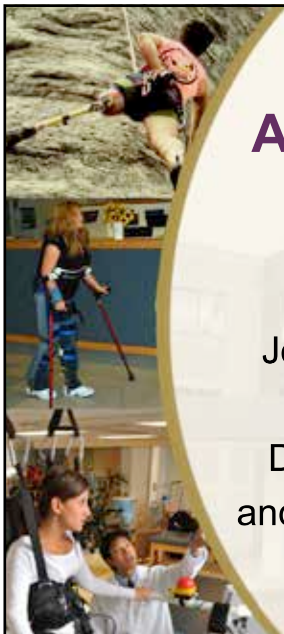

Amputation Rehabilitation and Prosthetic Rx

A. Esquenazi, MD
John Otto Haas Chair and Professor
Department of PMR
Director Gait & Motion Analysis Lab
and Amputation Rehabilitation Program
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Educational Objectives

- Review amputation epidemiology
- Describe the Phases of Amputation Rehabilitation
- Compare prosthetic components
- Contrast Lower vs Upper Limb
- Review Prosthetic Prescription

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Amputation
a definition

- Amputation surgery should be considered a reconstructive procedure intended to create a functional residual limb capable of pain free weight bearing and function:
  - Meticulous technique and gentle tissue handling
  - Avoidance of skin grafts and adherent scars
  - Minimal periosteal stripping with balance of muscle forces should always be attempted

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Prevalence of Amputation

- Based on data from the NHIS-D there are 1.2 - 1.9 million persons living in the U.S. with limb loss

http://www.cdc.gov/nchs/about/major/nhis_dis.htm

- The patient population with limb amputations is expected to double in 25 years

Estimating prevalence of limb loss: 2005 to 2050 Arch PMR, Mar 2008

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Incidence of Amputation

- There are approximately 50,000 new major limb amputations every year in the US

National Health Interview Survey, 2005

- Worldwide estimated number of new amputations range between 1,000,000 and 1,500,000 per year

International comparison of LE amputation rates Ann Vasc Surg 2009

- US rate for LE amputation 47/100,000 vs. 5/100,000 UE amputation

http://www.amputee-coalition.org/people-speak-out/background.html

Esquenazi, Disability and Rehabilitation 2004

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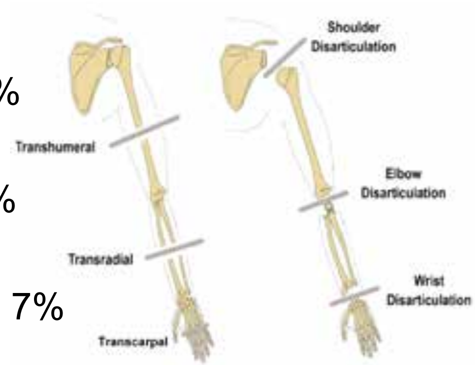
Upper Limb Amputation Levels

- Transcarpal 18%
- Wrist Disarticulation 10%
- Transradial 31%
- Elbow Disarticulation 5%
- Transhumeral 27%
- Shoulder Disarticulation 7%
- Forequarter 2%



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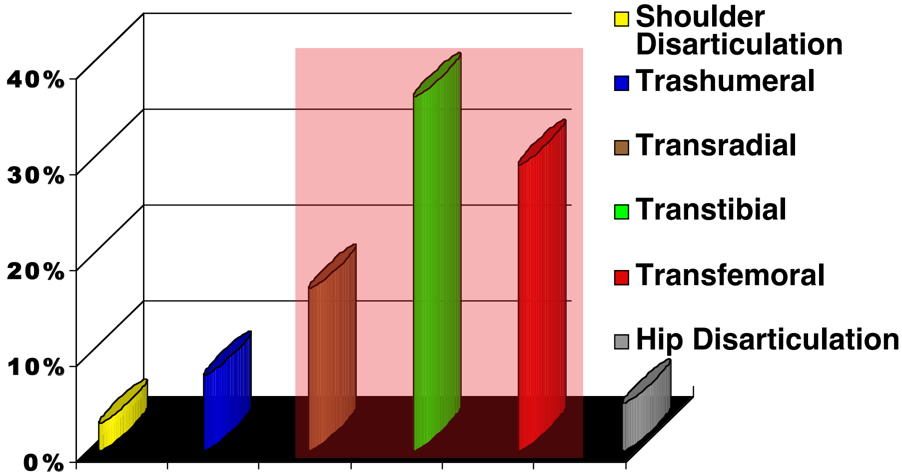
Incidence of Limb Amputation by Level



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Causes of UL Amputation

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Prevalence of UL Amputation

Of the 5/100,000 UE amputations in the US

- 3.8/100,000 were trauma related,
- 1.3/100,000 were dysvascular related,
- <1/100,000 were congenital or cancer related.

http://www.amputee-coalition.org/people-speak-out/background.html
Esquenazi, Disability and Rehabilitation 2004

