PERIODICUM BIOLOGORUM
VOL. 117, No 1, 147–159, 2015

UDC 57:61
CODEN PDBIAD
ISSN 0031-5362

Rehabilitation of lower limb amputees

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Key words: lower limb amputation, prosthetic rehabilitation

Received February 16, 2015.

Summary

Rehabilitation of amputees represents a complex process during the course of which an amputee receives professional aid and support, so as to adapt to the use of prosthesis, i.e. an artificial supplement for the lost body part. The process aims at achieving an independent performance of the amputee in all areas of everyday life and as high quality of life as possible. The rehabilitation encompasses not only the pre-amputation, postoperative, pre-prosthetic and prosthetic stage, within which an amputee is provided with a prosthetic aiding device, but also the subsequent long-term monitoring and follow-up. The implementation of the rehabilitation process runs in line with the bio-psychosocial model and requires a multidisciplinary and an interdisciplinary approach, so as to achieve a successful reintegration of an amputee and allow for a lifestyle resembling the pre-amputation one as much as possible.

The article brings the causes and types of amputation, the principles underpinning contemporary amputation surgery, prosthetics and rehabilitation during preoperative, postoperative, pre-prosthetic and prosthetic stages, as well as the stage goals and MOs of their attainment. Principles of evaluation of prosthetic rehabilitation outcomes in limb amputees, which make use of appraisal questionnaires, have been discussed as well.

INTRODUCTION

Rehabilitation of lower limb amputees encompasses the pre-amputation, postoperative, pre-prosthetic and prosthetic rehabilitation stage, within which an amputee is provided with a prosthetic aiding device. Throughout the course of this complex process, an amputee whose amputation arose as a consequence of an injury or a disease gets the chance to adapt to the prosthesis that supplements the lost limb part and to achieve the restitution of ambulation and other locomotive abilities with the aid of prosthesis. Medical rehabilitation should by all means be accompanied by an adequate psychological and social rehabilitation in line with the bio-psychosocial model, so as to attain the ultimate goal of each and every rehabilitation, that is to say, a successful reintegration of an amputee into an everyday life that resembles the style and quality of the pre-amputation daily living as much as possible. Rehabilitation strives to achieve the maximal possible physical, emotional, social, vocational and financial independency of an amputee and his/her maximal efficiency in all aspects of life.

According to the US data, the predominant causes of amputation are of a vascular nature, accountable for 82% of amputation cases and witnessing a 27-percent rise in prevalence within 1988-1996 timeframe. The second most represented amputation cause is injury (accountable for 16% of cases), while the share of amputations consequential to tumours

amounts to 0.9 % and that of congenital anomalies to 0.8 % of cases. The age of a given population further facilitates the rise in the foreseen amputation frequency rate in terms of doubling the amputation risk in persons over 65 *(1).* Within this context, diabetes poses as one of the major risk factors seen in 67 % of amputees *(2),* making the amputation risk in diabetic elderly 18 to 28-fold higher as compared to their non-diabetic peers (3). Additional risk factors are nicotine smoking and hypertension. According to data gathered on the international scale, the prevalence of amputation amounts to 17- 30 cases per 100,000 persons *(4).* Earlier studies have indicated that diabetics are at an18-percent risk of having another amputation within 2 years, and at a 45-percent risk of having another amputation within 4 years following the initial amputation *(5).* Although it often appears that the act of amputation actually represents a solid proof of the modern medicine failure, it should be pointed out that, in most cases (for instance, with gangrenous processes, malignant tumours, infections and severe injuries), amputation represents a life-saving surgery of vital importance for the patient. On the other hand, when it comes to functional problems and leg malformations, amputation need not be the only solution, so that the indication for such a surgery is relative.

Amputation surgery performed conformant to the principles of contemporary surgery, represents not only mutilating, but also a reconstructive surgery in terms of the residual limb formation. A successful surgery poses as the prerequisite for the subsequent provision of an adequate prosthetic device and ultimately makes a significant contribution to the successfulness of prosthetic rehabilitation. In cases of vascular insufficiency, the decision on the amputation level is left at the discretion of the attending surgeon, who shall take such a decision based on the clinical presentation, overall health of the patient, local status and the outcome of a thorough vascular diagnostic workup (angiography, Doppler of the leg blood vessels, plethysmography and oxygenation level), taking into account also the data on co-morbidities capable of jeopardising the surgery outcome. Even though the surgeon always strives to spare as much of the limb as possible, amputation should be performed within the area of vital and healthy tissue so as to allow for a favourable healing course and to avoid the need for re-amputation. In cases of blood flow insufficiency, the patient undergoes the so called "closed or flap amputation" followed by the residual limb formation (i.e. the bone resection and bone top flapping accompanied by myoplasty of the antagonistic muscles, nerve resection and adequate positioning of the surgical incision). The so called "open amputation" is a rare choice resorted to in cases of more severe inflammations or injuries, while the "guillotine amputation" represents an extremely rare choice made solely in cases of gas gangrene *(6).* Lower limb amputation is most commonly performed in the distal leg portion, in specific at the foot level (in form of toe amputation or partial Lisfranc- or Chopart-fashion foot amputation). The range of more proximal amputations includes Syme- or Pirogoff-fashion amputation performed at the talocrural joint level, transtibial amputation performed at the lower leg level, knee disarticulation performed at the knee joint level, transfemoral amputation performed at the upper leg level, hip disarticulation performed at the hip joint level and hemipelvectomy performed at the pelvis level.

Dilinghan and co-workers reported that lower limb amputations represented 97 % of all amputations performed within the 1988-1996 timeframe, their amputation level-based distribution thereby being the following: toe amputations 31.5%; foot amputations 10.5 %; ankle disarticulation 0.8%; trans-tibial amputations 27.6 %; knee disarticulation 0.4 %; trans-femoral amputations 25.8 % and hip disarticulations 0.4 % *(7).* According to Fletcher, in elderly patients trans-tibial amputations are done in 64-73 % of cases, trans-femoral amputations in 26-31 % of cases and knee disarticulations in 4.5 % of cases *(8).* Following an amputation, the odds for a successful provision of a prosthetic aid are dependent on a number of factors, above all on the grounds for amputation and the level at which the surgery was performed, as well as on the amputee's age. Mackenzie *(9)* claims that a successful provision of a prosthetic aid was attained in 97% of amputees within 3 months post traumatic amputation. In amputees whose grounds for amputation were vascular conditions or diabetes, the results are somewhat poorer; according to Fletcher, in amputees over 65, the provision of a prosthetic aid was successful in 78 % of trans-tibial and 57 % of trans-femoral amputees.

