Foot and Ankle Osteoarthritis: A Matter of Structure and Function

Howard J. Hillstrom, PhD
Director, Leon Root, MD Motion Analysis Laboratory
Hospital for Special Surgery, New York, NY
Phone: 212-606-1507; Email: HillstromH@HSS.edu

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Overview
- Introduction: Osteoarthritis and Clinical Foot Type
- Measurement of Foot Type: A Matter of Structure & Function
- Recent Epidemiology
- Computational Modeling
- Translation
  - Assessment
  - Pathology
  - Conservative Treatment Strategies
- Summary and Work Remaining

Introduction
- Osteoarthritis of the ankle, subtalar, midtarsal, and 1st metatarsal phalangeal joints may in part be due to trauma and long term exposure to excessive stress.
- This stress can originate from excessive body mass index, damage to soft tissues (cartilage, ligament), and malalignment.
- The precise role of these factors for disease onset and progression in the foot and ankle are the subject of current research.
- Inherent alignment in the foot and ankle is described by one’s foot type (planus, rectus, and cavus).
- Hallux valgus and hallux rigidus have recently been associated with pes planus feet in the Framingham Foot Study.
- The importance of understanding these foot types is that conservative and surgical treatments often target these malalignments in an effort to restore normal joint stress, reduce pain, and improve function.

But OA maybe a direct result of excessive stress to the cartilage matrix irrespective of the mechanism of origin:


There are Probably Multiple OA Etiologies

Key References
**Introduction: Foot and Ankle OA**

- 26.7 million in the US with OA and there is no known cure
- Numerous non-surgical Tx have been tried
  - Pharmaceuticals, nutraceuticals, viscosupplementation, physical therapy, weight loss, ambulatory aids, alternative medicine, orthoses, platelet rich plasma (PRP), and special shoe gear as individual or combinational therapies,
- Surgical options:
  - Chellectomy, Realignment Sx, joint distraction, mosaicplasty and cartilage transplantation, arthrodesis, and arthroplasty
- Arthrodesis or total joint replacement definitive Tx for many patients and ultimately the final common pathway

**Introduction - Pedal Anatomy**

28 bones (including sesamoids)
33 joints & 112 ligaments
13 extrinsic & 21 intrinsic muscles

The hindfoot = ankle + STJ

The rearfoot = ankle + STJ + MTJ

The midfoot = cuneonavicular joint, cuboid-metatarsal joint, metatarsal-cuneiform joints

The forefoot = MTPJ, PIPJ, DIPJ

**Foot & Ankle Clinical Foot Type Associations**

- **Pes Planus**: Hyper-pronation, Stress Fx, Shin Splints, Plantar Fascitis/Heel Spur Syndrome, Posterior Tibial Dysfunction, Peroneal Spastic Flatfoot, Osseous Coalitions, HV deformity, and Hallux Rigidus
- **Pes Cavus**: Hyper-supination, Hammer-toes, Intrinsic minus foot, Metatarsalgia, Neurological disorders
- Which foot type is associated with a given pathology?
- Why is one foot type associated with one set of pathologies and another a different set?
- What factors predispose some individuals with a pes planus foot type to be asymptomatic, some to get HV and yet some to develop hallux rigidus?
Clinical Concept of Foot Types

- RCSP = angle between calcaneal bisection and a line perpendicular to the ground
- FF-RF = angle between plantar lines at Met heads 1-5 and the plantar heel

<table>
<thead>
<tr>
<th>RCSP (°)</th>
<th>Pea Planus</th>
<th>Rectus</th>
<th>Pea Cavus</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 40° valgus</td>
<td>0 to 20° valgus</td>
<td>&gt; 10° of varus</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>FF-RF (°)</th>
<th>Pea Planus</th>
<th>Rectus</th>
<th>Pea Cavus</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 50° of varus</td>
<td>0 to 40° of varus</td>
<td>&gt; 10° of valgus</td>
<td></td>
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</tbody>
</table>

Measurement of Foot Type: A Matter of Structure and Function

- Foot Type Biomechanics: There is more than one type of foot

**Hypothesis:** Objective measures of foot structure and function can distinguish planus, rectus, and cavus foot types in asymptomatic individuals

**Clinical significance:** Measures of foot structure and function, if sensitive to foot type, may be able to differentiate pathology from asymptomatic feet and inform clinicians of how to improve foot function through basic modifications of foot structure.

