PRINCIPLES OF PROSTHETIC INTERFACE DESIGN

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THREE BASIC ELEMENTS OF A PROSTHESIS
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I. Components

• Foot
• Knee
• Pylon
• Rotators
THREE BASIC ELEMENTS OF A PROSTHESIS

1. Components
   • Pin
   • Suspension Sleeve
   • Straps
   • Vacuum
   • Lanyard

2. Suspension
THREE BASIC ELEMENTS OF A PROSTHESIS

1. Components
2. Suspension - Swing
3. Interface design - Stance
   • Weight Bearing Characteristics
EVOLUTION OF THE RESIDUAL LIMB
MORE ON DIABETES & FOOT ULCER

- Mechanical principles used in designing the interface
- Weight Bearing Characteristics: The forces applied to the residual limb to support the weight of the amputee during stance phase
WEIGHT-BEARING CHARACTERISTICS
WEIGHT-BEARING CHARACTERISTICS
RESIDUAL LIMB LENGTH

Pressure = $\frac{F}{A}$

- Force / Area
- Smaller the RL (area) = the greater the force
THREE CATEGORIES OF INTERFACE DESIGN

• Specific Weight Bearing
• Total Surface Bearing
• Hydrostatic
SPECIFIC WEIGHT BEARING

Mechanical principles provide the support for the residual limb similar to a bridge.
SPECIFIC WEIGHT BEARING

- Use of soft tissue areas to achieve weight bearing
- Create reliefs over boney prominences
- Opposing horizontal forces support vertical weight bearing forces
SPECIFIC WEIGHT BEARING

Most common materials used

- Pelite (soft foam interface)
- Lamination or Polypropylene (hard frame)
ADVANTAGES OF SPECIFIC WEIGHT BEARING

- Time tested - oldest of the 3 designs
- Proven success
- Prosthetists can easily make adjustments
  - Accommodate residual limb changes
  - Preparatory prosthesis
  - Wear of the soft interface
DISADVANTAGES OF SPECIFIC WEIGHT BEARING

- Does not take advantage of newer materials and design
- Applies the most pressure to the smallest areas
- High trim line in the back to achieve oppositional forces
  - limits knee flexion ROM
  - NO DISTAL connection suspension systems
WHO SHOULD GET SPECIFIC WEIGHT BEARING?

- Short to medium residual limbs
- Patients who require stable interface interaction
  - Firm resilient materials
  - Knee stability/supracondylar
  - High tight coronal trim lines
- Preparatory prosthesis
- Bony limbs
- Past users
WHO SHOULD GET SPECIFIC WEIGHT BEARING?

- Suspension Options
  - Suspension sleeves
  - Supracondylar
  - Strap
    - Cuff
    - Fork
TOTAL SURFACE BEARING

Mechanical principles provide the support for the residual limb similar to a Tempur-Pedic mattress.
TOTAL SURFACE BEARING

- Circumferential pressure provides the bearing characteristics
- Most common materials used are gels
- Pressure from the leg encourages the gel to flow from the areas of greater pressure to the areas of lesser pressure
ADVANTAGES OF TOTAL SURFACE BEARING

- Even distribution of pressure
- Comfortable
- Infinite liner selection
  - Thickness
  - Shore durometer
  - Covered or not
- Liners are easy to replace when they wear out because of generic sizing
  - Custom available
DISADVANTAGES OF TOTAL SURFACE BEARING

- The fit is sensitive to volume changes
  - Sock management is best to accommodate

- Traps fluids

- **Hygiene** plays an important role in the success

- Liners are expensive
  - Some insurance companies will not reimburse for more than 1
  - Liners can wear out fast if the RL changes
WHO SHOULD GET TOTAL SURFACE BEARING?

