Prosthetics-Upper Limb

Postgraduate course:

Biomedical Engineering

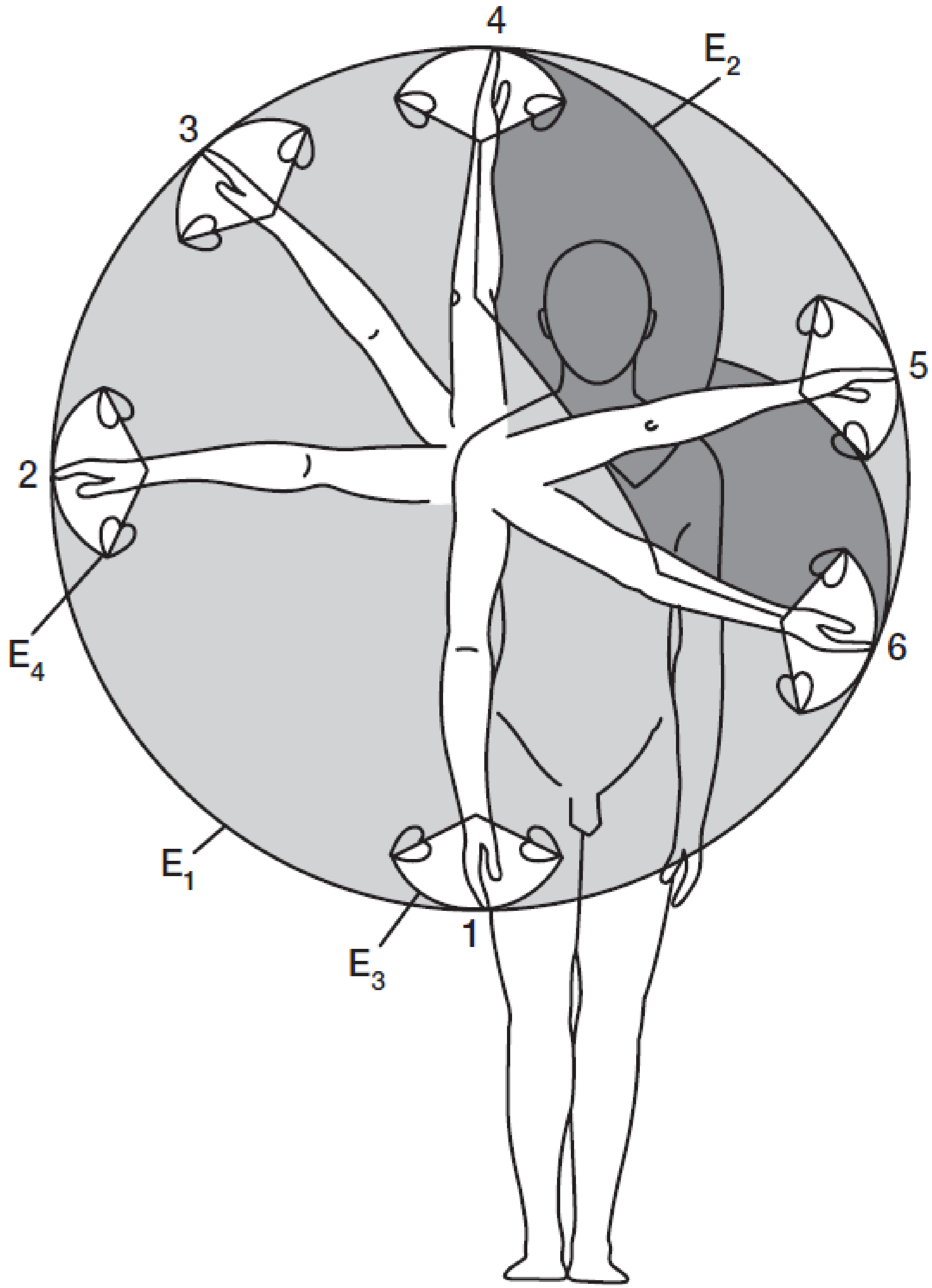
by

Despina Deligianni

Reasons for an Upper Limb Amputations:

THIS IS MOSTLY CORRELATED BY AGE.

- (0-15 years) CONGENITAL DEFORMITY OR TUMOR
- (15-45 years) TRAUMA
- (>60years) SECONDARY TO TUMOR OR MEDICAL DISEASE


4
E2
3
5
2
E4
6
E1
1
E3

Levels of upper extremity amputations:

- Forequarter
- Shoulder Disarticulation
- Transhumeral (AE)
- Elbow Disarticulation
- Transradial (BE)
- Wrist Disarticulation
- Partial Hand
- Fingers

Characteristics of a successful prosthesis

- Comfortable to wear
- Easy to put on and remove
- Light-weight
- Durable
- Cosmetically pleasing
- Must function well mechanically
- Require only reasonable maintainance

Prosthetic options

- No Prosthesis
- Cosmetic Restoration
- Body-Powered Prosthesis
- Electrically-Powered Prosthesis
- Hybrid Prosthesis
- Activity Specific Prosthesis

TYPES OF PROSTHESIS

- COSMETIC
- FUNCTIONAL

Mostly passive or cosmetic types on one end to primarily functional types on the other. The purpose of most prosthesis falls somewhere in between.

Cosmetic prosthesis look extremely natural but they often are more difficult to clean, can be expensive and usually sacrifice some function for increased cosmetic appearance.

Upper limb prostheses - Options

No Prosthesis

~ 75%

Cosmetic Restoration

Materials
• flexible latex (gloves)
• rigid PVC
• silicone

Multilayer structure

The material has a multilayer structure. Colored fibers inside imitate the natural vein structure of the human hand.

Advantages	Disadvantages
Lightweight	Difficult to perform activities that require bilateral grasping
Minimal harnessing	
Low maintenance	
No control cables	

Materials	Advantages	Disadvantages
Latex covering	Lightweight Inexpensive	Easily stains Often replacement
Rigid PVC	For short residual, heavy	Does not retain color if scratched
Silicone	More realistic and long lasting restoration Does not stain Longevity 3-5 years	Heavier than latex More expensive Can be used with certain types of prosthetic hands

J Rehabil Res Dev. 2013 Aug;50(5):723-32.

Comparison of mechanical properties of silicone and PVC (polyvinylchloride) cosmetic gloves for articulating hand prostheses

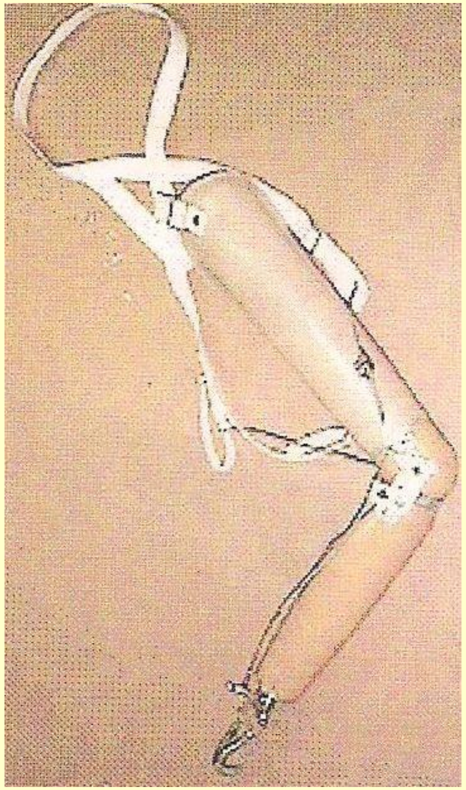
Gerwin Smit, MSc;* Dick H. Plettenburg, MSc, PhD
Department of Biomechanical Engineering, Delft Institute of Prosthetics and Orthotics, Delft University of Technology, Delft, the Netherlands

The **silicone gloves** required **less work** and dissipated **less energy** during flexing. They also had a **lower joint stiffness** and required a **lower maximum joint torque**. Based on energy requirements, joint stiffness, and required joint torque, the tested silicone glove is ***most suitable for application on an articulating hand prosthesis***.

Body-Powered Prosthesis

Basic requirements

- sufficient residual limb length
- sufficient musculature
- sufficient range of motion



	Advantages	Disadvantages
Body powered prosthesis	Ability for proprioception Used for tasks in water and dust Reduced maintenance cost	Uncomfortable Restricted range of motion Functional envelope
Types of control	Voluntary opening Voluntary closing	Grip force <3 kg even relaxed >25 kg, not allowing relaxation

BODY-POWERED PROSTHESIS:

ADVANTAGES	DISADVANTAGES
Moderate Cost	Most Body Movements needed to operate
Moderately Light Weight	Most Harnessing
Most Durable	Least Satisfactory appearance
Highest Sensory Feedback	Increased Energy Expenditure
Variety of Prehensors available	

Electrically-Powered Prosthesis

With small electrical motors to provide control – rechargeable battery system

Types of control of movement

• myoelectric control
• switch control (button press, harness)

Externally or electrically powered prostheses

Advantages	Disadvantages
Higher grip force (10-16 kg to 3-4 kg)	Heavy
Improved cosmetic appearance	No sensory feedback
Freedom from harnesses	Easier damage
Improved functional range	Last for 2-3 years
Improve function for high level amputees	Cost+maintenance

Hybrid Prosthesis

Combination
- body-powered elbow
- myoelectrically controlled terminal device

Activity Specific Prosthesis

Design exclusively for a specific activity

Suspension systems

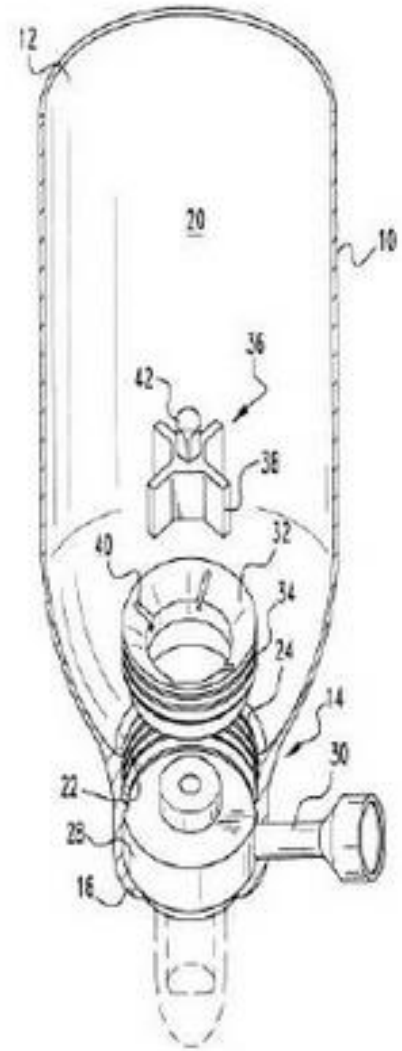
Function
- Suspension – securing prosthesis to residual limb
- Control of prosthesis

Types
- Harness
- Self-suspended
- Suction sockets

1. SOCKET:

It has a Dual-wall design

- Rigid inner socket to fit patient's residual limb
- Outer wall designed to be of same length and
  contour as that of opposite limb.



- The amputee's socket interface plays a major role in defining the comfort level of the user.
- The stump loses volume on a daily basis
- The amputees may need to change the socket in response to changes in body weight or alterations to the structure of the residual limb

The method by which the socket is attached to the residual limb is extremely important: an air splint system within the amputee's socket that can allow to make adjustments that improve the comfort level, size and fit of the socket.

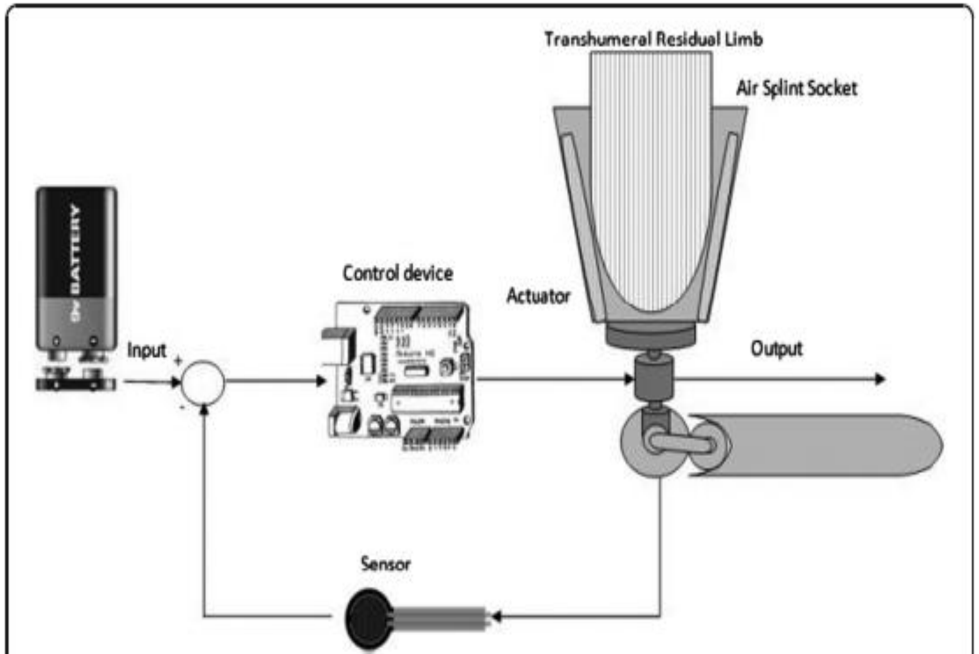


Figure 4 Block diagram of the air splint socket system; FSR pressure sensor used as an input, oscillometric pump used as an output, controlled by microcontroller.

