Amputee Gait-Energy Consumption and Gait Analysis

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Energy consumption in normal gait

• Linear Relationship:

  Gait speed and energy cost of walking (O2 consumption)

(Perry, J (ed), Gait Analysis: Normal and Pathological Gait, 1992)
Energy consumption in normal gait

Figure 4-6

Energy consumption in abnormal gait

- Ambulation with a prosthesis:
  - Walking speed is slower (Chosen Walking Speed)
    Minimizes the rate of energy used during walking
  - (Duff, Kerrigan, Corcoran et al, Arch Phys Med Rehabil, 1996)
Energy Consumption in Amputees

- Chosen Walking Speed (CWS) (m/min)
  - Declines at each higher amputation level for both traumatic and vascular amputee groups
    - Transtibial: 71 m/min
    - Knee disarticulation: 61 m/min
    - Transfemoral: 52 m/min
    - Hip Disarticulation: 47 m/min

(Waters, Perry, Antonelli et al, JBJS, 1976)
# Energy Consumption in Amputees

## Table 4-6

Gait Speed, Oxygen Consumption, and Oxygen Cost in Prosthetic Gait: Comparison of Etiology and Level of Unilateral Amputation

<table>
<thead>
<tr>
<th>Etiology and Level: Parameter</th>
<th>Traumatic Transtibial</th>
<th>Traumatic Transfemoral</th>
<th>Dysvascular Transtibial</th>
<th>Dysvascular Transfemoral</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Waters et al, 1976</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gait speed (m/min)</td>
<td>71</td>
<td>52</td>
<td>45</td>
<td>36</td>
</tr>
<tr>
<td>O₂ rate (ml/kg/min)</td>
<td>12.4</td>
<td>10.3</td>
<td>9.4</td>
<td>10.8</td>
</tr>
<tr>
<td>O₂ cost (ml/kg/m)</td>
<td>0.16</td>
<td>0.20</td>
<td>0.20</td>
<td>0.28</td>
</tr>
<tr>
<td><strong>Torburn et al, 1995</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gait speed (m/min)</td>
<td>82.3</td>
<td>–</td>
<td>61.7</td>
<td>–</td>
</tr>
<tr>
<td>O₂ rate (ml/kg/min)</td>
<td>17.7</td>
<td>–</td>
<td>13.2</td>
<td>–</td>
</tr>
<tr>
<td>O₂ cost (ml/kg/m)</td>
<td>0.22</td>
<td>–</td>
<td>0.21</td>
<td>–</td>
</tr>
</tbody>
</table>
**Energy Consumption in Amputees**

- **Level of amputation (Traumatic)**
  - BKA
    - 20-25% (Short-40%)
    - (Long-10%)
  - BKA + BKA
    - 41% (Gonzalez-1974)
  - AKA
    - 60-70%
  - AKA + BKA
    - 118% (Traugh-1975)
  - AKA + AKA
    - 260% (Huang 1979)
Energy Consumption in Amputees

- (Gonzalez, Corcoran, Reyes, *Arch Phys Med Rehabil*, 1974)
- (Traugh, Corcoran, Reyes, *Arch Phys Med Rehabil* 1975)
- (Huang, Jackson, Moore et al, *Arch Phys Med Rehabil* 1979)
Energy Consumption in Amputees

• **Bilateral (TT) vs Unilateral (TF)**

• Bilateral TT exert less effort (41%) than a Unilateral TF (60-70%)

• Important to retain biological knee whenever possible

(Gonzalez, Corcoran, Reyes, *Arch Phys Med Rehabil*, 1974)
Energy Consumption in Amputees

- **Hip Disarticulation Prosthesis**

- > 200 % increase in energy compared with unimpaired walking

- High rejection rate

(Huang, Jackson, Moore et al, *Arch Phys Med Rehabil* 1979)
## Energy Consumption in Amputees (Traumatic vs Vascular)

