Applying Current Biomechanical Theory to Foot Orthosis Therapy

Here's the latest update on the use of these devices.

BY STEPHEN PRIBUT, DPM

Biomechanics Theory Evolves

Biomechanics is a critical component of nearly all we do as podiatrists. It is the study of the forces acting on and within biological structures and the impact these forces have on the structures. Biomechanics is not merely prescribing and fitting orthotics. All therapy, including muscle strengthening, balance training, stretching, and surgery—all of which alter forces and loads on the anatomical structures of the lower extremity—are impacted by biomechanics (See Table 1 for abbreviations used throughout this article).

Factors which affect lower limb biomechanics include muscle strength, anatomical structure, neuromuscular response to external forces applied and individualistic response to these factors, and external forces applied (including to the forces applied by foot gear or an orthosis). Our therapeutic remedies may include strengthening, stretching, balance exercise, shoe modification, surgery or orthosis prescription, use, and modification, as needed.

Translating Current Biomechanical Theory into Optimal Orthotic Therapy

The landscape of biomechanical theory looks considerably different today than at the turn of the century. From the 1950s through the 1980s, theories brought forward by Merton Root dominated the biomechanics learned by most podiatrists.[1] Root combined the then dominant theories on midtarsal joint locking, an oblique and longitudinal midtarsal joint (MTJ) axis, and a measurable subtalar joint (STJ) axis with his theories. Root developed a concept of the ideal normal lower extremity, the importance of function about a reproducible subtalar joint, a widely utilized classification of foot types, and a prediction of the dire consequences of "excessive pronation."

TABLE 1

Abbreviations

STJ subtalar joint
MTJ midtarsal joint
GRF ground reaction force
EVA ethylene vinyl acetate

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Root's theories led to several postulates that included a variety of ways to determine the neutral position of the STJ.[1] Some of the methods used to determine the STJ neutral position include palpating the margins of the talo-calcaneal joint, observation of a 2/1 ratio of supination to pronation about the STJ, feeling for a flat spot or dell in the motion, and observation of symmetry in the curves above and below the lateral malleolus. Root's definition of the neutral position of the STJ, where the joint is neither pronated nor supinated, is self-referential.

The MTJ was believed to lock in normal feet about the longitudinal and the oblique axes to act as a rigid lever for optimal propulsion. Root's theories were predicated upon measured static assessment of joint positions and ranges of motion. The cause of much pathology was believed to be pronation, and a secondary factor was thought to be excessive impact force (shock). When Root first described his theories, he had no research to back up his proposals. As measurement techniques improved, research did not confirm most of Root's theories. Impact force is no longer believed to be one of the primary causes of injury. Pronation is no longer considered the root of all evil. The Root model no longer describes either normal or an ideal.

While the debate of Root vs. not Root continues, the preponderance of recent research and opinion is against accepting Root as gospel. According to Jarvis, Nester, et al. "none of the deformities proposed by the 'Root model' were associated with distinct differences in foot kinematics during

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gait when compared to those without deformities."[2]

Thomas Kuhn, a philosopher of science, is often cited on his belief in paradigms as the sine qua non of science. Kuhn would call out the difference between theory and observation anomalies in the current paradigm.[3] Kuhn did not believe that paradigms were subject to testing. He proposed a new paradigm be adopted as anomalies arose. Thus, an old paradigm became less trusted and new paradigms competed to replace the existing paradigm. To Kuhn, adopting a new paradigm occurred in the same manner as a religious conversion. Discussions on alternatives to Root theory can be as heated as any religious or political debate.

However, as often as Kuhn is cited, Karl Popper is often mentioned as a better alternative philosopher of science since he believed in the value and validity of testing theories. Quantum theorist Paul Dirac said in an interview with Kuhn, "philosophy has not made any scientific discoveries."[4] This statement mirrors that of George Box, who said, "All models are wrong, but some are useful."

