Review Article

Prosthetic rehabilitation of the upper limb amputee

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ABSTRACT

The loss of all or part of the arm is a catastrophic event for a patient and a significant challenge to rehabilitation professionals and prosthetic engineers. The large, upper extremity amputee population in India has, historically, been poorly served, with most having no access to support or being provided with ineffective prostheses. In recent years, the arrival of organisations like Otto Bock has made high quality service standards and devices accessible to more amputees. This review attempts to provide surgeons and other medical professionals with an overview of the multidisciplinary, multistage rehabilitation process and the solution options available. With worldwide upper extremity prosthesis rejection rates at significant levels, the review also describes some of the factors which influence the outcome. This is particularly relevant in the Indian context where the service can involve high cost investments. It is the responsibility of all contributing professionals to guide vulnerable patients through the process and try to maximise the benefit that can be obtained within the resources available.

KEY WORDS

Amputee; myoelectric; prosthesis; rehabilitation; upper extremity

INTRODUCTION

There is little reliable data on the extent of upper extremity limb loss in India. However, despite significant advances in limb salvage surgery and trauma management it is sufficient to state that there is a high incidence and prevalence.

It is also reasonable to comment that most upper limb amputees have historically been poorly served by rehabilitation service providers in India. The volume, social NGO services offer very limited support and commercial services have lacked expertise and reliable technology. As a consequence most patients have either had no access to a solution or have tolerated a poor outcome, with the limitations to their lifestyle that this imposes. Over the last decade, however, there has been an emergence of improved services and accessibility to international products.

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There is an abundance of literature available on the subject of upper extremity prosthetic rehabilitation and it is not the intention of this paper to reiterate established facts. You are referred to a comprehensive and critical review by Martin [1] for an overview of the available literature.

The objective of this review is to provide the medical and surgical community with sufficient information on the rehabilitation process and outcome possibilities. They can then provide accurate counsel to their patients when faced with this difficult situation.

THE REHABILITATION PROCESS

The complete or partial loss of an arm represents both a significant psychological and physical loss to the patient. Adjusting to and compensating for this loss also poses a physical rehabilitation challenge that must be addressed by the coordinated involvement of various medical and para-medical disciplines. The rehabilitation process can be segmented into four phases.

Presurgical

When the decision to amputate, as opposed to attempt salvage, is taken the perception should not be of 'defeat' or of a 'limb lost'—this does not help the patients future. Rather the consideration should be on the creation of the foundation for a useful, functional prosthetic restoration. This presurgical phase is an important planning phase, which varies in duration according to the cause of the amputation. Where the amputation is a consequence of trauma and surgical priorities lie with the saving of life, only minutes may be available. In elective cases, greater consultation time can be taken. The principal activities in this phase involve the selection of an appropriate amputation site, the surgical technique to be employed, and the immediate medical regime to be followed.

Immediate postoperative

There is a postsurgery period, during which the process of wound-healing, oedema resolution, and the recovery from other injuries or pathologies must occur. The duration of this period varies significantly but in an ideal scenario that is 3–4 weeks, the majority of which is spent as an out-patient. During this phase, the patient can be mobilised, pain management can be undertaken, and counselling provided. This is also an opportunity to begin planning the prosthetic options available to the patient.

Prosthetic rehabilitation

The first challenge is to decide if prosthetic rehabilitation is appropriate for the individual patient and this is not always a simple decision. To make no attempt at rehabilitation may be a valid choice where either functional restoration is prevented, service access is limited, or cosmetic restoration not valued.

It is reasonable, however, to state that in the majority of cases the provision of a prosthesis can make a valued addition to the life of the patient and should at least be attempted. Evidence exists that attempting prosthetic rehabilitation immediately after amputation increases the chances of long-term success, whereas a 'wait and try later' approach makes successful rehabilitation less likely.[2]

Prosthetic device provision and rehabilitation is typically carried out as an out-patient on the premises of a prosthetic service provider. Training in the use of the prosthesis is an often overlooked, but major determinant in outcome success. In the Indian context, it is carried out by the prosthetic service provider, whereas in more developed rehabilitation environments it is supported by specialist physical or occupational therapists.

Continuing care

The patient requires regular and continuous care. Prostheses require maintenance and adjustment to accommodate changes to lifestyle demands or body dimensions. Modern prostheses are modular in construction and allow individual elements to be changed without the need to replace the entire device. However in India, where the patient is the primary purchaser of the prosthesis, it is important to explain the requirement for ongoing costs to maintain the prosthesis.

