**OBJECTIVES**

1. Review pertinent clinical concepts of Root Theory
2. Present new, conflicting experimental evidence
3. Propose clinical applications of these new insights

"It behooves the podiatry profession to first of all establish a common nomenclature which is specific in its meaning so that knowledge can be accurately transmitted. Secondly, the foot must be classified as to its various functional and structural types, with specific clinical methods for measurement and evaluation so that one foot type at a time can be given detailed study to further our knowledge of the problems we face."

Merton L. Root, 1963

**Criticisms of the Root Theory**

1. Reliability of clinical measurements
2. Dynamic subtalar joint position
3. Criteria for normalcy
4. Single axis model
5. Frontal plane rearfoot motion significance
6. Kinematic patterns of RF motion
7. Static measures = dynamic function

Criteria for a “Normal Foot”

“In the individual with normal lower extremities, the following conditions exist during normal static stance upon a level surface (ground).

I. The legs in the sagittal bisection of the calcaneus are perpendicular to the ground (vertical) and parallel to each other in both extremities.

II. The subtalar joints of both feet are positioned at their neutral positions.

III. The midtarsal joints are locked in their fully pronated positions.

IV. The full plantar surface of the forefoot of each foot rests upon the ground, all metatarsals bear weight, and the plantar surface of the forefoot parallels the plantar surface of the heel.”


“...there is also no evidence that the posterior bisection of the calcaneus is perpendicular to the plantar surface of the calcaneus, which is used as the reference plane for the frontal-plane forefoot deformity.”


KINETICS
Forces acting on a body part

KINEMATICS
Timing and movement of a body part

Kinematics of Rearfoot Motion

—Graph showing various phases and movements—
"As the midstance period begins, the leg begins to externally rotate and the subtalar joint begins to supinate."

"Just before the end of the midstance period, subtalar joint supination moves the foot into a slightly supinated position."

"Pronation of the foot is abnormal if the amount of pronation, during any period of locomotion, becomes excessive or if any pronation occurs at a time when the foot should be supinating."

"When treating the foot, the objective of functional orthopedic therapy is to reestablish normal motion and position of the foot during the stance phase of gait."

"Abnormal compensatory pronation of the foot is the most common cause of pathology within the foot."

"Abnormal pronation of the foot is defined as abnormal pronation of the entire foot which occurs at the subtalar joint. Abnormal pronation of the foot usually refers only to abnormal subtalar joint pronation, but, rarely, abnormal ankle joint pronation may also be included."

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"Normal" Rearfoot Motion

2 opposing views
1. Achieves neutral position before heel off
   - Root et al.
2. Remains at resting position until heel off
   - McPoil & Cornwall, 1994
     - Pierrynowski & Smith, 1996
     - Moseley, 1996
     - Liu, 1997

Should We Control Calcaneal Eversion?

CONTROVERSIES

- When does STJ achieve neutral?
- Rearfoot angle vs RCSP

Controversy

Root et al.:
- RCSP & NCSP calcaneus to ground

Others:
- Rearfoot angle calcaneus to leg

Figure A & B: The resting calcaneal stance position is determined by measuring the posterior intersection line of the heel to the ground with the foot relaxed.
Subtalar Neutral = Normal?

- Nine subjects
- Three dimensional treadmill analysis
- Max eversion at 44% of gait cycle
- Neutral STJ position at 66% and 74% of gait cycle

Subtalar Joint

When does pronation end and supination begin?

- 36% of gait cycle
  
  McPoil and Cornwall 1994

- 44% of gait cycle
  
  Pierrynowski, 1996

What initiates supination?

Independent Joints

Independent Axes

Figure A, B. The subtalar joint is moved to its end range of inversion (A) and eversion (B). Motion and excursion values are recorded.
Clinical Measurement
Calcaneal Inversion - Eversion
- 15 cadaveric legs
- Unlocked vs locked tibiotalar joint
- Manual vs radiographic measurements

Axis of Motion of the Pedal Joints
Fact vs. Fiction

“In this model, the subtalar and midtarsal joints have been described as dual screws connected to the talonavicular joint in opposite directions. This model introduced the concept of the position of the subtalar joint.

The range of motion of the midtarsal joint is controlled by subtalar joint position. In a pronated subtalar joint, the two axes of the midtarsal joint are in a more parallel orientation, increasing the range of motion. In a supinated subtalar joint, the two axes of the midtarsal joint are in a more oblique orientation, decreasing the range of motion.”

