indications to lower limb reconstruction in complete or partial amputations.

Age			**> 50**	**30-50**	**< 30**
Score			2	1	0
General conditions			Shock	Systemic disease, diabetes, hypertension, heart problems	Good conditions
Score			4	2	0
Ischemia time			≥ 6h, cold, ≤ 4h, warm 4	3-6h, cold 2	≤ 3h, cold 0
Score			4	2	0
Local conditions			Severe contamination, comminution, bone loss	Complex fracture without severe contamination	Neat lesions, no bone loss
Score			2	1	0
Soft-tissue problems	Severe lesions of posterior tibial nerve	Large skin and muscular-tendon losses	Severe skin problems but good muscle conditions	Partial skin necrosis	Good conditions
Score	4	3	2	1	0
** ≥ 8, controindication for remplantation; 6-7 possible remplantation; ≤ 5, indication for remplantation.*					

Tips and tricks in surgical technique

In the lower limb we frequently deal with lesions of large segments containing large muscular masses. Accordingly, ischemia is a critical factor. Mangled lower limbs are very often caused by high energy traumas: the patient must be carefully evaluated (cranial trauma, internal injuries) and stabilized before entering the operating theatre.

The first surgical step is a radical debridement to avoid subsequent necrosis and/or infections, but also to have clean margins. This facilitates our reconstruction plan thus reducing the need for grafts and the risks of secondary thrombus formation caused by damaged vessel stumps. Debridement of non-viable muscles is mandatory: excision of muscles in the lesioned distal segment leads to an "elementarization" [12] of the function, but especially in the lower limb this is not a problem and some authors suggest that the patient only needs a special kind of sensory biological prosthesis [13]. Furthermore, muscle excision dramatically reduces the risks of heart problems or renal failure after revascularization. Nerves and vessels are to be identified and prepared. In case of prolonged ischemia time, we use temporary shunt procedures (catheters connecting proximal and distal artery stumps) to reduce irreversible ischemic damage [14]. In this case, we also let the venous blood flow out for a while to wash out catabolites from the revascularized segment.

Bone fixation is the next step. Internal osteosynthesis may achieve good stability, but our experience in open fractures at this level with frequent complications (soft tissues necrosis with plate exposure, infections, etc.) has led us to prefer external fixation devices. Attention must be paid to position the fixator so as to not interfere with soft tissue reconstruction and future osteosynthesis. External fixators allow secondary changes (compression, distraction) and may be integrated or changed for secondary limb lengthening or to resolve some complications (i.e. delayed unions).

After rapid osteosynthesis, vessels are repaired. In lower limb replantation, we usually prefer to repair the artery first to reduce the ischemia time. This also leads to wash out of catabolites before vein reconstruction. Some blood loss may occur, and the anesthesiologist should be ready for infusion of extra blood units. We prefer the repair of both the arteries (posterior and anterior tibial artery), whenever possible, using 8.0 or 9.0 non absorbable sutures; interrupted sutures are preferred to avoid stenosis and spasm given by continuous sutures. Topical heparin is used to wash the vessel stumps and lidocaine to reduce spasms. Three to four or even more veins are to be repaired. If possible, we prefer the deep veins (for the absence of valves) but the saphenous vein may also guarantee good reflow. Sometimes our initial shortening does not allow direct repair for large vessel resection up to a sound vessel wall. In this case, vascular grafts are needed.

Nerve repair is essential to guarantee a good functional result, and in the lower limb is mainly in terms of plantar foot sensory recovery. Next, the posterior tibial nerve is the main trunk to

be repaired. Even if we are in emergency situation, at this time the limb has already been revascularized and we have to spend time in repairing the nerve. Thus, if possible, a direct suture with fascicular repair and without tension must be performed. When the trimming of the nerve stumps results in a nervous gap, nerve grafts (harvested from the sural nerve of the same limb) or conduits [15] (for short gaps) are used to fill it.
Muscle and/or tendon repair follows the general guidelines for these structures. We perform buried and mattress sutures, and are used to bury the tendon in the muscle in a fish-mouth configuration if the lesion is at the myotendinous junction. At the end of this repair, extensive fasciotomies must be performed to prevent severe secondary complications such as necrosis and Volkmann's contractures that would jeopardize the final functional result.
Soft tissue coverage is the last step, but perhaps the most important as the final functional result will depend on the quality of soft tissue reconstruction. It is very important to cover all the "noble" structures with vital flaps and if there is not the possibility to utilize local flaps (muscular or skin rotational flaps) free flaps are to be harvested as soon as possible. Emergency/early flaps, according to our experience and that of others [16], avoid risks linked with exposed structures (infections, necrosis) and have better survival in front of delayed procedures.