- All lengths
- All tissue consistencies
- All activity levels
- Patients with abnormalities
  - scar tissue
  - adherent tissue
  - invaginations
  - chronic breakdown
- Suspension inclusion
  - pin system
  - lanyards
  - seal-in
HYDROSTATIC

Mechanical principles provide the support for the residual limb by containing the body fluids

- Similar to a hydraulic cylinder
HYDROSTATIC

- Proximal seal of condyles contain the soft tissue (fluids)
  - Soft tissue is drawn distally
    - Provides distal padding
    - Solidifies soft tissue
HYDROSTATIC

- **Always** uses a gel liner
- **Always** a distal attachment
- Usually uses a pressure chamber for casting
ADVANTAGES OF HYDROSTATIC

- Sound mechanical principles of design
- Solidifies the soft tissue by containing it
- Total surface bearing due to use of pressure chamber
ADVANTAGES OF HYDROSTATIC

• Sound principles of design that are amputee friendly

• Provides a natural distal (bottom) padding because of the tissue elongation

• Lower trim line in back, which allows ease in bending
DISADVANTAGES OF HYDROSTATIC

- Sometimes encourages rapid volume loss
- Difficult to adjust
- Difficult to cast
- Sometimes creates pulling sensation on the bottom of the leg
WHO SHOULD GET HYDROSTATIC?

- Fleshy medium length residual limbs
  - Short - not enough soft tissue
  - Long - difficult to fit distal attachment
- Active patients
- Suspension inclusion
  - Pin system
  - Lanyards
  - Seal-in
THE ERTL PROSTHESIS

- Bone Bridge Procedure
- Attaches tibia to fibula
- Creates blunt end
- Can end bear for weight
- Accommodates volume changes
- Reduces the reliance on weight bearing considerations
TT INTERFACE CONCLUSION

• 3 styles of TT interface design to distribute weight off the distal end.

• Maximizing the anatomy of the residual limb will enhance performance.

• Many options that can be utilized for different patient types
TRANSFEMORAL INTERFACE DESIGN
TRANSFEMORAL INTERFACE DESIGN
RESIDUAL LIMB LENGTH

Pressure = \( \frac{F}{A} \)

- Force / Area
- Smaller the RL (area) = the greater the force
FIG 20B–5.
The relationship of femoral length and force distribution. A, the greater the femur length, the greater the ability to distribute pressure and forces. B, the short femur is subjected to a higher pressure concentration. (From Anderson M, Bray J, Hennessey C: Prosthetic Principles—Above-Knee Amputations. Springfield, Ill, Charles C Thomas Publishers, 1960, p 138. Used by permission.)
TRANSFEMORAL AMPUTATION LEVEL
ANATOMY OF AMPUTATION

• Major muscle groups are intact
  • Sagittal Insertion
    • Iliopsoas
    • Gluteus maximus
    • Gluteus minimus
ANATOMY OF AMPUTATION

- Major adductor muscle groups are NOT intact
- Coronal insertions
  - Adductor magnus
  - Semimembranosus
  - Sartorius
  - Gracilus
  - Semitendinosus
TRANSFEMORAL AMPUTATION

- Loss of control
  - muscles
  - bone
- Increases rehab time
  - cut bone
  - myodesis /myoplasty
  - difficulty controlling prosthesis
- Ischial containment
NORMAL HUMAN LOCOMOTION

- Biomechanically sound connection to the ground
- Femoral adduction
- Knee alignment
- Foot alignment
- 5-10 cm base of support
NORMAL HUMAN LOCOMOTION

- 5-10 cm Base of Support
  - Femoral Adduction
  - Knee Alignment
  - Foot Alignment
  - Connection to the Ground

- Pelvic Movement
  - Tilt
  - Rotation
  - Spine Control
TRANSFEMORAL BASICS

- Biomechanically sound Transfemoral Gait=
  - Spinal Control
  - Pelvic Stabilization
  - Femur control
    - Control pistoning
    - Maintain adduction angle
TRANSFEMORAL BASICS

- Lose connection to the ground
- Stability
  - IRC + lateral wall
  - Pelvic + femoral = Spinal
TRANSFEMORAL BASICS

Lose Connection to the Ground
- Femur is Floating
- Loss of proprioception
- Stability
- Control
- Implications to spine
Femur stabilization?
- Quad
- IRC

Suspension—Plays a role in Femoral Stabilization?
- Suction
- Pin
- Lanyard
TRANSFEMORAL BASICS

