Foot Orthoses: Theory and Research Evidence for Their Biomechanical Effects

Kevin A. Kirby, DPM
Clinical Associate Professor
Department of Applied Biomechanics
California School of Podiatric Medicine
Oakland, California, USA

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Mechanics

- A branch of physics that is concerned with motion and deformation of bodies that are acted on by mechanical disturbances called forces


Biomechanics: A Definition

- The science that examines the forces acting upon and within a biological structure and the effects produced by such forces.


Four Components of a Force

- **Magnitude**: quantity or amount of force
- **Line of action**: line along which force acts
- **Direction**: direction which force acts
- **Point of application**: point on object where force is acting

Ground reaction force acting on posterior-lateral shoe sole at heel contact during running

Force vs. Pressure

- **Force** is a mechanical disturbance or load applied to a body which causes it to move and/or deform
- **Pressure** is a force applied over a given surface area

Force vs. Stress

- **Stress** is force applied over a given cross-sectional area
- Stress in tendon, for example, will be increased in area of tendon that has less cross-sectional area, such as in area of tendon tear
Tissue Stress: Stress-Strain Curve

- Ligament, tendon, bone may be tested in materials testing machine (MTM)
- Slope at any place along stress-strain curve is stiffness of material/tissue
- In order for animal to avoid injury, structural tissues need to function within elastic range since injuries occur with in plastic range of tissue

What is a Foot Orthosis?

- “A foot orthosis is an in-shoe medical device which is designed to alter the magnitudes and temporal patterns of reaction forces acting on the plantar aspect of the foot in order to allow more normal foot and lower extremity function and to decrease pathologic loading forces on the structural components of the foot and lower extremity during weightbearing activities.”

Goals of Foot Orthosis Therapy

- “The goal of foot orthosis therapy should be to reduce the pathologic loading forces on the injured structural components of the body in order to allow healing of the injured structures, to prevent new injuries from occurring, and to promote more efficient dynamics of the body during weightbearing activities.”

Podiatric Biomechanics Had Assumed That Structure Can Predict Function

- Eight biophysical criteria for “normalcy” proposed by Root, et al in 1971
- Root, et al proposed that all feet and lower extremities which did not meet the criteria for “normal” were considered to possess structural defects and were, therefore, considered to be “abnormal”

Root’s “Deformities” Based on STJ Neutral

- Root classified “foot types” using frontal plane positions of rearfoot to tibia, forefoot to rearfoot, and first ray position relative to 1st - 5th metatarsal heads
- No scientific studies have shown any correlation between Root et al measurements and foot and lower extremity function and/or injuries

Tissue Stress Model

- Tissue stress model first proposed as a model for mechanical foot therapy in 1995 by McPoil and Hunt
- Tissue stress model is not a novel idea since it is based on same ideas are already in current use in treatment of parts of body other than foot and lower extremity
- Tissue stress model doesn’t rely on “unreliable measurement techniques”
Tissue Stress Model

- Tissue stress model and its clinical applications have been discussed by other authors as a clinical method by which to more effectively prescribe custom foot orthoses.


Fuller EA. Reinventing biomechanics. Podiatry Today, 3 (1), December.

Kirby KA. Tissue stress approach to mechanical foot therapy. Precision Intricast Newsletter, February 2002.


Kirby KA. Using the tissue stress approach in clinical practice. Precision Intricast Newsletter, April 2002.

Tissue Stress Approach to Therapy

- Orthosis goals are best achieved by specifically designing custom foot orthosis to reduce magnitude of stress on injured structural components and to also optimize function of foot and lower extremity for specific weightbearing activity.

- It is very important that while designing foot orthosis to reduce tissue stress and to optimize function, that no other injuries or pathologies result from orthosis therapy.

Using Tissue Stress Approach to Treat Lower Extremity Pathology

1. Specifically identify anatomical structures which are source of patient’s complaints
2. Determine structural and/or functional variables which may be source of pathological forces on injured structure
3. Design orthosis/shoe treatment plan which will most effectively reduce pathological forces on injured structural components, will optimize gait function and will not cause other pathology or symptoms

Steps in the Tissue Stress Approach

- 57 y/o white female with right medial foot/ankle pain and swelling, R > L flatfoot deformity and difficulty walking due to right foot and ankle pain
- Identify injured structures
- Determine structural & functional variables
- Design Tx Plan to reduce stress on injury

How Do Foot Orthoses Work?