The MTJ does not truly lock, and the concept of two axes of motion is no longer accepted.

The concept of a consistent and readily reproducible and valid subtalar joint axis was found to be fraught with problems. The MTJ does not truly lock, and the concept of two axes of motion is no longer accepted. Van Langelaan showed that the two-axes theory incorrectly suggested that supination and pronation of the STJ created an alteration in the relationship of the calcaneocuboid joint and the talonavicular joint axes, which impacted MTJ motion.[5] However, there is a physical, ligamentous connection between the navicular bone and the cuboid, which constrains their moving in concert. Recent research indicates that the two-axes model of midtarsal joint function is not valid and that a "significant disparity" had developed.[6,7] It is believed that there is only one linearly oriented axis of motion.[8]

The STJ axis, as we have stated, is not readily reproducible from one practitioner to the next. The precise location of the axis cannot be determined with reliable and reproducible precision. The axis itself will change as the joint is moved. In fact, it is important to remember that it is the joint movement which determines the position of the axis. Simon Spooner has said it best: "Joint axes are artificial kinematic constructs and only exist when a joint is in motion." We should consider this when attempting to use off-weight-bearing, static measurements to determine therapy. Likewise, the axis of the individual joints of the midtarsal joint are now described as more like a "bundle of axes" rather than just one.

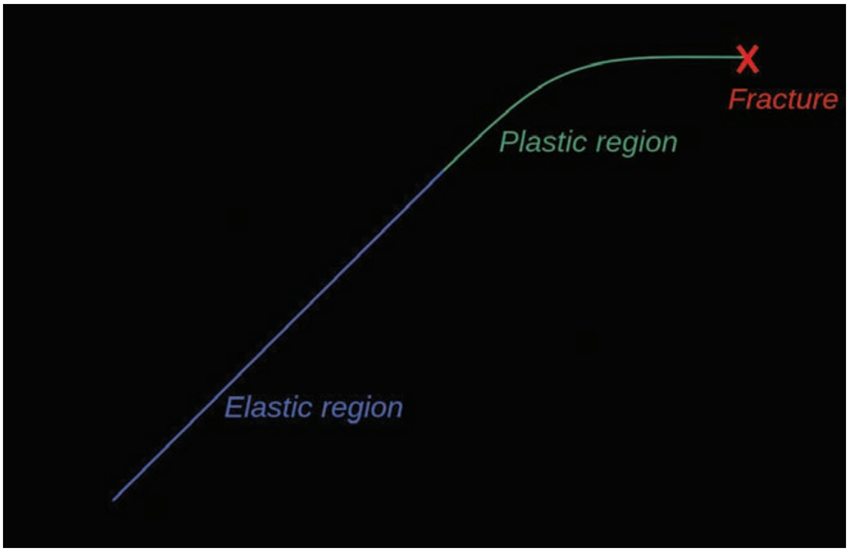

Figure 1: Elastic and Plastic Deformation

Elastic deformation allows a structure to return to its previous shape. Plastic deformation results in a permanent alteration. Ultimately the tissue will tear or bone will fracture.

Credit: By Moondoggy—CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=4171540

Trends in Biomechanical Models

Craig Payne's "Clinical Biomechanics Bootcamp" is one of the best online courses on podiatric biomechanics. In his program, he reviews 25 theories and models. We will focus on what seems to be a few important ones as a good place to start.

All studies performed over the last several decades still leave us in a Newtonian world. Kevin Kirby said in an early newsletter that we need to think like "engineers".[9] At least we must think like biomechanists. The laws of physics are critical. The concepts of elastic and plastic deformation, and of internal and external forces, are integral to understanding the reality of lower limb biomechanics. In review, elastic deformation occurs in a structure returning to its original shape after a force is removed, while plastic deformation is a force that has permanently deformed the structure. You must start with the basics of physics, mechanics, and anatomy when updating or beginning your journey into improving your knowledge of biomechanics (Figure 1).

