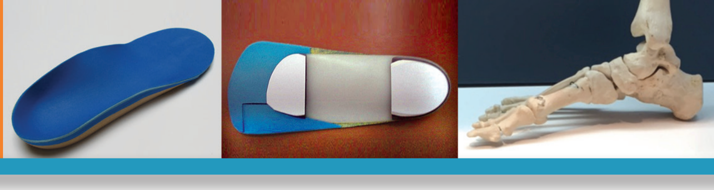

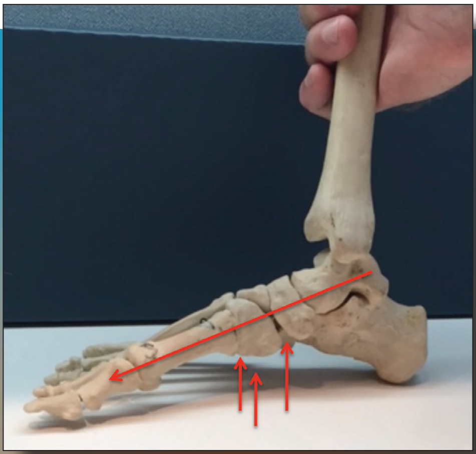

# Understanding the First Ray

Here's a review of its normal and abnormal function, identification, and clinical significance.

**BY JOSEPH C D'AMICO, DPM**

## Goals and Objectives

After reading this CME the practitioner will be able to:

1) Understand normal and abnormal function of the first ray with special emphasis on its integral role in medial longitudinal arch function and hypermobility.

2) Acquire knowledge of the various etiologic factors that result in first ray hypermobility.

3) Appreciate its normal and abnormal motion along with its attendant bio and pathomechanics.

4) Become familiar with various methods to subjectively and objectively identify its presence.

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### Functional Anatomy

The first ray is a single support unit comprising the distal end segment of a closely packed medial longitudinal arch whose proper function is critical in allowing the chief load-bearing segment of the human foot to accept body weight during static stance and to withstand ground reactive forces during ambulation (Figure 1, Table 1).[1–4] It is composed of the first metatarsal and internal cuneiform. The location of this articulation is significant since it intersects the transverse and medial longitudinal arches.[5]

Otto F. Schuster in the first text devoted to foot orthopaedics stated that the first metatarsal is the

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*First Ray (from page 109)*

shortest, by far the strongest and most important weight-bearing point in the forefoot.[6] The fact that it is the shortest metatarsal forces it to plantarflex during propulsion in order to keep it in contact with the supporting surface. The first metatarsal has an inclination angle of 15–25 degrees, which is the greatest of all the metatarsals.[7] During static stance the first metatarsal carries 40% of body weight.[8]

**The first metatarsal has an inclination angle of 15-25 degrees, which is the greatest of all the metatarsals.**

Ligaments surrounding the joint stabilize the first metatarsal-cuneiform articulation.[5, 9] Ligamentous support and stability is further enhanced and assisted by the anterior and posterior tibial tendons and most importantly by the peroneus longus tendon (Figure 2, Table 2). Duchenne recognized the importance of functional stability of the first ray and noted its dependence on agonist-antagonist muscle balance.[10]

The peroneus longus course runs obliquely through the cuboid canal from posterior and lateral to anterior and medial and inserts into the lateral aspect of the first metatarsal base and medial cuneiform. Peroneus longus contraction results in significant eversion of the first metatarsal base, thereby locking the medial cuneiform into the medial column. Johnson and Christensen attributed 8.06 +/-3.07 degrees to first metatarsal eversion and 7.44 +/- 2.64 degrees of eversion of the internal cuneiform to peroneus longus activity.[11]

## TABLE 1:
## First Ray Function

- Resist ground reactive forces
- Maintain medial longitudinal arch integrity during midstance supination
- Allow first metatarsal head to plantarflex at heel lift
- Allow acceptance of medially shifting body weight during propulsion without forefoot destabilization
- Provide medial stability for propulsive phase rigid lever mechanism

The effectiveness of this tendon on first ray stability is influenced by its direction of pull and application of force, which in turn is determined by the position of the subtalar and midtarsal joints.[12–14] In a normal functioning foot, contraction of the peroneus longus results in a lateral and plantarward pull on the first ray.[15] This application of force is enhanced during supination, creating a mechanical advantage, thereby restricting dorsal excursion of the first ray.

