Objectives

- To have a better understanding of:
  - The types of **PAIN** common to amputees, the cause or current theory for symptoms and the recommended management.
  - The common **DERMATOLOGIC** & musculoskeletal conditions in amputees and associated treatment.
  - The **ENERGY** cost of gait associated with the different levels of lower extremity amputation.
Advancements in Amputee Medicine

Distribution of Amputations

In the USA

- 185,000 amputations per year
- 1.6 million persons living w/ limb loss
- 86% are lower limb amputations
- Approx. 380,000 have a TTA
  - around 72% due to vascular d/z
  - around 7% due to trauma
Volume Management - Goals

- Pre-prosthetic:
  - Reduce swelling
  - Form optimal shape to best fit in to socket
- Post-prosthetic:
  - Maintain limb volume for proper prosthetic fit
  - Minimize dermatologic and MSK issues

Volume Management - Methods

- ACE wraps (Figure 8)
  - Initial mgmt
  - Risk of Choke Syndrome
    - (Circumferential wrap)
- Tubigrip/Stump Shrinkers
  - Chronic treatment
  - After incision has healed
Dermatologic Conditions

- Dermatitis (most common in traumatic)
- Ulcer/pressure sites (most common in vascular disease)
- Verrucous Hyperplasia
- Fungal/Bacterial Infection
- Callus
- Cyst

### Table 2: Dermatologic conditions in amputees and types of prosthesis

<table>
<thead>
<tr>
<th>Dermatologic condition</th>
<th>Total patients Number (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irritant contact dermatitis</td>
<td>32 (30.4)</td>
</tr>
<tr>
<td>Allergic contact dermatitis</td>
<td>25 (23.9)</td>
</tr>
<tr>
<td>Infected irritant contact dermatitis</td>
<td>5 (4.6)</td>
</tr>
<tr>
<td>Infected allergic contact dermatitis</td>
<td>3 (2.9)</td>
</tr>
<tr>
<td>Bacterial infection</td>
<td>12 (11.5)</td>
</tr>
<tr>
<td>Callus</td>
<td>11 (10.4)</td>
</tr>
<tr>
<td>Fungal Infection</td>
<td>4 (3.8)</td>
</tr>
<tr>
<td>Erosion</td>
<td>5 (4.6)</td>
</tr>
<tr>
<td>Verrucous hyperplasia</td>
<td>3 (2.9)</td>
</tr>
<tr>
<td>Epidermoid cyst</td>
<td>3 (2.9)</td>
</tr>
<tr>
<td>Keloid</td>
<td>1 (0.9)</td>
</tr>
<tr>
<td>Haematoma</td>
<td>1 (0.9)</td>
</tr>
<tr>
<td>Total</td>
<td>105 (100)</td>
</tr>
</tbody>
</table>
# Dermatologic Conditions – PVD