**Protocol:** 61 asymptomatic healthy adults: 21 – 80 years old included based upon goniometer classification criteria
- Subjects had 44 planus, 54 rectus, and 24 cavus feet
- Objective measures of foot structure & function measured on each

Methods – Foot Structure

- Malleolar Valgus Index (MVI) – a measure on hindfoot alignment
  \[ \text{MVI} = \left(\frac{\text{LA}-\text{LF}}{\text{LM}}\right) \times 100 \]

- Arch Height Index (AHI) acquired sitting & standing
  \[ \text{AHI} = \left(\frac{\text{AH}_{\text{standing}}-\text{AH}_{\text{sitting}}}{0.4 \times \text{BW}}\right) \]

- Arch Height Flexibility
  \[ \text{AHF} = \left(\frac{\text{AH}_{\text{standing}}-\text{AH}_{\text{sitting}}}{100}ight) \]
Methods – Foot Structure

1st MTP Joint Flexibility
EF (° /N-cm) = slope from 0 – 25% of DF vs M curve
LF (° /N-cm) = slope from 75 – 100% of DF vs M curve
θL = Laxity at 50 N-cm

Methods – Foot Structure

• Sagittal (Lateral view) and transverse (AP view) radiographs

Not included in this study


Methods – Foot Structure

• Sagittal (Lateral view) and transverse (AP view) radiographs

Not included in this study


Methods – Foot Function

Temporal-Distance Parameters
Tandem GaitMat II measures step length, stride length, stance time, velocity, etc

Methods – Foot Function

Plantar Pressure Parameters
CPEI (%) = (CPE / FW) * 100

3D Kinematics and Kinetics

• 12 camera based MoCap of a 6DoF marker set maybe used to study joint motion

Not included in this study

Results – Foot Structure

MVI(%), AHIfalling, AHIflooring were significantly different across foot type
AHIfalling, AHIflooring could distinguish planus, rectus, and cavus feet upon post hoc testing

<table>
<thead>
<tr>
<th>Foot Structure</th>
<th>Planus</th>
<th>Rectus</th>
<th>Cavus</th>
<th>GEE Results</th>
<th>Post-hoc Analysis (p-values)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MVI (%)</td>
<td>13.54</td>
<td>7.40</td>
<td>3.88</td>
<td>6.77</td>
<td>3.92</td>
</tr>
<tr>
<td>AHIflooring</td>
<td>0.38</td>
<td>0.04</td>
<td>0.29</td>
<td>0.30</td>
<td>0.001</td>
</tr>
<tr>
<td>AHIfalling</td>
<td>0.37</td>
<td>0.03</td>
<td>0.30</td>
<td>0.30</td>
<td>0.000</td>
</tr>
<tr>
<td>AHF (mmHg)</td>
<td>12.73</td>
<td>5.80</td>
<td>13.21</td>
<td>5.51</td>
<td>0.12</td>
</tr>
</tbody>
</table>
Results – Foot Function

Normalized stance and double support times were significantly shorter in planus vs cavus feet

### Results – Foot Function – Peak Pressure

**Peak Pressure Measurements by Foot Type**

- **Planus**
- **Rectus**
- **Cavus**

* p < 0.05

### Results – Foot Function – CPEI(%)

<table>
<thead>
<tr>
<th>Foot Type</th>
<th>CPEI&lt;sub&gt;100&lt;/sub&gt; (%)</th>
<th>CPEI&lt;sub&gt;25&lt;/sub&gt; (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planus</td>
<td>24 (8.12)</td>
<td>21 (5.47)</td>
</tr>
<tr>
<td>Rectus</td>
<td>16.57 (4.97)</td>
<td></td>
</tr>
<tr>
<td>Cavus</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Conclusions

- Several objective measures of foot structure and function were significantly different across foot type.
- Asymptomatic feet have different biomechanical structure and function – it may not be appropriate to assume there is only ‘one healthy foot’.
- These measures of foot structure and function will serve as a normative database for comparison with pathology to study the effectiveness of treatment.

### Recent Epidemiology
Factors Associated with Hallux Valgus

- Data from 600 MOBILIZE Boston Study participants (386 women and 214 men) were analyzed.
- Hallux valgus (HV) >15° deviation of hallux w.r.t 1st metatarsal
- HV was present in 58% of women and 25% of men.
- Higher BMI inversely associated with HV in women (P=0.001)
- Women, who wore high-heeled shoes (20-64 years of age) had increased likelihood of HV (RR=1.2, 95% CI: 1.0, 1.5).
- Men with BMI 25.0 - 29.9 had increased likelihood of HV compared to normal BMI (RR=1.9, 95% CI: 1.0, 3.5).
- Men with pes planus more likely to have HV (RR=2.1, 95% CI: 1.3, 3.3) compared to men without pes planus.

