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Lower limb amputation in trauma sequelae: choice of level and techniques

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Summary

The main purpose of amputation is to bring a specific patient, regardless of the initial scenario, to a new normality, characterized by the absence of pain and functional potential of the stump in terms of wearability and power. It is therefore implicit that the strategy is played on the choice of the level, using both analysis of the scenario of the patient and the perspective of the prosthetic project.
Hence the delicacy of the choice of the moment and the level of amputation, considering multiple possibilities arising from evolution of surgical techniques, interdigitation of skills between traumatologist and plastic surgeon, translation of some techniques initially used for amputations of the upper limb to amputations of the lower limb, to substantial innovations in limb prostheses.

Key words: amputation, trauma sequelae, inferior limb, limb salvage failure, cryoamputation

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Introduction

An appropriate choice of the amputation level offers the possibility of transforming a demolitive act into a resolutive act. Amputation in trauma sequelae is a demanding choice for both the patient and the surgeon, who both face together, accepting the impossibility of completing a restorative path carried out up to that moment to solve different scenarios by predominant factor, chronology, and status. This need arises from the necessity to face different clinical problems, that range from life threatening issues to a life dominated by persistent pain that can only be controlled with medical or invasive procedures repeated ad interim, up to a life dominated by difficulties such as repeated contamination of atrophic ulcers, osteomyelitis, vicious consolidation, and outcomes of compartment syndrome. Therefore, in relation to the history of a specific patient, the choice of the level of amputation can be presented in the acute or chronic phase, as a step that cannot be postponed or as a possible and tricky decision in the process of achieving a new normality.
The goal is represented by the ideal characteristics of a stump: absence of pain, useful skeletal support for walking with prostheses, adequate coverage of soft tissues to ensure wearability and, if possible, functional and functioning muscular equipment.

Currently, a fair percentage of amputations are still prone to revision surgery for different reasons. Approximately 40% of patients undergoing amputation due to trauma or trauma sequelae require a revision of the stump, and 13% a further proximal amputation. Among the influencing variables age, crush injury, compartment syndrome, hematomas, ossifications and calcifications, and neuromas have been identified [1].
The choice of level and the prosthetic project are strongly connected and must therefore be based on evaluation of the specific patient, on the value that each individual factor has on the choice of level, on the healing potential in both prognostic and chronological terms, and on the future in terms of collaboration of the patient.
Hence the complexity and the necessity to make personalization systematic by identifying the main variables to be considered, as they are individually capable of influencing the pursued recovery and stability of the result.

Possible lower limb prostheses

This is a sensitive analysis that needs to be discussed case-by-case, possibly in a prospective sense, and therefore before the amputation when defining the level. The variables involved are essentially represented by:

- evaluation of the future ability to take care of the stump;
- possibilities in learning and execution;
- residual limb skills;
- stability of the upstream joints, ipsilateral to amputation;
- stiffness of upstream joints, ipsilateral to the amputation, and of the contralateral limb;
- body mass index;
- cortical thickness and density of the candidate abutment level.

The choice of the level prospectively contextualized on various limb prostheses therefore allows to adjust or improve the K level (Fig. 1).
There are different types of lower limb prostheses essentially responding to the classic concept, which vary from joint components controlled by a microprocessor (e.g. knee and ankle), equipped with a bionic interface via IMES (implanted myoelectric sensors) and a skeletal interface via PID (prosthetic interface device) for implantation of a prosthetic stem with stoma at the femoral or tibial level, solving problems related to the length of the skeletal segment and to the residual muscle patrimony (OPRA and ILP prosthesis) [2].

Analysis

The main aspects to consider are:

- urgency: from emergency due to precipitation of general conditions (e.g. sepsis) to elective amputation (e.g. algodystrophy);

