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Title: Rehabilitation and prosthetics post-amputation

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Short title: Amputation and Rehabilitation

Abstract

It is paramount that surgeons performing amputations have an understanding of the rehabilitation pathway and the prosthetic options for their patients following the amputation procedure. Some surgeons consider an amputation a failure of their previous treatment, but for their patients, it is the beginning of their rehabilitation. In limb loss, the rehabilitation pathway could start antenatally or at the pre-amputation consultation, but input continues for the life of the patient.

An integrated pathway between the surgical and rehabilitation teams for patients, from the consideration of option of amputation, through surgical treatment and pre-prosthetic rehabilitation, to provision of a definitive prosthesis and achievement of their ultimate goals is essential.

This article is aims to provide an introduction to current practice in amputee rehabilitation. We will cover rehabilitation in upper and lower limb loss and describe the input of the multidisciplinary team led by the Rehabilitation Medicine consultant and indicate where future advances will be made.

Keywords: upper limb, lower limb, amputation, rehabilitation, prosthetics, phantom limb pain, prosthesis, stump

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INTRODUCTION

Amputation of a limb is a life-changing operation that results in profound alterations in the physical and psychological welfare of the patient. In the past, an amputation was considered by some surgeons to indicate a failure of treatment, particularly for mal-union of fractures. However, to patients, amputation is the start of their rehabilitation process meaning that for the first time they will be free of pain and able to aim for improved function.

Each year in the UK approximately 16,000 patients undergo a limb amputation.[1] Globally, amputation is one of the most common contributors to disability, with 30 million people worldwide living with limb loss.[2] A rehabilitation pathway after amputation, with appropriate provision of prosthetics, offer opportunities for people to re-build their lives, regain independence and dignity, and resume former activities.[3]

Most lower limb amputations performed in the UK are of the lower limb for peripheral arterial disease, complications of diabetes mellitus, or a combination of both. Amputees are typically older, with several comorbidities, including osteoarthritis in the remaining lower limb joints. Whilst the goal of most lower limb amputees is to walk, 20% of transtibial and 60% of transfemoral amputees will never walk again. As life expectancy improves, the prevalence of amputees unable to walk will increase – this includes those whose amputation occurred at a younger age due to trauma, but for whom aging impacts on their ability to mobilise. Inability to walk is associated with decreased ability to exercise, increased susceptibility to further comorbidity, reduced independence and lower quality of life. There are also impacts on health and social services with consequent increases in costs.

Trauma is the second leading cause of lower limb amputation, and the leading cause of upper limb amputation.[4] Upper limb amputations are a much smaller proportion of the total number of amputations in the UK, and worldwide, but as they generally occur in adults of working age, have a disproportionate impact on function and quality of life due to their effect on the ability of the patient to do bimanual tasks. They also result in an increased incidence of overuse injuries of the contralateral limb.

Amputations are described by the anatomical level of the bone or joint transected at the time of surgery. Therefore, for example, the two most common lower limb amputations are referred to as trans-tibial and trans-femoral. A knee disarticulation refers to an amputation through the knee. The terms “below knee”, “above knee” and similar are inaccurate and misleading and should not be used in modern clinical practice.

Amputee rehabilitation services are provided by 44 NHS centres in the UK. Each provides input to patients who are being considered for amputation, or are recently amputated, and they all provide lifelong follow-up to all amputees. Most are co-located with other rehabilitation services, as patients’ needs are often multi-factorial. Although all deliver general amputee rehabilitation services, the provision of more specialist equipment, such as highly specialised upper limb prosthetics and microprocessor controlled knees, is limited to the larger centres due to the level of expertise required in prescribing these prostheses.

AMPUTATION SURGERY

Knowledge of the current rehabilitation pathway and prosthetic options can guide the surgeon to fashion a stump that can be used by a patient in function long-term with minimal complications from prosthetic use. This may reduce need for further revision surgery. If there are any concerns about the procedure, the operating surgeon should discuss the patient with the Rehabilitation Medicine consultant linked to the acute service.