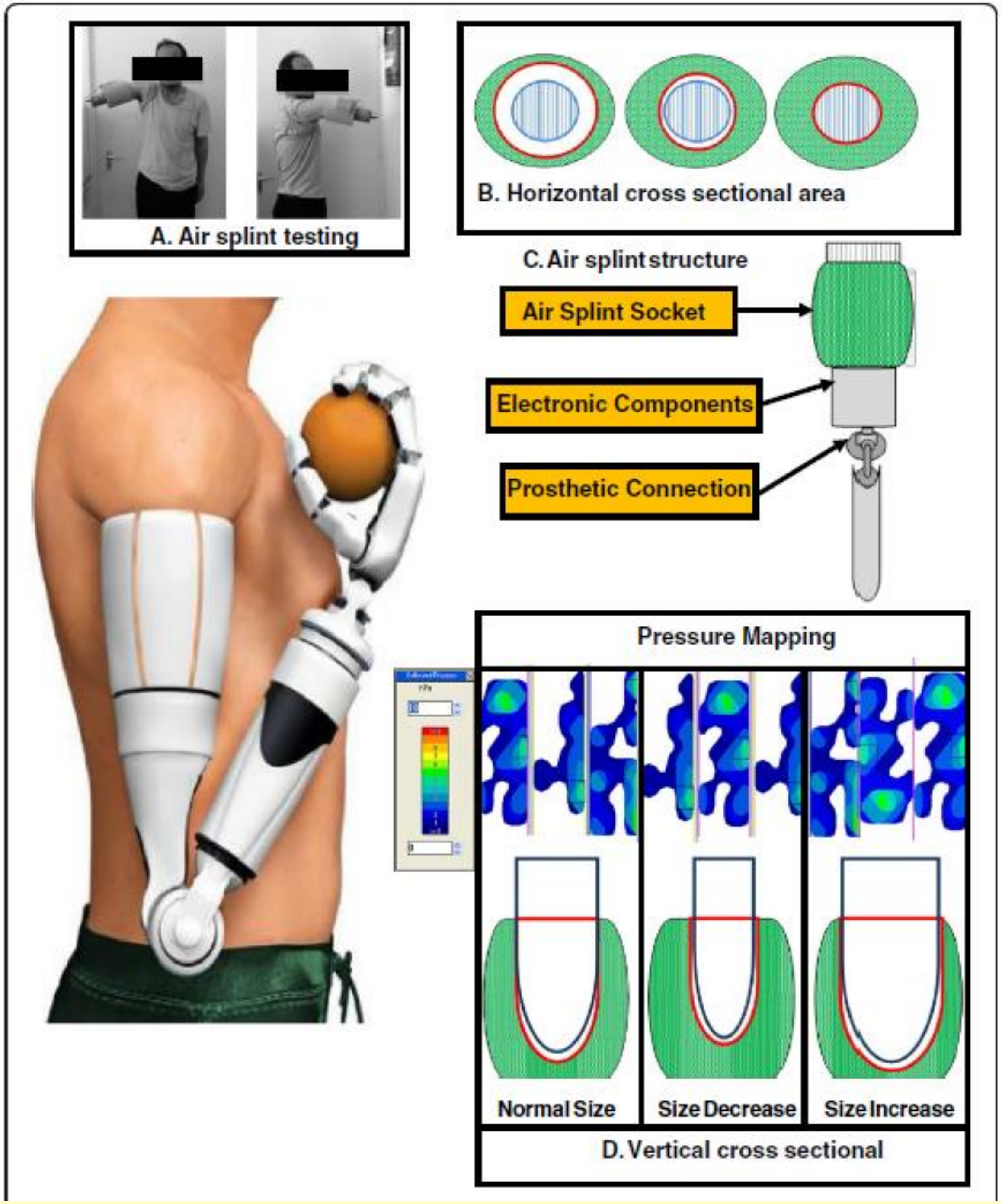
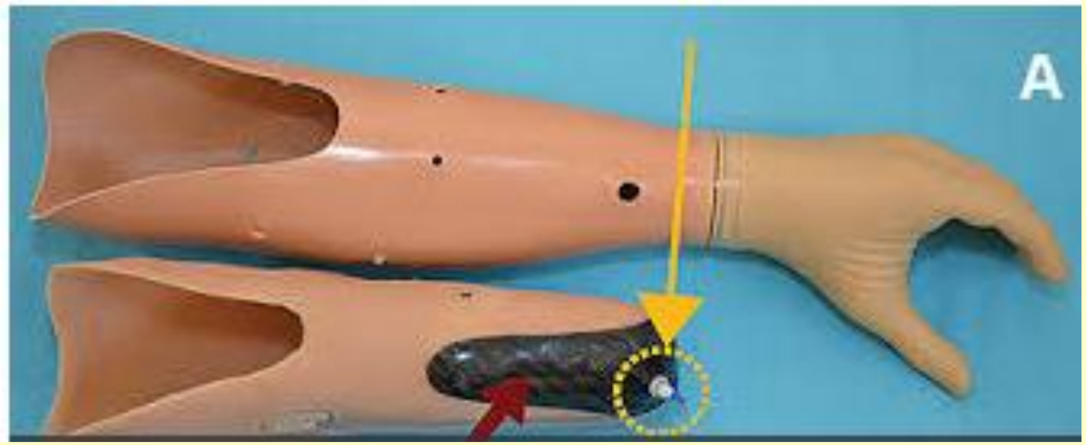

A. Air splint testing
B. Horizontal cross sectional area
C. Air splint structure
Air Splint Socket
Electronic Components
Prosthetic Connection
Pressure Mapping
Normal Size
Size Decrease
Size Increase
D. Vertical cross sectional

Figure 6 The F-socket sensor attach to the subject residual limb.

A custom silicone socket with air expulsion valve fixed to a carbon fiber prepreg internal frame.

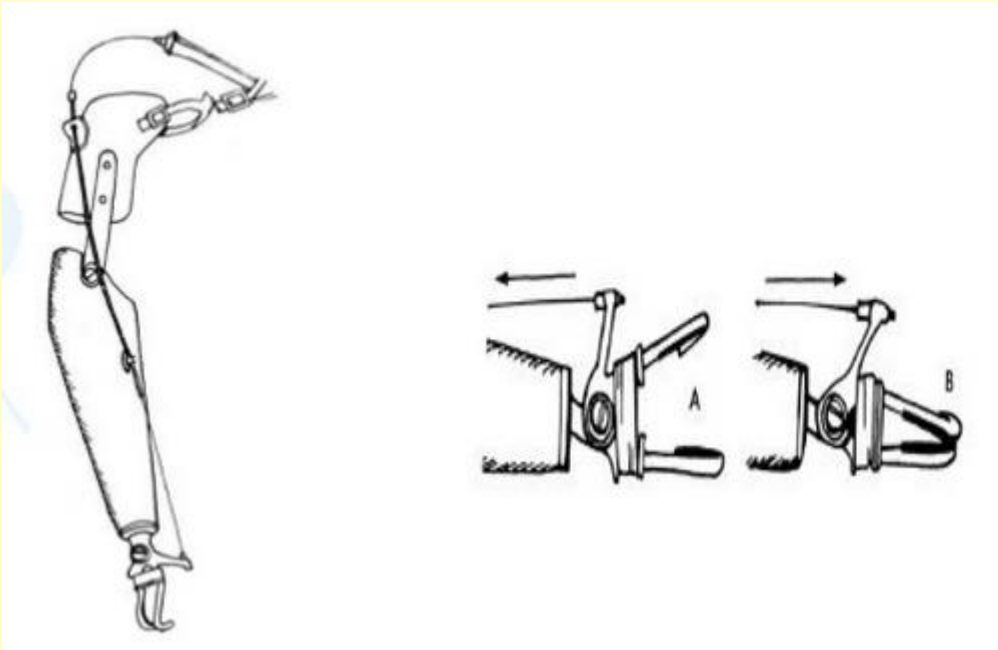


For individuals with transhumeral amputations

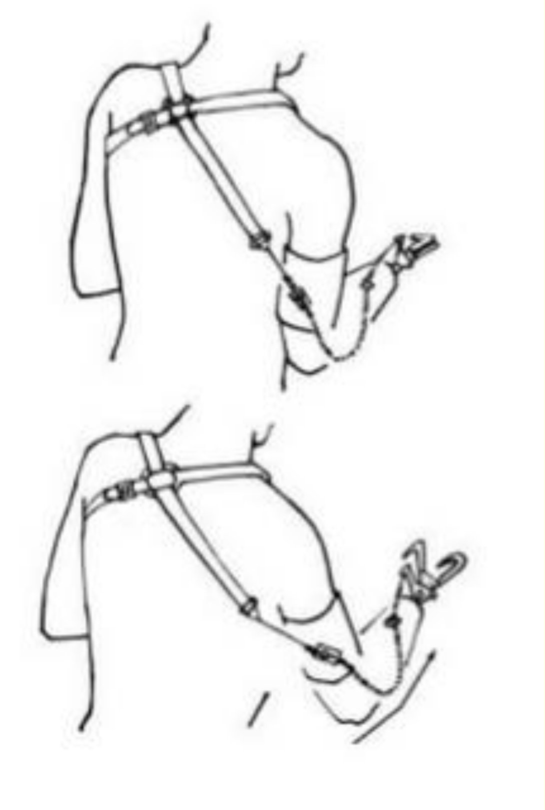
Control mechanisms

Body powered (harness)

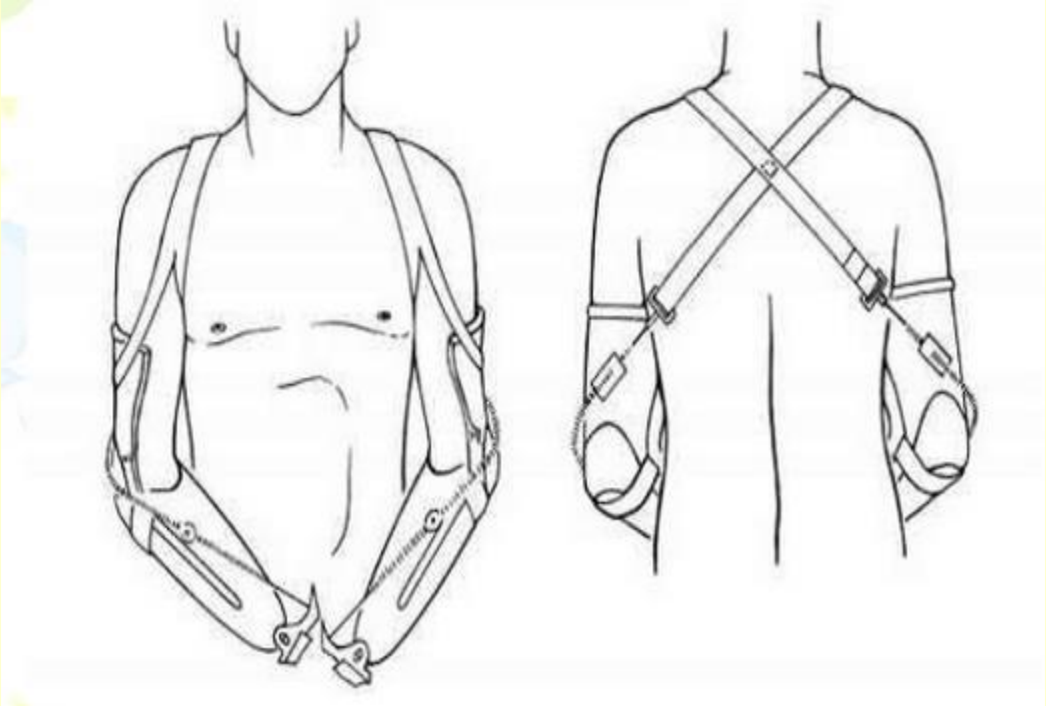
- Chest expansion
- Shoulder extension, abduction, flexion
- Elbow flexion



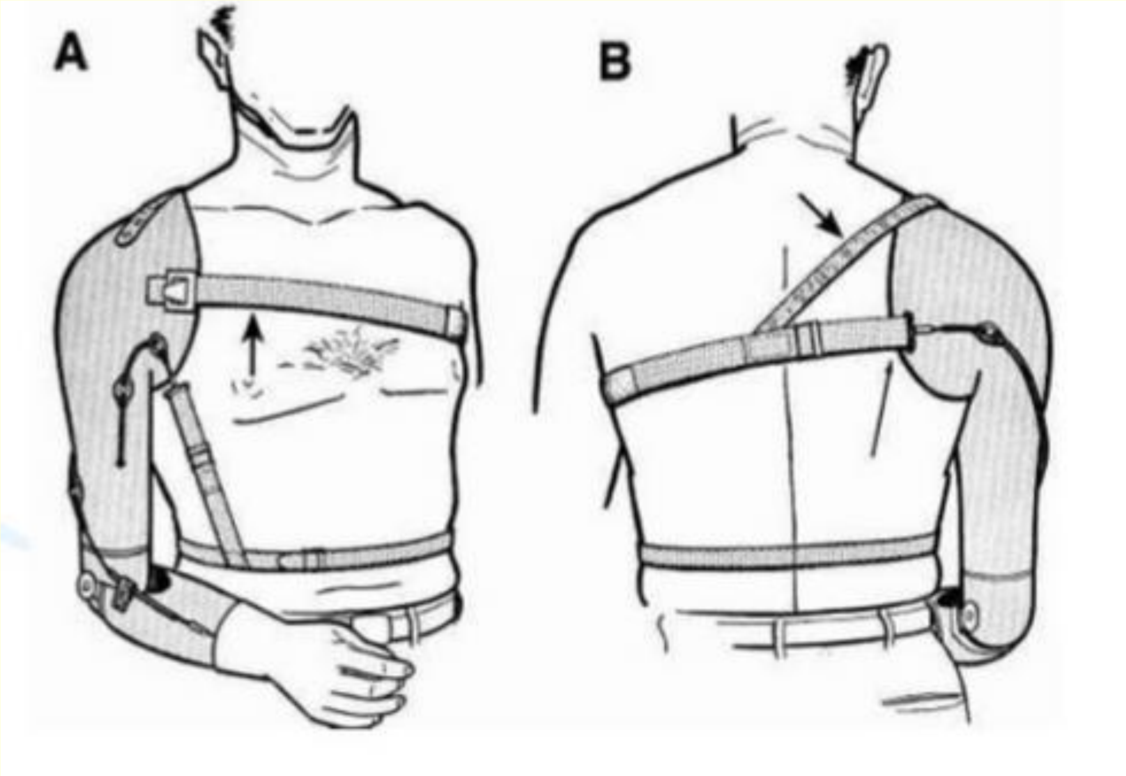
Glenohumeral joint (shoulder) flexion for operating a terminal device