K LEVEL	DESCRIPTION
K0	DOES NOT HAVE THE ABILITY OR POTENTIAL TO AMBULATE OR TRANSFER SAFELY WITH OR WITHOUT ASSISTANCE, AND A PROSTHESIS DOES NOT ENHANCE QUALITY OF LIFE OR MOBILITY.
K1	HAS THE ABILITY OR POTENTIAL TO USE A PROSTHESIS FOR TRANSFERS OR AMBULATION ON LEVEL SURFACES AT FIXED CADENCE. TYPICAL OF THE LIMITED AND UNLIMITED HOUSEHOLD AMBULATOR.
K2	HAS THE ABILITY OR POTENTIAL FOR AMBULATION WITH LOW-LEVEL ENVIRONMENTAL BARRIERS SUCH AS CURBS, STAIRS, AND UNEVEN SURFACES. TYPICAL OF THE LIMITED COMMUNITY AMBULATOR.
K3	HAS THE ABILITY OR POTENTIAL FOR AMBULATION WITH VARIABLE CADENCE. TYPICAL OF THE COMMUNITY AMBULATOR WHO CAN TRAVERSE MOST ENVIRONMENTAL BARRIERS AND HAS VOCATIONAL, THERAPEUTIC, OR EXERCISE ACTIVITY THAT DEMANDS PROSTHETIC UTILIZATION BEYOND SIMPLE LOCOMOTION.
K4	HAS THE ABILITY OR POTENTIAL FOR PROSTHETIC AMBULATION THAT EXCEEDS BASIC AMBULATION SKILLS, EXHIBITING HIGH-IMPACT, STRESS, OR ENERGY LEVELS. TYPICAL OF THE PROSTHETIC DEMANDS OF THE CHILD, ACTIVE ADULT, OR ATHLETE.

Figure 1. K level is a rating system to evaluate a person's rehabilitation potential or performance. It is useful for assessing the patient's general conditions and consequently deciding the level of amputation.

- general conditions: albumin > 3g/dl, lymphocytes < 1500/mm^3, smoking cessation for at least 7 days;
- skeletal outcomes: size of the skeletal segment candidate for the role of stump, stability of the segment if bi-osseous, stability of the upstream joints;
- fixation devices;
- infections;
- joint general conditions: ligament injuries, capsular contractures, arthrosis;
- peripheral nervous system: symptomatic neuromas, contextual radiculopathies, sequelae of neurological lesions including central ones;
- myotendons: tone and trophism, outcomes of compartment syndromes, integrity of insertions;
- skin and subcutis: keloids and outcomes of scars, burns,

adhesions, trophism, loss of substance, fistulas and their course;
- vascularization: with the same anatomical heritage any alterations related to blood pressure, vasculopathies;
- edema;
- type and geography of pain;
- patient's compliance;
- history of compartment syndrome or crushing trauma.

Some of these factors can be corrected by interlocutory interventions before the final amputation; others, not precisely definable, controllable, and correctable, dictate the level of amputation.
When the sudden worsening of general conditions or of one or more aspects, on the other hand, dictates emergency conditions, these considerations are inevitably immediate clinically rather than instrumentally. This creates a level of emergency or urgency, sometimes incompatible with amputation, and it is necessary to gain time by using interlocutory solutions.
The main steps of each amputation are, in succession:
- removal of non-viable tissues;
- preparation of a usable and painless stump;
- preparation of the skeletal stump in order to eliminate pressure points and soft tissue ulceration points;
- prevention of hematomas and edema;
- prevention of neuromas;
- pharmacological management of postoperative pain.

The most important challenges in terms of level definition are represented by combinations of bone dysmorphism, infection, burn outcomes, degloving outcomes, and presence of fixation devices.

Useful resources to gain time

The main strategies available in cases in which more time is needed consist of debridement, cryoamputation, and NPWT.

Debridement

Debridement of tissues, including skeletal tissues, can be implemented with the aim of reaching and defining vital tissues, and then defining the level and technique of amputation, aimed at the implementation of a specific prosthetic replacement.

Cryoamputation

This represents a valid time-dependent resource to contain inflammatory or infectious processes, especially in patients who are not immediately fit for surgery. Cryoamputationbelongs to the category of delay/damage control and is also identified by other terms: physiologic amputation, dry-ice amputation, and freezing amputation.
This technique allows to interrupt the cycle of rhabdomyolysis in 24 hours, which would otherwise cause systemic effects. On the other hand, it requires surgical amputation within 72 hours, although in the literature cases of post-cryoamputation surgical amputation performed after 24 and 58 days are known.