PROSTHETIC RESTORATION AND REHABILITATION

An upper limb prosthesis should ideally compensate for the loss of fine, coordinated movements of the hand, provide tactile sensation, proprioceptive feedback, and have an esthetic appearance.[3] However, we do not live in an ideal world and inevitably compromises need to be made. Tactile sensation is a challenge for which a solution is yet to emerge and any form of proprioception achieved by a patient is an indirect consequence of their acquired skill in using the prosthetic device. For unilateral amputees, it is recommended that fine, dextrous movements should be undertaken with the remaining contra-lateral limb, even if it is the nondominant arm and actions like writing need to be re-learned. This leaves the gross functional restoration of limb movements and the creation of an adequate cosmetic appearance as the two fundamental challenges faced by prosthetic engineers.

COSMETIC RESTORATION

When designing a prosthetic solution, an individual compromise must be made between the needs for either cosmetic or functional restoration. In general terms, the greater the emphasis on functional restoration the greater the compromise on cosmetic appearance.

Where the priority is on the restoration of appearance, the design emphasis is on creating a simple, lightweight prosthesis. However, primarily cosmetic solutions are not completely without function:

(a) The limb may provide passive or opposing functions, such as stabilising a sheet of paper when writing.
(b) There is psychological benefit to those patients who are either self-conscious or who face societal pressures after amputation that should not be under-valued.
(c) There are postural benefits provided by the restoration of body symmetry, particularly in more proximal amputations. These add to the overall cosmetic benefit and may play a role in preventing associated muscular or skeletal problems emerging over time.
(d) For very young amputees, the early adoption of simple, cosmetic limbs supports bilateral development and increases the likelihood of a successful outcome with functional prostheses in later life.

It is important that the limitations of cosmetic restoration are explained to the patient carefully—a perfect replacement cannot be produced and should not be promised. It is also important to remember that there remains a role for training, even when no function is sought. The overall cosmetic effect is created by a combination of a convincing device, the correct wearing of the prosthesis, and its correct integration into everyday life—which can be assisted by advice on such issues as gait, clothing, and accessories.

Extremely life-like cosmetic replacements can be achieved for distal amputations of the hand or digits, by creating customised silicone prostheses [Figure 1]. Accurate impressions of the patient are taken and colour matching is achieved using digital photography and colour-filtering software. High quality silicone materials and skilled technicians can create extremely life-like replacements that have the added advantages of being highly durable, adherent to the skin, and discrete to wear. Silicone is chemically inert, therefore creating no interface problems even in the harsh Indian climate. Silicone replacement prostheses are cost-effective and can be a very useful complement to restoration surgery in rehabilitation after complex hand trauma.

It is interesting to note that many limbs, initially designed with an emphasis on function, often at great cost, are ultimately worn primarily for cosmetic effect.

FUNCTIONAL RESTORATION

Despite the importance of cosmetic restoration, the principal loss after amputation of the upper extremity is the loss of function and to attempt its restoration is therefore indicated and requested by the majority of patients.

The hand, arm, and shoulder together form a highly sophisticated organ, capable of complex sensory and physical functions. Prosthetic engineering attempts to meet this challenge by isolating a series of achievable functions that together or independently can make a useful contribution to the patients quality of life. A functional prostheses is therefore composed of a number or elements, each offering prescription options to the rehabilitation team.

FUNCTIONAL DEVICES

Individual device components attempt to replace the lost function

Shoulder function is rarely replaced. When prosthetic shoulder joints are provided, they are part of a primarily cosmetic device and function as passive replications of the range of movement of the shoulder. This does provide important benefits to the patient, by way of a more natural gait and can make dressing easier.

The elbow, as a simple hinge joint is straight-forward to

Figure 1: Cosmetic silicone hand

replace mechanically. Prosthetic elbow joints attempt to allow voluntary, controlled elbow flexion, and extension. When a desired elbow position is achieved, it is important that the patient has the ability to lock the elbow, to allow a secure anchor for hand function, and to unlock the elbow when required. Internal and external elbow rotation is passively achieved and controlled by friction devices, adjusted to prevent unwanted movement or interference with other limb functions.

Wrist rotation, allowing hand supination, and pronation can be achieved, either by positioning the wrist with the contralateral hand or more dynamically by using electrical motors. The most advanced prosthetic systems also now allow dynamic, electrically controlled, wrist flexion and extension. Active wrist movement completes hand positioning and allows for much more adaptable hand function to be achieved.