REHABILITATION OF LIMB AMPUTEES

Rehabilitation of limb amputees is a demanding process, but also a huge challenge that should be approached with a positive frame of mind both by rehabilitation professionals and the patient. One of the key postulates that enable the successful outcome of limb amputee's rehabilitation is an interdisciplinary, well-coordinated teamwork of healthcare professionals of various profiles (a physician specialised in the field, i.e. a physiatrist when it comes to Croatia, physiotherapists, occupational therapists, nurses, a psychologist and a social worker). If necessary, physicians specialised in other fields (an orthopaedist, a diabetes specialist, a cardiologist, a vascular disease specialist, a psychiatrist) or experts of other backgrounds (a priest, a nutrition specialist, a career guidance counsellor) may be summoned on a case-by-case basis. The rehabilitation team cooperates with the amputee's family members and friends, as well as with successfully rehabilitated amputees. The entire rehabilitation programme is patient-centred; nevertheless, the amputee is not merely the target every team member is focused on, but an active team member as well. The distinctive feature of the

amputees' rehabilitation is a close collaboration with orthopaedic technical services, while each and every healthcare professional involved into the process should master specific knowledge and keep abreast with the state-of-the-art in prosthetic technology and rehabilitation. The interdisciplinary teamwork model detailed above was first introduced in the USA by the end of the World War Two when managing veterans whose wounds necessitated limb amputations, and was later exercised in the rehabilitation of other patient populations as well *(11)*.

The advancements made in the rehabilitation of lower limb amputees also come as a result of advancements in amputation surgery and prosthetic technology, as well as a result of a better understanding of the psychosocial implications of an amputation. The distinctive nature of the rehabilitation process lies also within the need for a close collaboration with orthopaedic technical service staff, i.e. with orthopaedic technicians and masters of orthopaedic technology, while each and every healthcare professional involved into the process should be familiar with the state-of-the-art in prosthetic technology. Amputation represents an irreversible somatic phenomenon that bears both psychological and psychosocial consequences. The huge challenge to be faced by the amputee and the prime task he/she has to master is to embrace his/her prosthesis as an artificial supplement for the lost limb part both in its aesthetic and functional sense and to eventually cope with it so as to be able to lead as high-quality life as possible.

Most psychosocial studies devoted to lower limb amputees have reported an unfavourable psychological impact of amputation in terms of depression, anxiety, sorrow and grief, distorted body image and psychosocial impairments *(12, 13, 14)*. These studies should be regarded as important, since they point towards the consequences of amputation and their possible influence on clinical/therapeutic and rehabilitation procedures. However, more recent research has pointed towards positive, optimistic mind frame of amputees that helps them cope with depression; therefore, an individual assessment of the rehabilitation potential of each and every amputee is a must *(15, 16)*.

AGENDA AND COURSE OF THE LOWER LIMB AMPUTEES' REHABILITATION PROGRAMME

A person who had its leg amputated either in part or in full, experiences not only the loss of an anatomic part of his/her body, but also a functional loss, changes in body weight distribution, and coordination, proprioception and balance impairments. Rehabilitation of a leg amputee embraces complex procedures and interactions between the rehabilitation team and the leg amputee targeted at the restoration of safer and more stable prosthetic ambulation. The course of rehabilitation of amputees may be divided into several subsequent stages, as follows: 1) the preoperative stage; 2) the postoperative stage; 3) the preprosthetic stage; 4) the prosthetic stage; and 5) long-term clinical monitoring and follow-up. Following the primary prosthetic rehabilitation, a patient should be monitored for a long time and occasionally seen by a physician having the expertise in prosthetic rehabilitation, and should be allowed to seek prosthetic "maintenance" provided by orthopaedic technical services. Of note, rehabilitation of amputees should be left at sole jurisdiction of duly equipped healthcare facilities specialised in prosthetic rehabilitation carried out by interdisciplinary expert teams qualified for and trained in leg amputees' rehabilitation.

I) PREOPERATIVE REHABILITATION STAGE embraces the time-period precedent to an elective amputation surgery and takes place at the Surgery Ward. The rehabilitation team makes it its goal to prepare the patient and his/her family members for the elective amputation surgery and to inform them about the rehabilitation options. A patient pending amputation should be thoroughly informed about his/her condition and come to terms with the fact that amputation represents the only adequate therapeutic option left. The grounds for amputation might be an advanced gangrenous process and an advanced infection irresponsive to the therapy administered insofar, so that we often deal with patients in poor overall health, prostrated due to the prolonged disease, toxic shock and pain and of a poor cardiac/respiratory capacity. The mutilation of their body to come and dubious future prospects usually make these patients worried and less cooperative due to their low motivation. Another patient population in which an urgent amputation has to be performed are those suffering from severe limb injuries. The third patient population is represented by oncology patients suffering from malignant bone tumours or by patients with functional leg deficiencies or malformations, in which an elective amputation is to be performed; the overall health of the latter group is usually fairly good. The patient is prepared for the amputation based on the assessment of an interdisciplinary team which includes a physiatrist as well; the above assessment should be comprehensive and take into account all conditions the patient is suffering from. Within this frame, the state of the leg to be amputated, the detailed state of the contralateral leg (skin status, sensory status, vascular status, possible deformities), and patient's overall health (cardiovascular, respiratory, endocrine, neurological/psychiatric and muscle/skeletal status) should be evaluated. The treatment agenda should also be duly focused on adequate pain management by virtue of the administration of effective painkillers (commonly mild or stronger opioid drugs) and co-painkillers, with the addition of antidepressants and sedatives if so necessary. The surgeon informs the patient, his/her family or guardian about the elective amputation surgery, in specific about the pertaining risks, the foreseen level of amputation, the postoperative care agenda and the

fundamental principles of prosthetic aid provision and prosthetic rehabilitation, following which the patient gives an informed consent. The wishes of the patient should be heard as well; one should also gather information on the patient's social life (within the close and the wider community) and the possible means of support and then plan where and how to proceed with rehabilitation post amputation.