- Are the actions of orthoses on foot and lower extremity purely mechanical in nature?
- Do orthoses work by modifying proprioceptive response of foot to ground reaction force?
- What is best current theory that explains how foot orthoses work from a mechanical aspect?

- Subtalar joint axis location-rotational equilibrium (SALRE) theory does not rely on “foot deformities” or STJ neutral position to determine “compensation”
- Spatial location of STJ axis relative to plantar foot is reference position in SALRE theory
- Spatial location of STJ axis is important in determining internal forces within structural components of foot and lower extremity and in determining mechanical response of foot to external loading forces (eg. orthosis reaction force)

How Does an Orthosis “Control” STJ Pronation and Supination?

- If orthosis is designed to “control STJ pronation”, ORF will be shifted more medially so STJ supination moment is increased
- If orthosis is designed to “control STJ supination”, then ORF will be shifted more laterally so STJ pronation moment is increased

Mechanical Effect of Orthosis on Plantar Foot

- As STJ axis becomes more medially deviated, orthosis has decreased surface area medial to STJ axis to generate STJ supination moments
- STJ axis medial deviation decreases mechanical efficiency of orthosis at causing supination

Mechanical Effect of Orthoses on STJ

- Standard foot orthosis shifts more laterally located GRF to more medially located ORF, especially in midfoot
- Standard foot orthoses decrease external STJ pronation moment and increase external STJ supination moment due to orthosis contact with MLA of foot
- Orthosis acts to alter location, magnitude and temporal patterns of GRF which, in turn, alters rotational effects of GRF on STJ and MTJ/midfoot joints during gait

Mechanical Effect of Medial Heel Skive

- Medial heel skive increases STJ supination moment by shifting ORF to more medial location on rearfoot
Increased Medial Arch Height of Orthosis Increases Supination Moment

- As medial arch height of orthosis is increased, ORF shifts to more medial position on plantar midfoot which results in increased STJ supination moment.

Orthosis for Laterally Deviated STJ Axis

- Balance positive cast everted, with 2-4 mm lateral heel skive and extra thick medial expansion
- 3/16” to 4/16” polypropylene shell with flat RF posts
- Filler material added to lateral arch of plantar orthosis
- 2-5 valgus forefoot extension (i.e. reverse Morton’s)

Midtarsal Joint Rotational Equilibrium

- Maintenance of MLA height is a result of rotational equilibrium at MTJ and midfoot joints
- MLA will flatten under WB load until plantar ligaments and muscles all exert sufficient MLA raising moment to counterbalance MLA flattening moment from GRF, Achilles loading and tibial loading

Foot Orthosis Acts to Reduce Tensile Stress on Plantar Soft Tissue Structures

- With orthosis supporting longitudinal arch, orthosis will increase RF dorsiflexion moment and also increase FF plantarflexion moment
- Result is a decrease in plantar ligament and muscle tension force

Benno Nigg’s Preferred Movement Pathway Model

- In 2001, Nigg proposed “preferred movement pathway model” of orthosis function
- Nigg proposes that orthoses do not function by realigning skeleton but rather alter input signals into plantar foot that change “muscle tuning”
- Nigg proposed that if foot orthosis counteracts preferred movement path, then muscle activity will increase and that optimal shoe or foot orthosis design will reduce or minimize muscle activity

Foot Orthosis Research: Dilemma of Motion vs. Moments

- Application of a force to object, does not always produce observable motion of that object
- Therefore, lack of motion in object when force is applied does not mean that internal forces/moments have not been altered
Therapeutic Actions of Foot Orthoses

- Reduce plantar pressures in symptomatic areas of plantar foot
- Reduce pathologic moments acting across joint axes of foot and lower extremity
- Reduce pathologic internal loading forces on specific structural components of foot and lower extremity
- Improve balance and stability of body over foot during weightbearing activities
- Optimize function during weightbearing activities

Foot orthoses may be designed to specifically reduce force at areas of plantar foot where excessive plantar pressure is causing pathology and/or symptoms so that disability is lessened and gait function is improved.