Femur stabilization - How?
• Quad
• IRC

Problems with standard of care
• Cast/ modify/ fabricate/ fit
• Discomfort/ unsanitary
ISCHIAL RAMUS CONTAINMENT

A
Gluteus Medius

No Bone Lock

Distal Pressure

B
Counter Force

Bony Lock
IRC PROXIMAL TRIM LINE FUNCTION

- Ischial tuberosity does not escape medial capture
- Prevent lateral interface shift
- IRC Brim assists maintaining femur alignment
  - Adduction angle = 9 degrees
QUADRILATERAL VS. IRC
QUADRILATERAL VS. IRC
QUADRILATERAL VS. IRC
QUADRILATERAL VS. IRC
TRANSFEMORAL BASICS

• Suspension Options- current standard of care
  • Suction
  • Pin
  • Lanyard
  • Silesian Belt

• Suspension Problems
  • Pistoning
  • Clearance
  • Volume fluctuation

• What if we could use VAS?
VACUUM ASSISTED SUSPENSION

- History
- Transtibial Only
  - Proximal Seal - requires suspension sleeve
  - Liner choices, more TT - TT here before TF
  - Pump Clearance
  - TT VAS problems = bad fit, but not catastrophic
  - TF VAS problems = unreliable and problems lead to catastrophic failure
VAS- BETTER MECHANICS?

• NHL

• Suspension
  • Dynamic
  • Forces Increased Area under Vacuum

• Control
  • Rotation
  • Pistoning

• Surface Bearing
  • Weight Distribution
  • Proprioception
VAS
Vacuum Assisted Suspension Technology Allows Application of Alternative Interface Design
BRIMLESS TRANSFEMORAL
Transfemoral Interface Design

• No current standard of care in TFVAS principles because of Sealing Design

• Seal is INSIDE interface
  • Protects Seal
  • Rotational Control
  • Proximal or Distal Seal Options

• Silicone
  • Various durometers -100 -60 %
  • Padded distal end
  • Flow Characteristics
  • Distal Pad Option
VAS BRIMLESS
Advantages

• Assists in controlling rotation
• Allows for maximum use of the surface area
• Solid liner connection to the residual Limb
VAS BRIMLESS
Disadvantages

• Liners require care and handling and hygiene
• More expensive than traditional systems
• Not for everyone
  • Open mind
  • Eureka moment
VAS BRIMLESS

Indications

- Desire to try something new
- Past VAS user
- Desire to remove brim
  - Difficult to fit traditional IRC in conjunction w/ VAS
- Proper Length
  - At least 11-18cm
  - Depending on size
Some patients are...

- Not mechanically inclined
- Used to traditional methods
- Mental Aptitude
- Too Short (currently)
VAS BRIMLESS
Casting Procedure

- Simple volume matching
- Can use CAD
- Can use fiber cast instead of plaster
- “Contain” IRC
- Alignment lines
- Measurements from the model
WHAT IS VAS?

http://www.youtube.com/watch?v=9-CGdLatOcE
VACUUM ASSISTED SUSPENSION

Randomized Control Trials are needed to prove…

- Better Mechanics?
- Better Total Surface Bearing?
- Volume Fluctuation?
- What Materials are best?
VACUUM ASSISTED SUSPENSION

Must be something to it bc of manufacturing
• No current standard of care in TF VAS principles because of Sealing Design

What’s out there?
• Otto Bock
  • Urethane
  • P2, P3, E Pulse
• OWWW
• Electronic Pump
• Evolution
  • Aura
• Electronic pump
• Hand Pump
VACUUM ASSISTED SUSPENSION

- RCTs are needed
- Could be very beneficial because of Better Mechanics
  - Dynamic Suspension
  - Body Weight Support-by Better Total Surface Bearing
  - Proprioception-by Better Total Surface Bearing
  - Volume Fluctuation-by Eliminating pistoning
  - Dermatological Health-Materials that flow work best for VAS
TF + VACUUM ASSISTED SUSPENSION