In the pre-amputation stage, a kinesitherapy should be started as well to the effect of maintaining the current status and preventing secondary complications. The kinesitherapy programme is entrusted with a physiotherapist and is patient-tailored. Kinesitherapy comprises in-bed exercises involving healthy limbs and the trunk, as well as breathing exercises. Preferably, the patient should master aided ambulation (walking with the aid of crutches or walkers), avoiding thereby burdening of the leg soon to be amputated. The patient, and preferably also the members of his/her family, should be provided competent psychological support. In this point, it is also highly recommendable to introduce the patient with successfully rehabilitated limb amputees.

II) POSTOPERATIVE REHABILITATION STAGE refers to the immediate post-amputation period that starts at the amputation surgery point and ends once the postoperative wound healing is complete. This stage is predominantly carried out at the Surgery Ward or, should any complications arise, at the Rehabilitation Ward, under the patient's roof or in the nursing home. The common duration of this stage approximates to 10 to 14 days, provided that no complications have been witnessed. Postoperative rehabilitation also requires the provision of comprehensive interdisciplinary patient care, throughout the course of which the targets and goals listed below should be attained.

1) At this point, the primary concern is the postoperative patient care and local monitoring of the wound healing process so as to timely establish the development of possible post-surgery complications; however, due treatment of co-morbidities (diabetes, cardiovascular conditions or alike) should not be neglected, as well. Should a preoperative sepsis be caused by an infection, the latter should be further treated, too. On top of the aforementioned, measures taken to the effect of deep vein thrombosis and pulmonary embolism prophylaxis should be exercised as well. The contralateral leg continues to be monitored, especially if any signs suggestive of vascular status compromising have been seen. Such a comprehensive treatment may stabilise and improve the patient's status in a fairly short run.

2) The second major concern is pain management that targets not only the postoperative pain management, but also the management of neuropathic, "phantom" pain of a non-nociceptive neuralgic nature experienced in an amputated limb part. To that effect, pharmacotherapy (the administration of painkillers, anti-convulsive drugs and antidepressants) and non-pharmacotherapy (electro-analgesia –TENS, and acupuncture) can be employed. Phantom pain should be differentiated from the temporary, pain-free phantom sensation of the true presence of an amputated limb part.

3) The third major concern is the prevention of joint contractures both when it comes to the amputated and the unaffected leg, which may be accomplished by virtue of maintaining a proper in-bed position and kinesitherapy. In trans-tibial amputees, the leg should rest in an extended knee position, while with trans-femoral amputations a neutral position should be maintained. Gradual kinesitherapy should start on the postoperative day 1 under the supervision and with the aid of a physiotherapist. In the first few kinesitherapy days, only in-bed exercises should be attempted. These exercises should involve breathing exercises and exercises tailored so as to strengthen and increase the endurance of the intact leg, upper limbs and the trunk. The amputated leg should be the subject of isometric exercises tailored so as to reinforce the strength and endurance of major muscle groups, particularly the knee extensors in cases of trans-tibial amputation or hip extensors and adductors in cases of trans-femoral amputation. Limb joint mobility exercises aim to preserve the range of mobility of the target joints, in particular the hip joint in above-knee amputations and the knee joint in below-knee amputations. Bed rest in the pronated position also represents an effective mode of prevention of hip and knee flexion contractures and should be exercised twice a day whenever possible in a stepwise manner, gradually prolonging the duration of exercises up to 30 minutes, dependent of the patient tolerance. Should the patient be unable to tolerate the above position due to cardiac/pulmonary symptoms, the exercising should be attempted in the recovery position. On the postoperative day 3, in-bed sitting and balance exercises should be commenced, while on the postoperative day 4-5 exercises in an assisted standing position should be attempted, followed by prosthetic ambulation exercises (with an aid of a walker or a pair of crutches). In the next few days, i.e. on postoperative days 5-10, the previous agenda should be further pursued in an incremental manner, so as to gradually intensify and prolong the exercising session. If possible, it would be recommendable to provide the so called early-stage walking aids in terms of preparatory or training prostheses that allow for the verticalisation and short-path walking. The algorithm of the above procedures provides only for the general framework, while the actual rehabilitation course should be adjusted to the patient's overall health and recovery dynamics, as well as to his/her somatic capacities.

4) The fourth major concern is an adequate residual limb treatment so as to speed up the wound healing process, alleviate pain and aid in residual limb formation; the process shall be facilitated by virtue of leg elevation and

gradual pressurizing of the residual limb on the occasion of its dressing. A cushion can be put beneath the operated leg only for a short while, i.e. throughout the first 48 postoperative hours, since its further presence may favour the development of contractures. Cushioning of the unaffected leg should be avoided by all means.

5) Psychological support, as the fifth major task to be fulfilled within this stage, should be provided throughout the entire stage, not only through the contacts with healthcare professionals the attending team is composed of, but also through expert support provided by a psychologist or, should such a need arise, even psychiatrist. The latter should be summoned in cases of depression symptoms, posttraumatic stress disorder (PTSD) or mental disorders, as well as with (alcohol or opioid drug) addicts. The patient should be informed about and educated in all procedures undertaken by the attending team and take active part in the implementation of the foreseen goals in terms of proper gait maintenance, rehabilitation process, pain management appraised on the visual analogue scale (VAS), residual limb care and prosthetic aid provision planning.

By the end of this rehabilitation stage, the attained level of the patient's functional capacities should be assessed, including the current mobility level (his/her ability or inability of prosthetic ambulation and out-of-bed transfer), the level to which the patient has learned to cope with everyday activities and self-management (personal hygiene, independent feeding and dressing, etc.). To that end, it is advisable to use standard rehabilitation process efficiency tests, such as the Amputee Mobility Predictor (AMP), Functional Independence Measure (FIM), the Two- or Six-Minute Walk Test and the Timed-Up and Go Test (TUG). If not completed already, psychological testing should be done, together with the assessment of cognitive functions, so as to be able to adjudicate the patient's learning potential and the potential to master the use of a prosthetic device in the time to come.

