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Special Issue

# Upper extremity limb loss: Functional restoration from prosthesis and targeted reinnervation to transplantation

Brian T. Carlsen MD[a,b,*], Pat Prigge CP, FAAOP[c], Jennifer Peterson MA, PT[c]

[a] Mayo Clinic, Division of Hand Surgery, Rochester, MN, USA
[b] Mayo Clinic, Division of Plastic Surgery, Rochester, MN, USA
[c] Advanced Arm Dynamics, North Central Center of Excellence, Maple Grove, MN, USA

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ABSTRACT

For several decades, prosthetic use was the only option to restore function after upper extremity amputation. Recent years have seen advances in the field of prosthetics. Such advances include prosthetic design and function, activity-specific devices, improved aesthetics, and adjunctive surgical procedures to improve both form and function. Targeted reinnervation is one exciting advance that allows for more facile and more intuitive function with prosthetics following proximal amputation. Another remarkable advance that holds great promise in nearly all fields of medicine is the transplantation of composite tissue, such as hand and face transplantation. Hand transplantation holds promise as the ultimate restorative procedure that can provide form, function, and sensation. However, this procedure still comes with a substantial cost in terms of the rehabilitation and toxic immunosuppression and should be limited to carefully selected patients who have failed prosthetic reconstruction. Hand transplantation and prosthetic reconstruction should not be viewed as competing options. Rather, they are two treatment options with different risk/benefit profiles and different indications and, hence vastly different implications.



## Background

In the United States today, there are estimated 500,000 people with minor hand amputations and 41,000 people living with major upper extremity limb loss.[1] Upper extremity amputation results in devastating loss of form and function. Historically, the standard restorative treatment for these individuals has been with prosthetic devices. From the time since World War II, until recent, there was little progress in prosthetic design and implementation. The basic design for most patients with upper extremity amputation was a body-powered device utilizing shoulder motion with cables and pulleys for control. Studies conducted on prosthetic use by upper extremity amputees, demonstrate unacceptably high rejection rates with many patients electing to go without any functional restoration.[2–6] Understanding the issues leading to prosthetic abandonment is critical so that they can be directly addressed.

Upper extremity surgeons have been trained for years how to execute the technical aspects of amputation at any given level. However, there has been a lack of education among surgeons in regards to restoring function after amputation. A likely explanation is that there has been little role for the surgeon once the amputation is healed and the soft tissues are mature. However, recent advances have drawn much needed attention to this previously neglected patient population. Targeted reinnervation and hand transplantation are two innovative operations directed at restoring upper extremity function after amputation. Targeted reinnervation (TR) has enabled improved prosthetic control for individuals with proximal amputation and even the hope for "sensation" in the amputated part. In addition, recent advances in prosthetic design have greatly improved both form and function of the devices. During this same time period, hand transplantation has become a clinical reality. With 15 years of clinical experience, we now have an improved sense of the cost, risks, and benefits of this procedure. The purpose of this manuscript is to review upper extremity limb loss today, the challenges of restoring form and function to these individuals, while highlighting the exciting developments in the field, in particular, hand transplantation and targeted reinnervation.

## Historical perspective on prosthesis utilization

Numerous studies have examined the use of prosthetic devices in upper extremity amputees.[3,5–14] The research is difficult to

* Corresponding author. Division of Plastic Surgery, Mayo Clinic, 200 First Street S.W., Rochester, MN 55905, USA. Tel.: +1 507 538 1701.
*E-mail address:* carlsen.brian@mayo.edu (B.T. Carlsen).

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compare since each study's definition of prosthetic success varies, inclusion criteria are not the same for each study, a range of outcome measures are used, and the sample sizes are often small. The results of the studies are also difficult to extrapolate to new upper limb prosthetic technology as outcome measures have not yet been created or validated to fully assess an individual's functional outcome with use of the new upper limb prosthetic technology. Despite these limitations, the published results suggest that upper limb prosthetic abandonment is real, and the issues leading to abandonment need to be addressed.[2–7] These issues include lack of patient involvement in device selection, poor fit, pain while wearing the device, lack of functionality, lack of education on options regarding prosthetic technology, lack of education on available funding sources, unrealistic patient expectations, opportunity to use only one type of prosthetic device, lack of upper limb prosthetic rehabilitation knowledge and experience of the health care provider, and lack of prosthetic training. Other major factors involved in whether an individual rejects or wears the prosthesis are age of fitting a congenital upper limb deficiency and time post-injury to the fitting of an amputee. If the health care team addresses all of these issues, the chance for successful use and acceptance of an upper limb prosthetic is greatly improved.

Patients who are involved in choosing the prosthetic device(s) that best meets their needs are more likely to become successful users.[3] To improve the success rate of upper limb prosthetic use and manage the patient's expectations, the patient needs education on the six basic prosthetic options[15] and on available funding sources. It is also important to help the patient understand that a prosthetic device cannot replace a natural hand but instead is used as a tool to assist with functional tasks. In addition, several prosthetic devices may be needed to meet the patient's daily needs. For example, while a myoelectric prosthesis (Fig. 1) may be helpful for basic daily activities; the sensitive electronic components within the prosthesis cannot tolerate high forces for an activity such as golf. An activity specific prosthesis made of durable materials and with a specialized terminal end to hold a golf club would be a more appropriate prosthetic device (Fig. 2). The choice of which prosthesis to use relies heavily on the types of activities the patient needs and wants to participate in and what the patient's functional goals are. No matter the goal, no single device will be able to accomplish all desired functional tasks. When a patient has many activities that they wish to engage in, it may be necessary to provide multiple devices to achieve their functional goals.[8] A dogmatic approach to prosthetic fitting is no longer appropriate. In the past, if a patient rejected a body-powered device, it was assumed that they would not be a candidate for a myoelectric prosthesis. Rather, the reasons for rejection of the device should be explored and directly addressed. In our experience, these issues can be addressed and remedied.

A comfortable device is essential for use. Any problems leading to discomfort must be addressed. Socket interfaces and appropriate materials need to be chosen and should maximize comfort.[15–18] Whenever possible, skin friendly, soft and flexible materials should be used and sockets designed to maximize ROM and comfort. This enhances wear time and begins to address the need for more comfortable socket systems.

Prosthetic training affects an individual's function (Lake 1997, Resnik 2012). Training with a therapist knowledgeable in upper limb prosthetic components and control is a significant portion of prosthetic rehabilitation that leads to functional success of the upper limb amputee. Prosthetic training occurs during various stages. The stages, which may overlap, are the healing stage, pre-prosthetic stage, basic prosthetic stage and advanced prosthetic stage.[19] Prosthetic training enhances knowledge of the components, ensures a proper wear schedule, illuminates the control details, assists with functional integration of the prosthesis into activities of daily living and provides feedback to the prosthetist about possible design changes that would enhance function. During upper limb prosthetic therapy treatment, there is a constant emphasis on proper posture and proper body mechanics to help prevent compensatory body movements that may lead to acute and chronic musculoskeletal injuries.


**Fig. 1.** Activity of daily living with myoelectric hand prosthetic.

Fitting a patient with congenital upper limb absence within 11 months of age leads to greater acceptance than patients fitted at an older age.[3] Similarly, individuals that rejected prosthetics were fit 6 months after injury while those that accepted prosthetic use were fit within 3 months of injury.[3] Thus it is important to the success of an upper limb prosthetic fitting to fit an individual at a young age or soon after an amputation.


**Fig. 2.** Activity specific prosthetic for use after transradial amputation.