Among the primary hypotheses

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that are mandatory to an understanding of lower extremity biomechanics are:

1) The tissue stress theory of McPoil and Hunt (1995)[10]

2) The rotational equilibrium theory about the STJ of Kevin Kirby (1992)[11]

a) Medial and lateral deviation of the STJ axis

b) Thinking like an engineer[9]

3) Significance of the sagittal plane in the Sagittal Plane Facilitation theory of Howard Dananberg (1986, 2000)[12]

4) Individual differences lead to individualistic responses to biomechanical therapy (Nigg)

5) Kinetics are more significant than kinematics[13-16]

McPoil and Hunt described the tissue stress model in 1995 as an alternative to the Root model.

There are a good number of other contributions, particularly from Benno Nigg, who has generated many novel theories. These include muscle tuning, preferred motion pathway, and comfort as factors in the efficacy of both footwear and orthoses. Kevin Kirby's dictum to "think like an engineer" leads to the optimal pathway forward. It leaves us in a Newtonian universe, which is where we expect to remain.

Tissue Stress Theory

McPoil and Hunt described the tissue stress model in 1995 as an alternative to the Root model. They proposed a simple and logical way to evaluate and manage problems of pain and mechanically caused pathology. They used the principles of elastic and plastic deformation as leading to tissue stress and injury. They stated that they did not view their concepts as entirely new. In fact, the general principles they brought forward were ones that had been taught in courses and clinics at the New York College of Podiatric Medicine by Richard Schuster, DPM. But it was a novel presentation and formalized an approach to reducing pathological tissue stress.

A stepwise approach was suggested to evaluate and treat the patient. The first step was to determine the anatomical structures involved in creating the patient's symptoms. The second step was to assess what were the most likely structural or functional factors when added to the abnormal forces that created the pathology. An example would be tension on the plantar fascia creating abnormal tissue stress. This step should lead to determining what clinical therapies would be useful in lowering the abnormal stress in the affected tissue. The third step is to plan and implement a treatment program to address these stresses by decreasing abnormal loading forces, optimiz-

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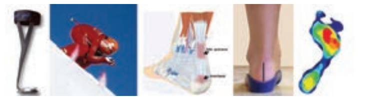

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ing gait and function, and avoiding the development of other pathology. This approach is well described by Kirby and Fuller.[17]

Rotational Equilibrium Theory about the STJ (Figures 2 and 3)

Kevin Kirby demonstrated a clinical method of determining the alignment of the STJ and proposed a rotational equilibrium theory of foot function.[18,19] Kirby took into account research that demonstrated the STJ axis would be different when the STJ was put in differing rotational positions.[5] He proposed that ground reaction forces (GRF) led to moments about the axis that depended on where they were applied in reference to the STJ axis. Feet could have a neutral axis or a medially or laterally deviated axis. A foot with a medially deviated axis would only have a small effective area to which a supination orthotic reaction force could be applied. The axis location will influence optimal orthotic design and was one of the concepts that led to the development of the Kirby medial skive.