If an elective amputation is a treatment option, patients should be facilitated with a pre-amputation consultation at the Amputee Rehabilitation Centre where the pathway can be discussed to aid them in making an informed decision and prepare psychologically. This is the only treatment that has been repeatedly shown to reduce post-amputation pain and phantom limb pain. It is important to manage patients' expectations, starting at this stage, while making them familiar with the challenges of limb loss and prosthetic use, as this will differ depending on their co-morbidities. Furthermore, prehabilitation can be discussed, to reduce surgical risks, enhance postoperative recovery and improve long-term outcomes. Peer support from a suitable and established amputee if appropriate is offered, as is information about patient support charities.

When considering amputation it is important to take into account an individual's prosthetic options and suspension strategies and to contour the bony edges to diminish painful pressure areas during prosthetic use. Various surgical methods can be used while dividing peripheral nerves to prevent or delay neuroma formation.

Planning and the pre-amputation phase

Lower limb amputation

The level of amputation impacts on the patient's predicted mobility and gait performance. A transtibial amputation is the most common level of amputation, comprising 52% of lower limb amputations in the UK each year. The operation carries good prognosis in terms of mobility with 80% of amputees mobilising with or without walking aids. However, the exact outcome will depend on the patient's general pre-amputation medical state, including the level of mobility. Energy expenditure when walking with a prosthesis increases by between 16% and 28%.[5]

A transfemoral amputation is selected when there is blood supply sufficiently compromised to heal a less extensive amputation or the knee joint cannot be salvaged. The length of the stump in a transfemoral amputation should be planned to leave a clearance of 12 cm above the fulcrum of the contralateral lower limb. This will enable the use of a variety of prosthetic knee components to equalise the knee centres bilaterally, avoiding a leg length discrepancy. The transfemoral level of amputation requires significantly higher energy expenditure on the part of the amputee to walk (varying between 60% and 110%). Therefore, lower levels of activity and mobility would be predicted.

There are a number of other amputation levels that can be considered, but each has very significant drawbacks in terms of allowing the patient to mobilise afterwards, without conferring any advantages. These should only be carried out after a discussion with the rehabilitation team. The partial foot amputation is commonly used in diabetic forefoot disease. This limb deficiency is usually restored with cosmesis using silicone fillers and is managed by a combined orthotics and prosthetic approach as the biomechanics of the foot are severely altered. A Symes's amputation potentially saves limb length and leaves a weight-bearing stump, but severely limits the prosthetic options as the prosthesis is bulky. Heel pad migration in the longer term is a substantial risk.

A knee disarticulation can also give a weight-bearing stump with preservation of thigh muscles and increased lever arm for performing transfers. However, the cosmetic appearance is poor as the socket will be bulky and there will be visible difference in the prosthetic and contralateral knee centres as the knee mechanism will be attached to the end of the long femur. In the Gritti-Stokes procedure the patella may detach causing pain and inability to weight bear through the stump. Knee disarticulation should only be considered for patients who will not progress to prosthetic provision due to their co-morbidities, for example, pre-existing complete spinal cord injury or severe cardiorespiratory disease that precluded walking prior to amputation.

Hip disarticulation and hemipelvectomy are carried out for very specific indications, usually advanced malignancy, and can result in satisfactory outcomes, but require very specialist rehabilitation input and prosthetic provision.

Bilateral transtibial and transfemoral amputations markedly increase the metabolic demands of walking compared to unilateral amputation and also require specialist rehabilitation input and prosthetic provision in order to maximise potential mobility. The rehabilitation programme for bilateral transfemoral amputees takes up to 18 months.

The stump (sometimes referred to as the residual limb) plays an important role in the transmission of forces from the body to the prosthetic limb. The ideal stump, therefore, should be a suitable length to accommodate the prosthetic equipment with appropriately fashioned soft tissues to accommodate what can, at times, be very high forces – sometimes multiples of the patient's body weight (figure 1).

The healed stump should be of adequate length to fit the prosthetic with sufficient leverage and stability. Preservation of length in the residual lever arm during surgery can generate greater torque, which in turn can improve functionality in a prosthesis with less pressure on the soft tissue. Torque is equal to the force applied multiplied by distance from the fulcrum.

