LOWER-LIMB PROSTHETIC BIOMECHANICS

Joan E. Edelstein, PT, MA, FISPO
Special Lecturer, Columbia University

©Copyright 2016. Joan E. Edelstein. All rights reserved
TRANSTIBIAL PROSTHESSES

GOALS

• Comfort
  Pressure distribution
    Socket shape
    Prosthetic alignment

• Function
  Stability
  Appropriate ease of knee flexion
  Alignment
SOCKET DESIGN DEPENDS ON PHYSICAL EXAMINATION

- Length
- Shape
- Scar
- Skin
- Range of motion
- Strength
- Comfort

DECREASE PRESSURE
Reduce Force (&/or Increase Area) to Reduce Pressure

TOTAL CONTACT

- Variable amount of load taken by all areas of amputation limb
- Usually peripheral (not end) bearing
- More area & leverage
- Tactile sensation
- Venous return
VERRUCOUS HYPERPLASIA

Lack of distal contact permits venous pooling

TISSUE TEXTURE
PRESSURE TOLERANT TISSUES

- Anterior & lateral compartments contribute tolerant tissue
- Posterior pressure tolerant tissue
- Socket build up (convexity)

PRESSURE TOLERANT TISSUES

- Triceps surae belly
- Patellar ligament (tendon)
- Pes anserinus (medial tibial flare)
- Lateral compartment
PRESSURE SENSITIVE TISSUES

- Tibial crest
- Tibial condyles
- Distal tibia
- Fibular head
- Distal fibula
- Hamstring tendons
- Socket relief (concavity)

SOCKET FABRICATION
SOCKET

- Pressure tolerant: build-up
  Concavity on model
  Convexity within socket

- Pressure sensitive: relief
  Convexity on model
  Concavity within socket

BUILD UPS & RELIEFS
CAD CAM (Computer-aided Design, Computer-aided Manufacture) SOCKET

More triangular than amputation limb exterior

SOCKET INTERIOR
SOCKET CONTOURS

- Steep anterior wall
- High force needed to prevent amputation limb from slipping

PTB SOCKET CONTOURS

- Patellar bulge indentation reduces force needed to prevent amputation limb from slipping = PTB socket
- Deeper bar = less load on other tissues
  BUT
  may be uncomfortable
PTB SOCKET CONTOURS

LOADING AREAS
SOCKET COMPARISON

• All are total contact

• Patella tendon bearing: PTB:
  - Major loading on patellar ligament
  - Medium to short, bony
  - Past wearer
  - High posterior trim line may limit sitting

• Total Surface Bearing:
  - Less prominent patellar bulge
  - All lengths, adherent scar
  - Distal pin suspension
  - Needs expensive liner
Medial relief is lower

Socket flexion:

- Reduces risk of slippage
- Facilitates quadriceps
- Aids early stance
- Prevents genu recurvatum
- Increases load on patellar ligament
SAGITTAL ALIGNMENT

Socket flexion

Lacking socket flexion, old prosthesis has posterior check straps to prevent genu recurvatum
• Adjustable leg
• **Static** alignment: patient stands
• **Dynamic** alignment: patient *walks*
**SAGITTAL ALIGNMENT**

- **Socket anterior:** knee easier to **flex**
- **Socket posterior:** knee more stable
- Foot moved in opposite direction

**SAGITTAL PLANE**

To increase ease of flexing knee:

- Socket shifted anterior to foot
- Socket flexed
- Heel cushion firm
- Shoe heel high
FLEXION CONTRACTURE

Standard alignment would make knee unstable
5/10/2017

FRONTAL ALIGNMENT

Lateral tilt reduces load on fibular head

Moving foot inward =
foot inset =
socket lateral slide

• Reduces pressure on head of fibula
• Narrow walking base
• Reduces lateral trunk bending
• Socket lateral slide = foot inset
• Reduces load on fibular head
• Narrow walking base

• Prefer foot inset
• Pressures at Proximomedial & Distolateral aspects
←---Inset

Outset ---→
IDEAL ALIGNMENT

• A-P: Socket over middle 1/3 of foot
• M-L: Proximomedial pressure + narrow base
TRANSFEMORAL BIOMECHANICS

- Socket
  * Quadrilateral
  * Ischial containment
- Alignment
  * Sagittal plane
  * Frontal plane
SOCKET: AMPUTATION LIMB FACTORS

- Length
- Shape
- Scar
- Skin
- Range of motion
- Strength
- Comfort
TOTAL CONTACT SOCKET

Load taken distally reduces load taken proximally

QUADRILATERAL SOCKET

- Major loading on ischial tuberosity
- Trochanter relief
QUADRILATERAL SOCKET

- Anteromedial: adductor relief
- Posteromedial: hamstring relief
- Anterolateral: rectus femoris channel
- Posterolateral: gluteus maximus channel

Scarpa’s Bulge
QUADRILATERAL SOCKET

Walls:
Anterior & lateral: 2-3 inches higher
MODIFYING MODEL to create posterior brim for quadrilateral socket

ISCHIAL CONTAINMENT SOCKET “Pelvic Lock”
QUADRILATERAL (Gray) vs. ISCHIAL CONTAINMENT SOCKET (White)

![Image of socket comparison]