The technique is inexpensive and simple, which provides for the application of both a proximal and distal tourniquet at the chosen level, and then positioning the limb wrapped in dry ice in an insulated container equipped with a water outcome point. The dry ice should be monitored and restored periodically. The proximal part is instead gently heated to avoid transmission of temperature, a phenomenon known as 'the frost line'. In case of unavailability of an insulated container, a waterproof bag can be used, which must be carefully kept away from the counter-lateral limb, to prevent freezing.
Analgesic pharmacological support is required for the first 24 hours, the period necessary for complete neutralization of tissues, and therefore also of sensitivity. After the first 24 hours, the analgesic requirement decreases.

VAC/NPWT Vacuum Assisted Closure/Negative Pressure Wound Treatment

The application of negative pressure dressings may help in the resolution of soft tissue edema, chemical contamination, or infection. This technique allows to isolate a segment candidate for amputation and subject it to negative pressure for a variable time before defining its level with certainty. In this case, tissue healing is not the main goal, so it is more correct to speak about negative pressure dressing treatment rather than negative pressure assisted healing [3].

External fixation

External fixation offers the possibility of controlling or modifying the length and morphology of the skeletal segment when the definition of the outcomes is still in progress. The advantages are represented by a modifiable synthesis, minimal impact on the soft tissues, and complete access to soft tissues, even in case of burns and complex wounds. Current techniques make this method compatible with negative pressure dressings and, in relatively simple cases, feasible with medium-level skills.

Problems concerning the choice of level

The main problems concerning the choice of level are:
- size and morphology of the skeletal segment candidate for the role of abutment;
- segment stability if biosseous;
- stability of the upstream joints;
- stiffness of the upstream joints;
- infections;
- peripheral nervous system;
- myotendons;
- skin and subcutis;
- vascularization;
- edema;
- type and geography of pain.

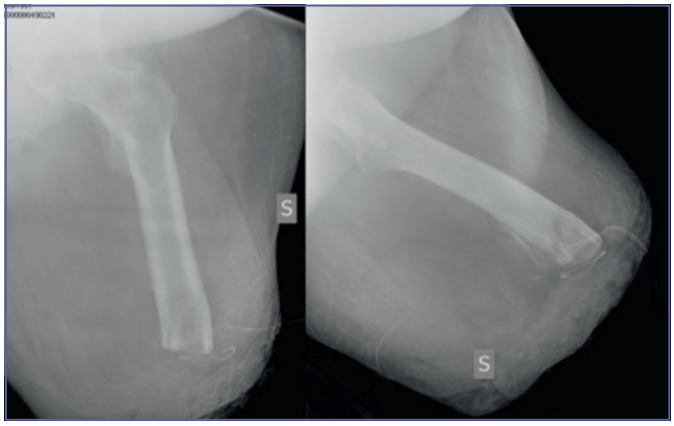

Figure 2. An example of osteodesis in modified Ertl amputation. From David Mackenet's and Benjamin Taylor's "Amputations".

Dimensions and morphology

The minimum size of segmental residues in case of amputation is known and substantially stable over the years. In the case of the leg, 12-18 cm distal to the tibial tuberosity represent the maximum proximal level [4].

Preserve an unstable joint

If the choice of the ideal distal level is related to the involvement of an unstable joint, it is possible to consider, particularly for the distal joints, arthrodesis or osteodesis. Examples can be subtalar arthrodesis in the case of the tarsus and osteodesis according to Ertl in the case of amputation below the knee (Fig. 2).

Prevention of neuromas and/or pursuing a functional neuromuscular stump

In terms of neuroma prevention, there is still no univocal vision. The only shared attitude is to prevent frictional microtrauma, and then nest the stump in depth proximal to an estimated reservoir and distant from bone structures.

However, some techniques recommended for the upper limb are also feasible for the lower limb and seem to allow better results. The most striking example is the Ewing amputation below the knee: through the retargeting of nerve stumps to different myotendinous groups in specific cases (metabolically and biologically selected patients), it is possible to restore the function of the prosthetic ankle and optimize the flexion and extension of the native knee, simultaneously preventing neuromas.

Prevention of dysmorphism and dysfunctions due to muscle imbalance

The most striking example is related to anatomical or neuromuscular deficits that can affect the adductors muscles after amputation above the knee. In this case it is extremely difficult for the patient to control the prosthetic limb due to the prevalence of the abductor muscles. Other rarer examples in amputations due to trauma are represented by the equine-varus attitude after trans-metatarsal amputation (TMA).