The patient is discharged from the Surgery Ward and is dismissed from acute care once the proper haemodynamic balance and the proper control over physiological functions and sphincters have been established. In case of inflammation or complications of other nature, the patient remains on-Ward. The optimal discharge point would be the point at which the overall health is properly stabilised and at which the patient is capable of prosthetic ambulation and coping (with a proper aid) with daily life activities. Should the patient's functional status be poorer than elaborated above, the rehabilitation programme should be continued either under the patient's roof or in the nursing home, under the supervision and with the professional aid of a physiotherapist.

III) PRE-PROSTHETIC REHABILITATION STAGE is a preparatory stage tailored to prepare the patient for the prosthetic device provision. This stage starts once the surgical wound is healed and is completed once the prosthetic device has been delivered and the pertaining rehabilitation has been started. Activities foreseen for this rehabilitation stage may take place at various locations, for instance under the patient's roof, in the nursing home, on the premises of longer-stay hospitals or at rehabilitation centres. The rehabilitation pursued at this stage is targeted at the preparation of the residual limb for the acceptance of the prosthesis and at the conditioning of the patient and his/her preparation for the strains to be expected with prosthetic rehabilitation via physical and kinesitherapy. The activities at this stage also aim at attaining independent aided mobility (with the aid of crutches, a walker or a wheelchair) and as independent everyday performance as possible, the latter being accomplished via occupational therapy.

Based on the domicile good clinical practice, the preparation of the residual limb for the acceptance of the prosthetic device and its fitting most commonly make use of an elastic dressing which facilitates the oedema diminishment and hypotrophy, and aids in residual limb fitting. Postoperative residual limb fitting may also resort to plaster dressing, a semi-hard polyethylene coating or a compressive elastic or silicone socket. In trans-tibial amputees, the desirable shape of the residual limb is a cylindrical one, while in trans-femoral amputees that shape must be conical. Posttraumatic oedema and haematoma are expected to regress within 15-20 days post amputation. The patient should be educated on residual limb hygiene and toilette and taught how to recognise the signs of residual limb-affecting complications.

The patient's conditioning and his/her preparation for the strains imposed by the prosthetic rehabilitation is attained through kinesitherapy carried out under the supervision of a physiotherapist. At the beginning, the kinesitherapy agenda complies with the one pursued within the postoperative stage and comes down to isometric and active exercises (of both open- and closed kinematic chain type), while later on more and more straining exercises (making use of manual or heavy bags burdening) are attempted, the initial burdening thereby approximating to 50% of the maximal established isometric strength. In cases of above-knee amputations, the therapeutic programme mainly focuses on the strengthening of gluteal muscles, while in cases of below-knee amputation that focus shifts to the strengthening of knee extensors. Kinesitherapy should strive to maintain the existent satisfactory joint mobility and to diminish contractures of the preserved proximal joints of the amputated limb and the contralateral leg, should such contractures exist. Kinesitherapy programme is designed based on the goals set following the initial functional evaluation (dynamometric measurement of the limb & trunk muscle strength and goniometry establishing the joint mobility). If not already mastered, an independent aided ambulation (with the aid of crutches, a walker cane hybrid or a wheeled walker)

should now be mastered by all means. Occupational therapy represents a continuous conditioning effort that strives to capacitate the patient to cope with everyday activities as independently as possible. Rehabilitation goals are attained based on the programme agenda; the dynamics and successfulness of their attainment should be monitored on a regular basis.

By the end of the pre-prosthetic stage, the provision of the prosthetic device and rehabilitation of roughly selected eligible patients lacking any obvious contraindications hindering the implementation of this demanding project is planned. Everyday practice has shown that the patient's functional status is best assessed using the Mobility Scale (Centres for Medicare and Medicaid Services Functional Levels – CMS), the latter scale later on being also of use in setting functional goals and guidelines for the provision of the prosthetic device and rehabilitation implementation *(17)* (Tables 1 and 2).

IV) PROSTHETIC REHABILITATION STAGE is primarily focused on the selection, fabrication and application of the prosthetic device, as well as on the pertaining rehabilitation and prosthetic ambulation mastering. The prerequisites for the implementation of this rehabilitation stage are willingness and motivation of the rehabilitee, who should be capable of actively participating in the rehabilitation process and should be impartially assessed to be in a satisfactory physical and functional shape that allows for the prosthetic rehabilitation. The patient should be capable of, and willing to, acquire prosthesis application- and prosthesis usage- related knowledge. As for somatic prerequisites, the patient should be fit so as to allow for a successful coping with prosthetic ambulation strains, while the contralateral (intact) leg should be adjudicated as capable of carrying the burden imposed by the body weight. The provision of a prosthetic device is contraindicated in cases of serious internal diseases (cardiac/pulmonary conditions that result in intolerance of more substantial strains), neurological conditions manifested by poor motor control, and inadequate mental and intellectual capacities disabling active participation in the education and rehabilitation process.

The approach rooted into our medical practice favours the application of the prosthesis and the commencement of prosthetic rehabilitation after the surgery scar healing, overall health stabilisation, mastered verticalisation and preferably also mastered aided ambulation (with the aid of crutches or a walker) on a 30-m track. In cases of blood flow insufficiencies, an ideal timing of the prosthetic rehabilitation launch would be 5 - 6 weeks following amputation, while in amputees having a traumatic amputation such rehabilitation is rendered impossible earlier than 3-4 weeks post amputation, dependent on the residual limb, i.e. surgical wound healing status and overall health of the amputee. Upon the admission to the Prosthetic Rehabilitation Department (hereinafter referred to as: the Department), the rehabilitation starts with a joint session of the prosthetic rehabilitation team and the patient that serves the purpose of evaluating the patient's overall health (including co-morbidities and possible contraindications for prosthetic rehabilitation, the patient's psychological and mental profiling and the establishment of the level of motivation and cognitive functions), clinical and functional status of the locomotive and neuromuscular system and the residual limb status. The patient is interviewed so as to gain insight into his/her daily and professional activities, living environment and prosthesis- and rehabilitation-related wishes and expectations. Following a physical examination, functional measurements (of muscle strength and joint mobility range) and testing of basic activities in terms of the ability or inability to walk using an aiding device together with the establishment of the mastered track length take place. In cases of patients moving around in wheelchairs, the possibility of verticalisation and out-of-wheelchair transfer gets to be tested as well. The rehabilitation team also seeks information on current capabilities of coping with daily activities and the degree of dependence on caregivers' help. On the occasion of the session and in agreement with the patient, the team makes prosthetic device provision plans. Provision of a prosthetic aid to each individual patient should allow for the choice between various types of prostheses and their components, i.e. modules adjusted based on the clinical status, age, needs and wishes of the target patient and his/her working and living environment.