Bilateral transradial harness



Shoulder disarticulation harness



Control mechanisms

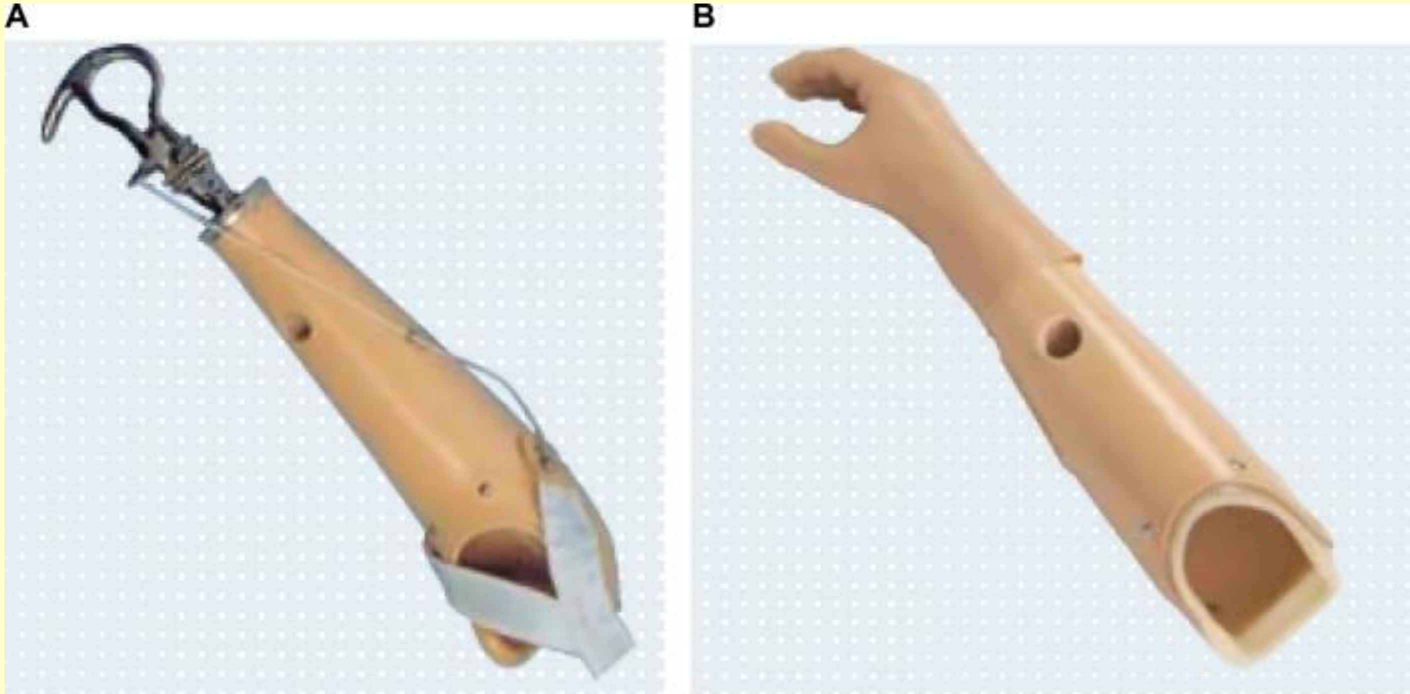
Externally powered prostheses - Electric motors inside prosthesis for wrist rotation /elbow flexion or extension

- Motors controlled by switches
- Motors controlled by myoelectric signals

Switch

- Inside or outside socket
- Activated on contact by amputee

(A) Body-powered prosthetic hand; (B) myoelectric controlled prosthetic hand



Electrically powered prosthesis

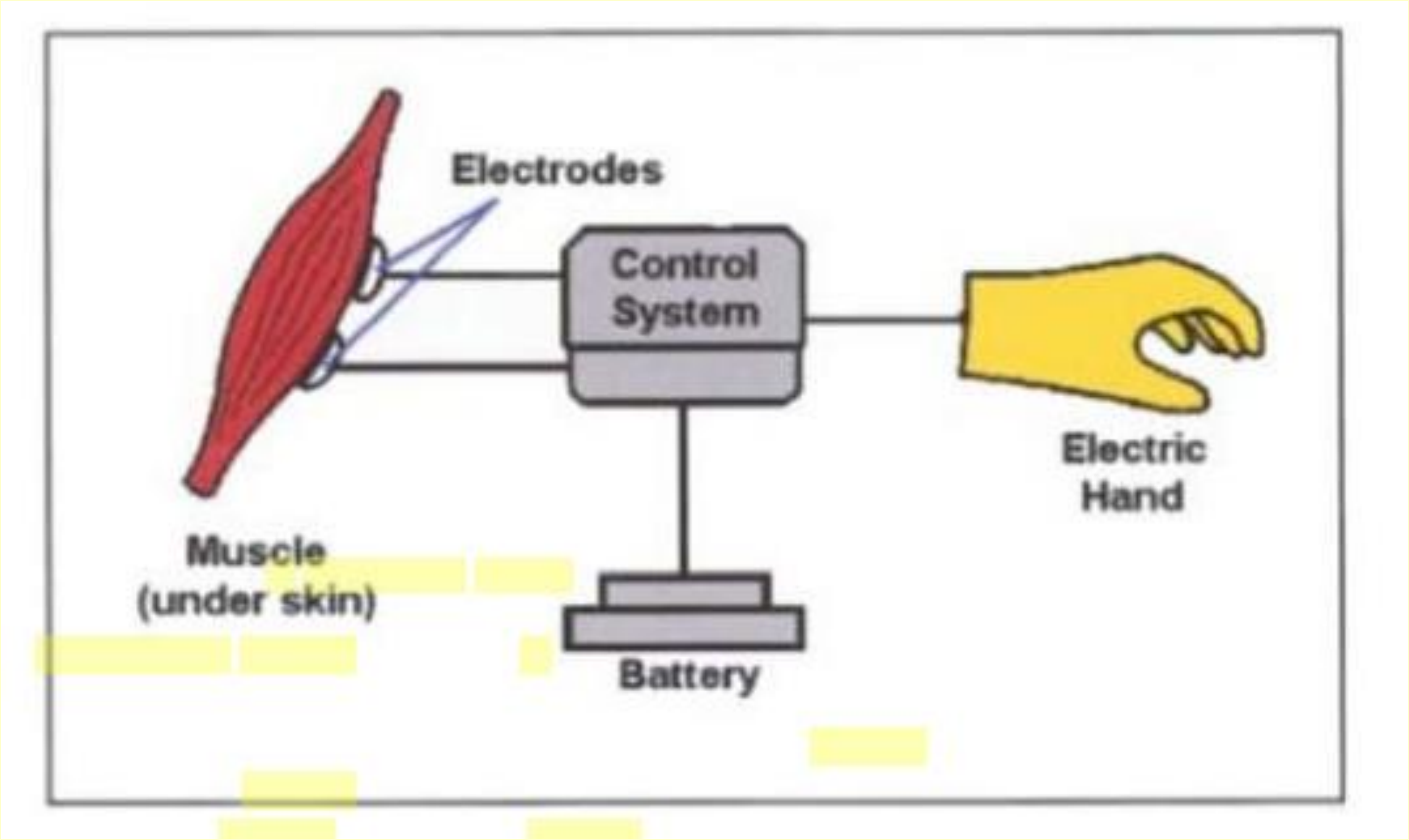
- The electrically powered prosthesis provides more grip force and enhanced functional envelope, while reducing or eliminating the overall harnessing necessary with a body-powered prosthesis.

Myoelectric switch control

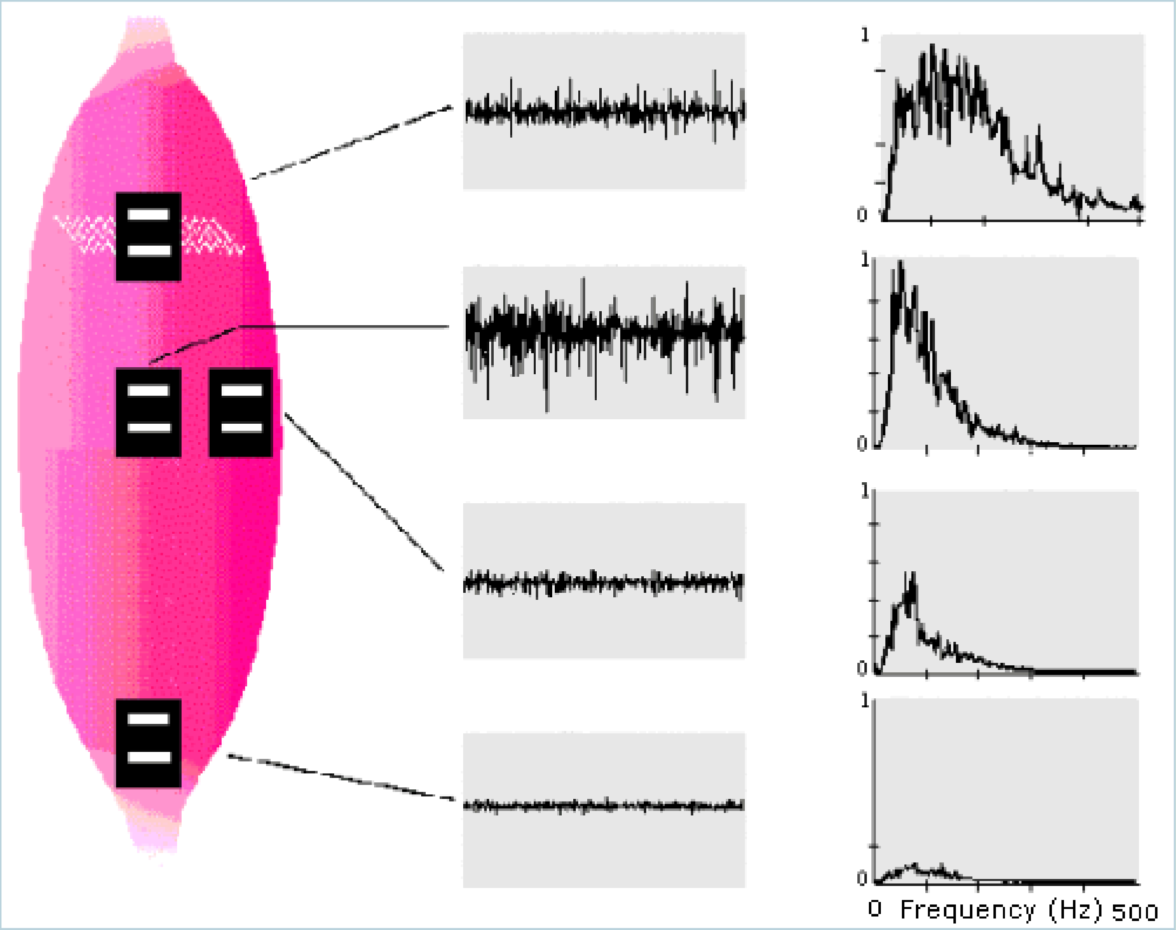
ADVANTAGES	DISADVANTAGES
Moderate or no Harnessing	Heaviest
Least Body movements needed to operate	Most expensive
Moderate Cosmesis	Most Maintaince
More Function; Proximal Areas, stronger grasp/grip in some cases	Limited Sensory Feedback
	Extended therapy time for training.

