Amputation Rehabilitation and Prosthetic Use

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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

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

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/nhisd/nhis_dis.htm
- The patient population with limb amputations is expected to double in 25 years

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
- 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

Amputation Levels

- Transcarpal 18%
- Wrist Disarticulation 10%
- Transradial 31%
- Elbow Disarticulation 5%
- Transhumeral 27%
- Shoulder Disarticulation 7%
- Forequarter 2%
Incidence of Limb Amputation by Level
- Shoulder Disarticulation
- Trashumeral
- Transradial
- Transtibial
- Transfemoral
- Hip Disarticulation

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.

Causes of Upper Limb Amputation at MossRehab
- Malignancy
- Trauma
- Vascular
- Congenital

Upper Limb Amputation by Age Distribution
- 0-15
- 16-35
- 36-55
- 56-90

Transcarpal
- Wrist Disarticulation
Prosthetics Course 2016

Transradial

Elbow Disarticulation

Transhumeral

Shoulder Disarticulation

Forequarter Amputation

Prosthetic Control Options

- Myoelectric
- Switch control
- Tension
- Brain Interface

- Voluntary opening
- Voluntary closing

- Prefabricated
- Customized
- Custom

- External power
- Body power
- Cosmetic
Passive Terminal Devices
• Cosmetic Restoration

Terminal Device Activation Systems

Body Powered
• Voluntary Opening
• Voluntary Closing

External Powered

Active Terminal Devices
Body Power
Voluntary Opening, Hook

Active Terminal Devices:
BP Voluntary Opening, Hook

Active Terminal Devices:
BP Voluntary Opening Farmers Hook

Active Terminal Devices:
BP Voluntary Closing, Hook
Active Terminal Devices:
BP Voluntary Closing, Hook

Active Terminal Devices:
Body Power, VO & VC Hands

More Acceptable Cosmesis

Partial Hand

External Power Terminal Devices

Powerful Grip +
Graded Prehension +
Ease of Operation
Better Cosmesis

Partial Hand
3D Printed

Myoelectric Control System

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

Multi Articulate Hands

• From lateral or tip pinch to multiple grip styles

Comparative T.D. Force Generation

Terminal Device Opening (myo hand vs myo hook)

T.D. Opening at Tip for grasp in cm

Wrist Components
Electric Wrist Rotation

Elbow Components
• Mechanical
• Electro-Mechanical
• Spring assisted
• External power
  – Switches and sensors
  – Myoelectric controls

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

Shoulder Components
• Bulkhead
• Flexion-Abduction
• Universal Joint

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

Prosthetic Suspension Systems
- Harness
- Anatomical
- Suction
- Friction
How does a BP prosthesis work

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

Body Powered Control Systems

<table>
<thead>
<tr>
<th>Shoulder Disarticulation</th>
<th>Terminal Device</th>
<th>Elbow Flexion</th>
<th>Elbow Lock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transhumeral</td>
<td>Bicapsular abduction &amp; Latissimus Dorsi</td>
<td>Bicapsular abduction &amp; Latissimus Dorsi</td>
<td>Scapular elevation</td>
</tr>
<tr>
<td>Transradial</td>
<td>Bicapsular Abduction &amp; Humeral Flexion</td>
<td>Bicapsular Abduction &amp; Humeral Flexion</td>
<td>Shoulder Depression &amp; Humeral Abduction &amp; Extension</td>
</tr>
<tr>
<td></td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

TR Harness Functions

- Suspension, TD Activation

TH Harness Functions

- Suspension, Elbow Activation, TD Activation
- Elbow must be locked to activate terminal device
Alternative Harness System

Shoulder Disarticulation Harness External Powered Prosthesis

TR Anatomical Suspension
Supracondylar Münster socket

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

Silicone Suspension for TR body powered prosthesis
Improves the suspension and comfort for some transradial amputees

Suction Suspension
Myoelectric systems can be suspended with suction
**Suction & Friction Suspension for myoelectric THA**

**Bilateral Shoulder Disarticulation**

**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

**Targeted Reinnervation**

**Evolution of Transhumeral Prosthesis**

- 22 movements
- 3 movements
- 7 movements

**Future Developments**

- 22 Movements
JRRD 2010, Reiber, Get al. and the Prosthetics Expert Panel

Function and Prosthetic Device

<table>
<thead>
<tr>
<th>Functional Level &amp; Prosthetic Use</th>
<th>Upper %</th>
<th>Upper Median</th>
<th>Lower %</th>
<th>Lower Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>No prosthesis use</td>
<td>14</td>
<td>20.3</td>
<td>12</td>
<td>24.9</td>
</tr>
<tr>
<td>Prosthetic use</td>
<td>234</td>
<td>54.3</td>
<td>185</td>
<td>77.9</td>
</tr>
<tr>
<td>Prosthetic use and functional level</td>
<td>281</td>
<td>52.0</td>
<td>201</td>
<td>71.4</td>
</tr>
</tbody>
</table>