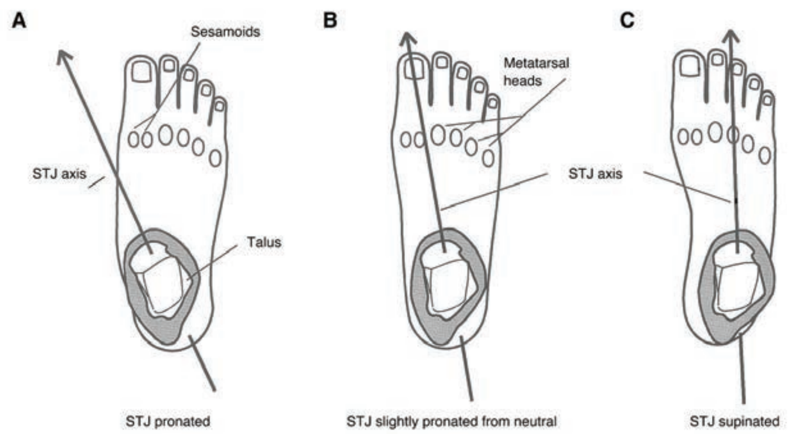

Figure 2: Position of STJ Axis in a Normal Foot

In relaxed bipedal stance B represents the normal STJ axis going from the posterior lateral calcaneus posteriorly to near the first intermetatarsal space. Image A shows the foot pronated and the STJF axis medially displaced. Image C shows a supinated foot with the STJ axis laterally displaced.

Image is provided courtesy of KA Kirby

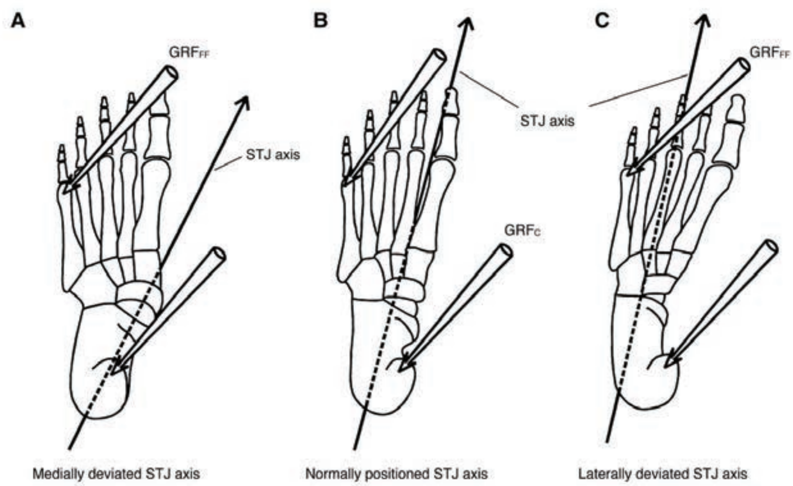

Figure 3: The impact of the STJ Deviation on GRF

Image A shows a foot with a medially deviated STJ axis. This foot demonstrates a small rearfoot moment arm for GRF. The forefoot GRF shows a long moment arm laterally which results in a large moment of pronation about the STJ axis. Image B shows a normal position of the STJ with essentially a neutral impact on the STJ axis. Image C shows a laterally deviated STJ axis with a longer moment arm of GRF in the RF resulting in a strong moment of supination at the STJ.

Image is provided courtesy of KA Kirby

Sagittal Plane and Gait

Much of visual gait analysis and discussion of kinematics (observation of joint movement) centers around frontal plane motion. Dananberg noted that the amount of sagittal plane motion available is much greater than that in the frontal plane.[12] He pointed out the role of Jacqueline Perry in identifying the foot “rockers”: ankle, heel, and forefoot.[20] Blockages or loss of motion at any point dramatically affect gait. An example is seen in hallux rigidus, in which weight-bearing is shifted laterally in terminal stance.

The future of the captured foot image is likely to be a 3D scan.

Responses to Orthotics Are Individualistic and Not Systematic; Kinetics Are More Important Than Kinematics

Benno Nigg and others have shown that the mechanical effect of foot orthoses were not systematic and differed from one individual to the next.[15,21] However, when a more similar set of subjects were classified as “pronators”, a more systematic impact was seen on muscle activity.[22] It will be difficult to see the difference in a clinical visual gait evaluation since the difference in the frontal plane is limited to a few degrees. The importance of noting the individualistic effect of orthoses means that every patient is different and must be closely monitored, evaluated, and re-evaluated to determine necessary orthotic modification. Foot orthosis therapy is a

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process where follow-up and changes to the devices are often needed. Make certain you communicate this to your patient before you begin treatment.[23]