## Table 1: Patient demographic and amputation information for five most common skin problems

<table>
<thead>
<tr>
<th>Condition</th>
<th>Ulcer</th>
<th>Irritation</th>
<th>Inclusion</th>
<th>Cyst</th>
<th>Callus</th>
<th>Verrucose Hyperplasia</th>
<th>All Skin Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td>56.5 (±15.1)</td>
<td>59.5 (±16.7)</td>
<td>44.1 (±16.3)</td>
<td>56.7 (±15.9)</td>
<td>60.3 (±13.1)</td>
<td>54.7 (±16.3)</td>
<td></td>
</tr>
<tr>
<td><strong>Age at amputation</strong></td>
<td>50.5 (±18.4)</td>
<td>48.7 (±24.4)</td>
<td>32.2 (±21.0)</td>
<td>39.2 (±22.9)</td>
<td>43.9 (±21.2)</td>
<td>44.1 (±22.3)</td>
<td></td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>112 (79.4%)</td>
<td>68 (73.1%)</td>
<td>67 (84.8%)</td>
<td>51 (85.0%)</td>
<td>40 (85.1%)</td>
<td>418 (79.2%)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>29 (20.6%)</td>
<td>25 (26.9%)</td>
<td>12 (15.2%)</td>
<td>9 (15.0%)</td>
<td>7 (14.9%)</td>
<td>110 (20.8%)</td>
<td></td>
</tr>
<tr>
<td><strong>Reason for amputation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peripheral vascular</td>
<td>44 (51.6%)</td>
<td>18 (22.8%)</td>
<td>24 (40.0%)</td>
<td>22 (46.8%)</td>
<td>254 (48.2%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disease ± diabetes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trauma</td>
<td>26 (18.4%)</td>
<td>38 (40.9%)</td>
<td>42 (53.2%)</td>
<td>26 (43.3%)</td>
<td>15 (31.9%)</td>
<td>186 (35.2%)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>15 (10.0%)</td>
<td>7 (7.5%)</td>
<td>19 (24.5%)</td>
<td>10 (16.7%)</td>
<td>10 (21.3%)</td>
<td>88 (16.6%)</td>
<td></td>
</tr>
</tbody>
</table>

* indicates a significant difference when compared with all other skin problems with respect to that factor ($p < 0.05$).

## Dermatologic Conditions: Ulcer/pressure sores
Dermatologic Conditions:
Dermatitis

http://www.dermnetnz.org

Choke Stump Syndrome
Dermatologic Conditions:
Verrucous Hyperplasia

Dermatologic Conditions:
Fungal Infection

http://www.dermnetnz.org
Etiology of common Skin problems

**Provocative Determinants:**
- Higher level of amputation
- Poor socket fit
- Smoking
- High Frequency of washing stump (≥ 1 time/day)

**Derm Treatment/Recommendations**

**Socket modification, Hygiene, Skin care, Medications**
Pressure Sensitive Areas

Major source of PAIN

Amputee Pain

- Stump pain
- Phantom Limb Sensation (PLS)
- Phantom Limb Pain (PLP)
Stump Pain

- Pain in the residual portion of the limb or stump
  - Bone spurs (#1 cause of MSK residual limb pain)
  - Boney overgrowth
  - HO
  - Neuroma
  - Edema (Tx: wrapping/shrinker)
  - Skin conditions

- Treatment
  - Socket Modification/Replacement
  - Medications (NSAIDs)
  - Surgical

Phantom Limb Sensation and Pain

- Phantom Limb Sensation
  - Any sensation (paresthesia, dysesthesia, hyperpathia) of the missing limb except pain.
  - Often not treated

- Phantom Limb Pain
  - A painful sensation perceived in the missing limb after amputation, that is distinct from stump pain
  - Rates: 2% - 80% (vary depending on methods of study)
  - Prospective research: 60% - 70% have PLP 1 year after amputation
  - Believed to diminish with time

Parkes, 1972
Phantom Limb Sensation and Pain

- Phantom Limb Pain
  - May be related to “Pain Memory”
    - Painful phantom sensations mimic the pain felt before amputation
  - Cerebral imprinting is the commonly accepted theory
  - Neuroma formation may be related

Parkes, 1972

PLP Risk Factors

- Older (most under 35 yr have moderate or no PLP)
- Osteomyelitis – “always have severe pain”
- Left sided lesions
- Multiple surgical operations
- Recurrent depression
- Tender Stump

Parkes, 1972
PLP Treatment

- Time
- Non-Pharmacological
  - Mirror therapy
  - Biofeedback
  - Mental Imagery
  - Hypnosis
  - Meditation
- Surgeries/procedures
  - Chemo-denervation
  - Cryo-ablation
  - Neurostimulation devices

PLP Medications

- Short-term peri-operative treatment
  - IV ketamine and IV morphine
- Intermediate to long-term (8 weeks to 1 year)
  - PO morphine (Considered first-line therapy)
- Short to long-term pain relief (peri-operatively up to 1 year)
  - Peri-operative epidural anesthesia with morphine and bupivacaine
  - mixed evidence of efficacy
- Intermediate duration (6-8 weeks, but no significant change at 6 months)
  - Gabapentin 2400 - 3600 mg
    - (Topiramate as secondary option)
- Non-Effective Treatments (no better than placebo for long-term Tx)
  - Botox, Tramadol, Amitriptyline
Increased Energy Expenditure of Amputee Gait

Proximal/contra-lateral muscles need to compensation for missing muscles for balance and propulsion.