The correct stump length is important to incorporate the necessary prosthetic components. It is understandable the traumatic stumps may not fulfil the perfect surgical criteria when surgical salvage is attempted, but aiming for a length as optimal as possible is desirable. However, length should not be preserved at all costs as prosthetic components need to be able to fit into the potential space between the end of the stump and where the foot, in the case of the lower limb, or terminal device, in the case of the upper limb, needs to be positioned.

Upper limb amputation

In planning an amputation of the upper limb, the surgeon should consider an appropriate surgical technique, aiming for quick primary healing, satisfactory cosmetic appearance and a good potential for prosthetic use.

Sufficient soft tissue coverage is achieved by a good myodesis or myoplasty in diaphyseal amputation. A myodesis would provide more stability of the musculature, especially in someone considering an upper limb myoelectric prosthesis. A good quality scar, healed through primary intention, non-adhered, and free from pain will enable the patient to engage in rehabilitation with a prosthesis in a timely manner.

Transected stump muscles atrophy with time, so sufficient muscle should be preserved at the time of surgery. However, excessive redundant soft tissue is a significant problem in donning the prosthetic limb, as well as limiting the modes of suspension of the prosthesis, such as suction suspension. The risk of skin infection is also increased, due to excessive soft tissue invagination.

Soft tissue coverage with local tissue flaps and avoiding skin grafts is ideal when this can be achieved. The balance between agonist and antagonist muscles is important to avoid future joint contractures and problems with prosthetic prescription. Neuroma formation is not uncommon in amputees, and while they may not always be symptomatic, when they are, prosthetic comfort is compromised which impacts on function requiring excision of the neuroma.

The Roehampton Stump Score was developed by the Douglas Bader Rehabilitation Centre at Queen Mary's Hospital in 2011 as the preferred measure of quality of the stump for rehabilitation and prosthetic provision. The amputating surgeon can also refer to the Amputee Rehabilitation and Prosthetic Standards published by the British Society of Rehabilitation Medicine.[6]

POST-OPERATIVE REHABILITATION

Rehabilitation is an educational and problem-solving clinical intervention that aims to reduce the impact of the limb loss on the amputee's functioning. This is achieved through three main strategies – restoration of the function of impaired structures, reorganisation of impaired pathways to deliver improved abilities, and reducing the discrepancy between the limited ability of disabled people and the demands of their environment.

The first post-operative day is when an assessment will be carried out by the physiotherapist qualified in amputee rehabilitation. This will include a referral for a wheelchair with a stump board when appropriate to prevent knee contractures for lower limb amputees (figure 2).

Prevention of falls that could risk breakdown of the immature stump and to facilitate healing with primary intention is essential to further rehabilitation. Care of the myoplasty or myodesis and the scar, control of oedema (figure 3), and prevention of contractures while strengthening the muscles is important prior to prosthetic use as these are the main factors predictive of poor outcome.[7]

Prior to discharge, or in elective surgery, prior to admission, an environmental visit should be carried out to the patient's home to ensure the feasibility of safe discharge and the plan for what adaptations that will be required following the amputation.

When a patient is referred following surgery to the amputee rehabilitation centre, a consultant in Rehabilitation Medicine specialised in amputee rehabilitation assesses the patient together with the multidisciplinary team (MDT). Identifying the amputee's impairments, as well as the rehabilitation potential in an individual, will enable the MDT to guide the patient to generate SMART (specific, measurable, attainable, relevant and timely) goals which may or may not include provision of a prosthesis. For instance, not all upper limb patients will be suitable for functional or passive prosthetic use, especially in more proximal amputations.[8] Lower limb amputees with significant cardiovascular compromise may not be able to walk with the added weight of a lower limb prosthesis and may find improved mobility using a wheelchair.

Input from the team is holistic, including addressing pain related to amputation, and prevention and management of overuse injury. Occupational therapy input can facilitate compensatory methods in a person’s own environment, while psychological needs are explored by the clinical psychologist to support the patients through the many issues experienced by amputees, including loss, grief, body image challenges, adaptation to change.