Orthoses Convert Ground Reaction Force to Orthosis Reaction Force

- Areas of increased GRF in medial arch and medial heel

Therapeutic Efficacy of Foot Orthoses

- In study of 81 patients, 91% were “satisfied with orthoses” and 52% “wouldn’t leave home without them.”
- 76% of 500 distance runners reported complete resolution or great improvement of symptoms
- 102 athletic patients with patellofemoral pain syndrome, 76.5% of patients improved and 2% were asymptomatic after 2-4 weeks of orthosis therapy
- 70% of 180 patients “definitely helped” by orthoses
- 83% of 520 patients were satisfied and 95% reported their problem had partially or completely resolved with orthoses
- 75% reduction in disability rating and 66% reduction in pain rating with foot orthoses occurred in 15 patients with plantar fasciitis
- In study of 275 patients that wore orthoses for over a year, the majority of subjects obtained between 60-100% relief of symptoms, only 9% reporting no relief of symptoms

Custom Foot Orthoses are Effective at Treating Many Athletic Injuries

- Success rate with custom foot orthoses in treatment of running injuries is 50 - 90%
Positive Physical and Mental Therapeutic Effects of Foot Orthoses

- In prospective study of 79 women over age of 65, subjects that received custom foot orthoses and guidance on shoe fitting had significant improvements in mental health, bodily pain and general health compared to non-orthosis control group
- Researchers determined that foot orthosis intervention was “markedly effective not only in physical but also in mental aspect”


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Recent 3D Motion Research Shows Orthosis Effects

- Latest studies utilizing 3D motion analysis, force plates and inverse dynamics analysis show alterations in foot and lower extremity kinetics with foot orthoses
- Recent studies show changes in kinematics with orthoses
- Researchers determined that foot orthosis intervention was “markedly effective not only in physical but also in mental aspect”

In general, changes in kinematics with foot orthoses are not as dramatic as changes in kinetics… but midfoot motion may be where kinematics show most changes with orthoses

Kinematics vs. Kinetics: Research Evidence of Orthosis Mechanics

- Many early studies found little to no significant difference in kinematics of gait when comparing the effects of wearing orthoses vs. no orthoses


Research Evidence of Kinematic Changes with Foot Orthoses

- Decrease in maximum rearfoot eversion angle
- Decrease in maximum internal tibial rotation
- Additional effects of orthoses on other lower extremity mechanics in runners


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Orthoses Also Cause Changes in Kinetics

- Decrease in maximum internal ankle inversion moment

- Decrease in impact peak and vertical loading rate

- Resultant knee joint forces and knee joint moments altered by up to 100% when posted orthoses are used in runners

Research Evidence: Orthoses Are Effective in Treating Certain Pathologies

- Reduce pain and disability in RA and JRA

- Reduce pain and disability in knee OA

- Reduces pain and disability from ankle bleeds in hemophilia A

- Patellofemoral pain syndrome

- Plantar fasciitis

- Reduce plantar pressures in neuropathic diabetic feet

- Relieve plantar pressure and pain from metatarsalgia

- Prevents stress fractures in metatarsals and femur

Large Prospective Study Shows Orthoses Decrease in Injury Rate in Military

- 400 military officer trainees were followed prospectively over 7 week period of basic training
- 2 groups: 200 - no orthoses, 200 - with orthoses
- Total injuries in no orthosis group = 61
- Total injuries in orthosis group = 21
- Significant injury risk reduction with orthoses (P < .0001)
- Over 10x reduction in MTSS with orthoses
- 7x reduction in CECS with orthoses

Prospective Study Shows Orthoses Effective in Treating PFP Syndrome

- 179 subjects (100 female) with PFPS of 6+ weeks duration were treated with orthoses vs flat inserts vs physiotherapy
- Orthoses produced significant improvement in treatment success (85%) vs flat inserts (58%)
- Orthoses produced same improvement as physiotherapy

