Biomechanical Mechanisms Contributing to Foot Pain

Howard J Hillstrom, PhD
Director, Leon Root, MD Motion Analysis Laboratory

e-mail: HillstromH@HSS.edu

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Outline

- Introduction and Practice Gap
- Biomechanical Rationale: Relationship Between Foot Structure and Foot Pain
- Biomechanical Rationale for Footwear Prescription
- Case Study and Implications for Intervention and Practice

Introduction and Practice Gap

- The vast majority of pedal pathologies do not have a scientifically proven etiology.
- Clinicians examine their patients, formulate a hypothesis for the cause, acquire data to test this hypothesis, and derive a diagnosis.
- Treatment(s) that have helped previous patients with that diagnosis and stage of pathology are applied.
- If successful stop & collect fee; if not proceed to next most promising treatment.
- The precise cause of foot pain for many pedal pathologies remains unknown which makes precise treatment selection challenging.

Introduction

- The foot and ankle is one of the most mechanically complex structures in the body.
  - 28 bones (with sesamoids), 33 joints & 112 ligaments
  - Controlled by 13 extrinsic & 21 intrinsic muscles.
- Many foot pathologies tend to occur in individuals with specific foot types.
  - Pes planus feet: hallux valgus, hallux limitus, posterior tendon
  - Pes cavus feet: hammer, claw, and mallet toes, metatarsalgia

Foot Pain

Intrinsic Factors
- Foot Type
- Primary OA
- Auto-immune
- Systemic

Extrinsic Factors
- Trauma
- Secondary OA
- Neurologic
- Shoe gear

HALF FLIGHT STAIR TEST

Note: Patient may not use walking aids during the test.
1) Time to ascend/descend steps: seconds
2) Total time (add above times): seconds
3) Record maximum level of pain during the test:
   RIGHT KNEE: mm
   No pain    Moderate Pain   Extreme pain
   LEFT KNEE: mm
   No pain    Moderate Pain   Extreme pain
4) Did patient require use of handrail or wall support
   YES or NO

Biomechanical Rationale: Relationship
Between Foot Structure and Foot Pain

• Foot function: foot structure dependent

Is Foot Structure and Function Related?

Cavus          Rectus          Planus

Central Hypothesis

Objective measures of foot structure and function will exhibit significant differences across planus, rectus, and cavus feet

Clinical Motion Analysis

LRMAL Physical Therapists evaluate the patient’s structure and prepare them for motion analysis testing to document their function

Clinical Stratification of Foot Type

<table>
<thead>
<tr>
<th>Cavus</th>
<th>Rectus</th>
<th>Planus</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCSP</td>
<td>≥4° valgus</td>
<td>0° ≤ RCSP ≤ 2° valgus</td>
</tr>
<tr>
<td>FF-RF</td>
<td>≥5° varus</td>
<td>0° ≤ FF-RF ≤ 4° varus</td>
</tr>
</tbody>
</table>

N = 61 subjects
22 = planus
27 = rectus
12 = cavus
Structural Measures
Malleolar Valgus Index (MVI)
- a measure of static hindfoot alignment

\[ \text{MVI} = \frac{\text{LA} - \text{LF}}{\text{LM}} \times 100 \]

Note: greater MVI indicates more pronated hindfoot alignment.

Arch Height Index (AHI)
- a measure of static arch height and arch flexibility

\[ \text{AHI}_{sitting} = \frac{\text{AH}_{sitting}}{\text{TFL}} \times 100 \]
\[ \text{AHI}_{standing} = \frac{\text{AH}_{standing}}{\text{TFL}} \times 100 \]

Functional Measures
Plantar Pressures
- a measure of dynamic foot function

• All 61 test subjects walked across the plantar pressure measuring system at their Comfortable self selected walking speed
• In comparison with the gold standard factory calibrator over the range of 0-850 kPa at baseline, 1 week, and 1 month follow-up, error in Emed-x measurements never rose above 2% FSE.

Arch height and flexibility

Song J et. al.: Foot Type Biomechanics: Comparison of Planus and Rectus Foot Types, JAPMA, 86:1,16-23, 1996.