The amputee will continue with outpatient rehabilitation with their local amputee physiotherapist prior to provision of a definitive prosthesis, where the compression therapy (compression stockings), wound and stump care would be reviewed including use of stump board to prevent knee flexion contractures. Ongoing problems with stump wounds do not necessarily preclude wearing a prosthesis, and there is some evidence that prosthetic use can expedite wound closure by secondary intention.[9]

Early gait training

Outpatient rehabilitation therapy is focused on maximising the potential for independent living. Rehabilitation at this stage includes assessment of the current medical status and quality of the residual limb, goal setting and review of earlier goals, continuation of wheelchair training, compression therapy, sit-to-stand practice, and progression to early walking aid (EWA) use. Two of the commonly prescribed EWAs are the Pneumatic Post Amputation Mobility aid (PPAMaid) and the Femurette. The former is predominately used in amputees with a transtibial amputation, but can be used following transfemoral amputation. The latter incorporates a knee joint, which can allow the MDT to make an assessment of the potential of the amputee to manage a knee joint during gait training without a lock (figure 4).

During this phase an amputee is assessed for a definitive prosthesis and suitable goals are agreed. Co-morbidities potentially causing insufficient cardiorespiratory function, neurological conditions resulting in physical and cognitive deficits are carefully considered as these can impact on walking.[10] For patients with bilateral transfemoral amputations foreshortened prostheses are used to determine the patients' ability to progress to standard full-length prosthetic prescription. The patient's height is much shorter using these specialised prostheses making the patient's centre of gravity lower resulting in better balance and stability in gait training (figure 5).

Following successful fitting of the prosthetic limb, the amputee will continue rehabilitation, often for several months, aiming for independent donning and doffing of the prosthetic limb, gait re-education, progressing to maximum independence with activities of daily living and mobility.

An EWA might not be an option for obese amputee due to their body habitus. In this case, the decision about early fitting of the definitive prosthesis would enable the patient to engage in timely rehabilitation. There are no set criteria disqualifying overweight or obese patients from accessing the amputee rehabilitation pathway; however pre-morbid activity, co-morbidities and weight limits for the prosthetic products will impact on the decision regarding prosthetic limb provision. Many lower limb prosthetic components have a maximum body weight limit for the amputee of 125 to 150kg. For patients being considered for an elective amputation, the procedure might be deferred pending weight loss when appropriate.

Prosthetic prescription components

The socket and interface (the layer between the residual limb and the interior surface of the socket) are important parts of the prosthetic prescription for body weight transmission. Sockets can be manufactured manually (hand cast) or computer aided. For transfemoral amputees there are two types of sockets – quadrilateral and ischial containment sockets. The decision on which to use is made depending on factors such as residual limb length, patient activity level and potential for ischial weight-bearing comfort. The socket can be suspended by a soft or rigid belt. For amputees with high activity levels and minimal stump volume fluctuations, a self-suspending socket is considered.

In transtibial amputation, the patella tendon bearing socket with added suspension options or the total surface bearing socket with an interface liner are the main sockets used. In this situation, the type of socket used depends on the amputee's ability to tolerate localised pressure on the patella tendon, and the paratibial and popliteal areas. The liner determines how weight is transferred to the stump and it can address other common stump problems such as poor suspension, friction causing pain, fluctuating stump volume and skin problems.

Each amputee’s needs can be managed within the prosthetic prescription and the equipment may include thigh corsets and side steels when better knee stability is required, for example after reconstruction of the knee ligaments. With progression into higher levels of mobility, the prescription may change to meet new goals including sporting activities.

Prosthetic knee prescription in transfemoral amputations

There are many types of prosthetic knee joints available at present. The prosthetic knee will flex and extend through the swing phase and extend during the stance phase, resembling the anatomical joint’s movement. The speed and smoothness of movements depends on the amputee’s walking speed, progress in gait training and type of the prosthetic knee. Prosthetic knees are categorised according to how they flex and extend. Monocentric knees move around a single axis, whereas polycentric knees have several axes of movement. There are various methods of controlling the knee, both in the stance and the swing phase. Monocentric knees have stance phase control – either a stabilising mechanism or a hydraulic yielding mechanism. Polycentric knees do not require stance control as they are inherently stable by design.