Myoelectric control	Advantages	Disadvantages
	No need of control harness Cosmetic restoration Operation everywhere	Need of a battery system Heavier than other systems More maintenance More expensive
Training Amputees learn to select and control the muscle(s) appropriate to perform a required function or task		

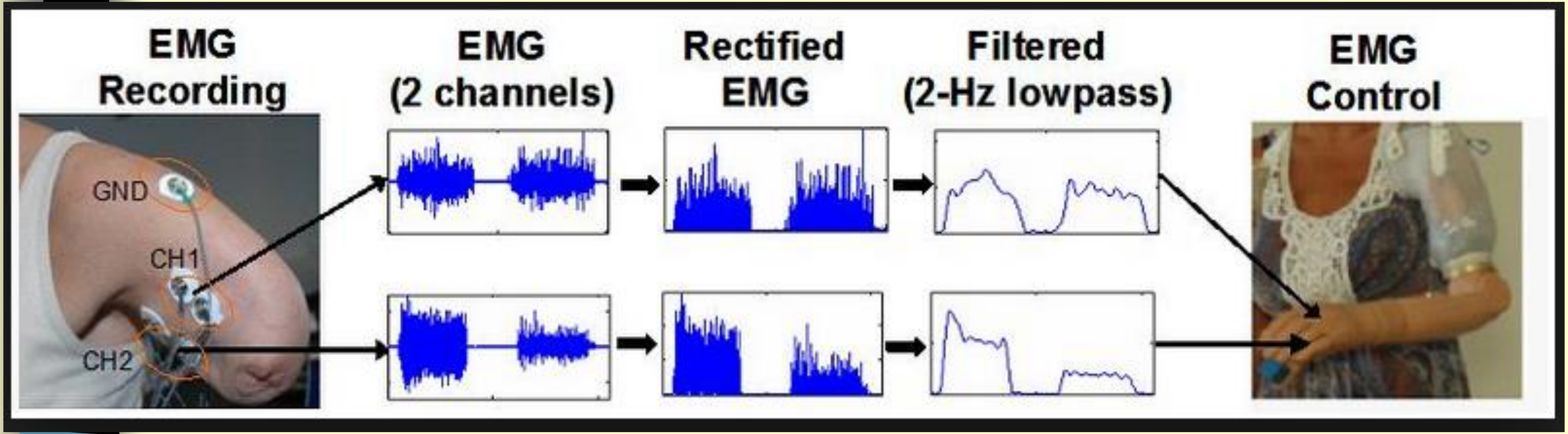
The basic concept of myoelectric control



Force-EMG signal relationship

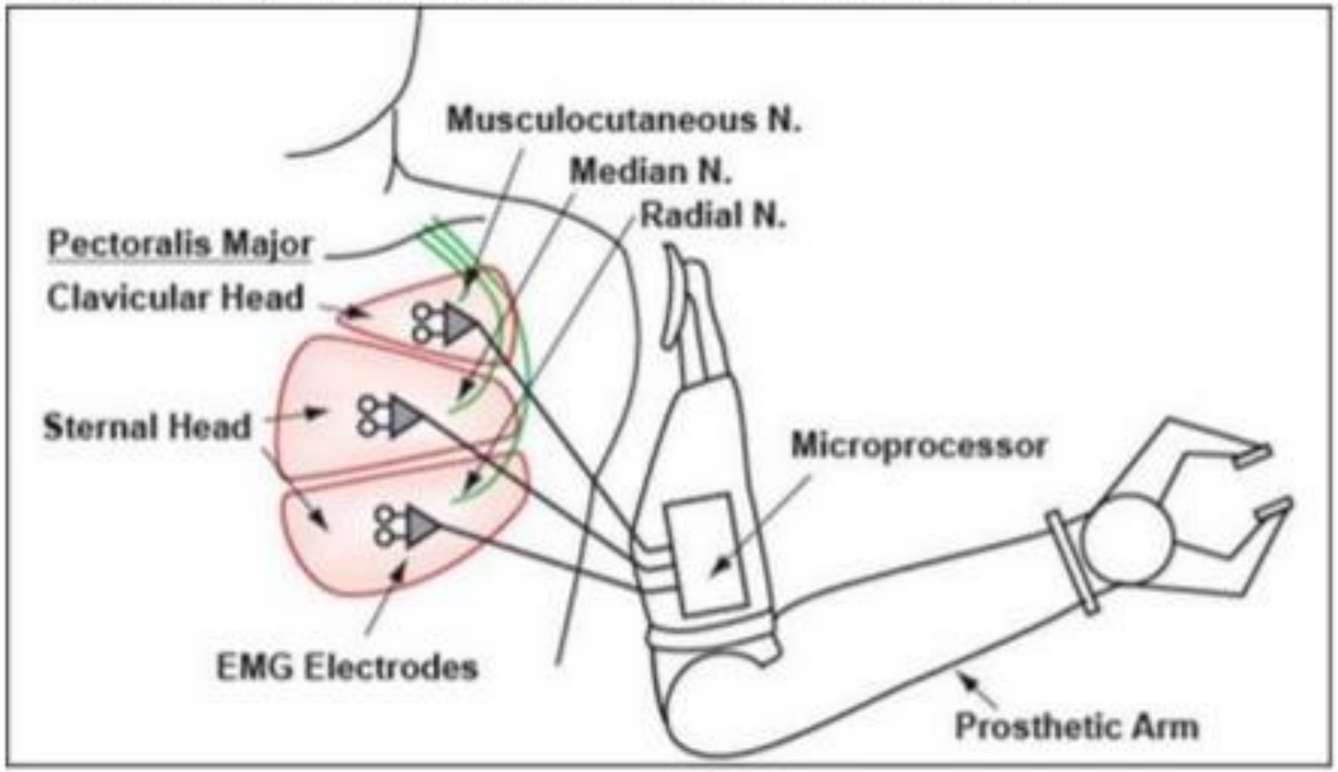


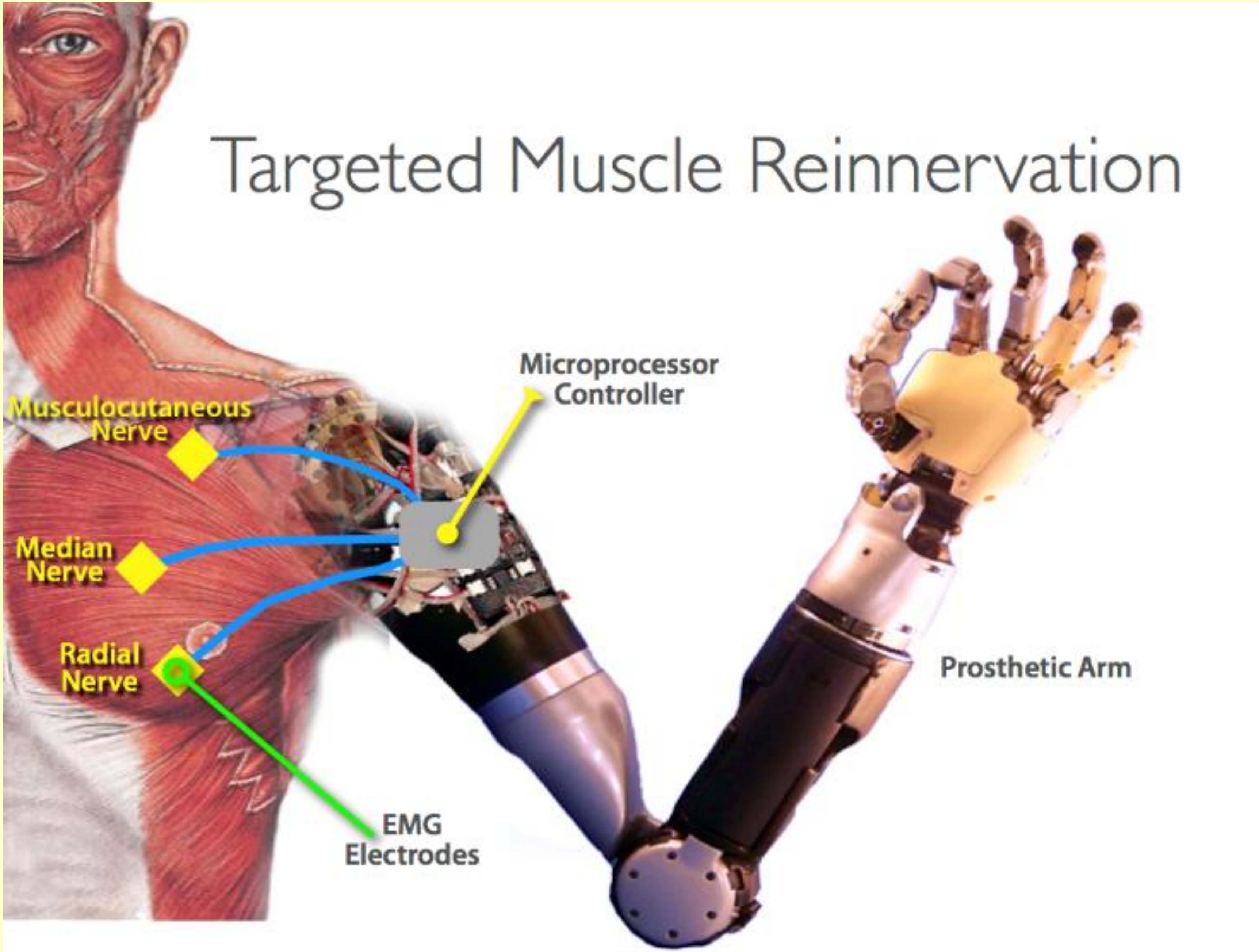
Range and frequency of EMG signal (5-200 µV) depend on the location of the electrode


EMG
Recording
GND
CH1
CH2
EMG
(2 channels)
Rectified
EMG
Filtered
(2-Hz lowpass)
EMG
Control

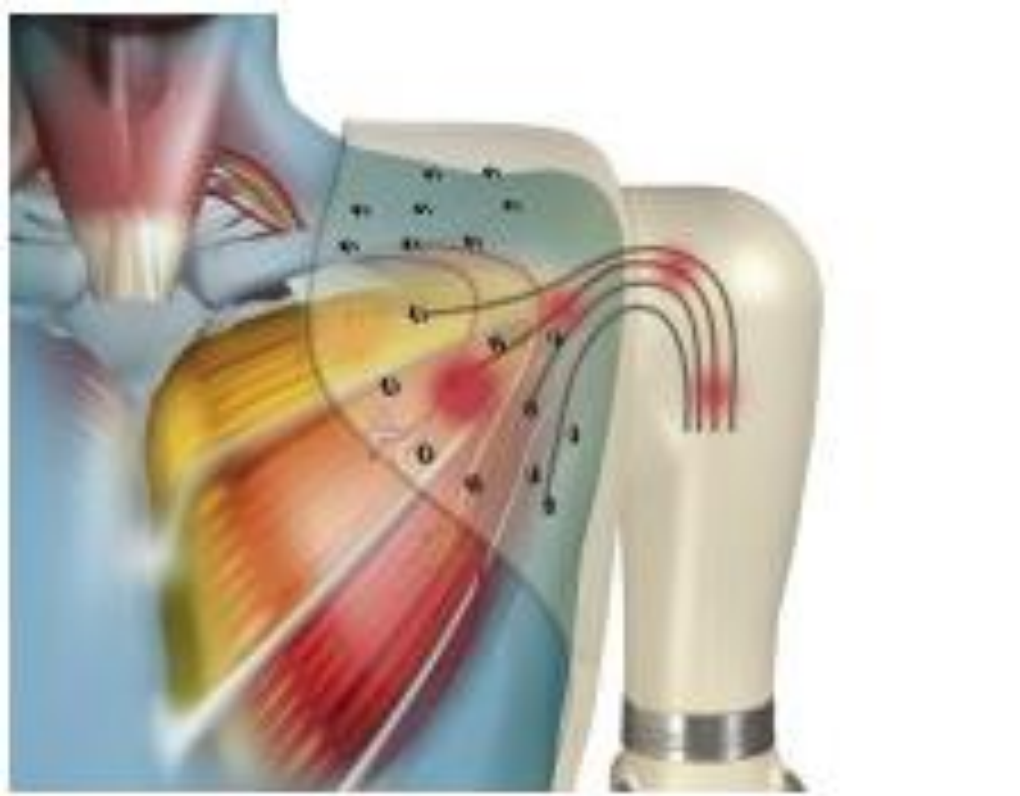
JRRD Volume 48, Number 6, 2011 Pages 643–660
Journal of Rehabilitation Research & Development

Electromyogram pattern recognition for control of powered upper-limb prostheses: State of the art and challenges for clinical use. **Erik Scheme, MSc, PEng; Kevin Englehart, PhD, PEng***
Institute of Biomedical Engineering, University of New Brunswick, Fredericton, Canada




Targeted Muscle Reinnervation
Musculocutaneous Nerve
Median Nerve
Radial Nerve
Microprocessor Controller
Prosthetic Arm
EMG Electrodes

The next generation of myoelectric prostheses



Following an amputation, peripheral nerves still carry orders for motor control from your brain, but the commands never reach their destination in the amputated muscles. **TMR redirects those nerve signals to other muscles that can control the prosthesis.** In a surgical procedure, nerves in the residual arm are reattached to a healthy muscle elsewhere in the body, such as a chest muscle. Then, when the patient wants to move the arm, the nerve signals originally used for arm movement cause the chest muscle to contract. Electrodes in the chest muscle sense the electrical activity and send a control signal to the prosthesis.
In effect, you move the prosthesis just by choosing to move it. With a conventional myoelectric-controlled prosthesis, you have to think about engaging a certain muscle to prompt a movement unrelated to that muscle.

With a TMR prosthesis, the nerve signals that your body originally used for arm, wrist, and hand movement are actually used to control your prosthesis. TMR lets you make multiple movements of the prosthetic arm simultaneously without stopping to think about each action.