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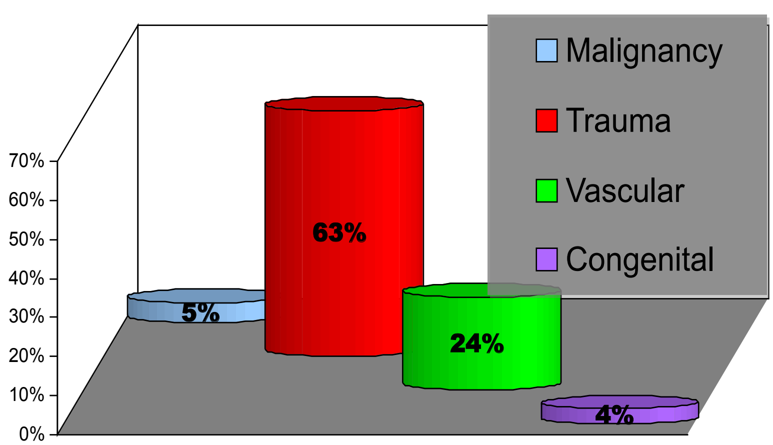
Causes of Upper Limb Amputation at MossRehab n=67



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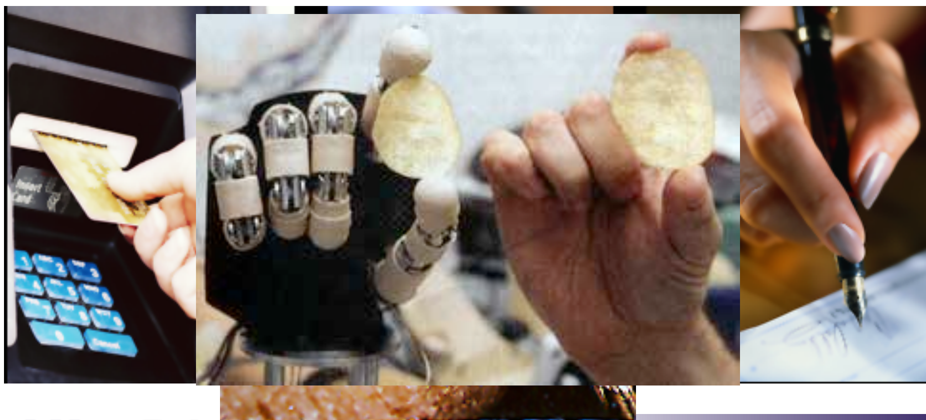
The human hand is a complex instrument with 80 degrees of freedom



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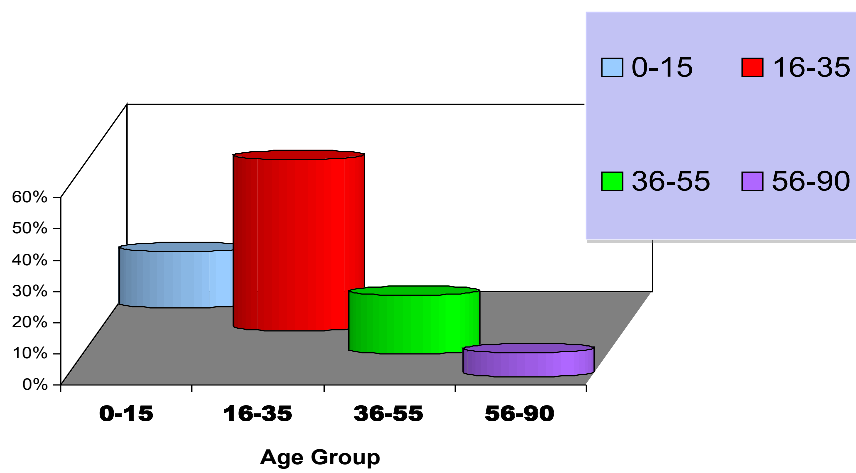
Upper Limb Amputation by Age Distribution



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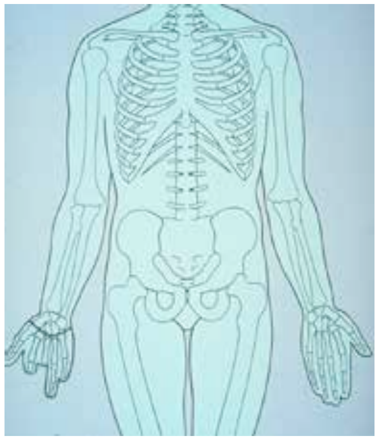
Transcarpal

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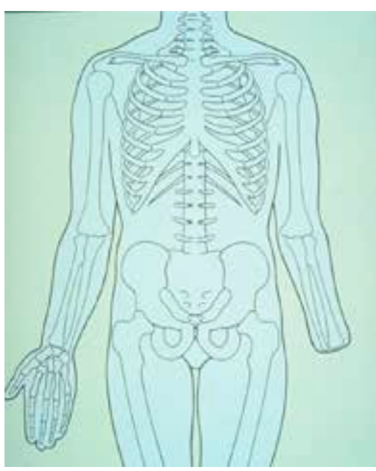
Wrist Disarticulation

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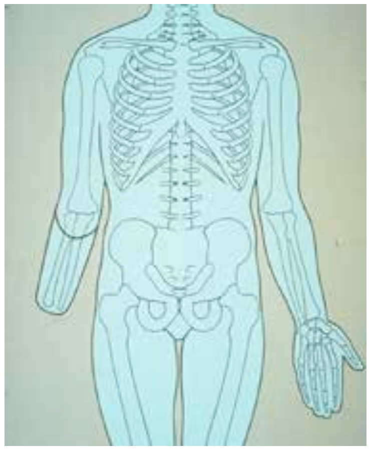
Transradial