Myodesis and myoplasty, planned and implemented at the same time of the amputation, allow to check the functionality of the abutment and future prosthesis. The myodesis currently contemplated in case of amputation below the knee allow for better performance of both the knee and the gait.

Another example is the lengthening of Achilles tendon (TAL, Tendo Achilles lengthening) which allows to prevent equine postures, as well as the transposition of the tibialis anterior tendon (STATT, split tibialis anterior tendon transfer) allows to prevent equine-varus-supinated attitude in case of trans-metatarsal amputation. Other possible tendon transfers to prevent the equine-varus attitude are transfer of the peroneus brevis pro peroneus longus and, alternatively, stabilization of the first metatarsal via re-insertion respectively of the flexor hallucis to the first metatarsal and re-insertion of the extensor of the fingers to the fourth metatarsal, according to the technique described by Roukis.

For example, in the case of this patient (Fig. 3), the victim of a domestic fall during the COVID pandemic, who presented to the emergency room in May 2020, the list of problems (LP) imposed amputation, and the combination of clinical data (LC) imposed a more proximal level to the presumed one, which was estimated only on radiographic data.

LP:

- bi-osseous fracture;
- loss of skeletal substance by resorption;
- radiographically and clinically non-functional knee, clinically edematous and painful, unused for months.

LC:

- obesity;
- diabetes;
- thrombosis of the posterior tibial artery;
- edema of the foot and ankle.

The scenario inevitably led to amputation above the knee (Fig. 4), given the possibility of respecting the insertion of the adductor muscles and of having, at that level, valid nervous, vascular and skeletal stumps, as well as a safe and valid myo-cutaneous coverage. The choice of a below the knee level of amputation would have exposed the patient to an unpredictable joint function (disused for 4 months), compromised vascularization (thrombosis of the posterior tibial artery), and myo-cutaneous coverage estimated on edematous tissues, therefore with preventable healing delay.

The level chosen in this case was medio-diaphyseal combined with adductor myodesis.

Healing of the stump occurred in about 4 months and currently the level of agility does not exceed K1.

Figures 3-4. Leg fracture in 58yo male occurred in March 2020 and diagnosed 3 months later than the trauma. Edema, pain and soft-tissue conditions imposed an above the knee amputation.

Another example (Fig. 5) is that of a 48 year-old man, smoker, seen about 3 months after damage control and osteosynthesis for proximal tibia fracture and traumatic injury of the tibial artery, with an anterior fistula with osteomyelitis and algodystrophy (Fig. 6). This led to amputation above the knee as fifth surgery (Fig. 7). The succession of surgeries was:

- damage control + arterial graft;
- ORIF with negative cultures and restored vascularity;
- removal of fixation devices, cultures, external fixator, then NPWT;
- debridement;
- amputation.

The choice of the level in this case was strongly dictated by the potential shortness of the residual tibial segment, by the presence of the fistula, and the presence of fixation devices. Healing of the stump took place in about 30 days and was followed by progressive prosthesis up to bionic prosthesis with the achievement of level K4.

Conclusions

The systematic analysis of the specific problems in the individual patient interfaced with the future prosthetic project can currently guide the choice of the level of amputation for subacute or chronic trauma sequelae of the lower limb. A third factor, represented by techniques borrowed from amputation of the upper limb, allows the integration of surgical actions aimed at the neuromuscular junction in order to improve the future performance of the stump in terms of sensitivity, pain, and agility. An example is Ewing's amputation, which clearly reflects the extent of the evolution of the surgical technique, and how much the act of regularization of the bone residue, once almost the final time of the amputation surgery, is today one of the most important acts, which will be followed by tenodesis, nerve retargeting, soft tissue reconstruction and using targeted dressing [5]. Other contextual orthopedic or plastic acts may be arthrodesis or prosthesis, osteodesis, or positioning of the stem in case one opts for OPRA/ILP, which will then be followed by other interventions planned at a distance, such as the completion of the implant and preparation of the stoma. The price of these innovations is essentially represented by surgical times and technology that are very different from what is considered when amputation is intended. The gain, however, is represented by a more pleasant quality of life and better segment performance.

Figures 5-7. Osteomyelitis and resorption of external tibial plate in 48yo male after open fracture ORIF due to road trauma. In this case, due to the impossibility to treat osteomyelitis an above the knee amputation was performed to preserve the functioning of the hip and residual segment.

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Authors' contributions
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Ethical consideration
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