Foot Disorders, Structure, and Function

- Purpose - assess the relation between specific foot disorders, foot posture, and foot function.
- Participants from population-based Framingham Foot Study.
- Quintiles of MAI and CPEI from plantar pressure trials used to create foot posture and function subgroups.
- Adjusted OR per disorder were calculated for foot posture and function subgroups relative to referent 3 quintiles.
- Planus foot posture associated with increased odds of hammer toes and overlapping toes.
- Cavus foot posture not associated with these foot disorders.
- OR of HV and OL toes increased with pronated foot function.
- HV and HR significantly decreased with supinated function.

Foot Structure, Function and Pain

- Examine associations of foot posture & function to foot pain.
- Data collected on 3,378 members of the Framingham Study who completed foot examinations in 2002-2008.
- Foot pain (six locations) – response to question “On most days, do you have pain, aching or stiffness in either foot?”
- Foot posture categorized as normal, planus or cavus with static pressure measurements-modified arch index (MAI).
- Foot function categorized as normal, pronated or supinated using CPEI from dynamic pressure measurements.

Hallux Valgus

- Does HV etiology differ by sex?
- HV Foot Structure and Function
  - Planus foot posture significantly associated with arch pain in men (OR 1.38, 95%CI 1.01 - 1.90).
  - Cavus foot posture was protective against ball of foot pain (OR 0.74, 95% CI 0.55 - 1.00) and arch pain (OR 0.64, 95% CI 0.48 - 0.85) in women.
  - Pronated foot function significantly associated with generalized foot pain (OR 1.28, 95% CI 1.04 - 1.56) and heel pain (OR 1.54, 95% CI 1.04 - 2.27) in men
  - Supinated foot function was protective against hindfoot pain in women (OR 0.74, 95% CI 0.55 - 1.00).
  - Interventions that modify abnormal foot posture and function may have a role in the prevention and treatment of foot pain.
Foot Pathologies Associated with Foot Type

- Study purpose: to investigate association of pes planus and the prevalence of foot pathologies
- Framingham cohort = 2994 participants (5778 feet)
- Hypothesized: those with pes planus will have higher odds of hallux valgus, hallux rigidus, and plantar fasciitis than those who are non-planus
- Pes planus was CPEI=19.4% (TekScan MatScan)*
- 74% classified as pes planus - mean age 65.5 (9.9) years
- Those with pes planus had increased OR for HV (OR 1.6, 95% CI 1.4, 1.8) and HR (OR 1.6, 95% CI 1.1, 2.3)
  - Also significant after adjusting for age, gender, and BMI

Effect of Turf Toe on 1st MTP Joint Function

- Hypotheses: (1) history of turf toe associated with increased peak hallucal and 1st MTP plantar pressures; (2) decreased 1st MTP joint ROM correlates with increased peak hallucal & 1st MTP pressures.
- 44 athletes from one National Football League team were screened for a history of turf toe during preseason training.
- 1st MTP DF significantly lower in halluces with history of turf toe (p = 0.04).
- Peak hallucal pressures were higher in athletes with turf toe (p = 0.05) even after normalizing for athlete BMI (p = 0.0003).
- Peak 1st MTP pressure not significantly different
- 1st MTP dorsiflexion didn’t correlate with peak pressures.

Epidemiology of Ankle OA

- Between 1991 and 2004, 639 patients with KL grade 3 or 4 ankle arthritis presented to University of Iowa Orthopaedic Foot and Ankle Surgery service.
- 445 (70%) were post-traumatic, 76 (12%) were RA and 46 (7%) were idiopathic (primary OA).
- The post-traumatic ankle OA patients most commonly associated with past rotational ankle fractures.
- Majority of ankle OA is associated with previous trauma, whereas the primary cause of knee or hip arthritis is idiopathic.

Computational Modeling

To analyse the stress distribution in standing posture:
1. Fix base of the 1st metatarsal (A)
2. Apply ground reaction forces:
   - under distal phalange (B)
   - under head of the 1st metatarsal (C)
**Simulation of pes planus and pes cavus feet**

<table>
<thead>
<tr>
<th>Pes planus</th>
<th>Rectus</th>
<th>Pes Cavus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Metatarsal declination = 11.35°</td>
<td>1st Metatarsal declination = 20.22°</td>
<td>1st Metatarsal declination = 30.70°</td>
</tr>
</tbody>
</table>

**Translation to Conservative Treatment**

- Pathology Assessment
- Conservative Treatment Strategies

**Hindfoot Alignment and 1st MTP Joint OA**

- Hypothesis: individuals free of 1st MTP joint OA, who have hindfoot valgus are more likely to develop 1st MTP joint OA than are those with normal hindfoot alignment.
- Retrospective cohort sample consisted of 1592 men and women, ≥40 years of age, participating in the Clearwater Osteoarthritis Study (1988 to 2001).
- Biennial exams, including radiographs, were conducted.
- KL ordinal scale used for incidence of first MTP joint OA.
- Individuals with hindfoot valgus were 23% more likely to develop 1st MTP joint OA than without (RR = 1.23; p-value < 0.006).