Hand function

The complexity and subtlety of the human hand has long posed a significant challenge for prosthetic replacement.

The simplest reproduction has historically been in the form of a 'split-hook' [Figure 2]. These terminal devices allow a high degree of fine dexterity, are lightweight, durable, and cost effective. However, they are now a relatively rare prescription due to the cosmetic compromise and low social acceptability. Prosthetic hands have been historically limited to single joint movements that allow the replication of one simple grip—the 'three-digit chuck grip'. The hand is able to open and close in a simple but very useful movement.

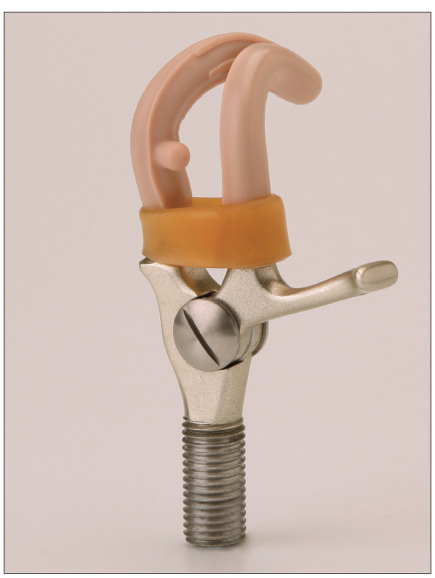

Figure 2: Hook terminal device

The simplest, cable-controlled prosthetic hands are referred to as 'voluntary-opening' hands—the hand is opened voluntarily and closes automatically to grip an object when the opening force is removed. The opening speed and force can be controlled if required but the grip speed and force are pre-set mechanical characteristics.

Advanced, electrically controlled hands can allow both voluntary opening and closing. In the more advanced designs, the hand speed and grip force can also be controlled by the patient, allowing for a more subtle and adaptable range of hand functions to be performed.

It has long been the expectation of patients and the ambition of prosthetic rehabilitation to allow independent, articulated finger movement in prosthetic hands. This is a relatively straightforward mechanical task, the application of which has been prevented by the need for complex drive and control mechanisms. Emerging technologies, however, are now introducing multijoint hands that offer more subtle grip options, including independent digit articulation. The development of these bionic technologies will continue and further advances can be anticipated [Figure 3].

The functions that a prosthesis attempts to dynamically reproduce are therefore relatively simple—elbow flexion/extension with locking and unlocking, wrist rotation, with wrist flexion/extension now emerging and hand opening and closing with adaptable grip options.

Replacing the complex movements of the hand and arm with less than 10 individual functions may seem a poor substitution, until one considers the complexity

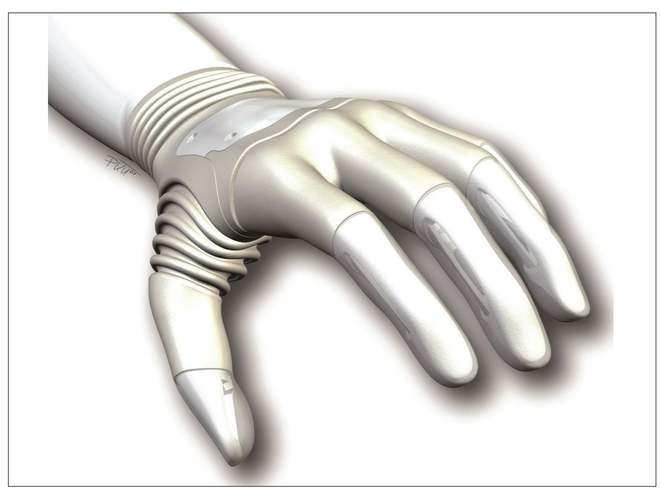

Figure 3: Multi-articulation hand

of providing control systems and drive mechanisms for these functions.

DRIVE MECHANISMS AND CONTROL SYSTEMS

The movements and functions that can potentially be provided by the devices described in the previous section can only create a useful benefit when they can be initiated and controlled in a coordinated manner by the patient.

The simplest method is to use the unaffected limb to passively control the function required. This is occasionally used for simple voluntary opening of mechanical hands or for the wrist and elbow function. However, the objective is a return to a bilateral life and there are two principal control options that allow the contralateral limb to remain uninvolved.

BODY-POWERED AND CABLE CONTROL

The most commonly applied control system is to use forces generated by more proximal joints to create linear movements in a cable system. This can be designed to operate functional devices in the prosthetic arm. Historically, hand and elbow functions have been achieved using cable control mechanisms.