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TABLE 2

Orthotic Corrections of Adult Acquired Flatfoot

Material: Usually Polypropylene, graphite, sometimes less firm material
Standard cast fill
Wide orthotic
Deep heel cup 18-22 mm
Kirby medial skive 2-6mm
Cast inversion
Medial flange
Navicular sweet spot
Flat un-canted rearfoot post of firm EVA
Poron top cover

TABLE 3

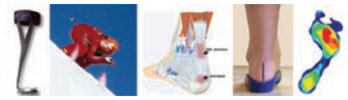
Lateral Foot and Ankle Injuries Predisposing Factors

Cavovarus foot
Hallux rigidus
Decreased supination resistance
Chronic ankle instability
Ankle equinus

TABLE 4

Conditions Associated with Cavus Feet

Ankle instability
Subtalar instability
Peroneus brevis or longus longitudinal tear
Painful os peroneum syndrome
Jones fracture of the 5th metatarsal
Avulsion fracture of the 5th metatarsal
Stress fracture of the 4th or 5th metatarsal
Cuboid stress fracture
Sesamoidopathy



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Foot Orthoses in Light of Current Theory

The foot orthosis is a common method of conservative therapy. Orthotic therapy must be directed towards the pathology and not merely the deformity. The stresses which cause the symptoms need to be defined and then lessened in accord with tissue stress theory.

The basic components of the prescription have remained stable but the goals and means of achieving success have changed dramatically over the past 30 years. The future of the captured foot image is likely to be a 3D scan. But currently many practitioners still use a plaster of Paris cast. The off-weight-bearing suspension casting technique incorporates loading and pronating the MTJ while usually dorsiflexing the hallux to achieve maximum plantarflexion of the first ray. This gives a forefoot posture that closely mirrors the foot in the propulsion phase. The impression is taken in a position that may not be a scientific neutral position but is an acceptable clinical approximation.

The orthotic prescription itself still includes choosing the material, the orthotic width, the heel cup depth, the amount of cast modification, the type (if any) of posting, forefoot extensions, a top cover, and medial or lateral flanges. Recent additions to the prescription usually include a medial (or sometimes lateral) Kirby skive from zero to six degrees and the amount of cast inversion. These two changes are usually employed rather than an external posting of the rearfoot. The rearfoot is now most often posted in zero degrees with a zero degree grindoff. The forefoot posting is most often either intrinsic or an external valgus post.

Selected Clinical Entities

The prescriptions below are only examples and not meant to serve as a specific prescription for any patient. They should be reviewed and changed as necessary.

Posterior Tibial Tendon Disorders and Adult Onset Flatfoot

The most frequent cause of adult acquired flatfoot is posterior tibial tendon dysfunction. As the condition develops, the STJ axis comes to lie in an abnormal position with an excessive medial deviation. This results in most ground reactive forces (GRF) contributing to further pronation. Only a relatively small area remains in which a supinatory moment (orthotic reaction forces) may be applied effectively. The small moment arm and the location of the STJ axis must be considered when making your orthotic prescription. A poorly designed orthosis could apply a pronatory force (external orthotic reaction force) to the STJ.

This type of foot often displays a prominent, subluxed navicular bone and an everted calcaneus, which results in a lowering of the medial arch. The forefoot is usually abducted on the rearfoot. The rearfoot is often severely pronated with calcaneal eversion. The foot splays and becomes longer. The medial aspect of the foot will be overloaded and often will ride over a narrow orthotic; since the foot is wider than most orthotics, a wide orthotic with a medial flange is helpful. A deep heel cup is important and other rearfoot modifications that are needed include a Kirby medial skive of 4 to 6 mm and cast inversion (Table 2).