UPPER-LIMB BODY-POWERED PROSTHESIS:

All conventional body-powered prosthesis have following components:

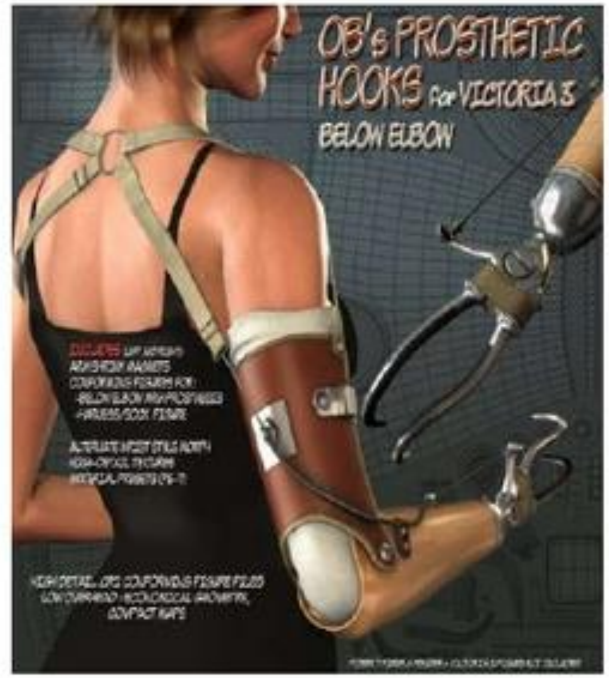
1. SOCKET
2. SUSPENSION
3. CONTROL-CABLE SYSTEM
4. TERMINAL DEVICE
5. COMPONENTS FOR ANY INTERPOSING JOINTS AS NEEDED ACCORDING TO THE LEVEL OF AMPUTATION.

Types of Terminal Devices:

1. Passive Terminal Devices (More Cosmetic than Functional)
   - Functional e.g Child Mitt used on infant's first prosthesis to assist in crawling.
   - Cosmetic.
2. Active Terminal Devices (More Function than Cosmetics)
   - Can be both
     - Body Powered (Cable controlled)
     - Externally Powered (Electrically controlled).

   Cable controlled Active terminal devices can be
     - Voluntary opening devices
     - Voluntary closing devices

PROSTHETIC HAND



PROSTHETIC HOOK

Specialized terminal devices - Specialized terminal devices are customized for a sport, hobby, or profession. You could have a baseball mitt attached to the wrist or a pool/snooker rest.






Active terminal devices can be either prosthetic hands or Hooks

PROSTHETIC HAND	SPLIT HOOK
Heavier in weight	Lighter in Weight
More difficult to see objects being grasped	Easier to see objects being grasped
More complex Mechanically	Simpler Mechanically
Less Versatile as a Tool	Versatile as a Tool
Cannot get into pockets	Will fit into Pockets
More cosmetic in appearance	Not cosmetic

5. COMPONENTS FOR ANY INTERPOSING JOINTS AS NEEDED ACCORDING TO THE LEVEL OF AMPUTATION

A. WRIST UNITS

B. ELBOW UNITS

C. SHOULDER AND FOREQUARTER UNITS

A. WRIST UNITS:

The wrist unit provides orientation of the terminal device in space. Once positioned, the wrist unit is held in place by a friction lock or a Mechanical lock.

Quick-Disconnect Wrist Unit

Easy swapping of terminal devices that have special functions.

Locking Wrist Unit

To prevent rotation during grasping and lifting.

Wrist Flexion Unit

Improved function of midline activities e.g; shaving, buttoning, perineal care

B. ELBOW UNITS:

Elbow units are chosen based on te level of amputation and the amount of residual limb. It is helpful to remember that supination and pronation of the forearm decreases as the site of amputatin becomes more proximal.

i. **Flexible Elbow Hinge**
   i. Medium and Long TransRadial Amputations
   ii. Wrist Disarticulations

ii. **Rigid Elbow Hinge**→ Short Transradial Amputation

iii. **Internal Locking Elbow Joint**→ Transhumeral Amputation.
   Internal Elbow allows 135 degree flexion

C. SHOULDER AND FOREQUARTER UNITS

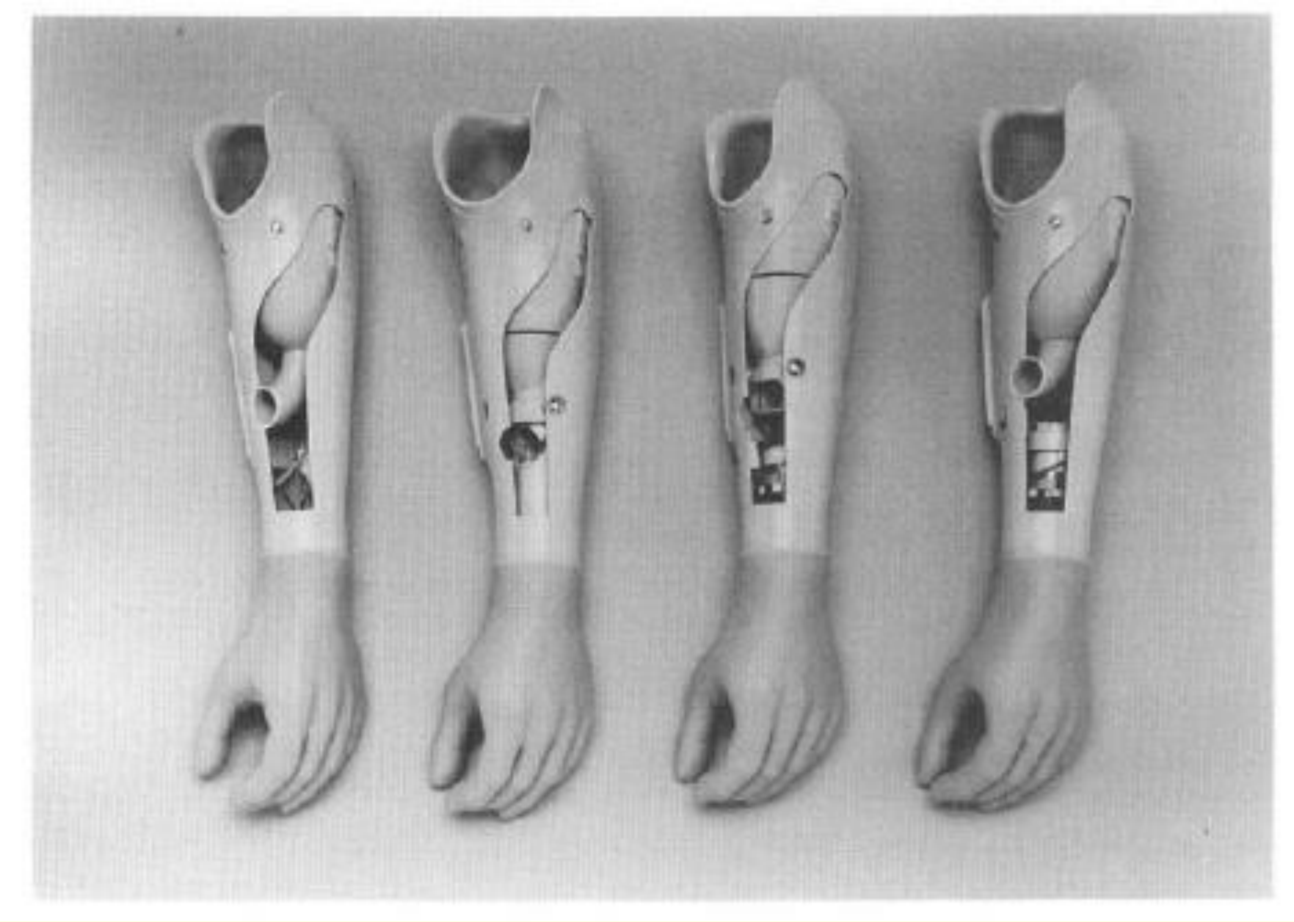
FOR AMPUTATIONS AT SHOULDER AND FOREQUARTER LEVELS.

In cases of amputations at these levels, function is very difficult to restore due to;

- Weight of the prosthetic component
- Diminished overall function when combining multiple prosthesis.
- Increased energy expenditure required to operate the prosthesis.

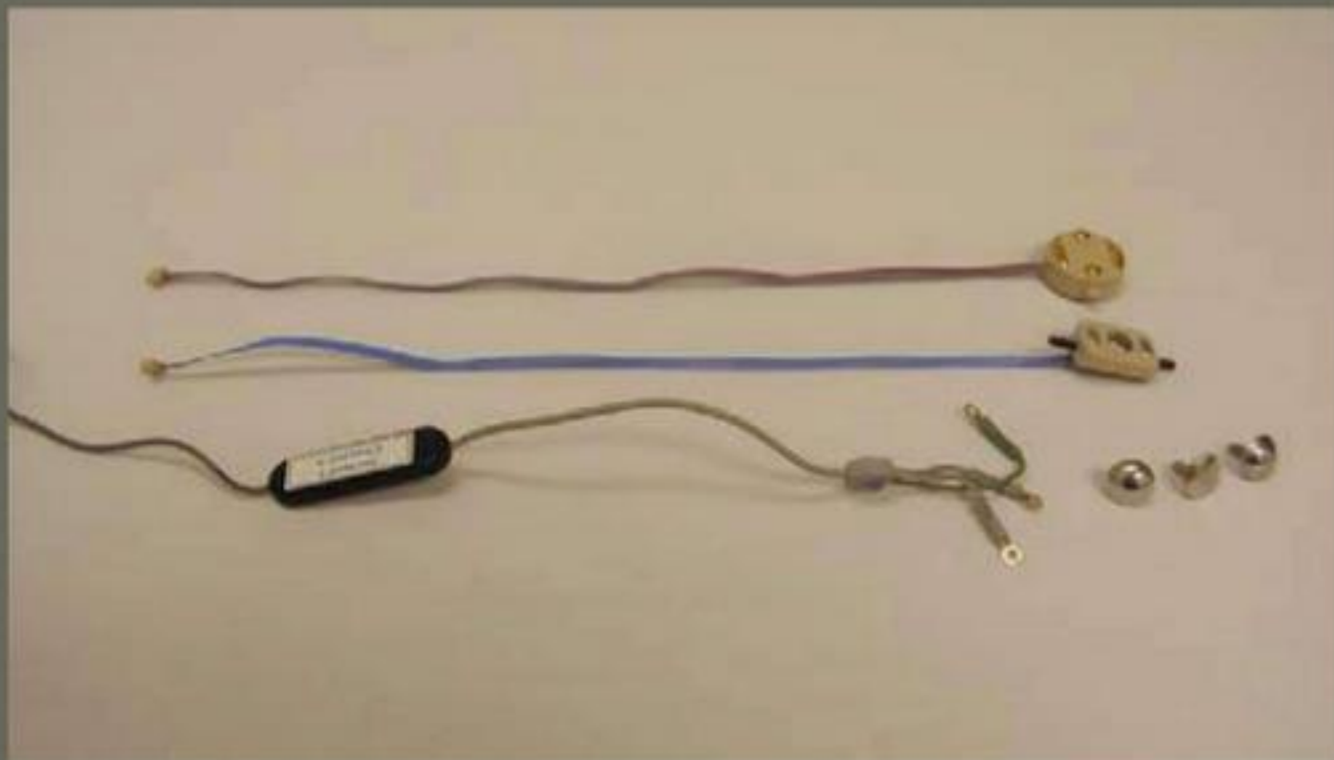
Thus, patients mostly choose either;

- A purely cosmetic prosthesis to improve body image and fit of their cloths.
- No prosthesis at all.

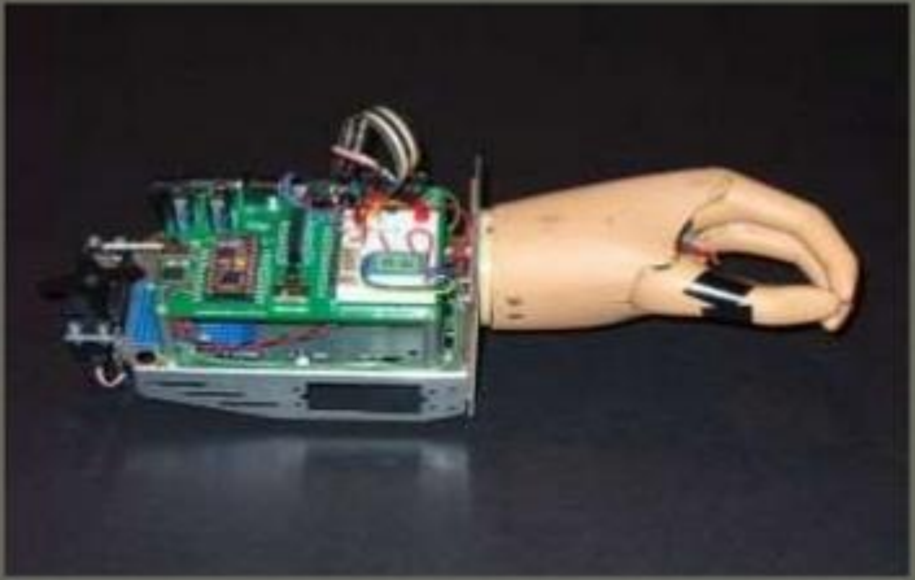


Myoelectric prosthetic forearm with electronic hand. (Courtesy OTTO Bock USA.)

Electrodes for the Myoelectric prosthesis



Prosthetic Hand Control via Force Sensors



Bionics hand with individually driven figures and thumb.

4. Force-sensing resistors

- Some electrical prostheses employ a force-sensing Resistor . These types of input devices consist of a force-sensing resistor matrix.
- The amputee activates the force-sensing resistor by moving the shoulder complex, a phocomelic finger, residual humeral neck, or other residual anatomy.
- It reduces the incidence of phantom limb pain
- Special care is require in force-sensing resistors , Improper installation results in premature failure and greater expense and can produce uncomfortable perspiration, moisture, and uneven shear force.