In a pronated foot due to an altered cuboid position, the pulley system is significantly diminished and peroneus longus contraction is unable to stabilize the first ray with resultant first ray instability and dorsal migration (Figure 3). The tibialis anticus acts con-

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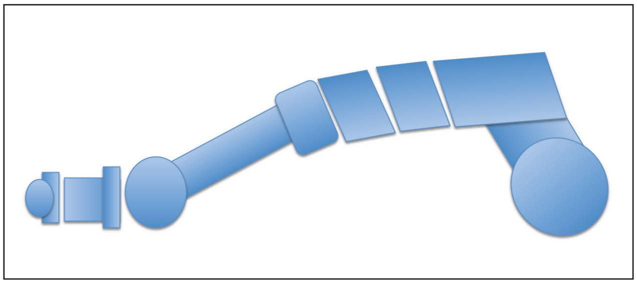

Figure 1: The medial longitudinal arch with the first ray as its distal anchoring segment.

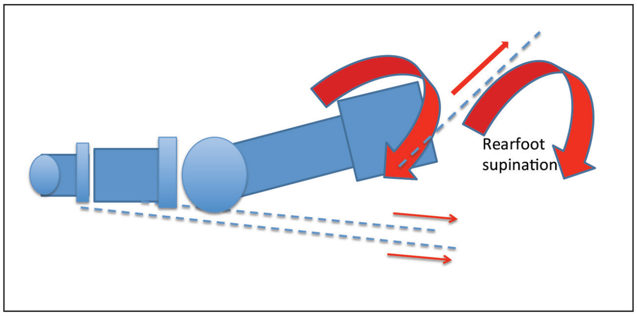

Figure 2: First Ray Stability—Assisted by the windlass effect of the plantar fascia along with rearfoot supination the first ray is stabilized by joint compressive forces and the flexor hallucis longus and brevis as well as peroneus longus tendons allowing plantarflexion of the first metatarsal below the level of the lesser metatarsals.

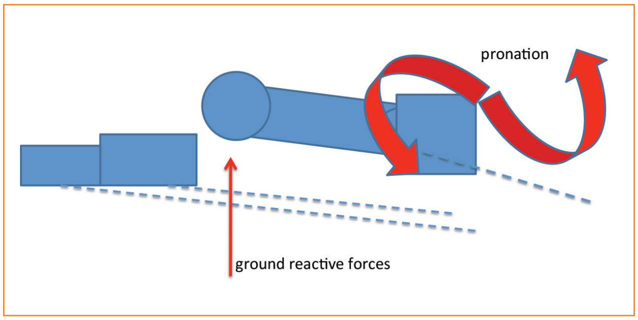

Figure 3: First Ray Hypermobility—Due to excessive pronation the peroneus longus having lost its mechanical advantage along with the flexor hallucis longus and brevis is unable to stabilize the first ray as a result ground reactive forces produce dorsal displacement.

## TABLE 2:

## First Ray Stability Requirements

- First metatarsal plantarflexion below the level of the lesser metatarsals
- Peroneus longus, flexor hallucis longus and brevis stabilization
- Flexor hallucis brevis fusion with ab and adductor hallucis forming synergistic tri-directional stabilization
- Normal sesamoid function
- Plantar fascia effect
- Rearfoot supination

*First Ray (from page 110)*

junctively with the peroneus longus, assisting it in the maintenance of propulsive phase medial longitudinal arch stability.[16]

Sesamoid stabilization is also necessary for proper first ray function and is achieved via the flexor hallucis longus and brevis tendons. First ray stabilization is aided by bone-to-bone contact and the resultant compressive forces within the joint, enabling this vital pedal segment to resist propulsive phase gravitational forces so it does not become mobile at a time when it should be stable.[17]

**The curved beam representing the medial longitudinal arch functions in early stance to absorb shock, adapt to terrain and begin to accept and support body weight.**

Additionally and significantly, the windlass effect of the plantar fascia reinforces medial longitudinal arch stability and according to Huang, et al. provides the highest relative contribution to arch stability, followed by the plantar ligaments and spring ligament.[2,16,18]

The ability of the foot to absorb shock, adapt to terrain irregularities, as well as accept the weight of the superstructure as it passes over it has been likened to a curved beam and truss.[1,18–22] The curved beam, representing the medial longitudinal arch, functions in early stance to absorb shock, adapt to terrain and begin to accept and support body weight (Figure 4). As the load on the foot becomes more vertical during the stance phase and the calcaneus and metatarsals are pressed into the ground, the medial longitudinal arch now functions in a truss-like fashion (Figure 5).