- Justin Wernick
- Russell G. Volpe

Should We Control Calcaneal Eversion?

### CONTROVERSIES
- When does STJ achieve neutral?
- Rearfoot angle vs RCSP
- Independence vs Interdependence of joint movements

"The tarsal bones together form an articulated ring of bones. The talus articulates with the calcaneus, the calcaneus with the cuboid, the cuboid with the navicular, and the navicular with the talus: a so-called kinematic chain with only 1 kinematic degree of freedom. Under weightbearing conditions, this kinematic chain acts as a mechanism in engineering terms, if a motion is imposed upon one of the links, the other links are also forced to move."

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"Because of the complex mechanical relationships between the tarsal motions and between these and other complex motions in the tarso-metatarsal joints, the use of axes of rotation as tools for a reliable quantitative clinical evaluation of foot function has no firm basis so far."

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HINGE AXIS?


- Six cadaver specimens
- Axis-finder rod
- LED path photography
- MRI serial cuts
- Single axis, at tips of malleoli
Traditional Biomechanical Exam

• Static Measurements
• Open Kinetic Chain
• Calcaneus is Point of Reference

“The assessment of the range of motion of the subtalar joint is done in a non-weightbearing position, but there is a difference between the weightbearing and non-weightbearing range of excursion of the calcaneus in the frontal plane, indicating motion in the joint.

Static measurements are used as part of the biomechanical assessment of patients, but in light of these reports and other work on the reliability of the measurements, their usefulness must be reconsidered.”


Figure A: With the patient standing in the angle and base of gait and the subtalar joint held in its neutral position, the angle of the bisection of the lower leg relative to the ground determines the tibial position.

Figure A & B: The resting calcaneal stance position is determined by measuring the posterior bisection line of the heel to the ground with the foot relaxed.
CKC
- Universal Joint Rotation
- Torsion Transmission
- Tibia: Dominant Lever

The Myth of the Subtalar Joint

Should We Control Calcaneal Eversion?

CONTROVERSIES
- When does STJ achieve neutral?
- Rearfoot angle vs RCSP
- Independence vs Interdependence of joint movements
- Importance of STJ control of LE
Calcaneus = Subtalar Joint = Foot

3 Myths of Podiatric Biomechanics
1. The calcaneus controls the subtalar joint
2. The subtalar joint controls the foot
3. The foot controls the leg

“Frontal plane movement of the calcaneus has been the primary indicator for measurement of foot pronation in studies on foot orthoses, while control of excessive foot pronation has been the primary objective in the prescription of functional foot orthoses.”
- William R. Olson

“One method of estimation of correction for the severe pronator is the “5-to-1 rule” Five degrees of plaster correction produces 1° of calcaneal inversion (rearfoot change). Measurement of the patient presents with an R CSP of 10° everted on the involved left side. Utilizing the 5 to 1 rule in an attempt to bring the rearfoot back to a vertical position, a 50 degree inverted orthotic correction should be ordered.”
- Richard Blake
Controlling Calcaneal Eversion Effects of Functional Foot Orthoses

<table>
<thead>
<tr>
<th>AUTHOR</th>
<th>DECREASED EVERSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarke et al.</td>
<td>2.5º</td>
</tr>
<tr>
<td>Cavanagh</td>
<td>2º per 6mm wedge</td>
</tr>
<tr>
<td>Rogers et al.</td>
<td>1-2º</td>
</tr>
<tr>
<td>Smith et al.</td>
<td>1.2º</td>
</tr>
<tr>
<td>Taunton et al.</td>
<td>1-2º</td>
</tr>
<tr>
<td>Sims</td>
<td>2º</td>
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</table>

"Simms and Cavanagh noted that although studies have claimed that foot and ankle symptoms are usually dramatically decreased with the use of foot orthoses, the objective improvement in rearfoot motion is considerably more modest, suggesting that therapeutic success is not necessarily due to restoring the foot to what is functionally considered “normal.” This raises the possibility that foot orthoses are effective for reasons that are not entirely clear."


“Variation in the spatial location of the subtalar joint axis affected the overall biomechanics of the foot during weight bearing activities.”


“Therefore, during many weightbearing motions, the foot may approximate a relatively rigid unit with all the bones of the foot rotating around the central pivot of the talus at the subtalar joint axis.”