For distal amputations, elbow flexion and extension can be used to open the prosthetic hand. Where the amputation is proximal to the elbow, combinations of shoulder movement and bi-scapular abduction are used to create linear movement for hand opening and elbow function.

This type of control is still widely prescribed by virtue of its mechanical simplicity and therefore low cost. However, the achievement of useful function requires practice and skilled application and there are significant limitations to the range of movement that can be achieved. In addition, the patient has the inconvenience of a harnessing and cable system that can be uncomfortable to wear, limits clothing options and significantly compromises the cosmetic appearance of the limb [Figure 4].

ELECTRICALLY CONTROLLED

Electrically powered and controlled prostheses have been a viable prescription option since the 1970s. Until recently, they have offered the wearer the same functions as body-powered devices—but with much more adaptable and flexible control options.

Electric prostheses use small, lightweight motors in the hand, wrist, or elbow to drive the required functions. The power is provided by small, rechargeable batteries that are housed in the structure of the prosthesis. The motors and battery power replace the cables and body movements of more traditional prostheses [Figure 5].

The most frequently used form of electrical control is to capture small electrical potentials created when muscles contract. These are referred to as myoelectrically controlled prostheses.

Muscles that are intact after the amputation surgery are used to control limb functions. Typically, the extrinsic finger flexors and extensors of the forearm are used to

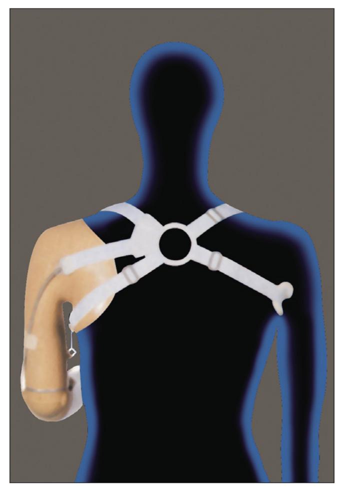

Figure 4: Operating harness

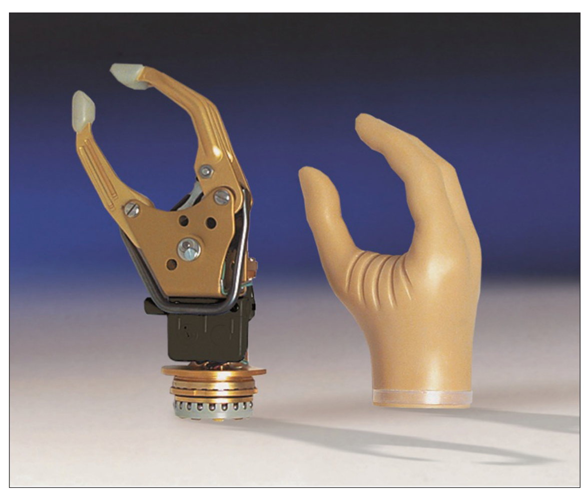

Figure 5: Myoelectric hand

control hand opening and closing in distal amputations and the bicep and tricep are used for more proximal amputations. Surface electrodes are carefully positioned within the prosthesis structure in such a way that when the limb is worn these electrodes lie on the respective muscle bellies and can detect electrical activity within them. The electrodes amplify, filter, and process the electrical signal—which is then passed to microprocessors within the prosthesis where they act as switching signals to deliver power from the batteries to the functional device.

Appropriate training and careful signal processing can allow a patient to generate a variety of myoelectric signals that can be used to control multiple functions. Control can be sufficiently subtle to allow a hand response proportional to the strength of the muscle contraction used to generate it—a small contraction can result in slow hand closing or a light grip and *vice versa*—extremely useful function to a patient wishing to hold fragile objects or to apply a strong grip in other situations.

There are a number of scenarios in which myoelectric signals may not be available or usable—very proximal amputations, heavy scarring, grafting, or patient comprehension problems. In these cases, it is still possible to use electrically powered prostheses but with alternative switching mechanisms employed. These include push switches that can be activated by movements of the residual limb, pull switches that capture longitudinal movement in harness systems and rocker switches.

It is very common for electrically powered prostheses to be controlled by a hybrid system. Hand function may be controlled myoelectrically, elbow flexion mechanically, and elbow locking by an electrical pull switch.

It is variously reported[3] and this author experiences that electrically powered prostheses, when correctly fitted, can provide important and accessible function to the amputee.

