

Upper Extremity Prosthesis – What Is New in It?

S. Abdul Gafoor¹, Mohan Raj M²

Abstract

Over the past 40 years, technology has dramatically affected the field of upper limb prosthesis. With improvement in the electronics industry, along with advances in the miniaturisation and mass production of electronic components, myoelectrically controlled prosthesis has become reliable and widespread in their use. Compared to lower extremity amputees, the acceptance of prosthetic replacement is less in upper extremity amputees. This may be due to different factors like functional needs, cosmetic factors, motivation of the patient, inadequate training following conventional prosthetic fitment, etc. More and more developments are going on in upper limb extremity prosthesis which will fulfill the need of the upper limb amputees. Such developments ensure better rehabilitation though cost is a limiting factor. This article is an earnest attempt to review the recent trends in upper limb prosthetics.

Key words: Upper limb amputees, myoelectric prosthesis.

Introduction:

The human hand is a very sophisticated and beautiful tool. It provides plenty of information and means by which one interact with environment. The hand is also a powerful tool of communication. The hand can be used to augment the meaning and feeling behind the spoken word, or it can sometimes take the place of the word. Hence the loss of hand results, not only in functional ability of that individual, but also ends in profound psychological trauma and apprehension.

The ideal prosthesis has to replace the lost body parts, both in appearance and function. The sensibility, power and grace of the lost body parts should be replaced. Though the idea appears simple, it is very difficult to accomplish. Present technology is far from ideal.

The search for ideal upper extremity prosthesis is continuing. The conventional prosthesis is functionally inferior, cosmetically unacceptable to any individual,

who lost their hand, as it is heavy and do not provide any information regarding the texture, shape, temperature and proprioception. However each has advantages within their intended use. eg, body powered hooks are well suited to the demands of manual labour. They are simple and tough in design. Prosthetic hand obviously provides a more natural appearance than hooks and can provide adequate function. Electric hand provides the user with a wide range of gripping force, all with minimal effort by user.

Clinically the most physiologically natural method of controlling an electric hand is through myoelectric control. Myoelectric control is also a dynamically natural appearing system because the act of controlling the prosthesis is invisible in contrast to other control methods that require body motion of more proximal body segments.

History:

The concept of using myoelectric signals to control prosthesis dates back to the 1940's. Reinhold Reiter, a physics student at Munich University created the first known myoelectric prosthesis between 1944 and 1948¹. This prosthesis was mounted on a bench top, had vacuum tubes in the electronic system and used one muscle for opening and closing the hand (single site control) (Fig1).

Myoelectric systems are commercially available during 1960's. Kobrinski, a Russian became the first person to make a myoelectric hand, which found place in clinical use². This prosthesis was made fully portable by the

Authors' affiliation:

¹ MBBS, D.P.M.R, M.D, Professor

² MBBS, D.P.M.R, M.D, Associate Professor

Department of PM&R, Govt. Medical College, Kozhikode

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Correspondence:

Dr. S. Abdul Gafoor, Professor, Department of PM&R, Govt. Medical College, Thiruvananthapuram, Email: drsagafoor@gmail.com.

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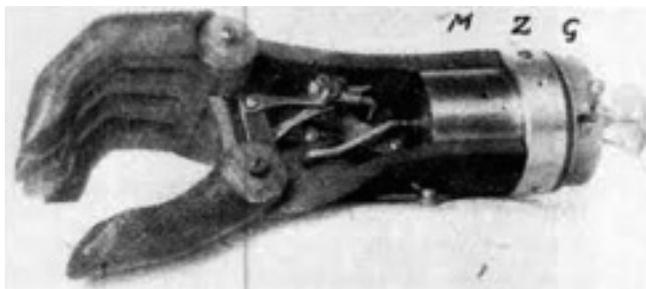


Fig 1: Reiter's First Myoelectric Prosthesis

use of transistors, the batteries and electronics, was separately and connected to the prosthesis by cables. During 1957-1960 collaboration between Otto Bock, a German company and an Austrian hearing aid company Viennatone led to the first transradial myoelectric system. Then the developments were rapid. Today myoelectric hands are available in different sizes for both children and adult. Electric elbows and wrist rotators are also available in a variety of sizes. With improvement in the battery technology, myoelectric prosthesis has become lighter. The need for recharge is also less.