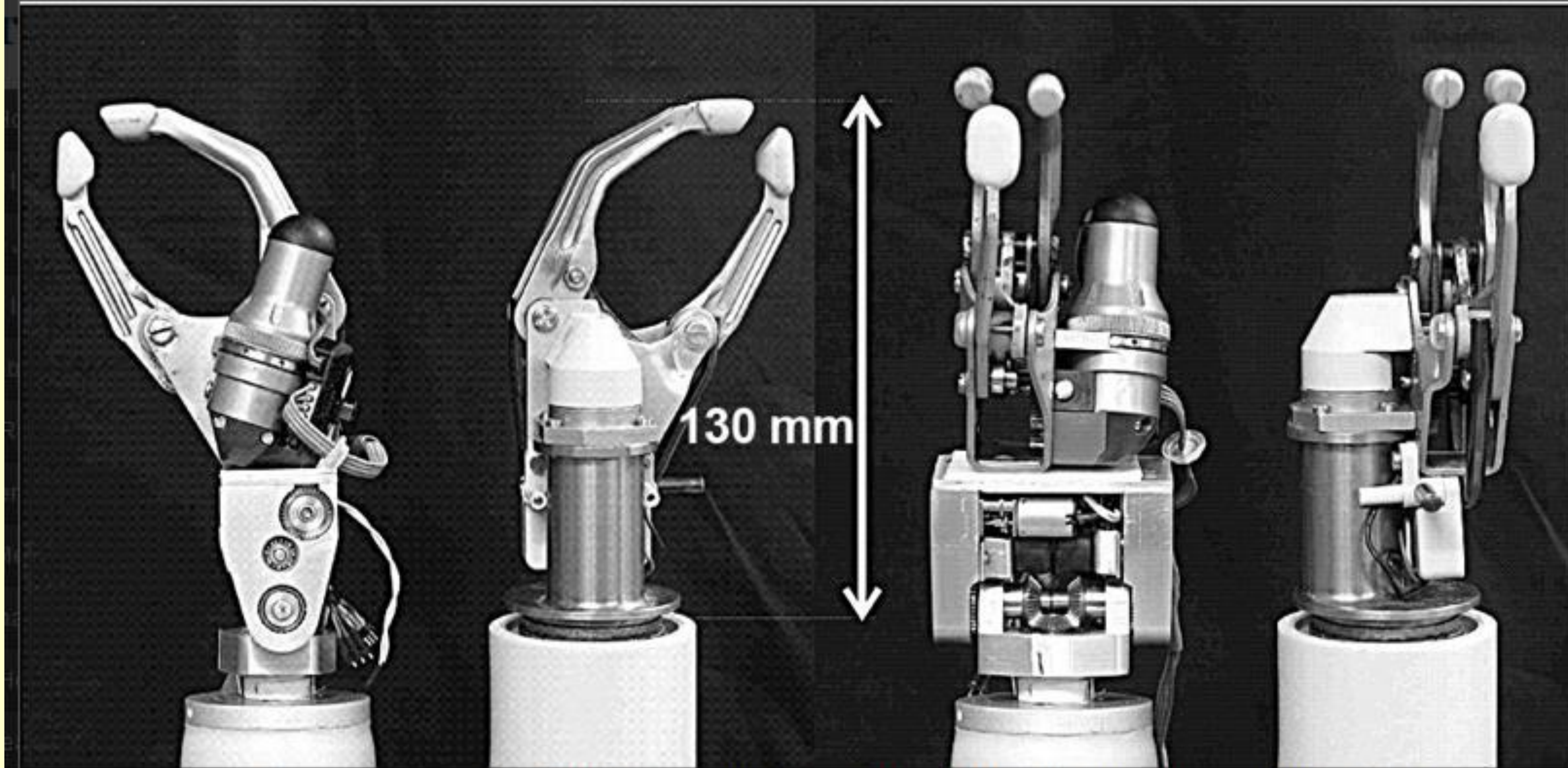
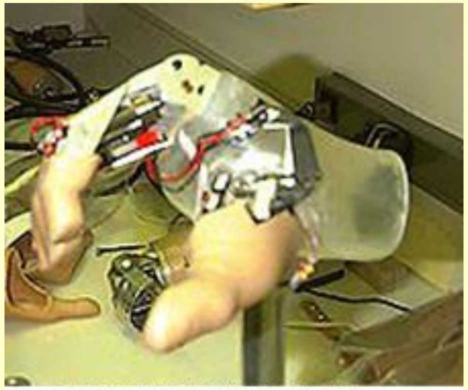
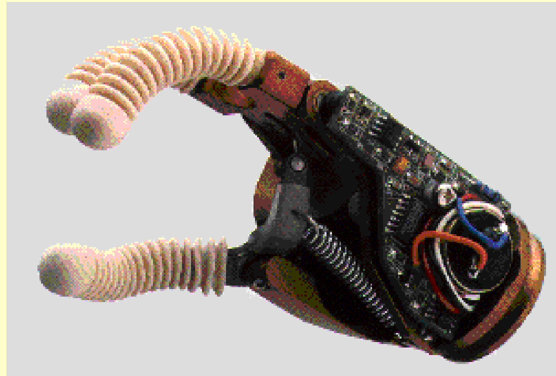


Figure 4. Second-generation two-axis wrist with Otto Bock transcarpal hand (Otto Bock HealthCare; Duderstadt, Germany) mounted on distal end for comparison with conventional size 7 3/4 hand. Pronation axes are aligned.

Upper limb prostheses

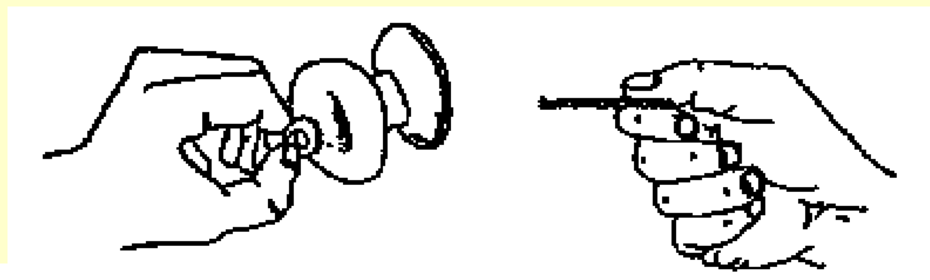


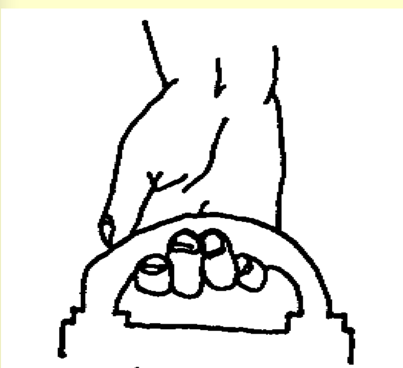
THE CIRCUITRY OF A MYOELECTRIC HAND
Courtesy : Inventors.About.com

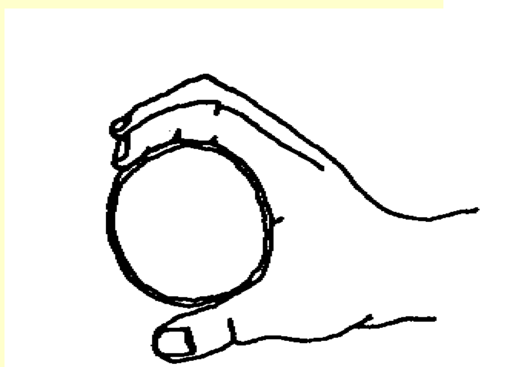


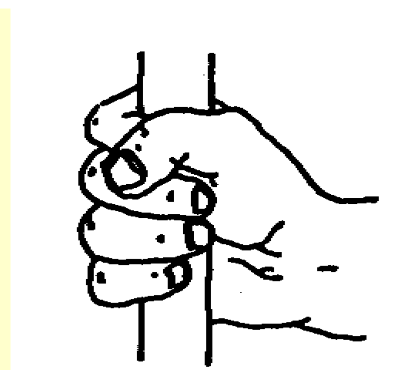
MYOELECTRIC ARM WITH A BATTERY ATTACHMENT
Courtesy : http://www.animatedprosthetics.com