Aided by the windlass mechanism tightening the plantar fascia, the truss model relies on normal first

**During static stance the first metatarsal carries 40% of body weight.**

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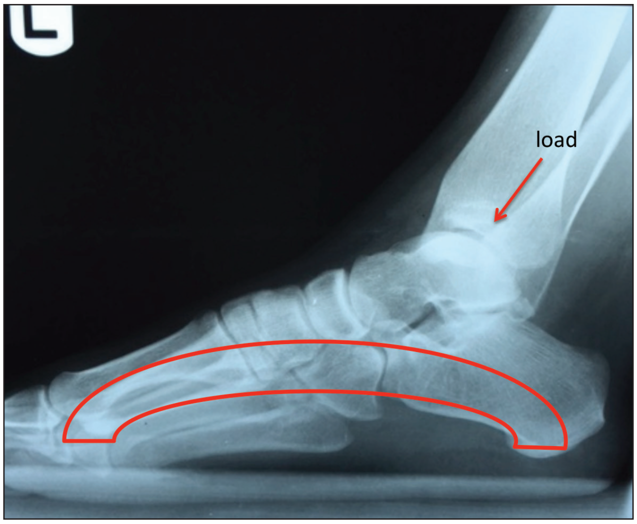

Figure 4: Early stance curved beam medial longitudinal arch functional analogy.

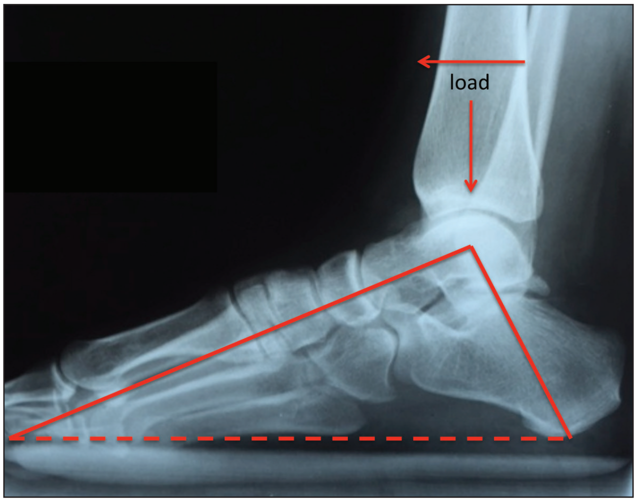
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Figure 5: With the calcaneus and metatarsals pressed into the ground and aided by the plantar fascia the medial longitudinal arch functions in a truss-like fashion as body weight moves forward over the supporting foot. A stable first ray is necessary for its proper function.

*First Ray (from page 111)*

ray to function to enable it to act as a stable pillar for the medial longitudinal arch.[1] As noted by Rush, et al., the windlass mechanism is more efficient when the hallux, sesamoid apparatus, and first metatarsal are in correct alignment. In fact, there is a 26% increase in first metatarsal plantarflexion with the first MPJ in correct alignment vs. a deviated articulation.[20]

**In a normal functioning foot, contraction of the peroneus longus results in a lateral and plantarward pull on the first ray.**

The medial longitudinal arch also provides the Achilles tendon with a long lever arm to act on the forefoot enhancing a stable propulsive gait.[8]

### First Ray Hypermobility

First ray stability is critical in controlling the structural integrity of the foot.[1, 13, 21, 23–26] Hypermobility is generally described as excessive range of motion in a joint.[27] A more appropriate functional definition of hypermobility is movement of a part at a time when it should be stable.[13, 23–25] Dudley J. Morton, a Columbia University anatomist, in 1928 was the first to describe first ray hypermobility and instability of the metatarsocuneiform joint in the sagittal plane.[23]

Hypermobility of the first ray is a destructive process caused by compensatory subtalar and midtarsal joint pronation due to compensation for inherent phylogenic and ontogenically-induced characteristics and structural imperfections (Table 5, Figure 6).[13, 23–25, 28–30] First ray hypermobility collapses the structural framework of the medial longitudinal arch, thereby diminishing the ability of the foot to become a rigid lever necessary for propulsion (Figures 7a, b, c).