Myoelectric Control – Principles:

During every voluntary contraction of a muscle, a small electric signal is generated as a natural byproduct. Myoelectric control (Fig 2) uses the action potentials of the residual muscles to control electrically powered components. Electrodes are generally placed in the prosthetic interface over the belly of the muscle and are oriented along the muscle long axis. It is remembered that the signals produced in residual stump is in microvolt. These signal are amplified, then processed by a controller that switches the motors on or off in the hand, wrist, or elbow to produce movement and function³. The myoelectric control may be of two types: a) Dual site control b) single site control.

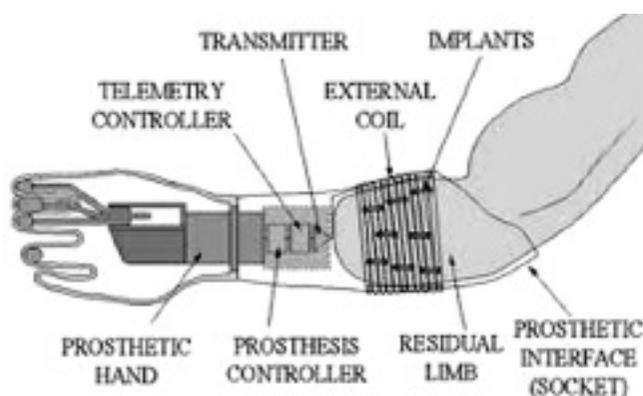


Fig 2- Implantable Myoelectric Sensors

In dual site control, two antagonist muscles of the residual stump are used to generate the current for the working of the prosthesis. eg, in below elbow amputee both flexor and extensor group of muscles are used for closing and opening of the prosthesis. In single site control, one group of muscle is used to control two functions. In this type, one type of muscle contraction selects hand closing and another type of contraction select hand opening. Two commonly used types of single site systems are the rate sensitive and amplitude sensitive controls. When the rate or amplitude is slow or small the controller selects hand closing and when the signal is fast or strong hand opening results.

In general, there are two types of control schemes that can be described sequential and dedicated. Sequential control means that two or more components are controlled from a common source. An example of this type is the conventional body powered transhumeral fitting, where the elbow and terminal are controlled by the same body motion like glenohumeral flexion or bicepular abduction. In this system, the elbow has to be locked to operate terminal device. Hence simultaneous control is not possible. Examples of sequential control in myoelectric systems are use of two antagonistic muscles for hand operated and wrist rotation or hand and elbow operation. This requires switching between the two components either through myoelectric switching such as rapid co-contraction or operation through a switch. Here also simultaneous control is not possible as in conventional body powered prosthesis⁴.

Dedicated control refers to a system where each component is controlled by a dedicated control source; allowing simultaneous control. Example is hybrid transhumeral prosthesis, where hand function is accomplished myoelectrically using two antagonist muscle and a body powered elbow is operated by glenohumeral flexion. Here the two components are controlled independently and simultaneously. Hence the system is more efficient than the sequentially controlled system.

Microprocessors:

The feasibility of using computer chips in prosthesis has led to advanced feature of prosthetic design. eg. the sensor hand manufactured by Otto Bock, which monitors the slippage of an object, which being held in the electric hand. If the objects begin to slip, the microprocessor tells the hand to increase the grip force. This type of automatic control makes the myoelectric hand (Fig 3) easier to operate and move.



Fig 3 - Myoelectric Hand

Programmable Controllers:

Advance in microprocessor technology, led to the introduction of programmable control systems in prosthesis. These microprocessors are available with on board field programmable chips. There are dozens of control schemes that can be configured using a programmable controller⁵. Automatic calibration for each activity can be programmed in this system. This feature automatically adjusts the electronic parameter to provide optional function in spite of possible signal strength changes, which occurs in an amputee, who experiences muscle fatigue during the course of the day.