SOCKET WALLS

<table>
<thead>
<tr>
<th></th>
<th>QUADRILATERAL</th>
<th>ISCHIAL CONTAINMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterior</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Anterior</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Medial</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Lateral</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>
SAGITTAL ALIGNMENT

5 degrees initial flexion

- Reduces lordosis
- Facilitates gluteus maximus to stabilize knee during early stance
- For quadrilateral socket: also seats ischium
SAGITTAL ALIGNMENT

- Socket on wood block onto adjustable leg
- Knee bolt can be located forward or backward

Normally, weight line passes:
- Posterior to hip. Anatomic hip is stable
- Anterior to knee. Anatomic knee is stable
- Anterior to ankle. Triceps surae needed for standing
SAGITTAL ALIGNMENT
Weight line usually anterior to knee

Knee axis relative to trochanter/ankle line:

• Posterior: Stable, for feeble patient
• On line = “trigger”: Athlete
• Anterior: Stance control knee unit
SAGITTAL ALIGNMENT

To maximize stability:
• Socket flexion
• Knee axis posterior to socket
• Ankle anterior to socket
• Soft heel cushion
• Soft shoe heel
• Low shoe heel
SAGITTAL ALIGNMENT

Other means of increasing stability:
• Polycentric knee unit
• Manually locked knee unit
• Stance control knee unit
• Cane

FRONTAL ALIGNMENT
Lateral trunk bending compensates for lack of femoral stabilization

Adduct lateral socket wall in attempt to stabilize femur

Force couple:
High medial wall + Distal lateral wall
Longer amputation limb provides more area for medially directed stabilizing force, thus more comfortable.
FRONTAL ALIGNMENT

• Lateral socket wall adduction
• High medial wall
• Ischial containment:
  * Higher medial wall: “pelvic lock”
  * Narrower mediolateral dimension
• Outset foot

Foot outset increases frontal stability,
BUT
Increases lateral trunk bending
FRONTAL ALIGNMENT

Other means of increasing stability:
• Pelvic band:
  has single-axis hip joint
• Cane
• Osseous integration

THE END
TRANSFEMORAL BIOMECHANICS

- Socket
  * Quadrilateral
  * Ischial containment
- Alignment
  * Sagittal plane
  * Frontal plane
SOCKET:
AMPUTATION LIMB FACTORS

- Length
- Shape
- Scar
- Skin
- Range of motion
- Strength
- Comfort
TOTAL CONTACT SOCKET

Load taken distally reduces load taken proximally

QUADRILATERAL SOCKET

• Major loading on ischial tuberosity
• Trochanter relief
QUADRILATERAL SOCKET

- Anteromedial: adductor relief
- Posteromedial: hamstring relief
- Anterolateral: rectus femoris channel
- Posterolateral: gluteus maximus channel

QUADRILATERAL SOCKET

Scarpa’s Bulge
QUADRILATERAL SOCKET

Walls:
Anterior & lateral:
2-3 inches higher
MODIFYING MODEL to create posterior brim for quadrilateral socket

ISCHIAL CONTAINMENT SOCKET “Pelvic Lock”
QUADRILATERAL (Gray) vs. ISCHIAL CONTAINMENT SOCKET (White)

SOCKET WALLS

<table>
<thead>
<tr>
<th></th>
<th>QUADRILATERAL</th>
<th>ISCHIAL CONTAINMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterior</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Anterior</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Medial</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Lateral</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>
SAGITTAL ALIGNMENT

5 degrees initial flexion

- Reduces lordosis
- Facilitates gluteus maximus to stabilize knee during early stance
- For quadrilateral socket: also seats ischium
SAGITTAL ALIGNMENT

- Socket on wood block onto adjustable leg
- Knee bolt can be located forward or backward

Usually, the weight line passes:

- Posterior to hip. Anatomic hip is stable
- Anterior to knee. Anatomic knee is stable
- Anterior to ankle. Triceps surae needed for standing
SAGITTAL ALIGNMENT

Weight line usually anterior to knee

Knee axis relative to trochanter/ankle line:

• Posterior: Stable, for feeble patient

• On line = “trigger”: Athlete

• Anterior: Stance control knee unit
**SAGITTAL ALIGNMENT**

To maximize stability:
- Socket flexion
- Knee axis posterior to socket
- Ankle anterior to socket
- Soft heel cushion
- Soft shoe heel
- Low shoe heel
SAGITTAL ALIGNMENT

Other means of increasing stability:
• Polycentric knee unit
• Manually locked knee unit
• Stance control knee unit
• Cane

FRONTAL ALIGNMENT
Lateral trunk bending compensates for lack of femoral stabilization.

Adduct lateral socket wall in attempt to stabilize femur.

Force couple:
High medial wall + Distal lateral wall.
Longer amputation limb provides more area for medially directed stabilizing force, thus more comfortable.
FRONTAL ALIGNMENT

• Lateral socket wall adduction
• High medial wall
• Ischial containment:
  * Higher medial wall: “pelvic lock”
  * Narrower mediolateral dimension
• Outset foot

Foot outset increases frontal stability,
BUT
Increases lateral trunk bending
FRONTAL ALIGNMENT

Other means of increasing stability:
• Pelvic band:
  has single-axis hip joint
• Cane
• Osseous integration

QUESTIONS?
COMMENTS?