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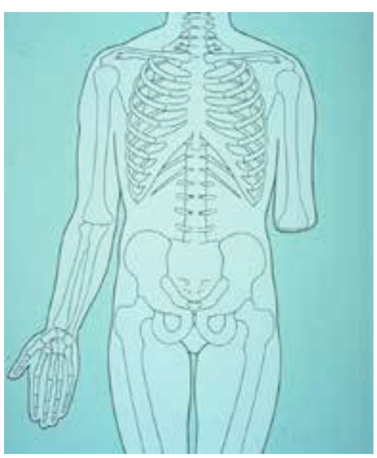
Elbow Disarticulation



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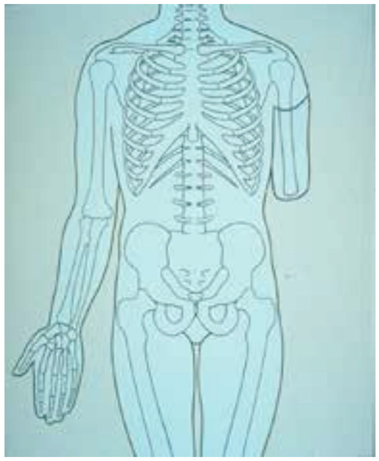
Transhumeral



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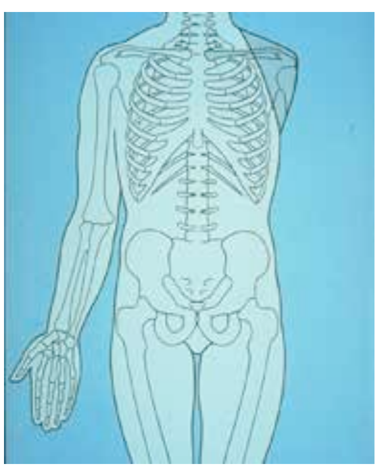
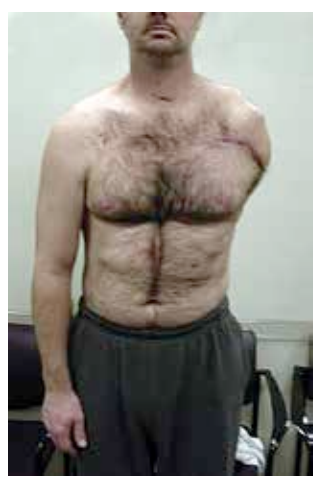
Shoulder Disarticulation





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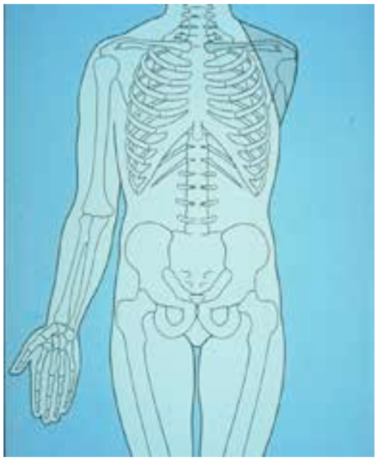
Forequarter Amputation



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Other injuries and Complications

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Prosthetic Control Options

- Myoelectric
- Switch control
- Tension *
- Brain Interface*

- Voluntary opening
- Voluntary closing

- Prefabricated
- Customized
- Custom

- External power
- Body power
- Cosmetic

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Passive Terminal Devices

- Cosmetic Restoration

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Terminal Device Activation Systems

Body Powered

- Voluntary Opening
- Voluntary Closing

External Powered

- Electric

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Active Terminal Devices

Body Power

Voluntary Opening, Hook

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Active Terminal Devices:

BP Voluntary Opening, Hook



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Active Terminal Devices:

BP Voluntary Opening Farmers Hook



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Active Terminal Devices:

BP Voluntary Closing, Hook

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Active Terminal Devices:

BP Voluntary Closing, Hook

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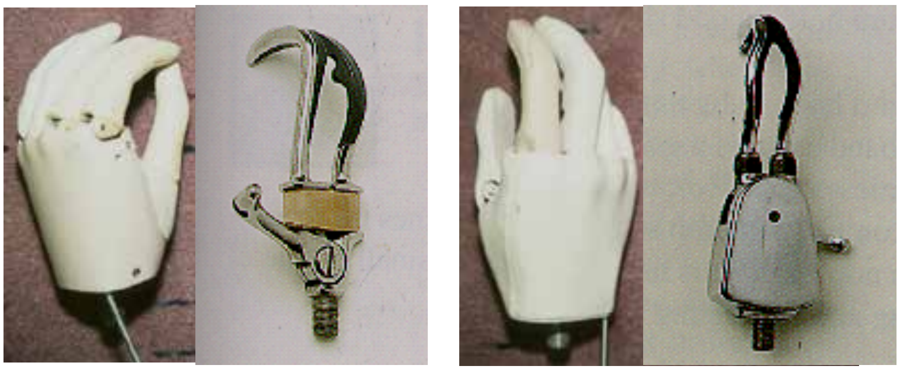
Active Terminal Devices:

Body Power, VO & VC Hands



More Acceptable Cosmesis

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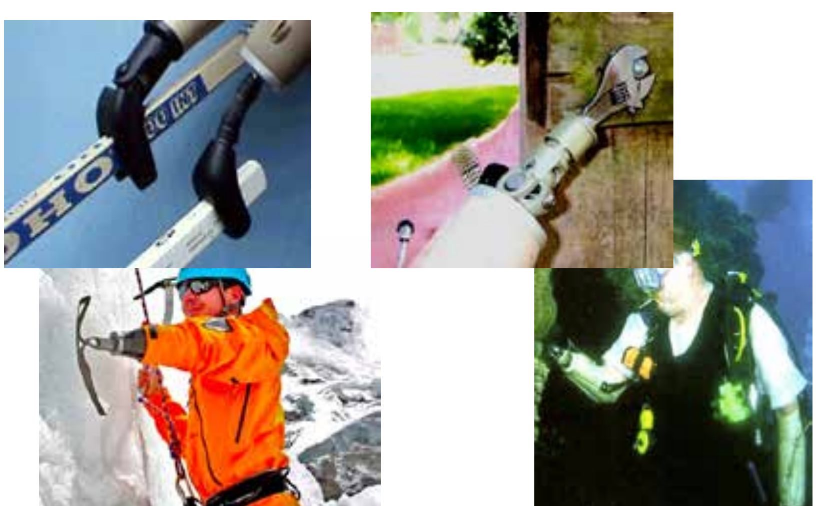
BP Function Specific Prosthetic Devices



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Partial Hand

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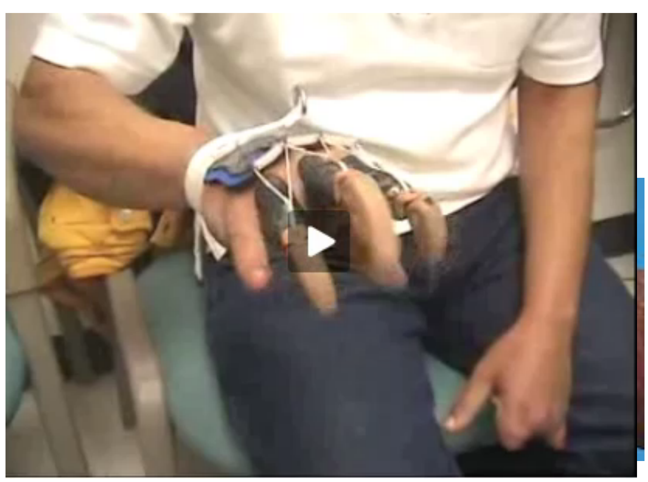
Partial Hand



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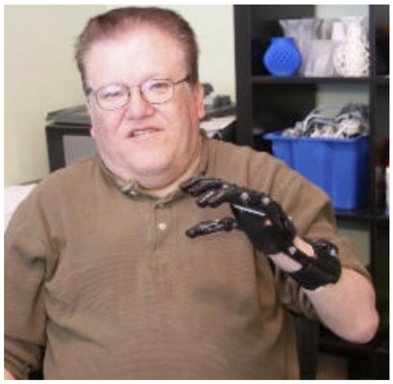
Partial Hand 3D Printing



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External Power Terminal Devices

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Myoelectric Control System

Makes use of remaining muscle signals after amputation to control prosthetic functions

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External Powered UL prosthetic use

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BP vs Myo Comparison

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Myorelectric Control
hand vs hook

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Multi Articulate Hands
5 motors

- From lateral or tip pinch to multiple grip styles

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Myoelectric Multi Articulation 5 motors

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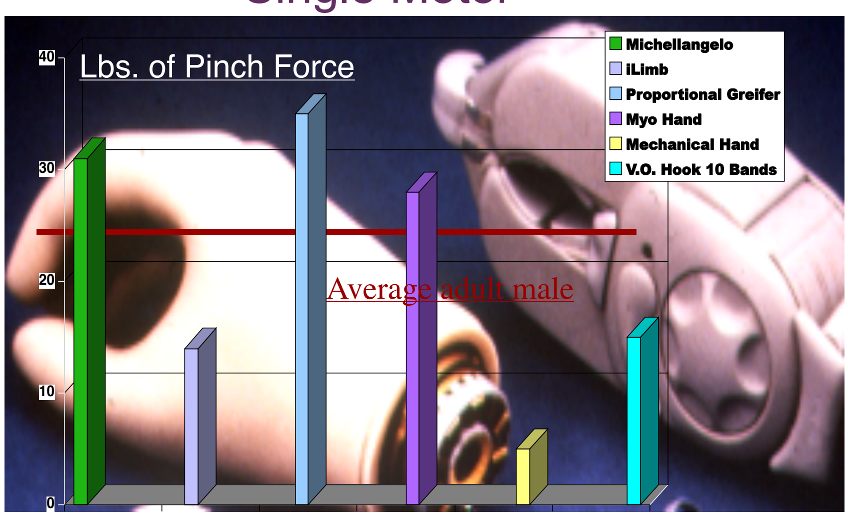
Comparative T.D. Force Generation Single Motor



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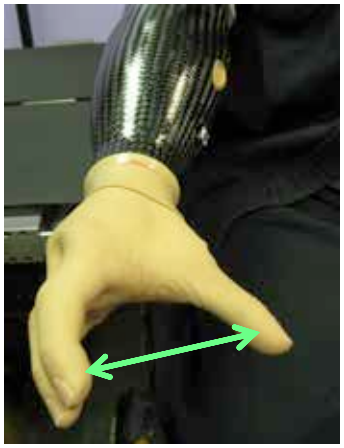
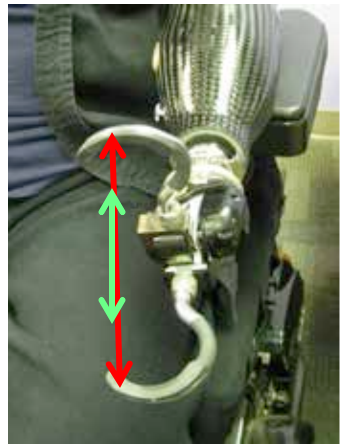
Terminal Device Opening (myo hand vs myo hook)