Altered first ray biomechanics with accompanying

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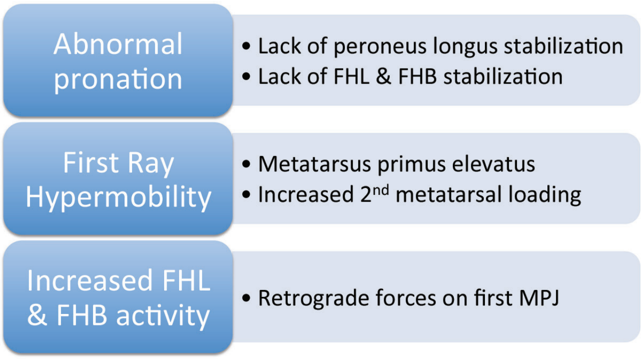

Figure 6: First Ray Hypermobility

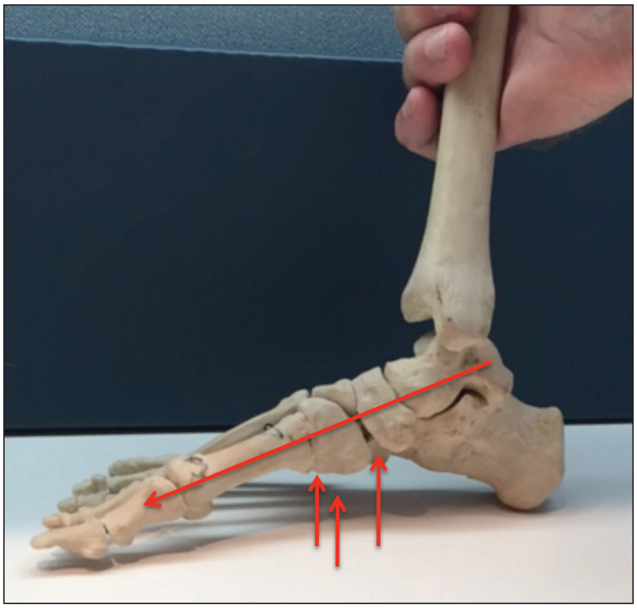

Figure 7a: Early Midstance—Note the navicular-cuneiform relationship as well as the compact nature of the first metatarsal-cuneiform articulation.

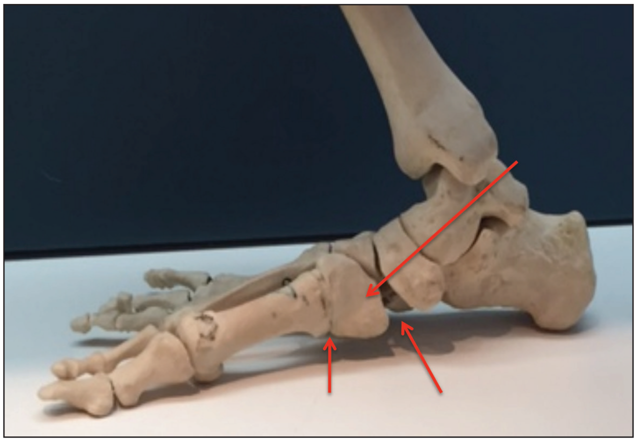

Figure 7b: Late Midstance—Note the significant plantarward divergence of the navicular-cuneiform articulation vs. the unchanged sagittal plane relationship of first metatarsal and cuneiform.

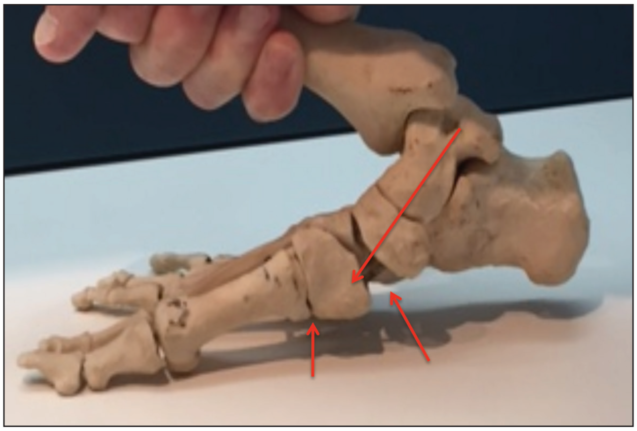

Figure 7c: Propulsion—Continuing pronounced pathologic divergence of the navicular-cuneiform articulation accentuated by internal limb rotation while the first metatarsal-cuneiform segment remains unchanged.