- History

- Transtibial Only
  - Proximal seal-requires suspension sleeve
  - Liner choices are primarily for TT-
    - Evolution of TF
    - Application of TF

- Pump
  - Reliability
  - Clearance
TF + VACUUM ASSISTED SUSPENSION

TF Current Options

• Double wall
  • Pump clearance
  • Difficult to fabricate
  • Unreliable

• Minimal area exposed to vacuum

• Connection to liner + interface

• TF VAS problems= unreliable and problems lead to catastrophic failure
  • TT VAS problems= bad fit , but not catastrophic
**VACUUM ASSISTED SUSPENSION**

- History has been Transtibial only
  - Proximal seal-requires suspension sleeve
  - Liner choices + Pump clearance
    - More TT choices - TT here before TF
- TT VAS problems = bad fit, but not catastrophic
- TF VAS problems = unreliable and problems lead to catastrophic failure
Clinical Trials are needed...

VAS could be beneficial because of better mechanical principles?

- Dynamic suspension
- Sub-atmospheric?
- Total surface bearing?
  - Body weight support
  - Proprioception
  - Dermatological health
- Volume fluctuation? How?
Control?

- IRC + Femur
- Thigh =
- Pelvic control =
- Spinal control

TRANSFEMORAL + VAS
TRANSFEMORAL INTERFACE/ALIGNMENT
BRIMLESS VERSUS ISCHIAL RAMUS CONTAINMENT VACUUM ASSISTED SUSPENSION TRANSFEMORAL INTERFACES

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RANDOMIZED CLINICAL TRIAL
USF SPTRS RCT, 2011. n = 10

• 12 Transfemoral Amputees, 10 males 2 females
• 2 dropped out due to unrelated medical reasons
• 1 could not tolerate IRC
  • Included in this analysis

Funded by Southern Bone & Joint
• Averaged Age= 42.9 years (+14.7, 21-70)

• Average RL length was 60.25% (+18.7%,) of the sound side.

• Subjects’ average time as an amputee was 8.3 years (+10.1, 0.8-26 years)
  • Average AMP score was 40 (+6.4, 27-45).
  • All subjects had medium or firm tissue consistency.
  • Alignments were duplicated
  • All subjects were fit with a Symmetry IRC and Brimless interface + given 2 days to accommodate prior to testing each interface in random order.
OUTCOME MEASURES

- Skeletal kinematics using X-Ray/Fluoroscope
  - Femur add/ abduction angle

- Internal interface pressure
  - Techscan, F-socket

- Agility / Balance
  - 4 square step test
  - Biodex SD

- Temporal spatial
  - Gaitrite gait matt

- PEQ
IRC VS. BRIMLESS
+0.7cm vs -3.5cm
X-RAY = WEIGHT BEARING

IRC

BRIMLESS
X-RAY “PROSTHETIC SWING”

IRC

BRIMLESS
X-RAY “PROSTHETIC STANCE”

IRC

BRIMLESS
FLUOROSCOPE VIDEOS

IRC

Symmetry

Real Time (15fps)

STANCE  SWING  STANCE  SWING
X-RAY “PROSTHETIC STANCE”

- IR
- Lateral Wall
- Anterior
- Posterior
- Rectus
- Femur
- Adductor Relief
- Media
- IRC
FLUOROSCOPE VIDEOS
FLUOROSCOPE VIDEOS

IRC

Symmetry

Real Time (15fps)

STANCE  SWING  STANCE  SWING
~ BRIM VS. BRIMLESS CONCLUSIONS

• Biomechanical ~ Equivalence
  • Skeletal kinematics
  • Internal interface pressure

• Agility / Balance Equivalence
  • 4 square step test
  • Biodex SD

• Temporal spatial ~ Equivalence
  • Gaitrite gait matt

• PEQ Favored Brimless
CONCLUSION

• 3 styles of TF interface design to distribute weight off the distal end + assist in control of the pelvis/spine.

• Proximal brim of the TF interface determines weight bearing characteristics, alignment, and gait.

• Maximizing the anatomy of the residual limb will enhance performance.
THERE ARE NO PROSTHETIC PANACEAS