With developments in multijoint hands and sophisticated levels of function, the current constraint is in the ability to control these emerging functions and to allow their simultaneous and harmonious use. Recent work on increasing available control options has focused on a surgical technique called targeted muscle reinnervation (TMR).[4] The objective is to separate the major arm nerves from the proximal arm plexus and to transfer them to the residual nerve branches of remaining muscles in the environment of the stump. This creates meaningful neuromuscular units that can serve as impulse generators for the myoelectrical prosthesis. The signals are being integrated by a complex software programme that can then govern an artificial limb with several degrees of freedom. These signals provide the basis for an intuitive motor control so that the patient can perform complex movements with the artificial limb in a natural way.

SUSPENSION

For the prosthesis to function correctly and to achieve its cosmetic objectives, it needs to be securely suspended on the patient. This is traditionally done with a simple harnessing system, which may also provide anchor points for a complimentary control system. Harness systems are, however, intrusive to wear and the objective is to minimise harnessing while maximising suspension and control.

For proximal amputations, using cosmetic or electrical prostheses, it is possible to design the prosthesis so that the natural shape of the residual limb is employed to secure the limb—for instance the shape or flexion angle of the elbow. For higher amputations, it is increasingly common to use adherent interface materials such as silicone, with an integrated locking mechanism, to provide very secure and discrete suspension without the need for intrusive harnessing.

The functional and cosmetic options available to the rehabilitation team are numerous, but it should be remembered that they are rarely employed in isolation. Most prostheses are in fact hybrids of different control and cosmetic elements. In addition patients are often best served by using more than one type of limb[5], according to specific circumstances—for instance, the regular use of a purely cosmetic limb, complemented by a separate functional prosthesis for occasional specific tasks.

OUTCOME DETERMINANTS

When attempting the rehabilitation of a lower limb amputee, a good functional prognosis can be predicted with a high degree of confidence—assuming that the complementary requirements of good medical devices, appropriately trained professionals and contemporary application techniques are employed. When attempting to compensate for upper extremity loss, a more cautious prognosis is called for and many studies have indicated a low success rate. This rate of rejection has been reported variously at high rates,[6] ranging from 23% to 26% for adults and significantly higher (35–45%) for children. The factors that contribute to this relatively low level of success have been variously investigated.[2] It is clear that when attempting the prosthetic rehabilitation of an upper limb amputee and before a prescription is finalised, a careful consideration must be made of the individual factors that may influence the outcome.

There are many factors identified that determine the likelihood of a successful outcome.[2] These can be classified into personal factors (age, amputation level, hand dominance, amputation cause, and time since amputation). The amputation level is an important determinant of the outcome. The more proximal the amputation the greater the challenge of providing functional restoration and the higher the level of dissatisfaction with the functional outcome.[3] Conversely it is equally difficult to provide functional outcomes for amputations more distal than the transcarpal level. There is less agreement on whether the loss of the dominant hand increases or decreases the likelihood of a successful outcome.[2]

Social factors also need to be considered, particularly in India (education level and type of employment). Access to good rehabilitation services and the quality and type of prosthesis employed are also determinants. Interestingly for the commercial Indian environment, the attitude to the cost of the prosthesis also can affect the outcome. It is important to recognise these determining factors. Research shows that when more than one negative factor is present, there is a good chance that the outcome will be compromised and this should be carefully considered when making prescription recommendations.

SUMMARY

The loss of an upper limb results in a sudden and major restriction in function, sensation, and appearance.[2] This event and our attempts to compensate can lead to high levels of frustration among upper extremity amputees. It is clear that if the outcome of prosthetic rehabilitation is poor and we impose a device that has limited use and is inconvenient to wear, this level of frustration will increase and the prosthesis is likely to be rejected. Patients should not be encouraged to see their prosthesis as a 'like for like' replacement of the lost limb. Rather if should be considered a tool that performs useful functions in certain circumstances.

This author also experiences that outcome dissatisfaction is often the result of poor initial communication and unrealistic outcome goals being promised. In the current rehabilitation environment in India, upper limb patients must use private commercial services that often incur very significant costs. Sadly the clinical judgment of these services can be distorted by a 'sales' mentality and often ignore negative outcome indicators for short-term commercial gain. It is strongly recommended that the reputation and experience of prosthetic service providers is thoroughly researched by both the prescriber and the patient. As practising professionals in this field we owe it to our patients to offer accurate information on outcome possibilities, insist on the highest service and device standards, and continue to support patients in the long-term.

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