<table>
<thead>
<tr>
<th>Level of amputation</th>
<th>Metabolic cost above normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symes</td>
<td>15%</td>
</tr>
<tr>
<td>Traumatic TT</td>
<td>25%</td>
</tr>
<tr>
<td>Vascular TT</td>
<td>40%</td>
</tr>
<tr>
<td>Traumatic TF</td>
<td>68%</td>
</tr>
<tr>
<td>Vascular TF</td>
<td>100%</td>
</tr>
</tbody>
</table>

(Huang, Jackson, Moore et al, *Arch Phys Med Rehabil* 1974)
Energy Consumption in Amputees

- Traumatic vs Vascular
- Amputees of traumatic etiology:
  - Walk faster
  - Exert less oxygen cost (ml/kg/m)

(Waters, Perry, Antonelli et al, JBJS, 1976)
Energy Consumption in Amputees

- **Traumatic vs Vascular**
  - **Vascular amputees:**
    - Older
    - Cardiovascular disease
    - Lower energy reserves
    - Anaerobic energy
Energy Consumption in Amputees

- Prosthesis vs Walker/Crutches

- The increased energy cost over baseline of walking with a comfortably fitting prosthesis is less than that expended when walking w/out prosthesis using walker or crutches

(Waters, Perry, Antonelli et al, JBJS, 1976)
Energy Consumption in Amputees

- Reduce energy cost of prosthetic gait by developing:
  - Dynamic Responsive (energy storing) feet
  - Cadence Responsive Microprocessor Controlled Knee Units
Energy Consumption in Amputees

• Mechanical vs Microprocessor-controlled knee
  - 15 subjects, long term users of mechanical knees
  - Trained with microprocessor controlled knee units
  - Significantly increased physical activity related energy expenditure levels

(Kaufman, Levine et al, Arch Phys Med Rehabil, 2008)
Energy Consumption in Amputees

• Mechanical vs Microprocessor-controlled knee

- 21 unilateral, transfemoral amputees

- Transition from mechanical to microprocessor knee
  (Otto Bock C leg)
Energy Consumption in Amputees

Results:

• Stair descent score, hill descent time improved significantly

• Significant decrease in frequency of stumbles and falls

• Subject satisfaction significantly greater with microprocessor controlled knee

Analysis of Amputee Gait

- Observational Gait Analysis
- Identification of gait deviations
- Determination of the causes associated with each deviation
Analysis of Amputee Gait

- Identification of gait deviations
- Symmetry
- For unilateral amputees, look for differences in the patterns between the prosthetic and normal sides
Analysis of Amputee Gait

- **Determination of causes:**
  - **Prosthesis:** Malalignment
  - **Patient:** Restricted joint ROM
  - Muscular weakness
  - Fear
Analysis of Amputee Gait

- Observational Gait analysis components:
- At least two vantage points:
  - Sagittal plane motions - from the side
  - Frontal (Coronal) plane motions - from the front or back
Analysis of Amputee Gait

• Evaluation of each of the sub-phases of gait
  • Early Stance (initial contact to mid-stance)
  • Late Stance (mid-stance to terminal stance)
  • Terminal Stance to pre-swing
  • Swing (initial swing to subsequent loading response)
Analysis of Amputee Gait

Transtibial

- TRANSTIBIAL GAIT DEVIATIONS
Analysis of Amputee Gait
Transtibial

- INITIAL CONTACT THROUGH MIDSTANCE
Analysis of Amputee Gait

Transtibial

• Knee remains too extended at initial contact

• Prosthesis: Suspension-inadequate
  Heel lever-too short

• Patient: Insecurity
Analysis of Amputee Gait

Transtibial

- Knee flexes more than 10 degrees at initial contact
- Prosthesis: Suspension-too tight
- Patient: Knee flexion contracture
Analysis of Amputee Gait Transtibial

- Rapid or Poorly Controlled Knee Flexion
- Prosthesis: Heel cushion too stiff
  Heel lever too long
- Patient: Weak quadriceps muscles
Analysis of Amputee Gait