The provision of a prosthetic device is underpinned by the following principles: 1 early-stage provision of the prosthetic device; 2 a modular system-based fabrication of the prosthetic device; 3 a full contact-bearing use; and 4 an individual approach to prosthetic device provision planning and implementation. Early-stage provision of a prosthetic device implies the provision of prosthesis as soon following the scar healing as possible, which usually means roughly 4 – 5 weeks post surgery. Prosthesis fabrication mainly makes use of commercial and available definite components. The sole component that shall be replaced by a new piece later on due to its functional inadequacy expected to occur due to hypotrophy and oedema diminishment, is the bearing. Early-stage provision of a prosthetic device is accompanied by early rehabilitation that yields far better results as compared to a delayed rehabilitation, since the patient's motivation to master prosthetic ambulation has been witnessed to fade as the post-surgery period goes by. Prosthetic rehabilitation goals should be set in advance, that is to say, at the very beginning of the process, and should come as a result of an agreement between the patient and the rehabilitation team members, while further pursuance of the specific goals is to be left at the discretion of experts of referent backgrounds. The goals discussed above should be set in writing and should be specific, measurable and realistic

TABLE 1

Mobility Scale (Functional Levels defined by the Centres for Medicare and Medicaid Services).

K-level	Mobility level
K0	The patient is immobile and has neither the potential, nor the ability to ambulate or transfer (with or without assistance), so that the provision of a prosthesis would not improve his/her quality of life or the mobility level.
K1	The patient has the potential to use prosthesis for transfer or ambulation on level surfaces at a fixed cadence – the above is typical of limited or unlimited household ambulators.
K2	The patient has the potential to use prosthesis and the ability to traverse minor barriers, such as stairs or slopes – the above is typical of limited community ambulators.
K3	The patient has the potential to use prosthesis at a changeable cadence, which allows him/her to traverse most barriers, so that vocational and therapeutic activities or exercises demanding the use of prosthesis beyond mere locomotion can be pursued.
K4	The patient has the ability or potential to use prosthesis as an aid in activities that require skills beyond basic and are characterised by high impact, energy consumption or stress levels – the above is typical of the prosthetic demands of children, active adults or athletes.

TABLE 2

Mobility Scale-based guidelines for prosthetic device provision (Functional Levels defined by the Centres for Medicare and Medicaid Services).

K-levels	Adequate prosthetic device provision
K0	Patients are not advised to use prosthesis either for ambulation or transfer.
K1	Patients are advised to use prosthesis so as to attain the functional goal of unlimited or limited in-house ambulation.
K2	Patients are advised to use prosthesis so as to attain the functional goal of limited community ambulation.
K3	Patients are advised to use prosthesis in order to develop their functional potential that reaches beyond mere locomotion, so as to be able to traverse most of barriers and cope with more demanding vocational and other activities and more demanding exercises.
K4	Patients – typically children, active adults or athletes – are advised to use prosthesis even with the most demanding activities.

Prosthetic device provision usually commences upon the surgery wound healing; however, by virtue of exception, such a provision and restricted ambulation may be started even earlier, provided that the wound is free from infection and covered in granulations.

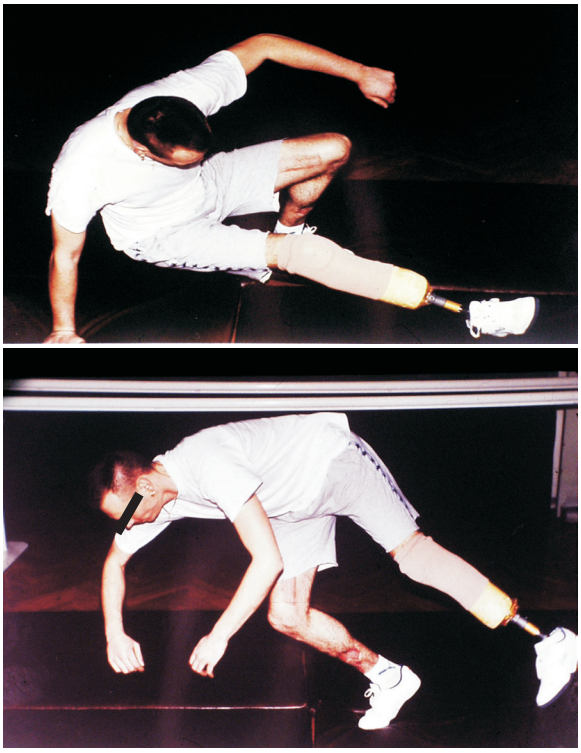
so as to be feasible. The prosthetic rehabilitation process is elaborated in-depth under the in-house algorithm adopted by the Department. It tackles several areas in terms of kinesitherapy, prosthesis-aided mastering of functional activities with a special emphasis on bipedal walking, and occupational therapy that strives to teach the patient how to cope with daily activities.

As with the pre-prosthetic stage, the kinesitherapy initiated in this stage, is a multi-component one, its components thereby being the reinforcement of muscle strength & endurance of intact limbs, the trunk and the residual limb (open- and closed kinematic chain exercises) and the increase in flexibility, i.e. mobility of all limb joints, than cardiovascular training primarily of an aerobic type tailored based on individual potentials of each rehabilitee, and finally the transfer exercises. Additional and distinctive kinesitherapy components are prosthesis-based verticalisation exercises and later on balance and prosthetic ambulation exercises together with exercises targeted at better coping with daily activities and prosthesis management. The programme is carried out by a physiotherapist and an occupational therapist under the supervision and guidance of a physician. The programme commences with a thorough functional evaluation and metrics of the muscle/skeletal system, neurological evaluation and metrics, assessment of self-care, transfer and verticalisation, and optionally also aided ambulation abilities, following which the kinesitherapy programme gets to be compiled, setting both short-term and long-term therapeutic goals. At this point, mastering of prosthesis-aided activities, i.e. functional rehabilitation goals' attainment follows the subsequent algorithm: 1: Mastering of proper prosthesis donning and doffing; 2: prosthesis-aided standing and sitting exercises, followed by the