Planar Pressure Reliability

ICC (2,1) > 0.9 for every plantar pressure parameter; parameter stability (~10% difference with unbiased estimate of mean) resulted from averaging 4 trials of each parameter – we’re averaging 5 trials for CPEI, peak pressure, etc

Foot Structure and Function - comprehensive normative data

- Objective biomechanical differences between pes planus, rectus, and pes cavus feet
- Foot function: foot structure dependent

Publications:

Biomechanical Rationale for Footwear Prescription

- Shoe structure interacts with foot structure to produce overall foot (lower extremity) function

Stride Rite Study of Children Learning to Walk

- Effect of shoe structure on stability, gait, and plantar loading

Central Hypothesis

- Shoe structure will affect stability, gait pattern, and plantar pressure distribution in “early walkers” during gait.
Methodology

**Shoe Testing System**

- Instron 4201 Tensile tester
- 4 shoe designs; 5 pairs each
- Pre-load (displacement): 15mm
- Range: 0 to 50 deg; Rate: 13.32 deg/s
- 20 trials (first 10 trials preconditioning; last 10 trials analyzed)
- Calculated flexibility (ΔAngle/ΔMoment):
  - Line of best fit from data captured in 5º increments starting @ 5º ending @ 45º

**Methods**

**Protocol**

- N = 26 early walkers were recruited
- Clinical assessment
  - Alignment & anthropometrics
- Qualitative stability testing
  - Hi-definition video
- Quantitative gait testing
  - Plantar pressure measurement
    - Pedar X
    - Emed X
  - Temporal-distance parameters
  - Gaitmat II
- Order of shoe design testing was randomized

**Results**

**H1: Structural characteristics will be different for each shoe design**

- Accept H1

**H2: Footwear will affect # of stumbles & falls in functional activities**

- Linear trend between stumbles & flexibility for Barefoot, UltraFlex, MedFlex, LowFlex, and Stiff shoes.

- Peak plantar pressure was significantly different across footwear conditions for all 12 masked regions except for the lateral midfoot and right 5th MTPJ.
- Peak hallucial pressure was decreased in the Stiff compared to UltraFlex, MedFlex, and LowFlex shoes.

- P = 0.796
Birkenstock Sandals
*N=20 adults mild to moderate pes planus*

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**Comfort Index - VAS**

- Overall Comfort
- Heel Cushioning
- Forefoot Cushioning
- Medial-Lateral Control
- Arch Height
- Heel Cup Fit
- Heel Width
- Forefoot Width
- Shoe Length

Note: VAS ranges from 0 – 100 mm, where 100 represent the most comfort level. (Mundermann A et al, 2001)

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**The association of vibratory perception with foot plantar pressures: the MOST Study.**

- Najia Shakoor, Howard Hillstrom, Doug Gross, Ke Wang, David Felson, Neil Segal, Cora E. Lewis, Michael Nevitt
- H1: Vibration perception deficits, since they are sensory in nature, may increase mechanical loading of tissues and joints in individuals with knee OA.

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**Biomechanical Rationale for Footwear Prescription**

- Shoe structure interacts with foot structure to produce overall foot (lower extremity) function
- The specific footwear required is person, pathology, disease stage, and application dependent
  - Children learning to walk may need flexible shoe technology
  - Patients with diabetes & Charcot arthropathy may need to be non-weight bearing in the acute stage and then in rocker bottom shoes with custom molded orthoses
  - Adults with planus feet may benefit from arch support walking or pronatory control while exercising
Case Study and Implications for Intervention and Practice

• Collapsing pes valgus
• Hallux limitus/rigidus

Surgical Reconstruction of Collapsing Pes Valgus Feet

• 16 patients (23 limbs) with a painful severe collapsing pes valgus deformity were recruited.
• Each patient was evaluated in the barefoot condition for MVI, CPEI and other pertinent gait parameters at baseline (pre-op) and 6 month post Evans calcaneal osteotomy.

Collapsing Pes Valgus

REHABILITATION

Case Study:
57 yr old male with painful 1st MTPJ

Hallux Limitus < 65°
Hallux Rigidus < 20°
Boney hypertrophy, osteophytes, possible JSN

1st MTPJ Flexibility

Flexibility Comparison Healthy vs. Hallux Limitus

Flexibility of the big toe joint

Hallux Limitus Plantar Pressures

Torque(in-lb)
Knee OA Pain is Predicted by Joint Space Narrowing and Peak Adduction Angle

- N=15 varus knee OA patients
- Several measures of structure were assessed: JSN, FT angle, ...
- Several measures of Function were assessed: M\_add, \theta\_add, velocity.
- Using a stepwise regression: VAS Pain during walking was predicted by JSN & peak Adduction angle: R\^2=0.73

Needed for foot pain but it would be pathology specific


Collaborators
- Jinsup Song, Scott Ellis, Smita Rao, Mark Lenhoff
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Questions?
Howard J Hillstrom, PhD
HillstromH@HSS.edu