Prosthetic Use and Functional Level:
- House walking (4)
- Community walking (4)
- Varying speed walker (5)
- Nonisko activities (6)
- High impact activities (7)

Total
- No prosthesis use: 14
- Prosthetic use: 234
- Prosthetic use and functional level: 281

Primary use of UL Prosthesis

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%).
**Principle Causes of UL Prostheses Rejection**

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

**Other Reasons for Rejection:**

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

**Comparison of Upper Limb Prostheses**

<table>
<thead>
<tr>
<th>Passive</th>
<th>Body-Powered</th>
<th>Battery Powered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightest</td>
<td>Mod. Lightweight</td>
<td>Heaviest</td>
</tr>
<tr>
<td>Better cosmesis</td>
<td>Worst cosmesis</td>
<td>Mod. Cosmesis</td>
</tr>
<tr>
<td>Minimally sensory</td>
<td>Best sensory feedback</td>
<td>Limited sensory feedback</td>
</tr>
<tr>
<td>No harnessing</td>
<td>Most harnessing</td>
<td>Less or no harnessing</td>
</tr>
<tr>
<td>May be high cost</td>
<td>Moderate cost</td>
<td>Most costly</td>
</tr>
<tr>
<td>Passive function</td>
<td>Functional</td>
<td>Functional</td>
</tr>
<tr>
<td>No energy expenditure</td>
<td>Most energy expenditure</td>
<td>Less energy expenditure</td>
</tr>
<tr>
<td>May stain easily</td>
<td>Most durable</td>
<td>More maintenance required</td>
</tr>
<tr>
<td>No body movement required</td>
<td>Most body movement to operate</td>
<td>Least body movement to operate</td>
</tr>
<tr>
<td>No grasp</td>
<td>Weaker grasp (VC)</td>
<td>Stronger grasp (active)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Possible longer training time</td>
</tr>
</tbody>
</table>

**Body-Powered Advantages**

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

**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

**Body power prosthesis most prescribed**

**Transradial Rx**
- Double wall socket
- VO hook
- Quick disconnect wrist
- Flexible hinges
- Triceps pad
- Figure 8 harness

**Transhumeral Rx**
- Double wall socket
- VO hook
- Quick disconnect wrist
- Internal lock elbow
- Bowden control cable
- Figure 8 harness with elbow lock strap
Lower Limb

Eskienazi LE Amputation by Age

- 10 to 20
- 21 to 45
- 46 to 60
- 61 to 85

Mortality After Diabetic Related LE Amputation
- 12% will die in 30 days,
- 42% in 3 years,
- 56% in 5 years

- Contributing factors:
  - Age
  - Level of amputation
  - Race
  - Tobacco use
  - Renal or cardiac co-morbidity

Trans-Tibial Amputation
- Aim is to preserve the knee
- Avoid skin grafts unless to save the knee
- Long posterior flap is preferred
- Residual tibia should be beveled and no longer than the junction of distal 1/3
- Fibula should be slightly shorter than tibia
- Perform myodesis closure
- Post-operative cast for protection

Joint Flexion Contracture
- Flexion contractures are frequent
- Predisposes ulceration
- Easily prevented with early rehabilitation
- Not easily treated
- Makes prosthetic fitting and walking more difficult
Post-Operative Casting

**IPORD**

- Rigid dressing:
  - Maintains good knee position
  - Controls edema
  - Protects skin from trauma
  - Allows early rehabilitation

Immediate Post Operative Pylon

- Prevents edema and joint contractures
- Promotes wound healing and stump maturation
- Allows early weight bearing and in some cases ambulation, i.e. trauma

TF Level Surgical Intervention

- Always try to preserve the knee
- Fish mouth closure
- Myoplastic closure to stabilize stump with hip adductors re-attachment distally to improve femoral control

New Surgeries

**Keep-Walking® Device**

Pain in Limb Amputation

- Four major sources of pain:
  - Post surgical pain
  - Residual limb pain
  - Prosthetic related pain
  - Phantom pain

HO in Amputation

- Incidence in up to 70% of traumatic amputees
- Less than 30% of vascular amputees
- More frequent in TFA
Heterotopic Ossification

Preparatory Prosthesis Phase

- Pre-prosthetic management
- Gait training with temporary prosthesis (pylon)
- Promote limb maturation
- Edema control and limb shape
- Pain management
- Prosthetic component selection

The Rx

- Please write a prosthetic Rx for a 64-year-old man with left TTA complications from DM.
- The patient works in a restaurant in Philadelphia.