*First Ray* *(from page 112)*

hypermobility have been implicated in various foot pathologies including: hallux valgus, metatarsus varus, flatfoot, posterior tibial tendon dysfunction, plantar fasciitis, medial tibial stress syndrome, metatarsal stress fractures, and plantar ulcerations, etc.[1, 12, 14, 20, 23–25, 29, 31–38]

**Ontogenic Influences**

Proportionally, the human infant has the largest head and the longest legs of any mammal, which during the last trimester are crowded into a relatively snug uterine environment. When soft limbs are folded, flexed, and pressed against the vertebral column of the mother, it induces curves and slants in the lower extremity. As a result the normal newborn possesses a great number of significant structural deficiencies, which must be outgrown or developmentally "unwound" against the deforming effects of gravity in a "plastic" environment encouraging retention rather than resolution of these imperfections.

One of these at-birth deficiencies is ligamentous laxity or joint hyperextensibility, which has been demonstrated to be the only one-to-one predictor of first ray hypermobility.[31] Kermanli noted that generalized ligamentous laxity produced ineffective dynamic locking of the medial column, inadequate tendon and ligament integrity, all contributing to collapse of the longitudinal arch as well as late midstance and propulsive phase mobility in place of stability.[39]

**Phylogenic Influences**

Modern man has not completed the evolutionary process to the point where most individuals have ideal foot structure. Primitive man was semi-arboreal with walking a minor factor in its daily existence. Feet were more hand-like prehensile organs suitable for climbing and grasping rather than weight carriers. Since there was no need for shock absorption there was no need for a longitudinal arch. As the longitudinal arch developed in civilized races, its height was influenced by heredity. When the change was made from semi-arboreal to terrestrial, those who lived and traveled on soft ground had little need of shock absorption. Therefore, nature provided them with a lower longitudinal arch, whereas those who traveled on stony, unyielding surfaces developed a higher longitudinal arch.

**Modern man has not completed the evolutionary process to the point where most individuals have ideal foot structure.**

A characteristic feature in the evolution of man's foot and ankle to plantigrade locomotion was the development of the peroneus longus and brevis from anterior to the ankle axis of motion to posterior, changing its function from dorsiflexor to plantarflexor, and assuming a propulsive function. Secondarily, as a result of increased forefoot stresses, the peroneus longus tendon migrated across the entire foot to act as a tie piece, maintaining the medial longitudinal arch against depression. Steindler emphasizes the "wandering" of the peroneus longus across the plantar aspect of the foot as a significant developmental factor incident to the loss of opposability of the great toe.[36]

### TABLE 3:
## Evolutionary 'Scars' Present in the Normal Newborn
*(adapted after Richard O Schuster, DPM)*

- Externally rotated extremities
- Hip, knee, and ankle flexion
- Hypermobility
- Metatarsus Primus Adductus
- Metatarsus Adductus
- Talar neck Adductus
- Coxa varum
- Genu varum
- Tibial varum
- Subtalar varus
- Forefoot varus
- Anterior femoral bowing
- Anterior tibial bowing
- Minimal tibial torsion

Since ontogeny recapitulates phylogeny, any delay or arrest of development or reversion to type regresses foot structure. Functional abnormalities may occur as a result of this reversion to a more atavistic state.[36]

Dudley J. Morton, in his 1935 text *The Human Foot*, and even earlier in articles and lectures, proposed first ray instability as a "source of trouble" for the human foot and attributed it to atavism.[23–25, 29] Many of the structural imperfections and atavistic characteristics or evolutionary "scars" that are retained in the feet of most otherwise healthy newborns born today are the basic cause for most orthopedic foot pathology (Table 3).[28, 29, 39]

According to Morton and others, the atavistic short first metatarsal lends itself to hypermobility with transfer of forces to the next most stable segment, the second

*Continued on page 114*

*First Ray* *(from page 113)*

metatarsal (Table 4).[23-25, 29, 41–43] Morton described the short first metatarsal as a “problem for normal foot mechanics”, citing dorsal first ray mobility rolling the foot inward with second metatarsal overload.[23–25]