### TABLE 6–5
Energy Expenditure of Different Levels of Amputation

<table>
<thead>
<tr>
<th>Level of Amputation</th>
<th>Incr’d Metabolic Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syme’s</td>
<td>15%</td>
</tr>
<tr>
<td>Traumatic TT BKA</td>
<td>25%</td>
</tr>
<tr>
<td>(short BKA - 40%)</td>
<td></td>
</tr>
<tr>
<td>Long BKA - 10%</td>
<td></td>
</tr>
<tr>
<td>Traumatic R/L BKA</td>
<td>44%</td>
</tr>
<tr>
<td>Traumatic TF AKA</td>
<td>60-70%</td>
</tr>
<tr>
<td>Traumatic R/L AKA</td>
<td>&gt;200%</td>
</tr>
<tr>
<td>(250% Huang)</td>
<td></td>
</tr>
<tr>
<td>Traumatic AKA and BKA</td>
<td>118% net cost</td>
</tr>
<tr>
<td>Vascular TT BKA</td>
<td>45%</td>
</tr>
<tr>
<td>Vascular TF AKA</td>
<td>100%</td>
</tr>
</tbody>
</table>

(From Traugh, 1975; Gonzalez 1974; Tan 1989; Huang, 1979.)

### TABLE 9–9
Energy Cost of Ambulation for the Amputee

<table>
<thead>
<tr>
<th>Amputation</th>
<th>% Incr’d E</th>
</tr>
</thead>
<tbody>
<tr>
<td>No prosthesis w/ crutches</td>
<td>50%</td>
</tr>
<tr>
<td>Unilateral BK w/ prosthesis</td>
<td>9-28%</td>
</tr>
<tr>
<td>Unilateral AK w/ prosthesis</td>
<td>40-65%</td>
</tr>
<tr>
<td>Bilateral BK w/ prosthesis</td>
<td>41-100%</td>
</tr>
<tr>
<td>BK plus AK w/ prosthesis</td>
<td>75%</td>
</tr>
<tr>
<td>Bilateral AK w/ prosthesis</td>
<td>280%</td>
</tr>
<tr>
<td>Unilateral Hip disartic w/ prosthesis</td>
<td>82%</td>
</tr>
<tr>
<td>Hemipelvectomy w/ prosthesis</td>
<td>125%</td>
</tr>
</tbody>
</table>

(Hires and Zohman, 1998.)

Cuccurullo 2nd ed., pg 463

Cuccurullo 2nd ed., pg 690
What is the energy expenditure of “normal” and “pathologic” gait?

Does walking speed affect energy use?

How is the increased (or normal) energy calculated?

---

**Energy Expenditure - Approximation**

- 1949, Weir
  - Published “New Method for Calculating Metabolic rate”
  - In ordinary breathing (at rest) and in open methods of indirect calorimetry, the heat output is equal to the product of the volume of expired air (ventilation) and the calorie value per litre.
  - This calorie value is almost exactly one-twentieth of the difference in the percentages of oxygen in inspired and expired air.
Energy Expenditure - Normal

- 1955, Passmore and Durnin show
  - linear relationship between
    - Energy used and Velocity
  - Similar to Kinetic energy
    - $\approx \frac{1}{2} \text{mass} \times \text{Velocity}^2$
- Energy calculated from analysis of collected $\text{O}_2$ concentrations with Beckman-Pauling oxygen analyzer.