Prosthetic Rx

- Construction design
- Socket
- Suspension
- Connecting parts
- Foot
- Knee (in TFA or higher)
- Cosmetic cover
- Accessories

Prosthesis Selection Criteria

- Desired function
- Reliability
- Appropriateness
- Effectiveness
- Weight
- Cost

TT prostheses
Endoskeletal Systems

- Adjustable
  - flexion / extension
  - abd / adduction
  - rotation
  - limited translation

- Re-alignable
- Allows for component interchange or replacement

SACH Foot
Solid Ankle Cushion Heel

- Widely used since the 1950s
- Simple, basic, reliable design
- For limited ambulators with stable knee
- Non-adjustable heel height
- No energy storage

Multi-Axis Ankle-Foot

Single Axis Ankle-Foot

Energy Storing Feet

Seattle Foot introduced in mid 80’s
Subjective sense of active push-off
For increased activity level
Moderate to higher cost
Adding Mobility to ES Designs

- Adjustable resistance
- Split toe design allows some degree of inversion-eversion

Shock Absorbing and Rotating Pylons

- Ceterus
- TT Pylon
- Vari-Flex

TT Amputation

High Performance feet

Silicone Partial Foot

Foot Selection Criteria

- Weight
- Cost
- Desired function
- Reliability
- Efficiency
Energy Storing Feet

- No O₂ advantage for slow, level walking
- Clear O₂ advantage for higher speeds and inclines
- No age restriction for ES feet, think function

Energy Cost of Ambulation at Different Levels of Lower Limb Amputation

Transtibial Socket and Suspension

Abnormal Pressures
Pressure Distribution

- Intolerant
- Tolerant

Prosthetic Socks

Transtibial Suspension
Sleeve Friction Suspension
- Neoprene
- Spandex
- Elastic rubberized
- Rubber

Iceross Silicone Suspension

Anatomic Suspension
Supracondylar / Suprapatellar
- Minimal pistoning
- SC adds ML stability
- SP adds hyperextension stop
- Easy to don, doff
- Localized forces = pressure
- Often combined with other suspensions

Anatomic Suspension
Removable Wall Supracondylar
Strap Suspension Cuff

Thigh Corset & Joints
- Very short RL
- Delicate or sensitive skin
- Knee contracture
- Cannot tolerate full WB
- Ligamentous disruption
- Bulky, heavy, awkward
- Quadriceps atrophy

Cosmetic Cover

Trans Femoral Componentry

Transfemoral Sockets
- Plug Fit
- Quadrilateral Ischial Weight Bearing
- Modified IPOS
- Ischial containment

Ischial Containment Frame Suction Socket
Donning a prosthesis
Push-in Pull-in

Transfemoral Suspension
- Suction
- Friction / Vacuum
- Anatomical
- Straps
- External Joint

Suction Socket Suspension
- Difficult to don & doff
- Limb volume must be stable
- Hygiene
- Perspiration
- Not adjustable
- Very secure
- Allows full range of motion

Silicone Suspension

Silesian Belt TES Belt

Pelvic Belt & Hip Joint
- Reduces hip torque
- Increases ML stability
- Bulky, heavy, awkward
- Interferes with toileting and seating in a car or low chair
**Knee Joints**

- Manual Locking
  - Knee of last resort
  - Maximum stability + chronic gait deviations
  - Interferes with sitting, falling safely
  - Try to avoid using 2 locking knees

**Weight Activated Stance Control**

- Adds stance phase weight-activated stability
- For limited ambulators + slow walkers
- Hip flexion deformity
- May make sitting very difficult for bilateral

**Knees Carbon Graphite Hydraulic**

- Reliable
- Some maintenance
- Manually adjustable
- Swing & Stance controllers
- Rubber seals may dry up over time

**Polycentric (4 bar)**

- Excellent stability + good swing phase function
- Use to increase stability and confidence while walking
- Or - to accommodate very long RLs such as KD
Swing / Stance Controllers for Knees

Hydraulic Cylinder Microprocessor Controller

Prosthetic Knee Selection Algorithm

Medicare Functional Levels (K system)
**Medicare Components Benefit**

<table>
<thead>
<tr>
<th>Level</th>
<th>Component Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>K0</td>
<td>None</td>
</tr>
<tr>
<td>K1</td>
<td>SACH or single axis foot</td>
</tr>
<tr>
<td></td>
<td>No fluid control knee</td>
</tr>
<tr>
<td>K2</td>
<td>Flexible keel, multiaxis foot</td>
</tr>
<tr>
<td></td>
<td>No fluid control knee</td>
</tr>
<tr>
<td>K3</td>
<td>Energy storing, flex or multiaxis foot</td>
</tr>
<tr>
<td></td>
<td>Fluid and microprocessor knees</td>
</tr>
<tr>
<td>K4</td>
<td>All except for powered components</td>
</tr>
</tbody>
</table>

**Microprocessor Functional Capability**

- Functional Level 3-4
- Provides resistance to flexion/extension during swing phase
- Enables variable cadence, ability to change walking speeds without hesitation
- On-board microprocessor analyzes gait and selects appropriate resistance for smooth swing phase.
- Provides variable cadence and ability to change walking speeds without hesitation
- Added expense due to computer technology
- Maintenance is essential

**Newer components**

- Patient wears an instrumented insole under the intact foot with a transmitter
- The forces on the insole determine the movement and location of the non-amputated leg
- Power Knee calculates and motors adjusts where the prosthetic leg should be

**Powered components**

**Microprocessor Controlled Powered Prostheses (HP)**
Prescribe based on function
Limited ambulator = basic design
Greater activity level = more sophisticated componentry design