Figures 1A and 1B. *Amputee Walking School – ambulation exercise making use of an above-knee prosthesis (A) within parallel bars and (B) outside parallel bars (barrier-traversing scenario).*

prosthetic ambulation exercises that make use of parallel bars and strive to set the walking biomechanics in order as much as possible (Figure1A); 3: Prosthetic ambulation on an even surface (outside parallel bars) (Figure1B) with the aid of crutches or a walker, if so necessary; 4: Sitting in a chair and getting up plus prosthetic transfers; 5: Traversing minor barriers during prosthetic ambulation; 6: Climbing the stairs; 7: Prosthesis-on falling and getting up scenarios (mostly in amputees of a younger age) (Figures 2A and 2B); 8 Prosthetic ambulation in a natural environment; 9: Getting in a and out of a car scenarios; and, optionally, 10: Prosthesis-on and prosthesis-off sporting activities (in younger amputees). Rehabilitation carried out under the roof of a specialised institution in the presence of a physiatrist/an orthopaedist and a physiotherapist, is of the outmost importance when it comes to bipedal prosthetic ambulation, since it continuously instructs and educates the rehabilitee on the proper walking pattern to the end of diminishing or, even better, avoiding the assumption of deviant walking patterns often seen in poorly rehabilitated individuals. The implementation of the rehabilitation programme should respect and take into account the capacities of an individual patient, mostly manifested in the speed at which certain rehabilitation stages and activities are mastered, following thereby the pre-set sequence of procedures to be implemented.

Provision of the prosthetic device in terms of its fabrication, application and necessary technical and biomechanical adjusting up to the point of both functional and esthetical optimum, takes place concurrently with the rehabilitation programme implementation. This is rendered possible due to an everyday presence and engage-



Figures 2A and 2B. *Amputee Walking School – advanced safe falling exercises attempted in younger below-knee amputees - (A) safe falling to the right scenario and (B) safe falling to the left scenario.*

ment of orthopaedic technicians on the Department premises; the technicians in question are not Department affiliates, but rather outsourced associates. They operate in collaboration with a physiatrist/an orthopaedist, a physiotherapist and the patient. Fabrication of the prosthesis in terms of the bearing fitting commences within the first two days following the first session of the rehabilitation team, on the occasion of which the need for the prosthesis was established and the prosthetic option was chosen. The motivation of a prosthetic rehabilitee is enhanced by the desire to achieve as independent daily performance as possible and (in younger persons) to reassume his/her professional duties so as maintain their financial and social standing, and to be able to continue with his/her hobbies and recreational activities. Successful rehabilitation is perceived as an opportunity to improve the chances for regaining "normal" ambulation; in this context, looking up to role models of successfully rehabilitated amputees further facilitates the process and increases patient motivation. In cases of primary prosthetic appliance provisions, the duration of the prosthetic rehabilitation of trans-tibial amputees approximates to 4 - 6 weeks, while in trans-femoral amputees the expected duration of this rehabilitation stage is roughly 6 - 8 weeks. In cases of bilateral amputation, the length of rehabilitation is prolonged, so that in amputees with bilateral transfemoral amputation its approximate length amounts to 3

months. In cases of recurrent (secondary) prosthetic device provision, the average length of in-hospital stay equals to 7 - 14 days; however, rehabilitation in out-patient settings is possible as well.

V) CLINICAL MONITORING AND FOLLOW-UP OF PROSTHETICALLY REHABILITATED AMPUTEES

Following the discharge from the rehabilitation centre, the patient uses his/her prosthesis as often as his/her age, lifestyle and living environment allow. In general, active individuals should aim to use prostheses all day long and with each and every activity of daily living (both vocational and recreational), while in elderly patients even a part-time use of prosthesis in certain limited environments can be considered a success. The patient continues to be monitored by a prosthetic rehabilitation specialist and presents for intermittent control visits, at least on an annual basis. Following the primary provision of the prosthetic appliance and the rehabilitation, the first control visit usually takes place in a month or two. Should the prosthesis bearing be established as inadequate due to residual limb atrophy and incapable of adequate retention, the fabrication of a new bearing is deemed necessary. Bearing refabrication can be carried out either in out-patient or in Day Care Hospital settings, while in more complex cases the so called secondary prosthetic rehabilitation taking 8-10 days is to be implemented. Adjustments of the prosthesis and its minor repairs are left at the discretion of orthopaedic technicians or Masters of Prosthetic Engineering, while major changes can be introduced solely in agreement with the attending physiatrist/orthopaedist. The patient should also be continuously monitored by other attending specialists, and should continue treating all of his/her conditions, diabetes, vascular insufficiency and cardiac condition included *(18, 19, 20, 21, 22, 23, 24, 25, 26).*

Rehabilitation of the elderly, which represent the majority of lower limb amputee population, faces specific challenges that influence the prosthetic device provision and rehabilitation procedures and affect their outcomes. This population is characterised by multiple morbidities (e.g. vascular insufficiency, coronary heart disease, diabetes, neuropathies, and alike), degenerative changes of the locomotive system and consequential ambulation kinematics disturbances, as well as by overall deterioration of functional and mental/somatic capacities. Risk factors most represented in this population are hypertension, diabetes, hypercholesterolaemia and smoking. The prevalence of ischemic heart condition witnessed in this population is 2.5-fold higher (present in 63% of such patients) than in persons free from peripheral vascular disease, while the prevalence of stroke surpasses that in persons having no peripheral vascular condition by 3.3 folds (11%) *(27).* According to Erjavec and co-workers, but also in our in-house experience, the successfulness of prosthetic device supply, especially in above-knee amputees, strongly depends on co-morbidities and cardiac strain capacities. Notwithstanding the importance of clinical experience in the rehabilitation field, the decision on prosthetic device provision in the elderly should also rely on an impartial assessment of somatic capacities. The latter capacities are evaluated on the occasion of an office visit and prosthetic rehabilitation planning or at the very beginning of rehabilitation, so as to be able to make the decision on the prosthetic device provision and making, and to decide on the most appropriate prosthetic rehabilitation programme based on the output of the targeted workup and evaluation and the results of endurance tests.