The primary deficiency in Morton’s syndrome dealt with the relative length of the first metatarsal. If one assumes a tripod model of the foot with the calcaneus, first, and fifth metatarsal heads as the bases, then if one of the pods were shorter, there would be a predisposition toward medial rotation of the foot. Posterior sesamoid displacement further functionally shortens the first met length, but Morton felt this was of lesser importance in the syndrome. Rush, et al. in a cadaveric dissection study confirmed Morton’s original theory, revealing a 26% increase in first ray plantarflexion and engagement of the windlass mechanism from a deviated to corrected first MPJ position. This suggests that windlass functions better when the first metatarsal, sesamoid apparatus, and hallux position are properly aligned and functioning.[20]

**According to Morton and others, the atavistic short first metatarsal lends itself to hypermobility with transfer of forces to the next most stable segment the second metatarsal.**

In 1952, Richard O. Schuster radiographically examined a non-patient control group and compared the first metatarsal length in a large patient population.[44] In the control group, 33% had a first metatarsal shorter, 33% equal, and 34% longer than the second metatarsal. In the patient population, 79% had a shorter first metatarsal by 1mm or more and 21% had a longer first metatarsal Furthermore, in the control group, the highest incidence was 1–2mm in those with a short first metatarsal, whereas in the patient group, the first metatarsal was 2–4mm short. In summary, there was a higher incidence and greater degree of shortness in the patient group vs. the control.

## TABLE 4:
## Morton’s Syndrome

- Short first metatarsal
- Posterior displaced sesamoids
- First ray base diastasis cuneiform “split”
- Hypertrophy cortices second metatarsal

Intrigued by his findings, Dr. Schuster proceeded to examine a large number of plaster casts in his laboratory and noted that 80% had a short first metatarsal by at least 1mm. Schuster concluded that a short first metatarsal must be one of the etiological factors in foot pathology, and the severity of the shortening may be directly linked to the degree of pathology accompanying it.

In addition to phylogenic and ontogenetically-induced pathological influences into the foot and leg capable of producing first ray hypermobility, acquired conditions such as obesity, limb discrepancy, neuromuscular disorders, etc. may also aggravate, complicate, precipitate, or perpetuate this situation. Inflammatory arthropathies such as rheumatoid or psoriatic arthritis are capable of producing first metatarsocuneiform synovitis with joint laxity resulting in frontal and sagittal plane instability.[37]

**The net effect of closed chain pronation on first ray motion is dorsiflexion and eversion.**

Therefore, as a consequence of phylogenic, ontogenic and acquired pathologic musculoskeletal influences, the question as to whether or not an individual will develop symptomatology is dependent upon the degree of mal-alignment and the extent and severity of acquired co-morbidities. Some individuals with minor to even moderate degrees of mal-alignment will not encounter problems since they are not active enough to render their imbalances symptomatic.[28]

### First Ray Motion

Hicks, in 1953, determined that normal first ray motion in the open kinetic chain is triplanar and runs nearly horizontal from posteromedial at the navicular to anterolateral at the third metatarsal base.[26] The total pronation supination range is 22 +/- 8 degrees and primarily consists of sagittal and frontal plane motion with a negligible amount occurring in the transverse plane. The sagittal and frontal plane motion is comprised of dorsiflexion with inversion and plantarflexion with eversion.[13, 28, 45–48] Accompanying dorsiflexion is approximately 2 degrees of adduction.[49, 50]

According to several authors, first ray motion primarily takes place at the metatarsocuneiform articulation, but they note that some motion

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Figure 8a: First Ray Clinical Mobility Test—With the ankle and subtalar joint in neutral position "sandwich" the lesser metatarsals and with the opposite hand dorsi- and plantarflex the first ray, noting the degree of movement above and below the second metatarsal head.

*First Ray* *(from page 114)*

may occur more proximally along the longitudinal arch.[5, 31, 43] Wanivenhaus, et al. demonstrated that first ray motion occurs at different levels within the medial arch column.[5] In this study, significant motion was noted between the medial and middle cuneiforms and navicular-cuneiform articulations with lateral compression of the metatarsal heads as is seen in the excessively pronated foot.