Transtibial

- Unequal Stride Length
- Prosthesis: Suspension-inadequate
- Patient: Pain with pressure on prosthesis
  Insecurity
Analysis of Amputee Gait

• Foot Slap
• Foot Slap

• Prosthesis: Plantar flexion bumper too soft
  Heel cushion too soft

• Patient: Insecurity/Fear
Analysis of Amputee Gait

- External Rotation of the Foot at Heel Strike
External Rotation of the Foot at Heel Contact

- Prosthesis: Socket too loose - rotatory torque
  Foot too outset
  Plantar flexion bumper/heel cushion too firm

- Patient: Hip muscles weak
  Insecurity
External Rotation of the Foot at Heel Contact
Analysis of Amputee Gait
Transtibial

• MIDSTANCE TO TERMINAL STANCE
Analysis of Amputee Gait

- Top of prosthetic foot leans medially
- Prosthesis: Socket-excessive adduction
  Foot-pronated or too far outset
- Patient: insecurity
Analysis of Amputee Gait

- Top of prosthetic foot leans laterally

- Prosthesis: Socket-insufficient adduction
  Foot-supinated or too far inset

- Patient: insecurity
Analysis of Amputee Gait

• Abnormal Varus/Valgus at knee

• Abnormal Varus
  Prosthetic foot set too far medial (inset)

• Abnormal Valgus
  Prosthetic foot set too far lateral (outset)
Analysis of Amputee Gait

• Lateral Trunk Bending
Lateral Trunk bending

- Lateral Trunk Bending
- Amputee leans toward the amputated side when the prosthesis is in stance phase
- Increases energy expenditure and disrupts smooth progression
Lateral Trunk Bending

- **Prosthesis**: (Transtibial/Transfemoral)

  Length is too short compared with contralateral limb

  Foot too outset (lateral)
Lateral trunk bending

- Prosthesis (Transfemoral)

  Medial wall too high/rigid
  Lateral wall unable to stabilize femur in adduction
  Residual limb too deep in socket
  Excess initial abduction
Lateral Trunk bending

• **Patient:**

  Groin/Lateral distal femur discomfort,
  Short limb
  Weak hip abductor muscles
Lateral Trunk Bending
Analysis of Amputee Gait
Transtibial

• TERMINAL STANCE TO PRE-SWING
Analysis of Amputee Gait

- Early heel rise
- Prosthesis: Socket in excessive flexion
  - Toe lever too short
  - Foot in too much dorsiflexion
- Patient: Hip/knee flexion contracture
Analysis of Amputee Gait

- Delayed heel rise

- Prosthesis: Socket set in too little flexion
  Toe lever too long
  Foot in too much plantar flexion
  Foot keel too stiff
Analysis of Amputee Gait

- Abnormal Step Width

- Step Width less than 2 inches
  Prosthesis: foot too far inset
  Patient: Ambulates with narrow base
Analysis of Amputee Gait

• Abnormal Step Width

• Step Width greater than 4 inches
  Prosthesis: foot too far outset
  Patient: insecurity
Analysis of Amputee Gait
Transtibial

• SWING PHASE
Analysis of Amputee Gait

• Medial Whip
Medial Whip

- Prosthetic foot moves in an arc that carries it toward the midline in swing- just after toe off
- Prosthetic knee appears to rotate externally
Medial Whip

- **Prosthesis:**
  - Foot aligned in too much toe-in
  - Cuff suspension problem
• Prosthesis: (Transfemoral)

• Socket in too much ER
  Silesian belt to tight
  Poor contact between skin and socket
  Knee unit in too much ER
Medial Whip

Medial Whip
Analysis of Amputee Gait

- Lateral Whip
Analysis of Amputee Gait

- Lateral Whip

- Prosthetic foot moves in an arc that carries it away from the midline in swing—just after toe-off

- Prosthetic knee appears to rotate internally
Lateral Whip

- **Prosthesis**: (Transtibial)
  - Foot aligned in too much toe-out
  - Cuff suspension problem
Lateral Whip