Endurance testing tools that have proven efficient at the point of admission into the rehabilitation centre are the Six-Minute Walk Test and the Functional Independence Measure (FIM). Walking abilities are best tested should the patient walk on a flat surface for 6 minutes (ATS Statement: Guidelines for the Six-Minute Walk Test), while the 2-Minute or shorter Walk Test has been proven an unreliable mobility indicator *(28, 29, 30).* Within this context, the most reliable indicator and predictor to be established at the rehabilitation admission point is the patient's ability to walk without assistance, using only an aiding device (either crutches or a walker); therefore, the pre-prosthetic stage of rehabilitation carried out under the patient's roof or in a nursing home under the supervision of a physiotherapist (home physical therapy) aims to capacitate the patient to attain the above goal by virtue of a targeted kinesitherapy and training.

Prosthetic ambulation implies an increased cardiac straining and an increased energy consumption, to be taken into account when planning further clinical course of action; as compared to independent ambulation of non-amputees, in trans-tibial amputees the above cardiac strain and energy consumption increases approximate to 40%, in trans-femoral amputees to 80%, while in bilateral above-knee amputees the increase of up to 200% can be witnessed *(6).*

In the prosthetic rehabilitation stage, elderly patients are taught how to master prosthesis donning and doffing (either independently or with assistance) and attend the Amputee Walking School that educates them in prosthetic ambulation, all of the aforementioned to the ultimate effect of mastering safe short-track prosthetic ambulation. Rehabilitation agenda and goals are adjusted on an individual basis, taking thereby into account the assessed somatic and mental capacities of the given patient of relevance for the exercise and training tolerance. The rehabilitation pursued at this point may have the following possible outcomes: a) provision of a prosthetic device; b) combined short-track use of prosthesis and long-track use of a wheelchair; or c) exclusive use of a wheelchair. The majority of elderly patients whose amputation was mandated by their vascular condition are less physically active, so that the desirable and realistic goal of the prosthetic

rehabilitation should be capacitating for a part-time prosthetic ambulation in duration of 5-6 hours a day, enabling them to traverse shorter tracks in the vicinity of their homes (limited community ambulators). Faster prosthetic ambulation allowing for circulation in a wider perimeter may be expected only in exceptional cases of community ambulators *(25, 26)*. According to Chin, ambulation with the aid of above-knee prosthesis is fairly slow (its expected rates ranging from 8.2 m/min to 21.6 m/min tops), so that it is reasonable to assume that, when it comes to longer tracks, most of the elderly patients shall resort to a wheelchair *(31)*.

Provision of a prosthetic device intended for younger amputees, in particular those whose amputation was mandated by trauma, but also tumour or malformation, should aim at providing a prosthesis whose technical properties shall allow for full reassuming of former activities (vocational, recreational and, dependent on the patient, even sporting activities). Rehabilitation of this patient population should be comprehensive and of high quality, and should provide education and training that ultimately capacitate the patient for an all day long-use of prosthesis with all vocational, sporting-recreational and other activities. In order to allow for a proper psychosocial reintegration, social and (if necessary) psychological rehabilitation should take place concurrently with medical treatment.

Rehabilitation of amputated children is somewhat distinctive in its profile; namely, paediatric patients do deserve and do have our special attention. Same as with adult amputees, the provision of a prosthetic appliance and rehabilitation of paediatric amputees should also be started as early as possible. In cases of traumatic amputation or amputation due to a bone/joint malignancy, the process should be started as soon as the postoperative wound has healed. In cases of congenital leg deformities, the first prosthesis is provided in the prime verticalisation stage, i.e. when the child is 9-12 months old. Primary provision of the prosthetic device goes through in-hospital rehabilitation that runs in the presence of the mother, while subsequent provisions go through out-patient channels. In general, children tend to adapt to prosthesis very well; however, due to the maximum use and wear-out, the lifetime of such a prosthesis is shortened and characterised by frequent height adjustments and bearing replacements. The issue often encountered in below-knee amputees is the varus deformity of the residual limb, arising as a consequence of a long fibula and occasionally mandating surgery. Rehabilitation of paediatric lower limb amputees should be adjusted to the child's age and the type and level of amputation, while the walking pattern should be age-appropriate. Rehabilitation of paediatric amputees necessitates a close cooperation with the parents. From the prosthetic point of view, children are at first typically supplied with a simpler prosthesis, while later on, in line with their growth rate, a more complex prosthetic appliances are provided *(25, 26)*.

THE ASSESSMENT OF PROSTHETIC REHABILITATION OUTCOMES

From the clinical standpoint, **the outcomes of the prosthetic rehabilitation of an amputee** may vary substantially; for the sake of rough orientation, the Department has adopted the following rehabilitation outcome ranking: a) mastered prosthetic ambulation, deemed as an excellent rehabilitation outcome; b) mastered prosthetic ambulation aided with crutches or a walker, deemed as a favourable rehabilitation outcome; c) aided ambulation making no use of a prosthesis, but rather of crutches, deemed as a poor rehabilitation outcome; or d) wheelchair ambulation, deemed as the poorest rehabilitation outcome.

The outcome and the success of rehabilitation of an amputee depend on a number of factors, so that they should be assessed at each functional level, taking both overall health and the coexistent factors into account, as well. According to the ICF, the latter factors are represented by a heterogeneous group of parameters related to health, body functioning, patient participation in the process and his/her activities, individual characteristics of a patient and the environment. **When addressing patient's health,** one actually refers to the grounds for amputation and to co-morbidities and injuries that might have affected the rehabilitation outcome. Important **body functions** are joint mobility and stability and muscle strength, not to neglect the cardiac/pulmonary status. Major **somatic parameters** are those descriptive of amputation (amputation level, shape and length of the residual limb, scars and other skin changes). As for the **activities,** ambulation usually poses as the major issue; however, limitations may also be encountered with daily, professional or even leisure activities, should these mandate longer standing or walking. **Environmental factors** may mirror either in tangible obstacles hindering the pursuance of certain activities or interventions facilitating and aiding that pursuance. **Individual factors** are age, motivation, desires and the psychological profile of a patient *(32, 33)*. According to Sansam and co-workers, the outcome of rehabilitation of amputees having their limb amputated due to a circulation disorder, is poorer as compared to that in amputees having their limbs amputated due to trauma or other causes (medium-quality evidence). Although supported solely by low-quality evidence, the impact of co-morbidities should not be neglected, since only rare amputees who had a stroke manage to master walking on 30-m tracks *(33)*. Van Velzen provided compelling evidence on poorer muscle strength and poorer balance witnessed in amputees. As compared to healthy individuals, amputees move slowly and in an asymmetric manner due to their balance impairment. Patients fully independent prior to amputation and having higher post-amputation Barthel index scores, were proven to be much better in prosthetic ambulation mastering *(34)*. The existent evidence, though of somewhat poorer strength,