![Energy Expenditure Graph]

Fig. 1. The linear relation between energy expenditure in calories/mg and the square of the speed. Experimental points derived from the studies of a number of different investigations. See text for further description.

Expired Air Collection System

![Expired Air Collection System]

Pinzur, 1992
Energy\_w = C_1 + C_2 \cdot \text{velocity}^2 \quad \text{(Energy per minute)}

\text{Divide each side by velocity}

Energy\_m = \frac{C_1}{\text{velocity}} + C_2 \cdot \text{velocity} \quad \text{(Energy per meter)}

\text{Fig. 3. Normal male subject. Relation between energy expenditure in cal/meter/kg and speed. Arrow indicates the "natural" walking speed of subject.}

### Energy-Speed Relationship Tables

<table>
<thead>
<tr>
<th>Group</th>
<th>Normal</th>
<th>Slow</th>
<th>Fast</th>
<th>Normal</th>
<th>Slow</th>
<th>Fast</th>
<th>Normal</th>
<th>Slow</th>
<th>Fast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Children (6–12 yr)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>413.99</td>
<td>188.77</td>
<td>132.19</td>
<td>14.79</td>
<td>12.28</td>
<td>10.31</td>
<td>8.2175</td>
<td>0.223</td>
<td>0.218</td>
</tr>
<tr>
<td>M</td>
<td>116.29</td>
<td>105.11</td>
<td>122.56</td>
<td>15.82</td>
<td>15.64</td>
<td>10.88</td>
<td>8.2596</td>
<td>0.237</td>
<td>0.259</td>
</tr>
<tr>
<td>T</td>
<td>154.49</td>
<td>87.96</td>
<td>124.96</td>
<td>15.32</td>
<td>12.75</td>
<td>10.63</td>
<td>8.2721</td>
<td>0.231</td>
<td>0.234</td>
</tr>
</tbody>
</table>

| Adults (30–59 yr) |        |      |      |        |      |      |        |      |      |
| F          | 422.02 | 188.77 | 132.19 | 14.79 | 12.28 | 10.31 | 8.2175 | 0.223 | 0.218 |
| M          | 116.29 | 105.11 | 122.56 | 15.82 | 15.64 | 10.88 | 8.2596 | 0.237 | 0.259 |
| T          | 154.49 | 87.96 | 124.96 | 15.32 | 12.75 | 10.63 | 8.2721 | 0.231 | 0.234 |

| Seniors (60–80 yr) |        |      |      |        |      |      |        |      |      |
| F          | 415.00 | 188.77 | 132.19 | 14.79 | 12.28 | 10.31 | 8.2175 | 0.223 | 0.218 |
| M          | 116.29 | 105.11 | 122.56 | 15.82 | 15.64 | 10.88 | 8.2596 | 0.237 | 0.259 |
| T          | 154.49 | 87.96 | 124.96 | 15.32 | 12.75 | 10.63 | 8.2721 | 0.231 | 0.234 |

| * | Mean \pm 1 SD |        |      |        |      |      |        |      |      |
| * | Significant (p < 0.05) differences between male and female subjects. |
| * | Significant (p < 0.05) differences between preceding value in younger age group. |

(Waters, 1988)
Power requirement (rate of O₂ consumption)
- milliliters of O₂ consumed per kg body weight per minute

Physiological work (O₂ cost) during level walking
- Amount of oxygen consumed per kilogram body weight per unit distance.
- Determined by dividing the rate of O₂ consumption by the speed of walking.