New approaches to reconstruction

The simultaneous treatment of fractures and associated soft tissue damage has expanded so much that it has created a new "orthoplastic" approach to limb trauma. Microsurgical flaps, especially in their composite variants, can solve severe loss of substance in a single operation. The new reconstructive solutions can be combined with traditional techniques: in the lower limb, a free fibula flap provides biological support in case of bone loss, while the use of external fixators provides mechanical support to the flap and allows length, axis, and rotation corrections.
Combined bone and soft-tissue reconstruction is not only a technical choice, but also a solution which, considering the right timing, will lead to lower complication rates and a faster recovery. According to the National Institute for Health and Care Excellence (NICE) guidelines, exposed lower extremity fractures should be treated with definitive fixation and soft tissue coverage within 72 hours after injury, if this is not possible at the moment of debridement [17]. In traumatic cases, once the wound is cleaned and properly debrided, an all-in-one reconstruction may be considered (bone osteosynthesis, and flaps coverage).
Of course, this is not to be applied in case of polytrauma where the concepts of the damage control (life before limb) are to be respected and the window of opportunity moves to 4-7 days after trauma.
Innovation comes not only from the design of new flaps, but also from the application of imaging techniques or new devices. Such applications allow for improved preoperative planning and the creation of 3D models that facilitate reconstruction with biological and nonbiological materials (such as premolded plates) to improve functional restoration. This is particularly important in complex reconstructions of three-dimensional defects [18].

Choice of the flap

The reconstructive technique is chosen to obtain the best possible outcome. For the lower limb, not only bone stability and soft tissue coverage must be ensured, but most of all, the maintenance of ambulation [19]. In order to preserve function, prevent infections, and ensure the use of footwear and acceptable aesthetics, reconstruction must take place within the aforementioned 72 hours. There are several different reconstruction solutions. The surgeon's preference and experience are critical. In addition, the lower limb has historically been divided into reconstructive zones, each with its own local flap options: for the thigh or trochanteric region the vastus lateralis and the tensor fascia lata; the gracilis and rectus femoris for the inguinal region, less commonly used the sartorius; for the knee and proximal third of the leg the gastrocnemius flap, most often medial. With the advent of fasciocutaneous flaps and microsurgical flaps, the traditional concept of reconstructive zones has become obsolete. There are no longer anatomical restrictions; the choice of flap is made according to the anatomical and functional requirements of the defect. For example, areas rich in muscle tissue, such as the thigh and hind leg, have no functional restrictions, and skin grafts, muscle flaps, or fasciocutaneous "perforating" flaps [20,21] can be chosen according to the desired aesthetic result. The remaining part of the leg generally needs only thin skin coverage, and perforator – propeller flaps are ideal for this function. In the knee region, whatever flap is used must allow maximum mobility of the joint, adequate and durable thickness, and a gliding surface for the patella (for example, by including a fascial structure in the deep portion of the flap that will be used). In the ankle and non-load-bearing regions of the foot, it is necessary to select flaps that are sufficiently thin so that footwear can be used, while the load-bearing regions of the plant should be treated with very durable and possibly sensory flaps to prevent ulceration and spoiled joint attitudes [22].
In case of different flaps adequate to cover the same defect, the choice should fall to the one with the least impact on the donor site. The gold standard is a linear skin scar and negligible functional impact. Muscle flaps can be performed with minimal skin site morbidity but can cause strength deficits. In the case of perforating or myocutaneous flaps with skin paddles of a size that do not allow direct closure of the donor site, a secondary flap or skin graft will be required, with a less acceptable aesthetic outcome for the patient. The attractiveness of many perforator-based flaps lies not only in the quantity and quality of transferable tissue, but also in the possibility of having some of the best possible donor site scars, easily concealed by the patient's clothing.

Conclusions

In conclusion, although the indication to save or amputate a lower limb is one of the most difficult to take in major trauma, there are now elements that can guide the surgeon's choice. The authors' evaluation system considers both the patient's condition and the characteristics of the injury, giving a score with prognostic value for the success of replantation/reconstruction. When the decision to proceed with replantation has been made, bone reconstruction should be combined with soft tissue reconstruction in an all-in-one surgical procedure if possible. In addition, flap coverage of the exposed fracture should be done as soon as debridement is performed, within 72 hours after injury to reduce infection rate and preserve the function and aesthetics of the lower limb.

Conflict of interest statement

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