At the most stable end of the spectrum, hand-operated knee locks will be considered for very frail patients, who might need to manually lock the knee at times (for donning), or to aid stability for certain activities where maximum stability is required. A semi-automatic knee lock is used in patients with poor stability or muscle weakness on the amputated side. Here the knee remains locked in extension during walking, but can be flexed to allow the patient to sit. The locking system is audible to facilitate use in amputees with sensory loss in their hands. Both types of knee unit are lightweight, which assists amputees with limited walking potential.

More active amputees will benefit from weight-activated knees with stance control. These units have a stabilising mechanism which is activated during stance when body weight is applied. This mechanism prevents further flexion of the unit, giving amputees stability. These knees can have either spring or pneumatic swing phase control depending on amputee's activity levels. Hydraulic knees are more technically advanced, resembling anatomical knees, allowing patient to walk with a reciprocal gait.

Microprocessor-controlled knees

The microprocessor-controlled knee is the newest generation of prosthetic knee, of which four types are currently funded by NHS England. There are set inclusion and exclusion criteria for patients and the decision regarding provision is made by the MDT. The microprocessor-controlled knee is suitable for high levels of activity, including demanding environments, resulting in reduced energy expenditure during gait, increased confidence, and fewer falls in bilateral transfemoral amputees.

Prosthetic feet

Prosthetic feet embrace a variety of prescriptions starting with the historical "SACH" foot (Solid Ankle Cushion Heel), uniaxial ankle, multiaxial ankle, energy-storing and patient-adjustable. The indications for each prescription will be determined by the proposed activity level (e.g. water activity, barefoot walking, the requirement for different heel heights) and the amputee's goals.

Running blades are available for sports activity; the prescription is individual, following MDT assessment and goal-setting. The Department of Health provides funding for prosthetic limbs for sports for children to enhance participation in physical activity (http://devicesfordignity.org.uk/starworks_cp/).

Upper limb prosthetics

There are different prosthetic options for upper limb amputations, such as passive prostheses (e.g. a children's mitt for crawling as a first prosthesis), body-powered, myoelectric, hybrid (electric and body power), and bespoke activity specific prostheses. The type of prosthesis is a joint decision taken with the amputee and the MDT.[11] Upper limb prostheses can be suspended with a sock, harness, pin lock or a suction fit, or via the humeral condyles for transradial amputations.

Passive prostheses are used for cosmesis, but may also be used for pushing or pulling tasks, stabilising items such as paper during writing, or carrying items hooked onto flexed fingers. Body-powered prosthetics make use of cables, pulleys and hooks. The suspension system is modified with a harness to allow the amputee to activate it through the remaining movements of the residual limb or the contralateral limb. Bespoke prostheses address an individual's specific goals with regards to hobbies, return to education, work and driving. This may include specifically adapted terminal devices to hold tools, bicycle handlebars or other devices.

For an amputee with a stable stump who is adept with a body-powered prosthesis, progression to a myoelectric or other type of electrically-powered limb may be appropriate. Myoelectric prostheses are powered by an integrated battery pack and use electromyographic signals from voluntary contracting muscles in the residual limb for activation of the terminal device – usually the digits of a prosthetic hand. The electronic sensors are embedded in the prosthetic socket and make contact with the surface of the residuum, which triggers a specific action in the prosthetic device to flex, rotate, open or close.

The prosthesis can be programmed to have multiple modes enabling a single muscular activation to produce different prosthetic movements depending on the sequence of muscular activity. This technology has been developed further to allow variety of grips. This is achieved by channelling the pattern of myoelectric signals through a microprocessor which instructs the terminal device to open and close in a particular manner. With time an amputee can learn the different muscle triggers to control very sophisticated movements.