J. David Skliar, DPM investigated first ray motion via cadaveric dissection in over 200 specimens and found that due to broad ligamentous attachments, attempts to dislodge the metatarsocuneiform articulation through forceful manual pressure were unsuccessful in obtaining any degree of movement.[17]

Saffo, et al. states that 90% of first ray motion occurs at the navicular-cuneiform articulation with only 10% occurring at the first metatarsocuneiform level.[51] Mizel demonstrated 5mm of first ray base dorsal movement with sectioning of plantar ligamentous attachments.[9] Other cadaveric studies have demonstrated 3.5 degrees of sagittal plane motion with little or no rotation.[9, 31, 43]

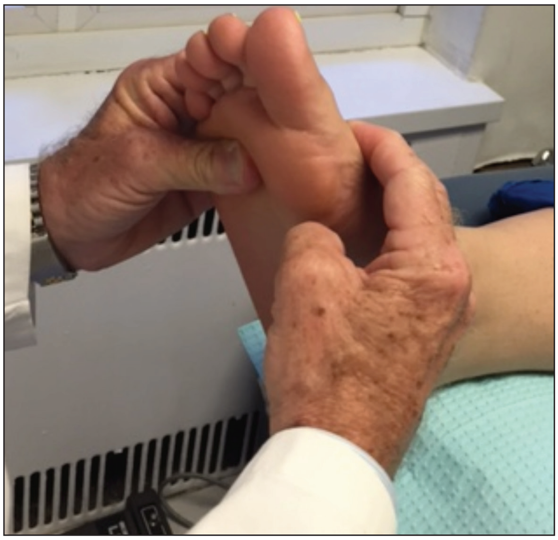

Figure 8b: First Ray Clinical Mobility Test—Plantarflexing the first ray.

Figure 8c: First Ray Clinical Mobility Test—Dorsiflexing the first ray.

Figure 9: Clinical Grasp Test—Grasp the foot at the tarsometatarsal articulation and with the ankle and subtalar joint in neutral position use the opposite hand to move the first ray dorsally and plantarward noting the degree of movement.

Kelso, et al., in an open kinetic chain cadaveric study of 24 specimens, determined the total sagittal plane motion of the first ray to be 12.38 +/-3.4 mm.[52] The absence of an intermetatarsal ligament allows the first ray increased mobility in the sagittal plane, whose end-range of dorsal excursion is limited by the plantar first metatarsocuneiform ligament.[53] Glasoe, et al. noted dorsal first ray mobility to range from 4–9 mm with an average of 6mm in young healthy individuals.[54] Fritz and Prieskorn examined first ray dorsiflexion in 100 healthy subjects and found it to average 4.37mm.[55] Klaue and Mann agree that greater than 4 degrees of sagittal elevation of the first ray indicates hypermobility.[31, 56, 57]

A cadaver study of the loaded foot in function by D'Amico and Schuster investigated the net effect of pronation on first ray motion and was unable to demonstrate dorsiflexion and inversion of the first ray with closed chain pronation.[17] The authors observed that the net effect of closed chain pronation on first ray motion was dorsiflexion and eversion and that the axes obtained by Hicks did not seem to apply to the loaded foot. Oldenbrook and Smith confirmed or implicated first ray eversion with pronation as well as numerous other authors including: Johnson and Christensen, Grode and McCarthy, McGlamry, Olson, and Seidel, Talbot and Saltzman, Dykyj, Scranton, Roukis and Scherer, et al.[11, 58–65] Eustace in 1993 performed a cadaveric study on 20 specimens and noted that the plantar tuberosity of the base of the first metatarsal moved

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*First Ray* (*from page 115*)

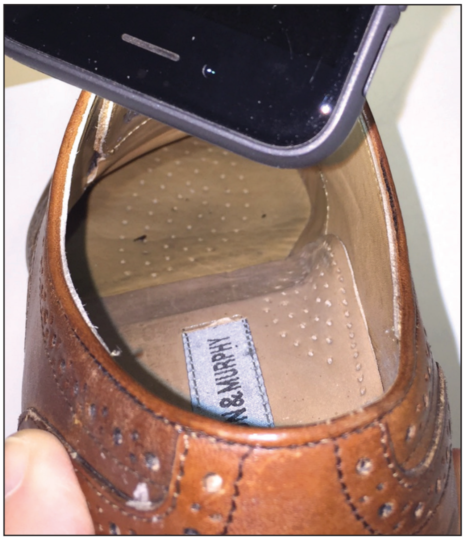

Figure 10a: Simplistic examination and documentation of in-shoe forefoot pressure patterns with i phone.