Orthoses Alter Rearfoot and Knee Moments

- 11 runners that showed lack of symptomatic response to standard orthoses were fitted with both standard functional orthoses and Blake inverted orthoses
- 3D motion analysis performed while subjects ran at 3.35 m/s (8:00 min/mile) with inverse dynamics
- Internal rearfoot inversion moment and inversion work reduced significantly with inverted orthoses
- Tibial rotation, knee adduction and knee abduction moment also significantly changed

Randomized Trial Shows Orthoses Better than Wait & See for AKP

- 40 subjects with anterior knee pain (AKP) of 6+ wks duration treated with orthoses vs wait & see approach
- Orthoses produced significant improvement in symptoms and function (p=0.008)
- Change in midfoot width from NWB to WB were more likely to report orthosis treatment success


Reduction of Plantar Pressure in Pes Cavus Reduces Pain

- 42 subjects with metatarsalgia, orthoses decreased metatarsal head pain, force impulse and peak pressure at met heads
- Prospective study of 151 subjects with cavus, wore custom orthoses, after 3 months showed significant decreases in foot pain, increases in quality of life and 3 times more forefoot plantar pressure reduction when compared to sham insoles


Orthoses Reduce Plantar Pressures

- Custom orthoses most effective at reducing pain and all orthoses significantly reduced pressure under 1st and 2nd metatarsal heads in 12 RA subjects
- Both normal and RA subjects showed significant reductions in plantar pressures and loading forces during stance phase of gait
- Reduce sub-hallux pressure during gait


Li CY, et al: Biomechanical evaluation of foot pressures and loading forces during stance phase of gait.


Orthoses Reduce Pressures and Heal Diabetic Ulcers

- Orthoses caused 30% reduction in maximum peak pressure in 81 Type II diabetic patients
- Peak pressure and pressure-time integral reduced in 34 adolescent Type I diabetic patients
- In 8 patients with plantar neuropathic ulcers that healed with custom orthoses, orthoses significantly reduced peak vertical pressure, reduced pressure/time integral and increased contact area versus the no-insole condition


Orthoses Prevent Stress Fractures in Military Recruits

- Prospective study of infantry recruits, foot orthoses reduced incidence of stress fractures 11.3-16.3% compared to non-orthotic control group
- Prospective study in military recruits, orthoses reduced incidence of femoral stress fractures in recruits with pes cavus and reduced incidence of metatarsal fractures in recruits with pes planus


Research Evidence: Orthoses Improve Pain and Disability in JRA

- Randomized trial of 40 children with juvenile idiopathic arthritis were found to have significantly greater improvements in overall pain, speed of ambulation, foot pain and level of disability when they wore custom foot orthoses when compared to those in study that received shoe inserts or shoes alone

Orthoses Control Ankle Bleeds in Hemophilia

- Foot orthoses were found to significantly control ankle bleeds and decrease pain, decrease disability and increase activity over a 6 week period in 16 subjects with hemophilia A


Orthoses Alter Knee Joint Moments and Pain from Medial Knee OA

- 30 subjects with medial knee OA treated with valgus wedged orthoses had pain levels significantly reduced at 3 and 9 weeks after orthoses


- 24 month prospective trial on 156 patients with medial knee OA showed significant decrease in NSAID usage


EMG Effects of Orthoses

- Orthoses significantly altered EMG activity of biceps femoris and anterior tibial muscles during running


- Orthoses significantly altered duration of anterior tibial muscle activity during walking


- Orthoses increased EMG intensity of most muscles of LE during stance phase of running...“One of the main effects produced by foot orthoses is a change in activation of muscles in the lower extremities”


Orthoses Improve Balance

- Orthoses significantly reduced postural sway in medial/lateral and inv/ev platform movements


- Decreased frontal plane CoP length and velocity with medially posted orthoses when subjects stood on orthoses in single leg stance


- Orthoses improve balance in pronated feet via reductions in medial-lateral sway during bipedal standing


Conclusion

- Orthoses alter location, magnitudes, and temporal patterns of GRF on plantar foot:
  - Alter both kinematics and kinetics foot and lower extremity joints
  - Alter external and internal loading forces on structural components of foot and lower extremity
  - Improve balance, allow improved gait function and reduce pathologic loading forces
  - Allow more rapid healing of injured structures of foot and lower extremity and assist in prevention of new injuries

Thank you!