“Finally, Huson’s theory on the constraint mechanism of the human tarsus, which has been supported by the tarsal kinematic research of Cornwall and McPoil, and the roentgen stereophotogrammetry studies done by Van Langeland, Benink, and Lundberg and Svensson are all consistent with the current author’s theory that the subtalar joint axis is the primary inversion/eversion axis of the foot.”


STJ: Pivotal Joint?

“The authors believe that the finding that the magnitude of navicular (midfoot) movement is greater than that of calcaneus (rearfoot) illustrates the importance of the midfoot for typical foot function during walking.”

Cornwall MW, McPoil TG: Three-dimensional movement of the foot during the stance phase of walking. JAPMA 89:56, 1999.
Figure 1. An osteoligamentous dissected specimen of the foot exarticulated at the ankle joint. The dorsal capsules of the talonavicular and calcaneocuboid joints have been removed. The foot is held in the neutral position corresponding with upright standing.

Figure 2. The talus has been moved as it does in supination of the foot while the calcaneus, cuboid, and navicular are kept immobile. The talar head has left the navicular socket laterally, creating a wide gap at the medial side of the talonavicular joint.

"The tibiofibular talar unit does not function independently of the subtalar or midtarsal joint but acts cooperatively in closed-kinetic chain performance. The complex movement pattern known as supination and pronation of the foot must occur in concert with talar movement in the ankle housing unless spontaneous or surgical ankylosis has occurred in the ankle."


"Talar positioning on top of the calcaneus is determined by ankle movement and midtarsal joint motions and varies depending on whether these are open- or closed-kinetic-chain events. Changes in any one of these joints alter the position and function of the others to varying degrees."


"The subtalar joint provides most of the transverse plane motion which is necessary at the distal extremity to allow internal and external leg rotation during the stance phase of gait. The subtalar joint pronates to allow internal leg rotation and supinates to allow external leg rotation."


"The ankle connects two unequal levers, leg and the foot. The longer lever is a pair of bones, the tibia and fibula. The massive tibia conveys most of the body weight directly on the talus and acts as a solid lever in ankle injuries. The foot, on the other hand, is composed of numerous small bones intercepted by joints, which weaken the lever."

Two Lever Theory

"The ankle connects two unequal levers, leg and the foot. The longer lever is a pair of bones, the tibia and fibula. The massive tibia conveys most of the body weight directly on the talus and acts as a solid lever in ankle injuries. The foot, on the other hand, is composed of numerous small bones intercepted by joints, which weaken the lever."

Two Lever Theory
**Two Lever Theory**

Between these two unequal levers (unequal in bulk, length, and strength) lies the talus. When the foot is dorsiflexed at the ankle, the talus becomes firmly lodged in the tibiofibular socket and serves as part of the proximal lever or the leg.

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**Transverse Plane**

Internal rotation of tibia = Internal rotation of talus

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**Tibial Rotation During Stance**

- 25 Subjects
- External markers
- 3-D motion of foot and shank


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Max velocity of tib internal rotation = 7% of gait cycle
Max velocity of tib external rotation = at toe off
Max amount rotation of tibia = 12° internal
Total range rotation of tibia = 17°

---

“We found that external rotation of the shank (indicating supination) began much earlier, at around 16% of the gait cycle. This is most likely a consequence of the fact that motion of the shank in the transverse plane can occur at the ankle and mid-tarsal joints without any change in the angle between the heel and shank in the frontal plane.”


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**When does External Rotation of the Tibia begin?**

<table>
<thead>
<tr>
<th>Percent of Walking Cycle</th>
<th>Avg. Internal Rotation</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>17%</td>
<td>7°</td>
<td>Levens et al</td>
</tr>
<tr>
<td>25%</td>
<td>7°</td>
<td>Reinschmidt et al</td>
</tr>
<tr>
<td>16%</td>
<td>7°</td>
<td>Nester</td>
</tr>
</tbody>
</table>

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**Movement Coupling**

1. Inversion of heel begins at 50-55% of gait cycle
   - Kepple (1990)
   - McPoil & Cornwall (1994)
   - Pierrynowski and Smith (1996)

2. External rotation of shank begins at 16% of gait cycle
   - Levens et al (1948)
   - Cornwall & McPoil (1995)
   - Reinschmidt et al (1997)
   - Nester (2000)

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**Movement Coupling**

How can the tibia externally rotate while the calcaneus remains everted (does not move)?