Respiratory exchange ratio (RER)
- Ratio of CO₂ produced to O₂ consumption under exercise conditions
- > 0.90 is indicative of anaerobic activity
- > 1 is indicative of severe exercise

Fig. 1. Rate of O₂ consumption at rest, standing, walking at CWS and FWS.
Aerobic Vs Anaerobic

\[ \text{C}_6\text{H}_{12}\text{O}_6 \text{ glucose (stored energy)} + 6\text{O}_2 \text{ oxygen \rightarrow \text{6CO}_2 \text{ carbon dioxide} + 6\text{H}_2\text{O \text{ water (+ usable energy)}} + 38\text{ ATP (usable energy)}} \]

\[ \text{C}_6\text{H}_{12}\text{O}_6 \text{ glucose (stored energy)} \rightarrow \text{2 Lactic Acids} + 2\text{ ATP (usable energy)}} \]

Aerobic is 19 times more efficient than Anaerobic

Pathologic Gait – Joint Fusion

Table 2
Energy expenditure following hip and ankle fusion and cylinder cast immobilization of the knee*

<table>
<thead>
<tr>
<th></th>
<th>Velocity (m/min)</th>
<th>( \text{O}_2 ) rate (ml/kg per min)</th>
<th>( \text{O}_2 ) cost (ml/kg per m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ankle fusion</td>
<td>67</td>
<td>12.0</td>
<td>0.17</td>
</tr>
<tr>
<td>Cylinder knee cast</td>
<td>64</td>
<td>12.7</td>
<td>0.20</td>
</tr>
<tr>
<td>Hip fusion</td>
<td>67</td>
<td>14.7</td>
<td>0.22</td>
</tr>
</tbody>
</table>

- Ankle Fusion:
  - 3% greater energy use then normal gait
  - 90% gait efficiency

- Hip Arthrodesis
  - 32% greater energy use then normal gait
  - 53% gait efficiency
Pathologic Gait – 3-Point Crutch Gait

Average rate of Energy expenditure was 32% greater than normal
Likely an underestimate – RER 0.9 – 1.1 (Partial Anaerobic conditions)

Pathologic Gait – Unilateral Amputee
Traumatic vs. Dysvascular

### TABLE 1
Energy expenditure of three-point crutch gait in two groups of fracture patients and of normal subjects walking without crutches during 5-min trial

<table>
<thead>
<tr>
<th></th>
<th>SLC  n = 17</th>
<th>LLC n = 8</th>
<th>Total n = 25</th>
<th>Normal walking*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate (beats/min)</td>
<td>156 ± 16</td>
<td>145 ± 18</td>
<td>153 ± 17</td>
<td>100 ± 14</td>
</tr>
<tr>
<td>Oxygen rate (ml/kg-min)</td>
<td>15.2 ± 3.1</td>
<td>16.8 ± 2.0</td>
<td>15.7 ± 2.9</td>
<td>11.9 ± 2.3</td>
</tr>
<tr>
<td>Oxygen cost (ml/kg-m)</td>
<td>0.31 ± 0.06</td>
<td>0.35 ± 0.06</td>
<td>0.32 ± 0.06</td>
<td>0.15 ± 0.02</td>
</tr>
<tr>
<td>Respiratory exchange ratio</td>
<td>1.02 ± 0.11</td>
<td>1.04 ± 0.09</td>
<td>1.03 ± 0.10</td>
<td>0.81 ± 0.07</td>
</tr>
<tr>
<td>Speed (m/min)</td>
<td>50 ± 11</td>
<td>50 ± 11</td>
<td>50 ± 11</td>
<td>80 ± 11</td>
</tr>
<tr>
<td>Stride length (m)</td>
<td>1.20 ± 0.14</td>
<td>1.18 ± 0.12</td>
<td>1.19 ± 0.14</td>
<td>1.40 ± 0.18</td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td>84 ± 15</td>
<td>84 ± 13</td>
<td>84 ± 14</td>
<td>114 ± 10</td>
</tr>
</tbody>
</table>

* Mean and 1 SD.