Myoelectric control of upper limb prosthesis has proven to be an effective and efficient means of controlling prosthetic components. This means of control has been extensively used for the last 40 years, during which time the system had become reliable and durable in most situations. Myoelectric control or any other control scheme should not be considered as optional control for the prosthesis but rather as one of the several effective ways of producing desired function. Technology continues to change, bringing new and sometimes better ways of fitting prosthesis. Microprocessor and programmable controllers have opened new horizon for improvement in function of the upper limb prosthesis. There is much work to be done before calling upper extremity prosthesis, as arm replacement, which is ideal for an individual. But progress is occurring towards the goal of replacing the function and appearance of the human arm by an ideal prosthesis replacement.

Indications⁶:

1. The patient has an amputation or missing limb at the wrist or above.
2. Standard body-powered prosthetic devices cannot be used or are insufficient to meet the functional needs of the individual in performing activities of daily living.
3. The remaining musculature of the arm(s) contains the minimum microvolt threshold to allow operation of a myoelectric prosthetic device.
4. The patient has demonstrated sufficient neurological and cognitive function to operate the prosthesis effectively.
5. The patient is free of comorbidities that could interfere with function of the prosthesis (neuromuscular disease, etc).
6. Functional evaluation indicates that with training, use of a myoelectric prosthesis likely to meet the functional needs of the individual (e.g. gripping, releasing, holding and coordinating movement of the prosthesis) when performing activities of daily living.

Advantages⁷:

1. Self contoured.
2. Self suspending.
3. Freedom of motion-can be used over the head, down by the feet, and out to the sides of the body.
4. Comfort.
5. Elimination of harness of conventional prosthesis
6. Superior pinch force of between 15 and 25 lbs. compared to 7 to 8 lbs with a cable-operated hook.
7. Using functional magnetic resonance imaging (fMRI), it is found that enhanced use of a myoelectric prosthesis in upper extremity amputees was associated with reduced phantom limb pain and reduced cortical reorganisation.
8. The below-elbow myoelectric system is well suited for amputees such as sales persons, students, business people and professionals who are engaged in light work.

Disadvantages⁷:

1. High cost.
2. Lack of direct feedback from control regarding

the position, velocity and force of the component controlled.

3. The user must rely on visual feedback for manipulation of prosthesis and environment.
4. Requires more maintenance, including charging, discharging, and the eventual disposal and replacement of the battery.
5. Burns may be seen in children after 2-3 years of use of prosthesis. This may be due to heat generated from electrical failure possibly from ingress of moisture.
6. Potential malfunction of the arm, resulting in costly repairs. Wearers also have to be very cautious around water. Severe damage to the motor and controller can result from water exposure.

The myoelectric unit is not usually recommended for patients involved in heavy work such as farming or construction.

Evaluation:

An evaluation of a rating scale called the Assessment of Capacity for Myoelectric Control (ACMC) was described by Lindner and colleagues in 2009⁸. For this evaluation of the ACMC, a rater identified 30 types of hand movements in patients who performed a self-chosen bimanual task, such as preparation of a meal, making the bed, doing crafts, or playing with different toys; each of the 30 types of movements was rated on a 4-point scale (not capable or not performed, sometimes capable, capable on request, and spontaneously capable). The types of hand movements were variations of four main functional categories (gripping, releasing, holding, and coordinating), and the evaluations took approximately 30 minutes.

Advances:

Targeted reinnervation is a surgical technique developed to increase the number of myoelectric input sites available to control upperlimb prosthesis (Fig 4). Because signals from the nerves related to specific movements are used to control those missing degrees-of-freedom, the control of a prosthesis using this procedure is more physiologically appropriate when compared to conventional control⁹.

