Stiffness properties of prosthetic feet under cross-slope conditions

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Outline

- Introduction
- Review of Literature
- Rationale
- Hypotheses
- Methods
- Data
- Discussion
Introduction

Prosthetic feet serve to aid the body in:
- Progression
  - Energy storage and return
- Weight-bearing stability
  - Durability, compliance
- Shock absorption

Recommendation criteria can be influenced:
- Experience
- Economy
- Patient knowledge and assertiveness
- Manufacturer visibility and recommendation
Review

- Clinical Testing:
  - Inconsistent results with relation to foot dependent change - Usually comparing feet to SACH (Hafner, 2002; Van der Linde, 2004; Perry 1997)

- Mechanical testing: emphasis on sagittal plane
  - Energy Return (Geil, 2002; Zahedi; Van Jaarsveld 1993; Klute 2004; Postema 1997)
  - Fatigue (Hahl, 2000, Meier, Rooyen 1997)
  - Forefoot or heel (Contoyonis, 2001; Ge Postema 1997; Rooyen 1997, Klute, 2002)
  - Shock absorption (Rooyen 1997)
  - ISO 10328, 22675- Fatigue
Review:

- Rooyen 1997 – Compared characteristics of 2 SACH feet and the effects of fatigue
  - Found significant difference between two SACH feet
- Geil 2000 – Demonstrated that prosthetic feet separate themselves by energy loss/energy return properties.
- Kabra 1991
  - Measured several characteristics of feet
  - Only article to measure supination/pronation properties.
- Zmitrewicz, 2006
  - Gait analysis of effect of ESAR and Multiaxis functions on gait
  - Found that amputees preferred multiaxis feet and that they may be very useful for older patients
Purpose

- Demonstrate range of compliance in various prosthetic feet at “mid stance” on sloped surfaces
- Illustrate a potential test method for evaluating the coronal plane compliance of prosthetic feet
- Demonstrate the utility of this or similar tests to classify prosthetic feet based on given characteristics
Rationale

- Slope creates point of rotation on one border of foot
- Prosthesis has tendency to rotate about point of contact without force exerted by amputee to maintain erect (proximal brim of socket)
- As foot deforms to comply with surface the weight line will become closer to the point of rotation reducing the force needed to be exerted by the amputee
Hypotheses

- A range of stiffness will be observed among prosthetic feet
- A lateral leaning slope will have a more pronounced impact on the stiffness (lateral border of foot will be less stiff)
  - Medial bias of construction of many prosthetic feet
- Multi axis feet will demonstrate less stiffness on non-flat surfaces than other feet types
Methods – Foot Selection

- Foot Selection
  - List of available feet

- Foot Specifications
  - Adult, Male
  - 175 lb. (~800 N)
  - Medium Transtibial Amputation
  - Size 27
  - Right foot (if requested)

- Based on previously used criteria, within range of nearly all feet while still allowing for carrying load of ~25 % body weight.
Methods – Test Set-Up

- Quasi-static cyclic testing
- Servo-hydraulic testing machine (Instron 8521)
- 3 conditions
  - Flat, Medial Slope, Lateral Slope
  - Custom built slope 7.5, 15 degrees
    - (rotated 180 deg. for Medial/Lateral slope)
- High Density Fiberboard construction
- Teflon sheets to reduce friction
- 7.5 deg. ~ slope of a wheelchair ramp
- 15 deg. ~ near end ROM of sub-talar joint of human foot
Methods - Testing

- Feet underwent cyclic loading
  - .25 hz, .75 kN amplitude
- Data recorded at 100 hz
- Data recorded on two separate days for each sample
- 5 trials for each foot, condition
  - Enough to have at least 2 complete cycles
## Variability: Day 1 vs. Day 2

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<th>Foot</th>
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All Feet; 400 N

- Graph showing stiffness (N/mm) for different prosthetic feet.
- Bars represent stiffness at the lateral and medial borders.
- Prosthetic feet listed include Single Axis 1, Dynamic Response 1, Dynamic Multi-axis 2, DR-Multi-axis 1, SACH 3, SACH 2, SACH 1, Multi-axiss 3, Multi-axiss 2, Flexible Keel 1, Flexible Keel 2.
Change in stiffness of foot at 400 N (50% BW)
Flexible Keel Feet; 400 N

- Flat surface
- Lateral slope
- Medial slope

<table>
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<tr>
<th>Condition</th>
<th>Flexible Keel 1</th>
<th>Flexible Keel 2</th>
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Stiffness (N/mm)
Conclusions

- Laboratory tests demonstrate differences between feet.
- Current classification systems do not clearly define foot function.
- Laboratory tests along with clinical evidence can be used for foot prescription recommendations.
Limitations

• What is clinically acceptable?
• Quasi-static
• Velocity?
• All feet?
• Different phases of gait?
Application

- Primary prosthetic recommendation
  - Initial foot for patient
- Enhanced (secondary) prosthetic recommendation
  - Follow up diagnosis based on patient feedback
- Drive foot manufacture
- Basic understanding of prosthetic foot function
Thank You

- Acknowledgements
  - Rob Kistenberg, MPH
  - Mark Geil, Phd
  - Rob Macdonald
References


• Zahedi, S., G. Harris, et al. Holy grail of prosthetic foot design - Elite Foot, Innovation Centre.

Questions?