PAIN AFTER AMPUTATION

Pain is common after amputation and is multi-factorial (figure 6). The Amputee Rehabilitation Centre team has extensive experience in managing post-amputation pain and will be able to differentiate stump pain from phantom limb pain and carry out an assessment of the functional impact on an amputee and guide suitable treatment options. There is no robust evidence for perioperative treatments that could prevent post-amputation pain. Pre-amputation pain is identified as a risk factor for post amputation pain, but whilst effective pre-amputation analgesia is essential in its own right, it has never been shown to reliably reduce post-operative pain.

Despite the considerable interest in the management of post-amputation pain, much of the work is from small, non-controlled studies.[12] Experience suggests that opioids are best used in the immediate postoperative period for effective pain relief, but are not recommended for long-term use. Pharmacological agents used to treat neuropathic pain can be effective in stump neuropathic pain and phantom limb pain. Local treatments can also be effective when a lesion is identified that is contributing to pain.[13] Many non-pharmacologic treatments have been tried for post-amputation pain, most with little effect.

FUTURE DEVELOPMENTS

Amputee rehabilitation is a rapidly evolving field with new rehabilitation techniques in constant development and new products coming to market each year. Some of the areas that will influence clinical practice in the near future are described below.

Upper limb transplantation

Since 2016, NHS England has funded hand and upper arm transplants delivered by a specialist surgical and rehabilitation team at Leeds Teaching Hospitals NHS Trust. Following transplant surgery, commitment to the postoperative rehabilitation programme and compliance with lifelong immunosuppressant therapy is expected. Therefore, a thorough screening process is required to select amputees who are suitable for this intensive treatment. The expected advantages are improved fine motor control, return of sensory feedback, warmth in the limb, and increased embodiment of the limb without the disadvantages of a prosthesis. The procedure is not currently considered suitable for congenital limb absence or for those who have required amputation secondary to the presence of tumour due to the risks associated with immunosuppression.

Osseointegration

Osseointegration for limb loss commenced in the 1990s based on successful experiences in dental osseointegration. The technique was thought to be a solution for patients with on-going problems with socket fitting, such as stump volume change, skin problems or discomfort when sitting, where all prosthetic options were exhausted. Initially developed by the team in Gothenburg, it has rapidly spread through Scandinavia, Europe, Australia and North America.

The classical operation is for patients with trans-femoral amputations, but implants are now being manufactured for numerous indications, including upper limb amputations. During the first stage of the procedure, a titanium implant is inserted into the shaft of the residual bone. The second stage, 6-8 weeks later, involves creating a skin penetration with insertion of the abutment that allows attachment of the external prosthesis. The rehabilitation protocol varies between centres but a multidisciplinary approach with the Rehabilitation Medicine physician, physiotherapist and prosthetist at the core of the team remains unchanged.

The expected benefits of osseointegration include better osseoperception which enhances embodiment of the prosthesis, improved mobility, increased concordance with limb wearing, greater sitting comfort and reduced risk of skin breakdown. Osseointegration can be considered following amputation from any cause, although it is associated with an increased risk of bone infection and therefore only amputees with a low risk of infection are suitable for this procedure.[14]

Novel prosthetic components

Osseointegration and implantation of neuromuscular electrodes in conjunction with bionic prostheses for upper limb amputees has been developed.[15] This enables the user to have more precise and reliable control of movement in the prosthetic limb.

Developing these innovations further is the aim of research groups around the world. We are developing new implanted electrodes that can route sensory information from the surface of the prosthesis and channel this to the transected peripheral nerves (www.senseback.com). This will allow more effective use of the limb, which is easier to learn to use and can be incorporated into more functional tasks.

The materials used in prosthetics are also in constant evolution. The latest work involves the use of soft robotics – mechanical devices that eschew traditional hard components in favour of flexible technology that is more accommodating and can move with a large number of degrees of freedom. A number of centres in the UK are progressing this work as part of a major collaboration funded by the Engineering and Physical Sciences Research Council (www.therighttrousers.com).

Amputation is a life-changing event for patients and their families, but when performed well and with the support of the rehabilitation team, it is the first stage of the patient's return to full participation in society. It is a rapidly developing field which necessitates close collaboration between the surgical and rehabilitation teams to ensure the optimum outcome for patients. Fostering these links in each locality will go a long way towards improving services.

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