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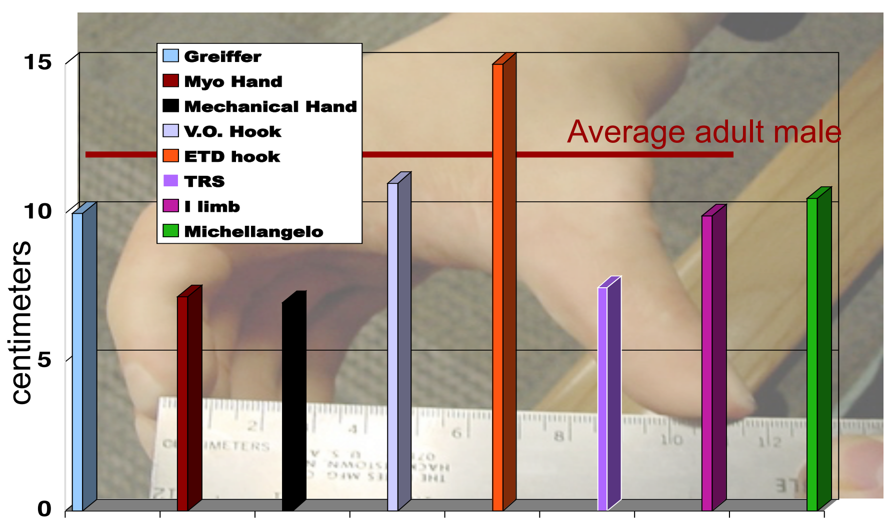
T.D. Opening at Tip for grasp in cm



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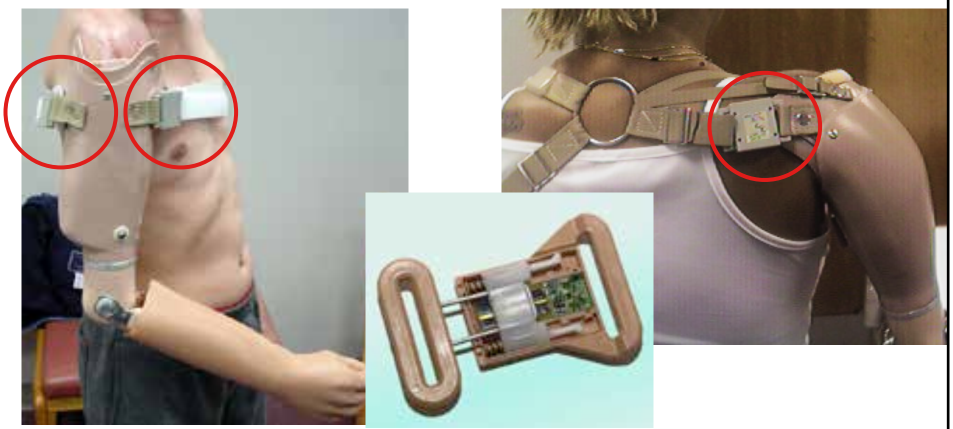
Switch Control
External Power Prostheses



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Myoelectric Control
External Power Bilateral
Shoulder Disarticulation

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Independence in ADLs is the goal
Passive Function Terminal Devices

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Wrist Components

External flexion

External flexion

Internal flexion

Friction rotation

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Wrist Flexion

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BP Spring Wrist Rotation

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Electric Wrist Rotation

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Electric Wrist Rotation

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Electric Wrist Rotation

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Elbow Components

- Mechanical
- Electro-Mechanical
- Spring assisted
- External power
  - Switches and sensors
  - Myoelectric controls

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Mechanical Elbow Designs

- Single Axis
- Polycentric
- Step-up Hinges
- Stump Activated Locks
- External Locking
- Internal Locking Elbow

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Electronic Elbows

Boston

Utah 3

ErgoArm Otto Bock

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Bilateral Electric Wrist Rotation

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Shoulder Components

- Bulkhead
- Flexion-Abduction
- Universal Joint

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Hybrid prosthesis
Forequarter Amputation

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63% of persons with
Upper Extremity amputation
use a
Body Powered Prosthesis

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Prosthetic Suspension Systems

- Harness
- Anatomical
- Suction
- Friction

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Prosthetic Harness Function

- Suspension
- Activation of TD
- Activation of Elbow
- Actuation of elbow lock

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How does a BP prosthesis works

- VO TD is closed by rubber bands
- VO TD is opened by tension on harness via Bowden control cable
- TD closes when harness relaxes
- For TH, elbow flexes then locked before TD opens

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Terminal Device Body Powered Activation Systems

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Body Powered Control Systems

	Terminal Device	Elbow Flexion	Elbow Lock
Shoulder Disarticulation	Biscapular abduction & Latissimus Dorsi	Biscapular abduction & Latissimus Dorsi	Scapular elevation
Transhumeral	Biscapular Abduction & Humeral Flexion	Biscapular Abduction & Humeral Flexion	Shoulder Depression & Humeral Abduction & Extension
Transradial	Biscapular Abduction & Humeral Flexion	NA	NA