- **Prosthesis**: (Transfemoral)
- **Socket set in IR**
  Knee unit positioned in IR
Analysis of Amputee Gait
Transfemoral
Lateral Whip
Analysis of Amputee Gait
Transtibial

- Catching the Toe in Midswing
- Prosthesis: Functionally too long
  Suspension system
  Limited ability to flex knee
  Foot in excess plantar flexion

Prosthesis actually too long
Analysis of Amputee Gait
Transfemoral

• TRANSFEMORAL GAIT DEVIATIONS
Analysis of Amputee Gait
Transfemoral

• INITIAL CONTACT THROUGH MIDSTANCE
Analysis of Amputee Gait
Transfemoral

- Excessive Knee Flexion
Analysis of Amputee Gait
Transfemoral
Analysis of Amputee Gait
Transfemoral

- **Excessive Knee Flexion**
- Prosthesis: Socket not set in enough flexion
  (Hip extensors-disadvantage)
  Knee axis anterior to Center of Gravity
  Foot in too much dorsiflexion
  Plantar flexion bumper too stiff
- Patient: Hip extensor muscle weakness
  Hip flexion contracture
Analysis of Amputee Gait
Transfemoral

• MIDSTANCE TO LATE STANCE
Analysis of Amputee Gait Transfemoral

- Pelvic Rise

- Prosthesis: Foot set in excessive plantar flexion
  Foot placed too far forward with respect to knee and socket
Analysis of Amputee Gait
Transfemoral

- Drop Off at Midstance

- Prosthesis: Foot in too much dorsiflexion
  Dorsiflexion bumper too soft
Analysis of Amputee Gait
Transfemoral

- Abducted Gait

- Prosthesis is held away from the midline, throughout the gait cycle, most notably during stance phase
Analysis of Amputee Gait

Transfemoral

- Abducted Gait
- Prosthesis: Socket in too much abduction
  Socket with inadequate lateral wall stabilization of femur
  Groin pain/pressure
  Attempt to minimize lateral-distal femoral pain
Abducted Gait

Patient: Weak hip abductors
Fear/insecurity
Analysis of Amputee Gait
Transfemoral

- SWING PHASE
Analysis of Amputee Gait

Transfemoral

- Excessive Lumbar Lordosis

- **Prosthesis**: Socket not set in enough flexion

- **Patient**:
  - Weak hip flexors/abdominal muscles
  - Short residual limb
Analysis of Amputee Gait

- Excessive Heel Rise
Analysis of Amputee Gait

Transfemoral

• Excessive Heel Rise

• Prosthesis:
  - Inadequate resistance to knee flexion in knee unit
  - Worn knee extension aide
Excessive heel rise
Analysis of Amputee Gait
Transfemoral

- Terminal Impact

- **Prosthesis:**
  - Insufficient resistance to extension in knee unit
  - Extension aide too strong
  - Extension bumper worn

- **Patient:** Fear/Insecurity
Analysis of Amputee Gait

• Vaulting
Analysis of Amputee Gait

• **Vaulting**
• The amputee raises body by early and excessive plantar flexion of the sound foot

• Allows for clearance of the prosthesis
Analysis of Amputee Gait

- **Vaulting**
- **Prosthesis:** Functionally too long:
  a) Suspension-inadequate
  b) Knee unit-too much resistance to flexion or locked in extension
  c) Foot-too much plantar flexion

  Actual height is too long
Analysis of Amputee Gait
Transfemoral
Analysis of Amputee Gait

- Circumduction
Analysis of Amputee Gait

- Circumduction

- Prosthesis follows a laterally curved line as it swings
Analysis of Amputee Gait Circumduction

- **Prosthesis**: Functionally too long:
  - Suspension - inadequate
  - Knee unit - too much resistance to knee flexion or locked in extension
  - Foot - set in too much plantar flexion
  - Actual height is too long
Analysis of Amputee Gait Circumduction

- Fear/insecurity
- Insufficient flexion of knee
- Medial brim of socket too high - impinges tissues during swing phases
Analysis of Amputee Gait
Circumduction