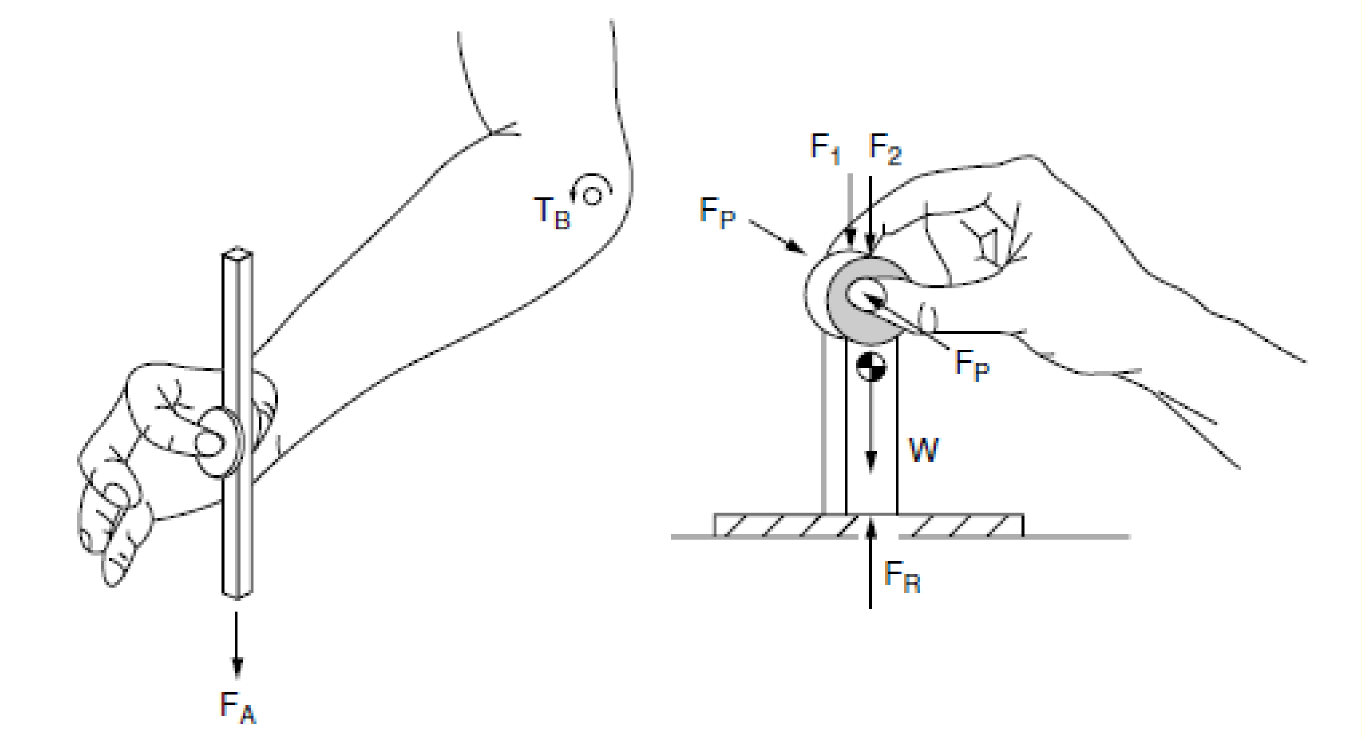
Hand movements





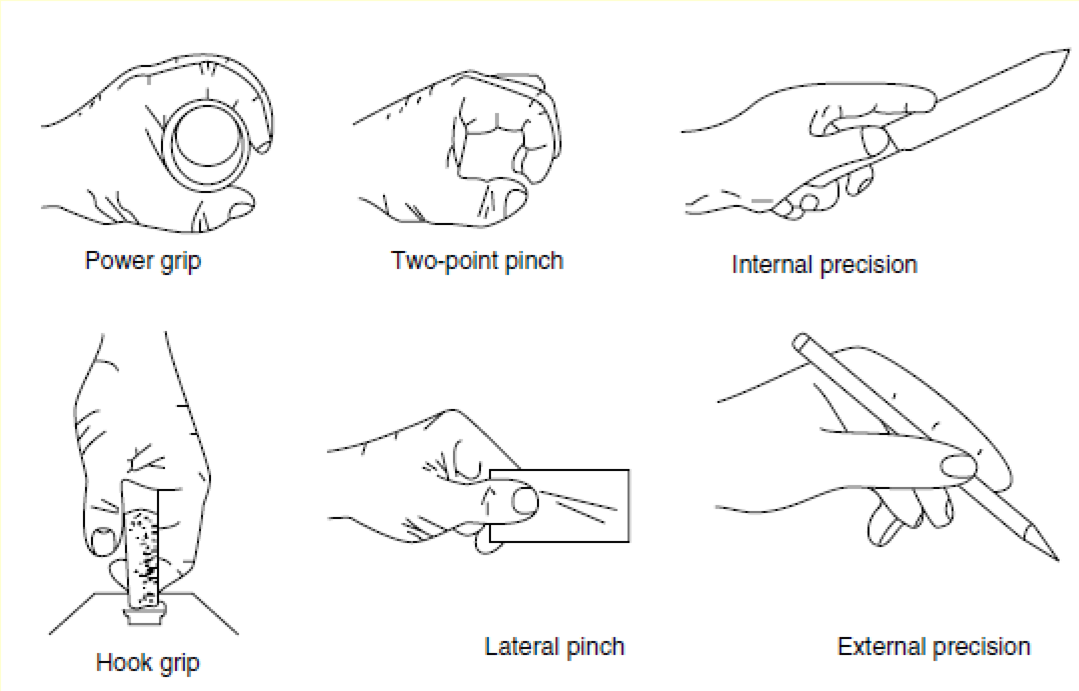






Forces on a precision grip

Types of grip

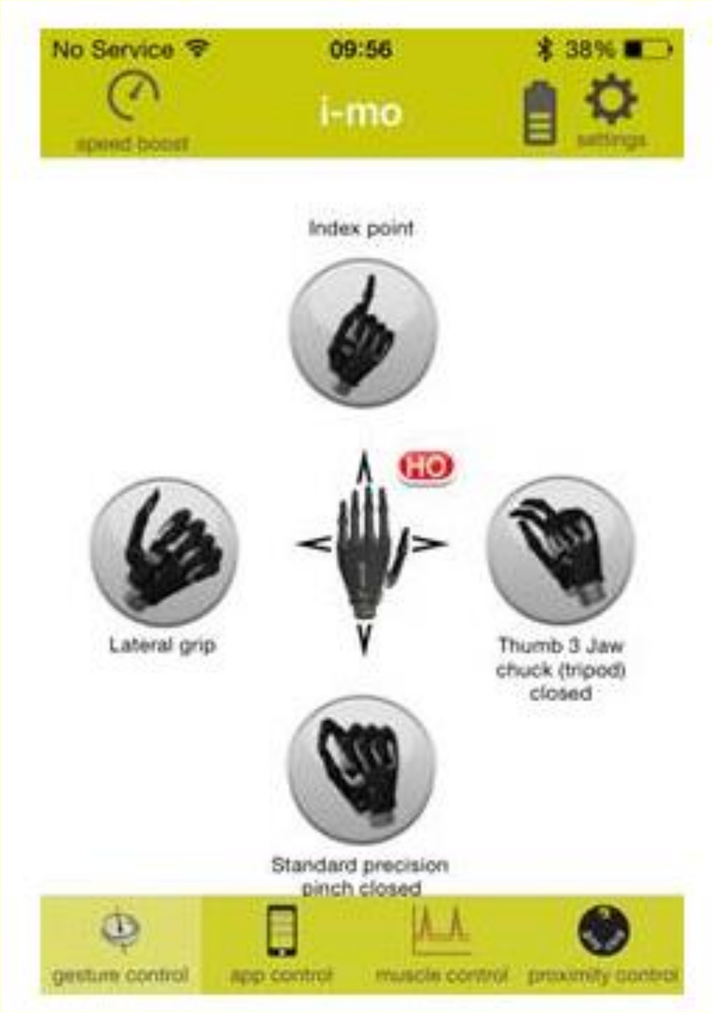


Relative Forces for Different Types of Grips

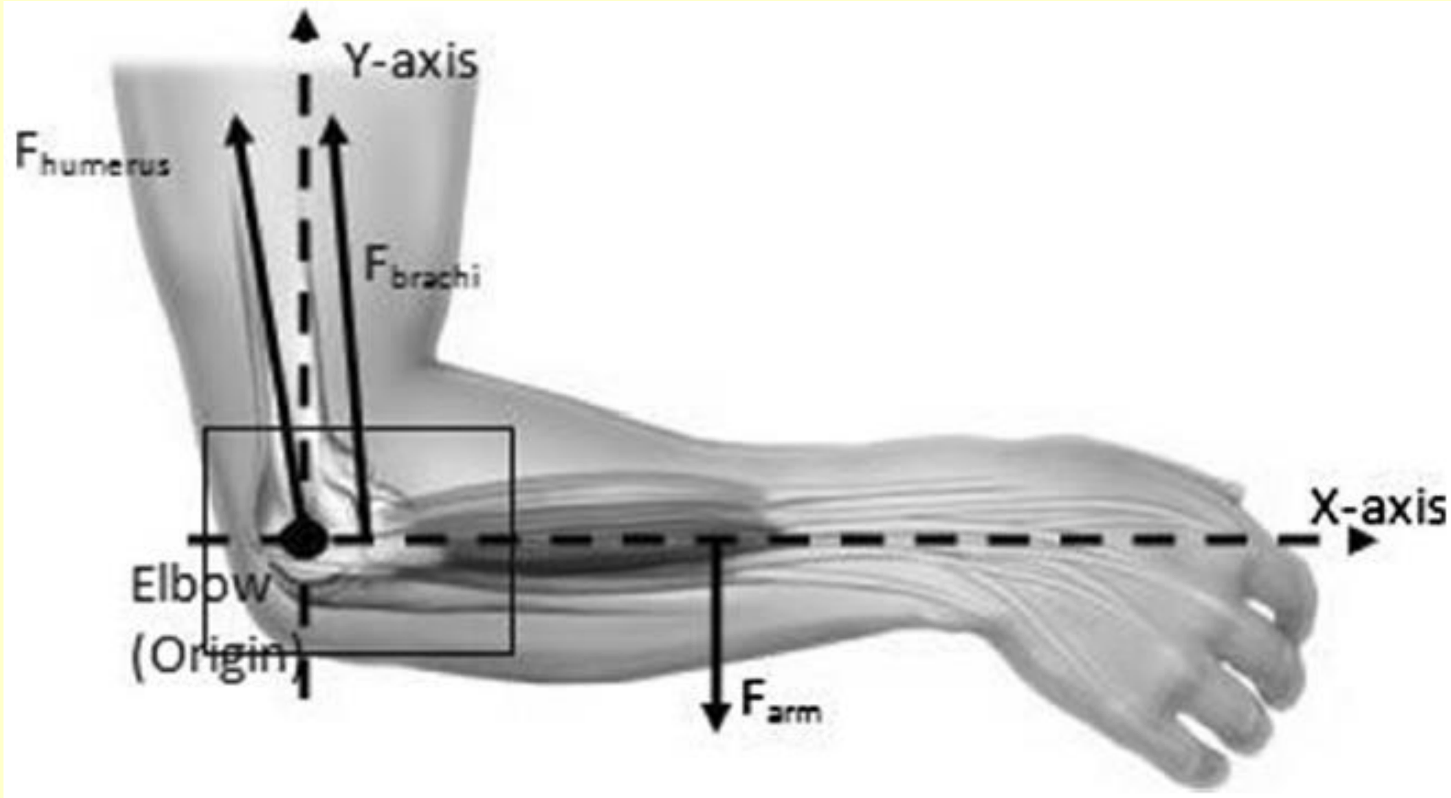
Grip	Male (N)	Female (N)	% of Power Grip
Power grip	400	228	100
Tip pinch	65	45	18
Pulp pinch	61	43	17
Lateral pinch	109	76	30

The **i-limb** is an externally powered prosthesis often controlled by myoelectric signals, meaning it uses muscle signals in the patient’s residual limb to move the device. Electrodes are placed on the user’s bare skin above two pre-selected muscle sites. When a user contracts these muscles, the electrodes pick up subtle changes in the electrical patterns and send these signals to a microprocessor which instructs the i-limb to open and close.

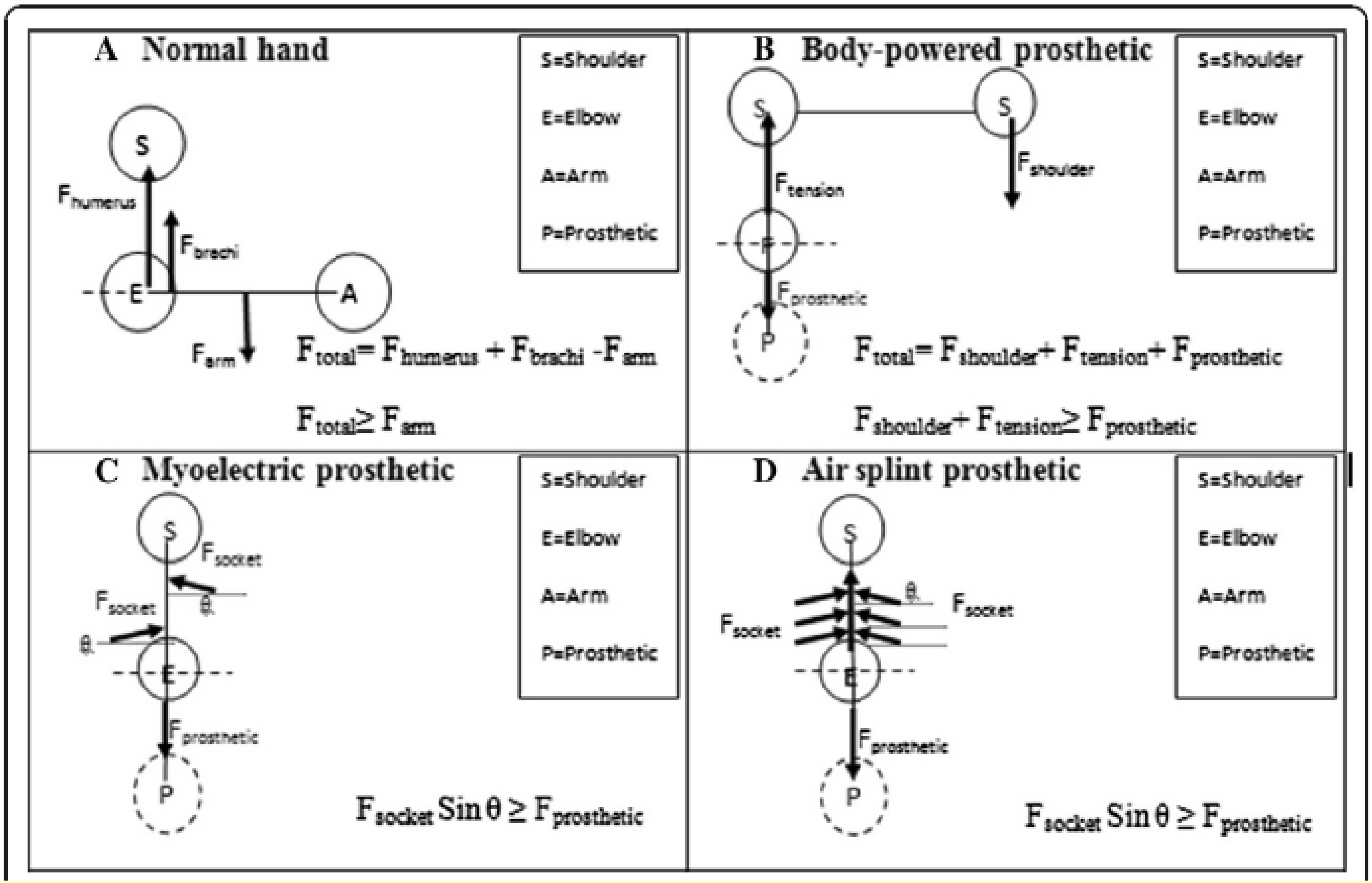
i-limb of Touch Bionics



The i-limb quantum™ incorporates the company's patented and groundbreaking gesture control, powered by i-mo™ technology. It allows the wearer to change grips with a simple gesture. Gesture control enables an automated grip to be accessed by moving the **i-limb quantum** in one of four directions. The **i-limb quantum** comes pre-programmed with a selection of practical grips, and these can easily be changes through the app.



The muscle action is usually shown diagrammatically as only supplied by the biceps, and its tension (N) times the distance (m) of its line of action from the elbow axis gives the flexing moment (Nm), which opposes the extending moment of the weight in the hand



Comparison of free body diagram from three different types of prostheses; B. Body-powered prosthetic, C. Myoelectric prosthetic, D. Air splint prosthetic and A. normal human hand. (S= shoulder, E= elbow, A= arm and P= prosthetic). The forces direction react referring to the X-axis and Y-axis.

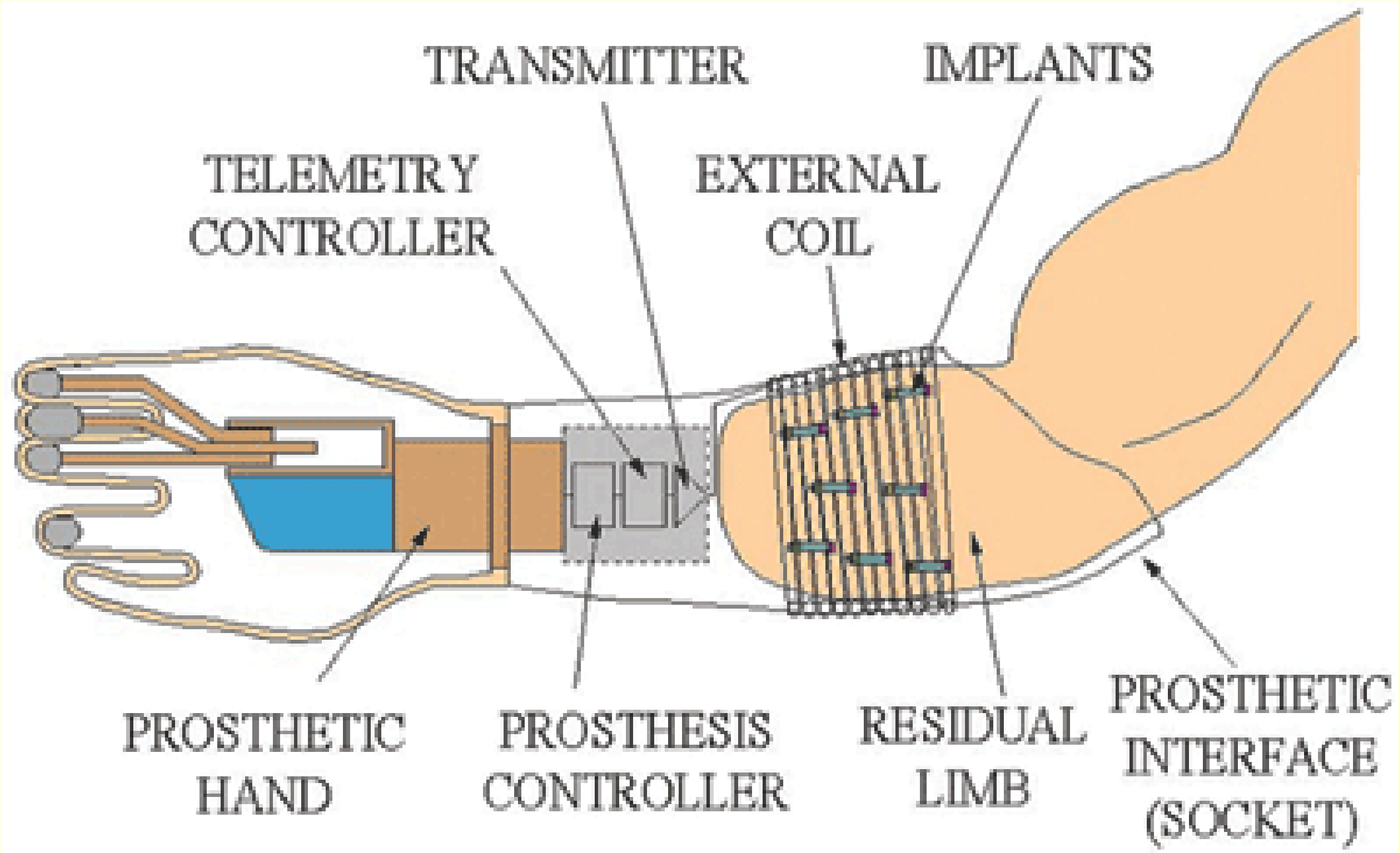
Result pressure profile applied for each type of prostheses