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TRA BP Harness

Figure 8 Harness Functions

- Suspension,
- TD Activation

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TRA Harness Functions

Figure 9 Harness Function

- TD Activation
- No suspension

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THA Harness Functions

Elbow Locking

- Shoulder elevation

Dual Control Harness Functions

- Suspension,
- Elbow Activation,
- TD Activation

Elbow most be locked to activate terminal device

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Alternative Harness System

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Shoulder Disarticulation Harness External Powered Prosthesis

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TR Anatomical Suspension Supracondylar
Münster socket

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TR Anatomical Suspension Supracondylar
Northwestern

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TR Anatomical Flexible Suspension

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Silicone Suspension

- Useful in cases where skin is delicate 2nd to scars
- Short residual limb friction provides suspension

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Silicone Suspension for TR body powered prosthesis

Improves the suspension and comfort for some transradial amputees

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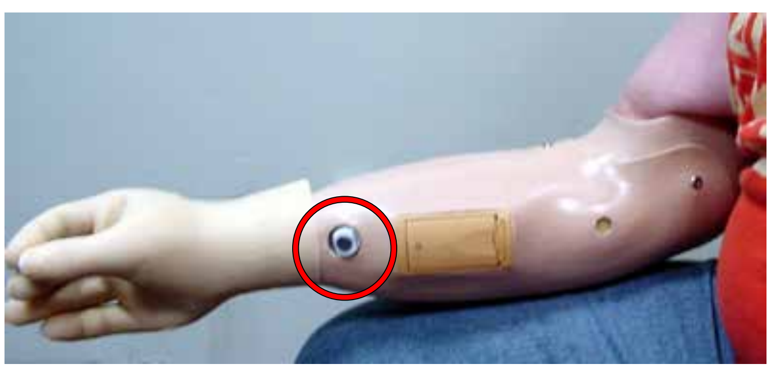
Suction Suspension

Myoelectric systems can be suspended with suction



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Suction & Friction Suspension for myoelectric THA

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Myoelectric Control Socket Design

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Bilateral Shoulder Disarticulation

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Innovative Suspensions Osseo-integration

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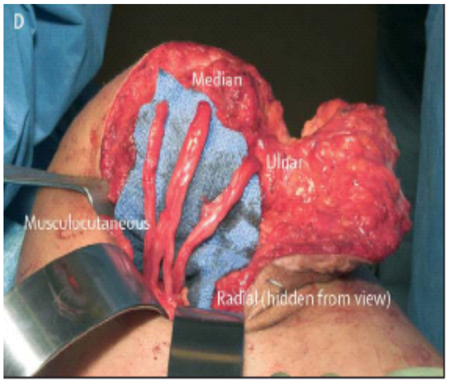
Targeted Muscle Re-innervation (TMR)



- Kuiken, et al; 2004
- Performed so far in +/- 20 patients
- Dissection of musculocutaneous, radial, ulnar, and median nerves
- Reimplanted on pectoralis and serratus muscles
- Allows simultaneous control of multiple prosthetic joints

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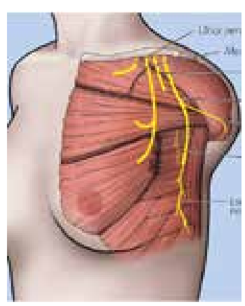
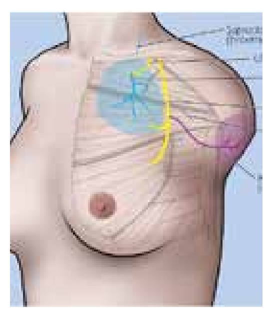
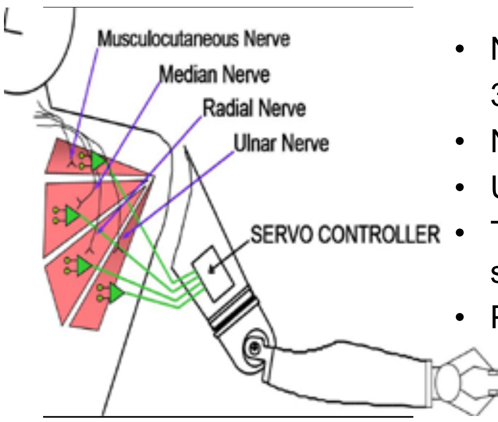
Targeted Reinnervation





Courtesy of Dr. Kuiken

Targeted Muscle Re-innervation (TMR)



- Nerves must regenerate:
  3 months for detectable signal
- Need intact brachial plexus
- Utilizes existing technology
- Time to proficiency much shorter, once training starts
- Potential for sensory feedback

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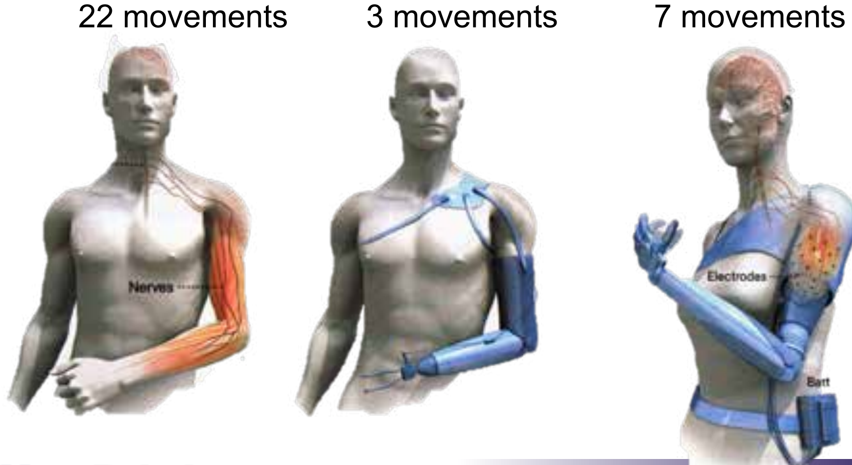
The Evolution of the Transhumeral Prosthesis