**Foot Orthoses can Alleviate foot pain**

- A study was conducted to evaluate the effects of non-custom-molded (over-the-counter) foot orthoses.
- Several parameters examined, including foot, knee, hip, and back pain; balance; and reduction in flexible deformities, such as hammer toes and hallux valgus.
- 41 individuals were analyzed using one of two types of prefabricated, non-custom insoles.
- Insoles significantly reduced some types of foot pain associated with HV (P = .04) and arch area (P = .004), knee (P = .002), and back (P = .007) by week 4.

**Translation to Conservative Treatment**

- Review paper: Aberrant foot structure linked to foot OA
- Non-pharmacological treatments serve as the first line of treatment and are frequently used for patients with musculoskeletal conditions of the foot and ankle.
- Since many patients present with multiple impairments, combinational therapies that target foot-specific as well as global impairments show promising results.
- While significant improvements have been made in the last decade for assessment and treatment of foot and ankle conditions, few randomised clinical trials have investigated patients with foot or ankle pathologies to provide global insights into this area.

**Results**

- Peak von Mises stress calculated for each foot type
- Stress distribution in the distal 1st Metatarsal head for the
  1. Rectus (6.09x10^5 MPa)
  2. Pes planus (1.10x10^5 MPa)
  3. Pes cavus (9.69x10^5 MPa) foot types
Orthoses in Midfoot OA

- Patients (n=30) with midfoot arthritis and age-, sex-, and body mass index-matched control subjects (n=20).
- Four-week intervention with FL orthoses.
- Pain and function - Foot Function Index-Revised (FFI-R).
- Significant improvements in pain and function, with lower FFI-R scores (P<.001), after 4-weeks with FL orthoses.
- FL orthosis decreased first MTP joint dorsiflexion (P=.024) and first metatarsal plantarflexion range of motion (P=.038), compared with the shoe-only condition.
- Orthosis used a "stiffening" strategy to the 1st metatarsal and 1st MTP joint.


Orthoses preventing military injuries

- Overuse injury is common in incidence and morbidity.
- 400 military officer trainees had their contact foot pressures measured during walking.
- Participants were randomized for customized orthoses.
- Both cohorts were followed up for injury through their basic training at the 7-week point.
- Orthotic group sustained 21 injuries whereas the control group had 61 injuries (P < .0001).
- In this military trainee population, orthoses were effective in the prevention of overuse lower limb injury.


Ankle OA Conservative Treatment Review

- Review article summarizes the currently available (poor) evidence of conservative treatment of asymmetric ankle OA.
- Use of dietary supplementation, vicosupplementation, platelet-rich plasma, nonsteroidal anti-inflammatory drugs, corticosteroid injections, physical therapy, shoe modifications and orthoses, and patient’s education in asymmetric ankle osteoarthrosis is outlined.
- "There definitively is a place for conservative treatment with reasonable success in patients whose ankles do not qualify anymore for joint-preserving surgery and in patients with medical or orthopedic contraindications for realignment surgery, total ankle replacement, and ankle arthrodesis."


The Biomechanical Price of High Heels

- Mootanah et al used Framingham database to assess clinical impact of high heel use across lifespan.
- 1,916 female participants aged 66.46 (±10.97) years.
- 71% had at least one foot disorder, 88% had at least one skin disorder and 34% had at least one nail disorder.
- 5% wore HHS at time of the study.

Summary and Work Remaining

- Foot structure and function are associated with foot pathologies including OA.
- Malalignment, obesity, and trauma are the primary factors associated with foot and ankle OA.
- The majority of ankle OA cases are post traumatic.
- The precise pathomechanical etiology of foot and ankle OA has not been scientifically established.
- To determine onset and progression of foot and ankle OA, and how pain modulates a patient’s functional limitations and disability, longitudinal studies are needed.
- In addition, RCT of treatments that target pain, abnormal structure, and aberrant function are required.
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Howard J Hillstrom, PhD
HillstromH@HSS.edu