Waters, 1976
Pathologic Gait – Unilateral Amputee
Traumatic vs. Dysvascular

TABLE II
UNRESTRAINED WALKING IN AMPUTEES
(MEAN VALUES AND STANDARD DEVIATION)

<table>
<thead>
<tr>
<th></th>
<th>Velocity (m/min)</th>
<th>Cadence (Steps/mn)</th>
<th>Stride Length (m)</th>
<th>Rate of Oxygen Uptake (ml/kg/min)</th>
<th>Net Oxygen Cost (ml/kg/m)</th>
<th>Heart Rate (beats/min)</th>
<th>Respiratory Quotient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vascular amputees</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Above the knee</td>
<td>36 ± 15</td>
<td>72 ± 18</td>
<td>1.00 ± 0.20</td>
<td>12.6 ± 2.9</td>
<td>0.35 ± 0.06</td>
<td>126 ± 17</td>
<td>0.98 ± 0.13</td>
</tr>
<tr>
<td>Below the knee</td>
<td>45 ± 7</td>
<td>87 ± 13</td>
<td>1.02 ± 0.13</td>
<td>11.7 ± 1.6</td>
<td>0.26 ± 0.05</td>
<td>105 ± 17</td>
<td>0.82 ± 0.06</td>
</tr>
<tr>
<td>Traumatic amputees</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Above the knee</td>
<td>52 ± 14</td>
<td>87 ± 13</td>
<td>1.20 ± 0.18</td>
<td>12.9 ± 3.4</td>
<td>0.25 ± 0.05</td>
<td>111 ± 12</td>
<td>0.90 ± 0.07</td>
</tr>
<tr>
<td>Below the knee</td>
<td>71 ± 10</td>
<td>99 ± 9</td>
<td>1.44 ± 0.16</td>
<td>15.5 ± 2.9</td>
<td>0.20 ± 0.05</td>
<td>106 ± 11</td>
<td>0.83 ± 0.08</td>
</tr>
</tbody>
</table>

Waters, 1976

Pathologic Gait – Unilateral Amputee
Traumatic vs. Dysvascular

- Increased cadence with shorter stride length is more economical than Reduced cadence with longer stride length

Waters, 1976, 1999
Pathologic Gait – Unilateral Amputee
Dysvascular

V1 – self-selected/normal walking speed
V2 – Maximum walking speed

Pathologic Gait – Unilateral Amputee
Traumatic vs. Dysvascular

- **Increased Energy**
  - Traumatic
    - TT = ________
    - TF = ________
  - Vascular
    - TT = ________
    - TF = ________

Waters, 1976, 1999
Pathologic Gait – Bilateral Amputee
Traumatic

- One subject (late 20’s)
- Meningococcemia with purpura fulminas
- B/L transradial and b/l knee disartic
- 2 years later (after rehab and wounds heal)
  - Fitted with stubbies
- 1 year later (after more rehab)
  - Fitted with non-computerized hydraulic knees joints (Mauch)
  - Independent walking w/in 1 year
- 4 years later.....ready to be tested

Perry, 2004
Pathologic Gait – Bilateral Amputee

- **Important**
  - All studies of bilateral amputees are:
    - Young
    - Not due to Vascular dz (trauma, CA, congenital)
    - Relatively healthy
    - RER > 1.0 (Energy cost may be much higher)

- **Increased Energy**
  - Per Perry, 2004 (% of normal, 1 subject): 120% - 304%
  - Per Huang, 1979: (4 subjects) 300% greater energy cost per unit distance
  - Per Corcoran et al, 1994: (2 subjects) 186% higher than predicted for normal
  - Per Hoffman, 1997: (5 subjects) 55% - 83% higher aerobic demands

- Walking speed is usually slower

---

**Take Home Points**

- **Skin Care**
  - Optimal hygiene
  - Proper socket fit

- **Phantom Pain**
  - Complex, exact mechanism unknown
  - No perfect treatment
  - Morphine and Gabapentin are good options

- **Energy cost of Amputee Gait**
  - Increases with level of amputation with slower walking speeds
  - More proximal amputation level may be underestimates
Works Cited

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