22 movements | 3 movements | 7 movements



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7 Movements Demonstration

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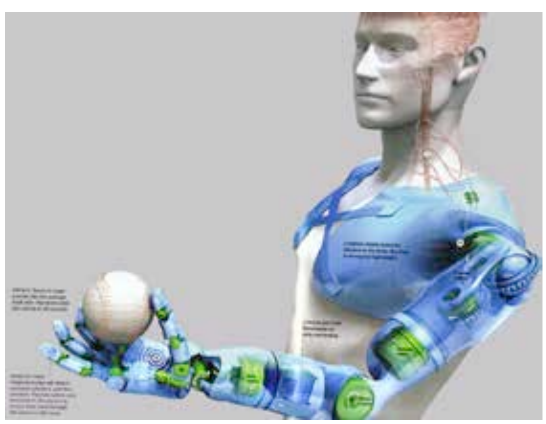
Future Developments
22 Movements



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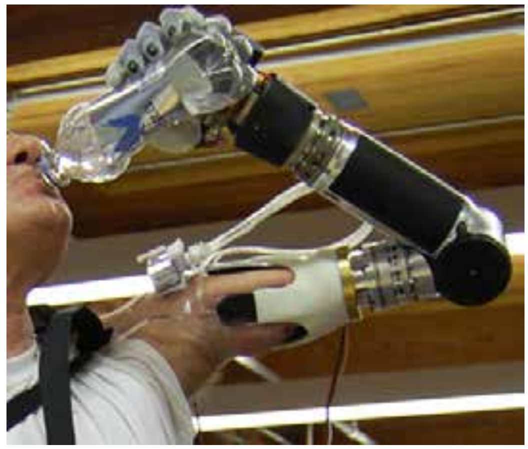
Drinking Function Differences



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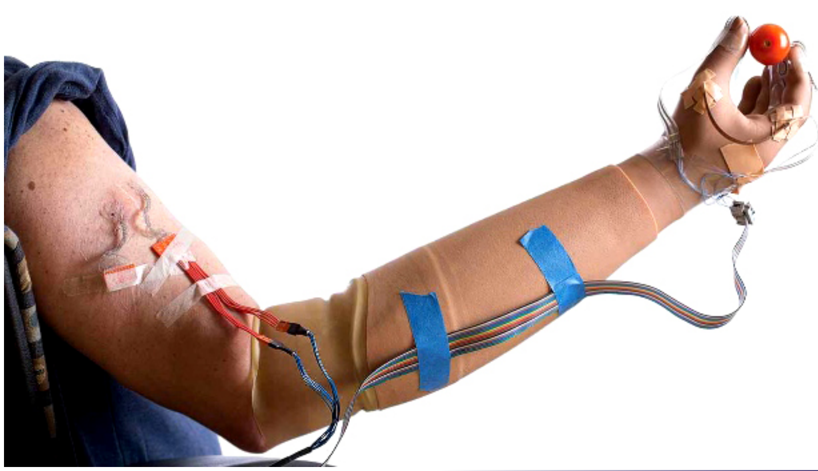
Sensory feedback



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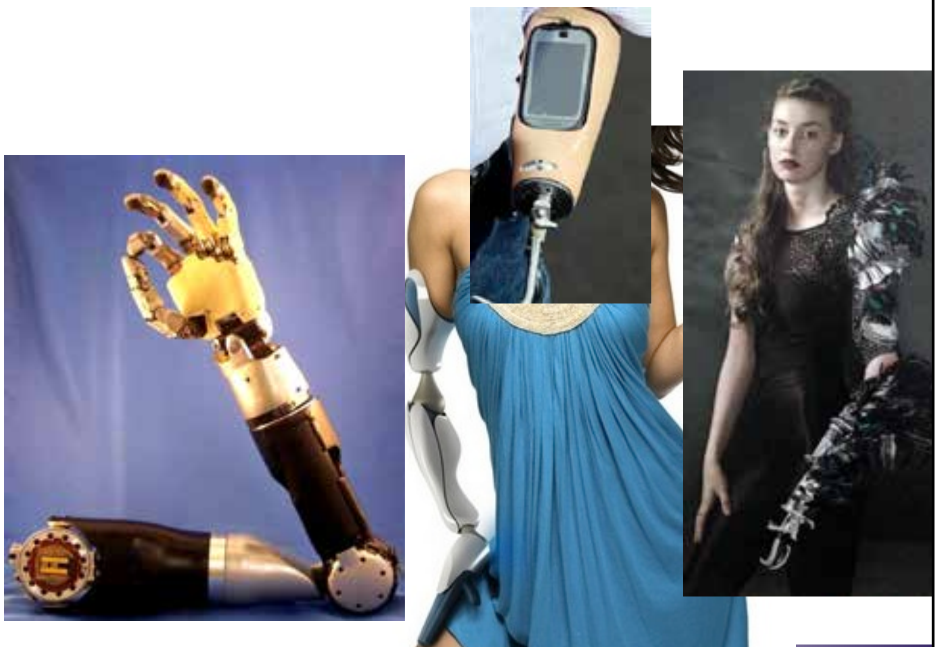