- Tibia can internally rotate on talus
- Rearfoot complex can internally rotate as one unit on the forefoot (transverse plane MTJ motion)

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**Rearfoot Tibia**

<table>
<thead>
<tr>
<th>Angle (Deg)</th>
<th>Stance Phase Duration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-10</td>
<td>0%</td>
</tr>
<tr>
<td>-8</td>
<td>10%</td>
</tr>
<tr>
<td>-6</td>
<td>20%</td>
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<tr>
<td>-4</td>
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<td>80%</td>
</tr>
<tr>
<td>8</td>
<td>90%</td>
</tr>
<tr>
<td>10</td>
<td>100%</td>
</tr>
</tbody>
</table>

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**Angular Displacement**

- Ang 1
- Ang 2
- Ang 3
- Ang 4
- Ang 5

- Time (one gait cycle)

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**References**


**Tibiotalar Delay**

- The talus does not immediately follow internal/external rotation of the tibia.
- Ant. Talo-Fib and Sup Deltoid have to tighten before talar motion is observed.


“Lateral rotation of the lower leg in the stance phase of gait allows a slight delay in transmitting this transverse plane rotation to the foot. This action is believed to be related to that of the horizontally aligned ligament fibers that surround the ankle and talus that must absorb these forces before transmitting them.”


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**Transverse Plane Movements in Gait**

**Ankle**

- 18° McCullough, Burge
- 15° Nester

**Midtarsal**

- 10.6° Nester
Ankle vs STJ

“Transformation of leg rotation into calcaneal eversion-inversion, and vice versa, has been suggested to occur mainly at the subtalar joint. When this is true, subtalar joint fusion must result in a significant loss of movement transferred between calcaneus eversion-inversion and tibial rotation. However, as shown previously, it did not.”


“Considering motion at only one of the three, i.e. the subtalar joint, is unlikely to describe the eventual motion which results from all three in combination since it does not account for factors affecting the other joints.”

Nester, 1997

Ankle, Subtalar and Mid-tarsal joints

“Rear foot Complex”
Downing, 1978
Nester, 1997

“Tarsal Mechanism”
Huson, 1991

“Ankle Joint Complex”
Hintermann, Nigg, 1994

Ankle Joint Complex

3 Segments: tibia, talus and calcaneus
2 Joints: ankle, subtalar

Universal Joint:
inversion of calcaneus = external rotation of tibia
eversion of calcaneus = internal rotation of tibia
CKC

- Universal Joint Rotation
- Torsion Transmission
- Tibia: Dominant Lever
Functional Foot Orthoses

1. Do not change skeletal alignment
2. Change input signal to CNS
3. Modulates muscle activity

Nigg, Benno: Foot Orthoses - Do They Align the Skeleton? Prescription Foot Orthotic Laboratory Association, International Conference Foot Biomechanics and Orthotic Therapy, Nov. 2001
Shin Muscle Activity On Various Sport Surfaces:

An EMG Study
By:
DOUGLAS H. RICHIE, D.P.M.
HERBERT A. DeVRIES, Ph.D.
CLIFFORD K. ENDO, D.P.M.

ECCENTRIC vs. CONCENTRIC PHASES
- Two separate counters
- Kistler accelerometer triggers timing circuit
- Concentric phase begins at g Max through mid-swing
- Eccentric phase begins at midswing through contact and g Max

JOURNAL AMERICAN PODIATRIC MEDICAL ASSOCIATION
VOL 83, No. 4, APRIL., 1993
Stationary Run

Eccentric Phase – Leg flexors lengthen immediately after foot touchdown

Concentric Phase – Leg flexors shorten immediately after g Max during propulsion
Conclusion

As the surface becomes harder and impact increases, the overall eccentric activity in the posterior musculature of the lower leg increases. This may be partly due to pre-activation of these muscles prior to foot touchdown.

Prior to footstrike a “pre-innervation” phase of muscular contraction occurs allowing stiffness and elasticity to the leg. As vertical impact increases, pre-activation of the muscles increases.
Where Do We Go From Here?

1. Re-design podiatric biomechanics curriculum
2. Emphasize importance of joint interdependence and foot-leg interdependence
3. Prioritize clinical & laboratory research
4. Beliefs must be based upon sound scientific methodology

“The field of foot orthopedics, and to some degree foot surgery, is a conglomeration of theory, techniques of treatment, and treatment modalities that are too frequently not based upon scientific fact.”

Merton L. Root, 1963

5. It is o.k. to say: “I don’t know…”