Subjects	Body-powered socket pressure, kPa Area (0.03±0.005 m)	Myoelectric socket pressure, kPa Area (0.045±0.005 m)	Air splint socket pressure, kPa Area (0.045±0.005 m)
1	5.78	6.02	3.22
2	7.47	7.45	5.24
3	4.32	5.72	2.91
4	7.35	7.62	5.61
5	8.21	8.01	5.97
6	6.58	6.48	4.93
7	6.21	6.09	4.23

Body powered prosthesis = 8.21 kPa, myoelectric prosthesis = 8.01 kPa, and air splint prosthesis = 5.97 kPa.

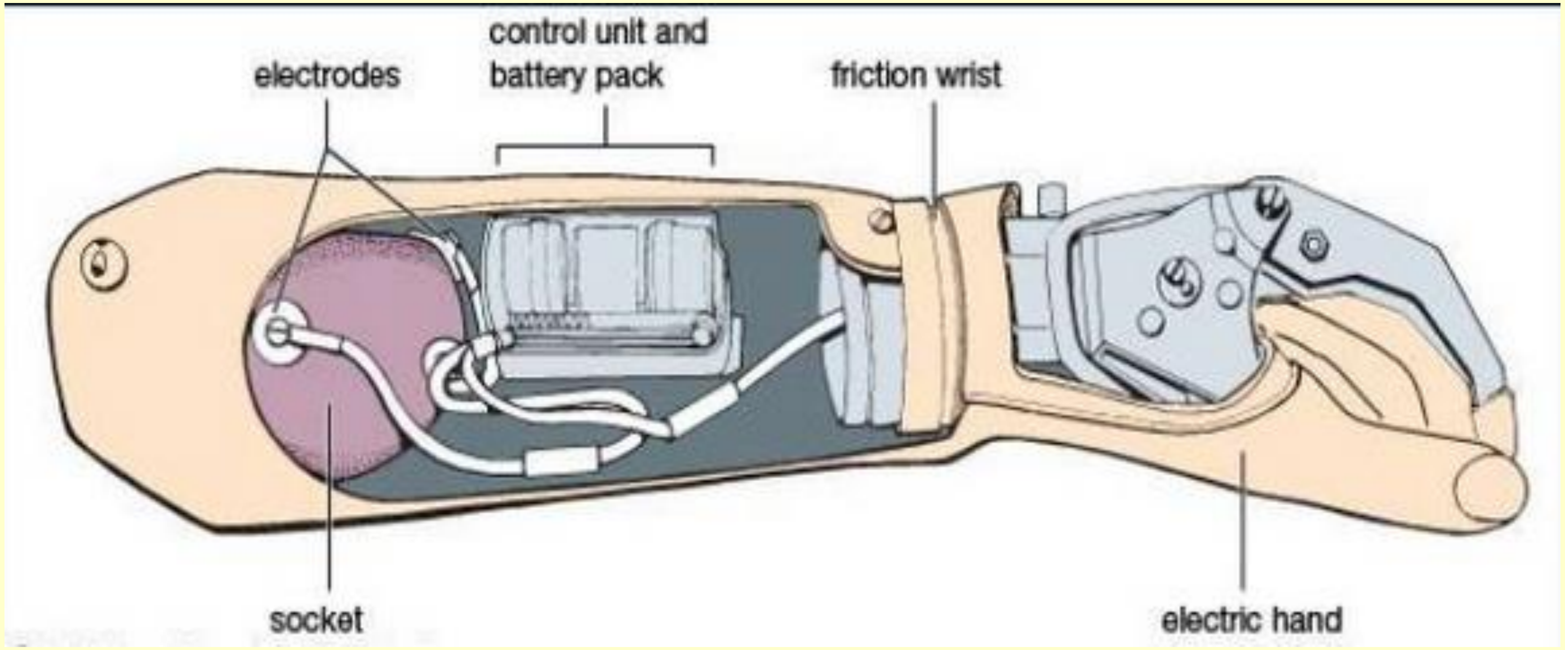
Comparison of force applied by each type of prostheses with the normal hand force

Subjects	Theoretical force F_{joint} (N)	Body-powered $F_{tension}+F_{shoulder}$ (N)	Myoelectric F_{socket} (N) (static area)	Myoelectric F_{socket} (N) (dynamic area)
1	9.73152	17.34	27.09	14.49
2	11.45808	22.41	33.525	23.58
3	9.26064	12.96	25.74	13.095
4	12.08592	22.05	34.29	25.245
5	12.5568	24.63	36.045	26.865
6	11.30112	19.74	29.16	22.185
7	9.73152	18.63	27.405	19.035


TRANSMITTER
IMPLANTS
TELEMETRY CONTROLLER
EXTERNAL COIL
PROSTHETIC HAND
PROSTHESIS CONTROLLER
RESIDUAL LIMB
PROSTHETIC INTERFACE (SOCKET)

"Myoelectric" is the term for electric properties of muscles. A myoelectric-controlled prosthesis is an externally powered artificial limb that you control with the electrical signals generated naturally by your own muscles.

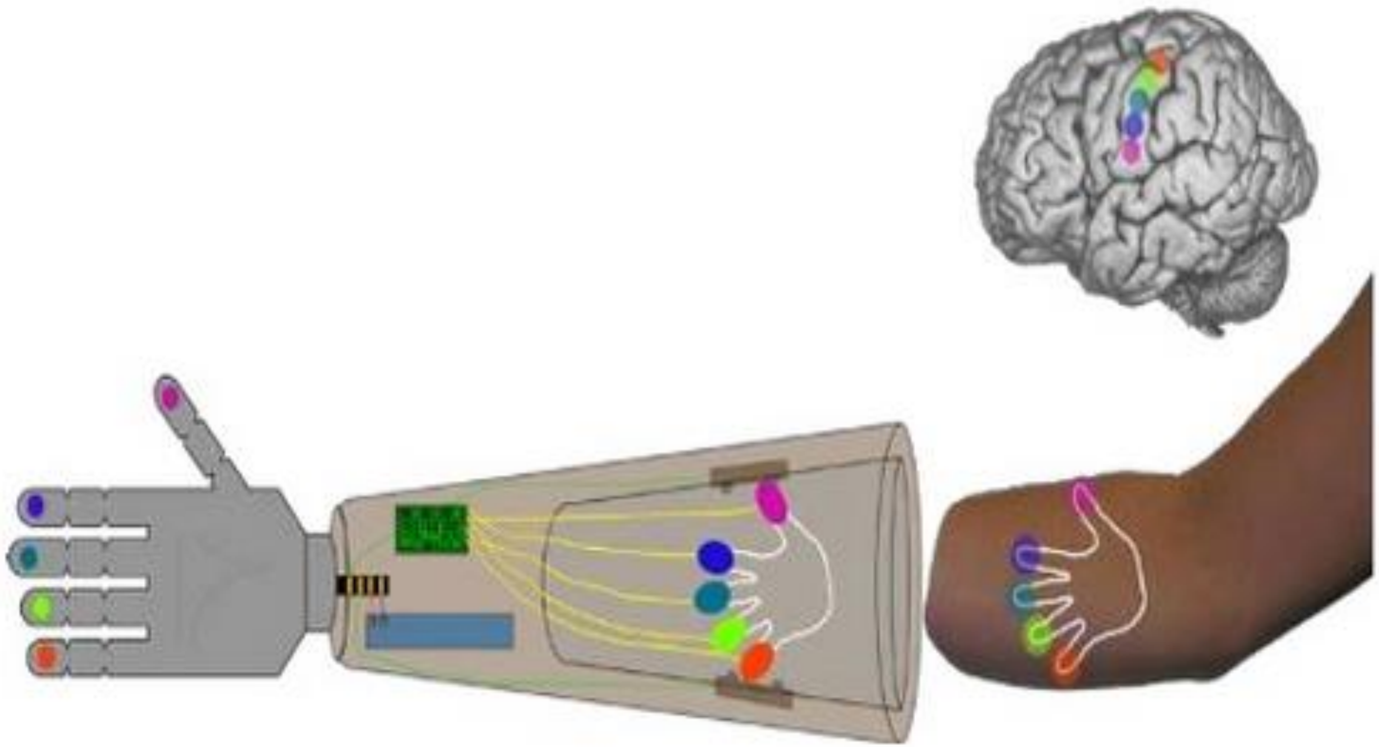
Basic diagram

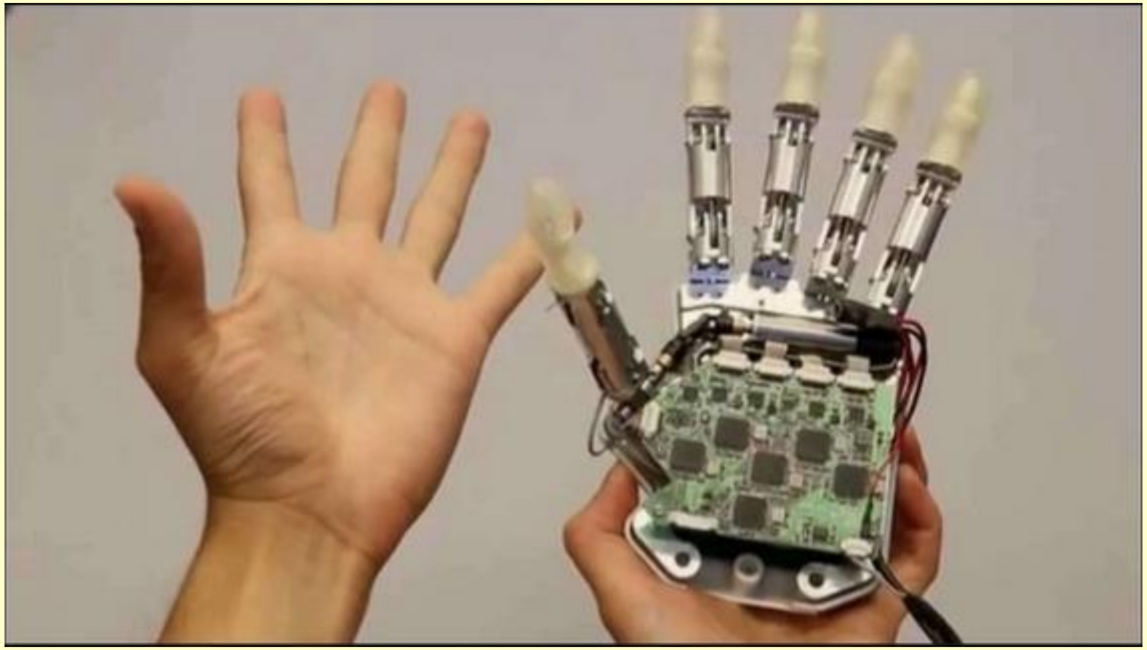


The working:

A myoelectric prosthesis uses the existing muscles in your residual limb to control its functions. One or more sensors fabricated into the prosthetic socket receive electrical signals when you intentionally engage specific muscles in your residual limb. Sensors relay information to a controller, which translates the data into commands for the electric motors and moves your joints. If muscle signals cannot be used to control the prosthesis, you may be able to use switches with a rocker or pull-push or touch pad.

RELAYING OF INFORMATION FROM RESIDUAL LIMB TO ELECTRIC ARM VIA CIRCUITRY:





Working principles of other types of myoelectric arms:

1)Implanted myoelectric sensors system:

These work with implants instead of electrodes, that attach to the residual limb. The information regarding motor impulses are transferred via a transmitter and a telemetry controller.

https://www.youtube.com/watch?v=AJHel9dVxPQ

Artificial Muscles?

Artificial muscles, also known as muscle-like actuators, are devices or materials that can mimic natural muscles and change stiffness, contract, expand, or rotate with an external stimulus. The idea is to mimic human muscles as closely as possible, including producing motions like expanding or contracting.

Artificial muscles are highly flexible and have wide applications in medicine, robotics, industry, and many other fields. In the same way, our muscles convert different chemicals into energy to operate; artificial muscles use electricity to facilitate mechanical motion.

What Can Artificial Muscles Be Used For?

- Audio speakers
- Power generators
- Motors
- Pumps and valves
- Sensors
- Medical devices

- Mainly within prosthetics