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Upper Limb Transplantation

Courtesy of Dr. Scott Levin

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Upper Limb Transplantation

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Prosthetic Training

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Training Bilateral TR

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Training
Self Feeding bilateral SD

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Training Quadrilateral amputation driving

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Toileting and Showering

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Virtual Reality Rehabilitation

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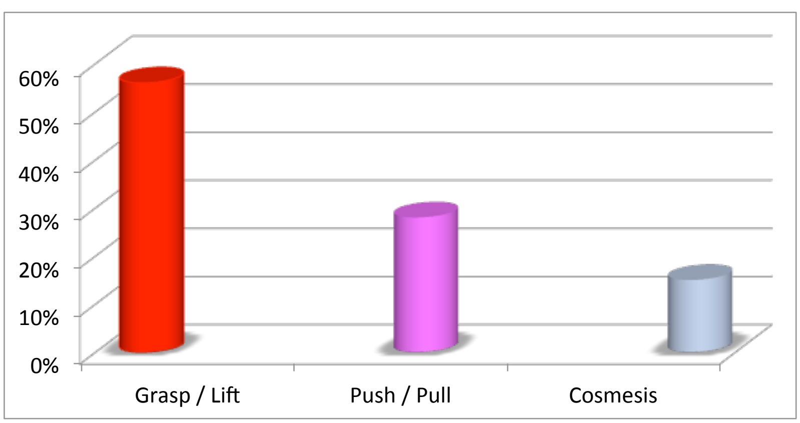
Self Management interventions for amputees in a virtual world environment. Winkler, Cooper, Esquenazi 2016

Primary use of UL prosthesis



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Function and prosthetic device

		Vietnam		OIF/OEF	
		#	%	#	%
Unilateral Upper Limb	**N =**	**47**		**50**	
Prosthesis used to perform:	Majority of daily tasks	13	27.7	18	36.0
	Minority of daily tasks	20	42.6	20	40.0
Total		**33**	**70.3**	**38**	**76.0**
No prosthesis used		14	29.8	12	24.0
Unilateral Lower Limb	**N =**	**178**		**172**	
Prosthesis used to perform (by functional level):	Do not walk (1, 2)	2	1.3	1	0.6
	Household walker (3)	15	8.4	10	5.8
	Community walker (4)	34	19.1	23	13.4
	Varying speed walker (5)	63	35.4	39	22.7
	Low-impact activities (6)	29	16.3	44	25.6
	High-impact activities (7)	7	3.9	45	26.2
Total		**150**	**84.3**	**162**	**94.2*** **
No prosthesis used		28	15.7	10	5.8**

*p < 0.05 ** p < 0.01 *** p < 0.001

Service Members and Veterans with Major Traumatic Limb Loss from the Vietnam and OIF/OEF Conflicts: Survey Methods, Participants, and Summary Findings JRRD 2010, Reiber, G et al. and the Prosthetics Expert Panel

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Unilateral Upper Limb Loss: Satisfaction and Prosthetic Device Use in Vietnam and OIF/OEF Soldiers

- Prostheses use is more frequent for TRA or distal levels
- Other hand is used more often in a compensatory fashion for higher levels.
- Most use prostheses (70% Vietnam and 76% OIF/OEF).
- BP devices are favored by the Vietnam cohort, while OIF/OEF cohort use both myoelectric and BP devices
- Frequency of prosthetic rejection due to dissatisfaction is high for the Vietnam cohort (23%) and higher for the OIF/OEF cohort (45%)

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McFarland, Winkler, Jones, Heinemann, Esquenazi, Reiber. JRRD 2010.

Principle Causes of UL Prostheses Rejection

- Decreased shoulder mobility
- Brachial plexopathy
- Delay in initial prosthetic fitting > 6 months
- Pain
- Hot and humid weather

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Other Reasons for Rejection:

- Limited usefulness
- Late fitting
- Excessive weight
- Socket discomfort
- Poor cosmesis
- Poor satisfaction
- Not enough training to become proficient user

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Comparison of Upper Limb Prostheses

Passive	Body-Powered	Battery Powered
Lightest	Mod. Lightweight	Heaviest
Better cosmesis	Worst cosmesis	Mod. Cosmesis
Minimal sensory	Best sensory feedback	Limited sensory feedback
No harnessing	Most harnessing	Less or no harnessing
May be high cost	Moderate cost	Most costly
Passive function	Functional	Functional
No energy expenditure	Most energy expenditure	Less energy expenditure
May stain easily	Most durable	More maintenance required
	Choice of terminal devices	Choice of TD and elbows
No body movement required	Most body movement to operate	Least body movement to operate
No grasp	Weaker grasp (VC)	Stronger grasp (active)
		Possible longer training time

Body-Powered Advantages

- Heavy Duty Construction
- Proprioception
- Less Expensive
- Lighter in Weight
- Reduced Cost and Maintenance

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Body-Powered Disadvantages

- Limited grip force
  (shoulder strength and # rubber bands tolerance)
- Functional envelope (ROM) is limited
- Harness can be uncomfortable and restrictive
- Less cosmesis
- Possible over-use, nerve entrapment syndrome

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Brachial Plexus Injury

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