Lateral Overload and Peroneal Tendon Complex Injury

Ankle sprains are known to be the most common musculoskeletal ankle injury.[24] Cavus foot structure is a predisposing condition. Concurrently with a lateral ankle sprain, the peroneus longus tendon is often injured. This can lead to chronic ankle instability. Other lateral foot injuries include cuboid stress fracture, peroneal tendon tendinopathy and tears, peroneal tendon subluxation, injury to the os peroneum, and fifth metatarsal base fractures.[25]

These tendons function early in stance as tibial decelerators in concert with the gastrosoleus complex. Late in stance, they assist in ankle plantar flexion. They are best known for acting

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TABLE 5

Orthotic Corrections for Lateral Overload

14 mm heel cup
Wide Shell—modify for shoes
Minimal or standard cast fill
0/0 EVA rearfoot post with no lateral bevel
Consider lateral flange
Consider lateral heel skive 2-4 degrees
3 degrees valgus extension

TABLE 6

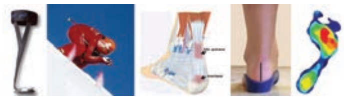
Orthotic Corrections for Plantar Fasciitis—Everted Rearfoot

18-20 mm heel cup
Wide Shell—modify for shoes
Minimum cast fill
2-4 mm medial heel skive
2-4 degrees inversion
EVA cover to toes
0/0 firm EVA heel post
Plantar fascial groove as needed

TABLE 7

Orthotic Corrections for Plantar Fasciitis—Forefoot Valgus

14 mm heel cup
Wide Shell—modify for shoes
Standard cast fill
3 degree valgus extension
0/0 firm EVA heel post
Plantar fascial groove as needed



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as antagonists to the tibialis anterior and posterior tendons and are the lateral stabilizers of the foot. Lateral ankle and foot injuries often occur in the cavus foot. See Tables 3 and 4 for predisposing factors for lateral foot injuries and conditions associated with cavus feet. See Table 5 for a sample orthotic prescription.

Plantar Fasciitis

Plantar fasciitis is one of the common clinical entities that we see. Plantar fasciitis symptoms are believed to be caused by an increase in tissue stress within the plantar fasciitis. There is a difference in orthotic design between those with a vertical heel and an everted calcaneus (Table 6).

See Table 7 for orthotic suggestions for plantar fasciitis associated with forefoot valgus.

Medial Tibial Stress Syndrome

Clinical evidence shows that medial tibial stress syndrome often benefits from supination moments applied to the STJ and a varus forefoot extension. The orthotic design will also decrease medial tibial bending moments. The latest thinking on the cause is that it is not a traction injury since the origin of the medial muscles is not at the usual location of tenderness. Research indicates that athletes who developed this condition demonstrated a longer calcaneal eversion time in gait and a contralateral hip drop (indicating weak hip abductors on the affected limb).[26]

Recent research indicates that bending moments occurring in the tibia may be a contributing factor.[27,28] Further research is needed. Restriction of activity, strengthening of both large and small muscles, and foot orthoses are usually effective treatments (Table 8).

TABLE 8

Orthotic Corrections for Medial Tibial Stress Syndrome

2-8 degrees cast inversion
2 to 4 mm medial heel skive
Minimal cast correction
16 to 20 mm heel cup
0/0 firm EVA heel post
Full length top cover
Varus forefoot extension

Conclusion

This article should serve as a starting point for current biomechanical theory. We have high-

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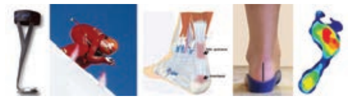

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lighted theories which have become accepted over the past 20 years. While the development of these newer theories began during the 1990s, continued research has led to anomalies in the previous leading model and the development of new theories. Besides what is presented, there are many other contributions to current biomechanical thinking, theorizing, and research. Learning more about biomechanics is intellectually rewarding and will certainly enhance your practice. Studying this subject will give you new strategies and confidence in achieving improvement in your patients' outcomes. **PM**

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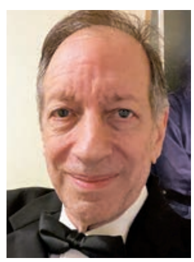

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