show that prosthetic ambulation is better mastered by individuals physically active prior to amputation, as well as by persons capable of maintaining balance while standing on one leg only. Even weaker, but still not a negligible impact on prosthetic ambulation mastering, is the impact of phantom pain or the pain experienced in residual limb *(34)*. Below-knee amputees commonly make good use of their prosthesis and are good at prosthetic ambulation, as oppose to above-knee amputees who often lack strength to properly master such ambulation, especially if provided with the so called mobile-bearing knee. Regardless of the level of amputation, prosthetic ambulation of elderly amputees is slower and copes only with shorter tracks, while wheelchairs are used for longer tracks.

Bilateral amputees, who are often also diabetics or suffer from a vascular condition, master prosthetic ambulation only in exceptional cases, since they usually lack strength and energy needed for prosthetic ambulation. Patients who have already mastered prosthetic ambulation upon unilateral below-knee amputation might be able to manage even upon the amputation of the other leg, regardless of the amputation level. Prosthetic ambulation is better mastered by persons having unilateral low limb amputation and persons having distal amputation *(34),* while the risk of failure rises with trans-femoral amputations *(35)*. As compared to healthy individuals, amputees walk slowly and in an asymmetric manner; such a walking pattern mirrors their poor balance *(33)*. Patients who are fully independent prior to surgery and having higher Barthel index scores, master prosthetic ambulation far better *(34)*.

Biomechanical analysis of the walking pattern, carried out using the appropriate metric devices and other equipment, provides the most comprehensive information about prosthetic ambulation. Such systems are of an optic/electronic design and are equipped with cameras and video-cameras that allow for a kinetic analysis. The metric platform measuring reactive surface forces allows for a kinetic analysis, while the tele-analytics of an electromyography type provides the input on body muscles' activity. The metric systems detailed above enable an impartial biomechanical detection and evaluation of functional walking pattern disturbances seen in amputees provided with an appliance, as well as the analysis of adaptive biomechanical walking pattern adjustments made by the amputees as compared to non-amputated individuals. However, due to their high cost, limited availability and complex interpretation of the results that necessitates an interdisciplinary collaboration of highly qualified experts, these systems are more in use in scientific research than in the routine clinical practice and rehabilitation of amputees *(37, 38, 39, 40, 41)*.

Following a certain period of prosthesis use, **the success of the prosthetic rehabilitation and its functional outcome** may be quantitatively and qualitatively assessed using a spectrum of standardised tools, some of them thereby being specifically tailored for the amputee population and some of them being of a more universal nature. Some of these tools fall within the self-appraisal category, while others rely on impartial metrics. Appraisal questionnaires used with amputees may be divided into three groups: questionnaires testing mobility, questionnaires testing functional capacities and questionnaires testing the quality of life of amputees.

1) The nature of appraisal questionnaires testing lower limb amputees' may be either general or specific. Tools of general nature are the following: the Timed Up and Go (TUG) Test (testing the time an individual needs to get up from a chair, walk 3 m and go back to the chair) and the Timed Walk Test testing the walking speed (expressed in m/s) within a 2-min or a 6-min timeframe. Tools specifically designed for lower limb amputees are the Amputee Mobility Predictor (AMP) and the Locomotor Capabilities Index (LCI). The questionnaires rank patient mobility and locomotive capacities of amputees provided with prosthetic devices prior to and following rehabilitation.

2) Validation tools used for functional testing of lower limb amputees may also be of general and specific nature. Those of a general nature are the Functional Independence Measurement (FIM) and the Barthel Index that investigate into the activities of daily living. The tool specifically tailored to assess functional capacities of lower limb amputees are the Prosthetic Profile of the Amputee (PPA), which allows for the collection of various data on prosthesis use and factors capable of influencing that use. A part of the above questionnaire is the Locomotor Capability Index (LCI) that evaluates locomotive capacities of the examinee.

3) Appraisal tools investigating into amputees' quality of life may also be divided into multi-purpose and specific-purpose tools. Multi-purpose tools at disposal are numerous; however, one suitable for use within this context is the Short Form 36 (SF - 36). The quality of life of patients who have completed prosthetic rehabilitation is validated using specific-purpose tools such as the Prosthetic Evaluation Questionnaire (PEQ) and the Orthotics and Prosthetics User Survey (OPUS). In part, the Prosthetic Profile of the Amputee (PPA) provides QoL-related information, as well *(42, 43, 44, 45, 46, 47)*.

According to Burger, evidence on the efficiency of rehabilitation of lower limb amputees is only scarce. High-level evidence has insofar supported only the notion that amputation diminishes muscle strength and impairs balance, as well as the notion that amputees walk slower and in a less symmetric manner. High-level evidence corroborate the fact that prosthetic walk is better mastered by fit unilateral amputees who have undergone an early prosthetic rehabilitation and have been timely provided with the prosthetic device *(48)*.

CONCLUSION

Based on the clinical experience and literature sources, it can be concluded that prosthetic rehabilitation underpinned by good clinical practice, entrusted with an interdisciplinary team that follows the guidelines for contemporary prosthetic rehabilitation and carried out in patients who had high-quality amputation surgery, may vouch for the successful provision of a prosthetic appliance. Should the above prerequisites be met, a satisfactory prosthetic rehabilitation outcome may be expected, not merely in terms of a successful use of the appliance on the amputated leg, but also in terms of psychosocial rehabilitation and reintegration of the amputee and as high quality of life as possible.

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