In humeral disarticulations, a novel nerve transfer procedure can be done to improve the control of a myoelectric prosthesis. The median, radial, ulnar

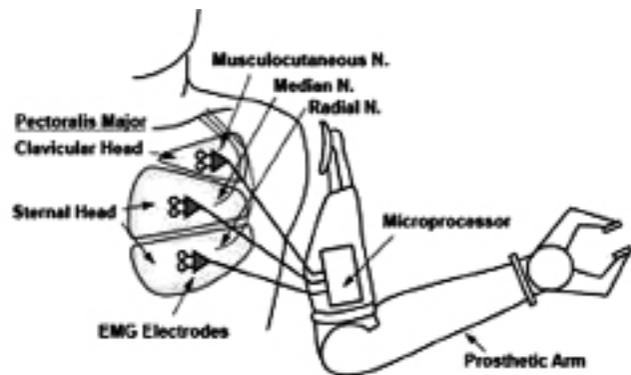


Fig 4 - Targeted Muscle Reinnervation in Person with Shoulder Disarticulation

and musculocutaneous nerves are transferred to the segments of the pectoralis major and minor muscles. The nerve transfer to small muscle segments is capable of creating a novel interface for better control of myoelectric prosthesis.

There is great mental effort needed during the initial stages of training with myoelectric prosthesis. A mechanism has been developed to help patients during the learning stages, without actually having to wear the prosthesis¹⁰. This mechanism is based on a real hardware and software for detecting and processing EMG signals. The association of autoregressive models and a neural network is used for EMG pattern discrimination. The outputs of the neural network are then used to control the movements of a virtual prosthesis that mimics what the real limb should be doing. The results show a very easy-to-use system that can greatly reduce the duration of the training stages.

The Utah Arm (Fig 5&6) is a myoelectric arm for above elbow amputees. It is developed in 1974, at the University of Utah's Center for Engineering Design. The Utah Arm 3 is a versatile, electrically driven arm which provides accurate control of both hand and elbow (simultaneously), and optional wrist rotation.

The Utah Arm 3+ is similar to the original electrically driven Utah Arm 3 but has more advanced function. This arm has Dual Lock System, Silent Freeswing, wireless Bluetooth communication, and total compatibility with virtually all Hands on the market.

Current research findings indicate that people could actually regain perception of hot and cold through prosthetics like the myoelectric arm. Bionic hands differ from mere prostheses by mimicking the original function very closely, or even surpassing it. Dennis



Fig 5- Utah Arm 3 with Connector Options for Separate Elbow and Hand Inputs



Fig 6- Utah Arm 3 +

Aabo Sørensen was the first person to use bionic finger tip that has the ability to feel. There are electrodes embedded in arm, and touch sensors in a prosthetic hand to stimulate his remaining nerves. With the hand, the user was able to recognise different objects by their feel, and grasp them appropriately (Fig7). Sensors in the silicon finger tip detect changes in the texture of articles and these signals are sent to the remaining nerves of the arm¹¹. So now the user knows how firmly they have to grip a fragile object without damage, which is very important.

Now there are advanced myoelectric prosthetic partial hand fingers for individuals with missing fingers eg, i- digits quantum. This gesture controlled prosthesis is very slim, light weight and so it is easy to use. It also has 50% more battery life. Loss of anywhere from one to five digits and palm can be replaced (Fig 8).

With these technological advances on the horizon, the quality of life for amputees is bound to improve.

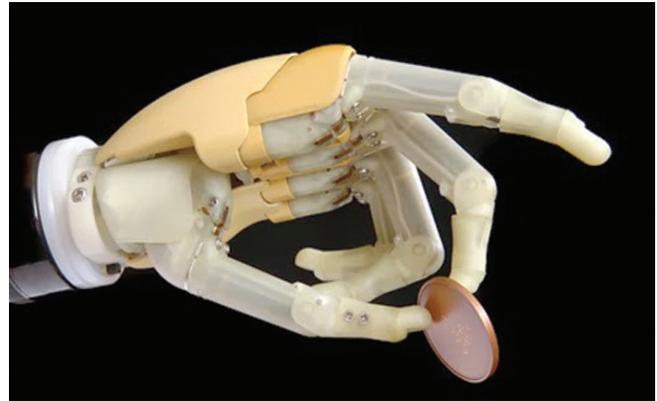


Fig 7- Myoelectric Prosthetic Hand with Touch-sensitive Fingers



Fig 8- Myoelectric Prosthetic Partial Hand Fingers

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