Figure 10b: In-shoe forefoot pressure patterns with revealing an absence of pressure sub first metatarsal head and increased pressure sub 2,3,4 met heads as well as hallux.

laterally or everted with closed chain pronation.[49]

In another study, Eustace, et al. radiographically analyzed 100 feet and demonstrated not only a significant relationship between first metatarsal pronation, i.e., eversion and the height of the medial longitudinal arch, but also found that it was the most dominant single variable.[50] In effect, the more the medial longitudinal arch collapses, the more the first ray rises. This is in agreement with Durrant, who noted that low declinations of the first ray accompanying excessive pronation causes the first ray to assume an everted position relative to the ground, whereas at higher declination angles, the first ray assumes an inverted position.[66]

**Early stance phase pronation absorbs shock, allows the foot to adapt to terrain variation and lowers the first ray towards the supporting surface.**

**Pathomechanics**

Whether or not the first ray is able to function in a normal stable manner is dependent upon its ability to resist ground-reactive forces, that in turn is dictated by the proper functioning of structures and mechanisms that serve to stabilize the medial longitudinal arch. These include the plantar ligaments, extrinsic musculature, and windlass effect of the plantar fascia. Any variation in normal foot and leg alignment with secondary disruption of the normal pronation-supination gait cycle timing sequence disrupts first ray function, leading to progressive first ray deformity.

Rush, et al. describes first ray hypermobility as a continuum of increasing pathomechanical motion with a diversity of clinical signs and symptoms as first ray insufficiency develops and progresses.[20] Morton, Lapidus, and Hansen depict the first ray as gatekeeper for forefoot pathology, with a hypermobile ray unlocking the forefoot, predisposing it to hallux abducto valgus, metatarsus primus varus and metatarsalgia.[19, 23-25, 29, 67–69]

Early stance phase pronation absorbs shock, allows the foot to adapt to terrain variation, and lowers the first ray towards the supporting surface. As body weight progresses forward, superstructural limb mechanics driven by reciprocal arm and limb pendulum motion rotate the pelvis externally over the support limb, encouraging a stable supinatory platform for propulsion. Pronation past the midstance phase of gait unlocks the midtarsal joint, eliminates the windlass effect of the plantar fascia, negatively al-

*Continued on page 117*

### TABLE 5:
## Etiology First Ray Hypermobility

- Short First Metatarsal
- Compensated Forefoot Varus
- Compensated Forefoot Valgus Flexible Type
- Compensated Equinus: gastroc/soleus, ankle, forefoot, metatarsal, hamstring, iliopsoas
- Superstructural Transverse Plane Deficiencies
- Ligamentous Laxity
- Limb Length Discrepancy longer limb
- Posterior Tibial Tendon Dysfunction/ Accessory Navicular
- Inflammatory Arhropathies

*First Ray* *(from page 116)*

ters the peroneus longus angle of application of force, dampens its contractive capacity, disrupts the conjunctive action of the tibialis anticus and peroneus longus, flexor hallucis longus and brevis and first MPJ joint compressive forces, destabilizing the first ray.[1, 11, 70]

Due to the accompanying navicular-cuneiform collapse, the first ray is unable to resist the reactive force of gravity and becomes mobile at a time when it should be stable. This relatively elevates the first metatarsal head above the level of the proximal phalynx, blocking or functionally limiting propulsive phase first MPJ dorsiflexion, and transfers forces to the second metatarsal head.[22, 45, 71, 72]

The net result is an inability of the first ray to accept body weight, stabilize the medial longitudinal arch segment, activate the dynamic windlass mechanism, and enable the body to freely and efficiently pass over the supporting foot. In an attempt to continue the "blocked" forward path of the superstructure, the interphalangeal joint of the hallux may become hyperextended. This first ray "looseness" allows the foot to further rotate medially, resulting in an inward, downward collapse of the longitudinal arch.

Therefore, any condition resulting in compensatory subtalar and midtarsal joint pronation throughout the midstance phase of gait with accompanying calcaneal eversion beyond the vertical is capable of producing a functional instability or destabilization of the first ray in effect dorsiflexing and everting this segment at a time when it should be plantarflexing (Table 5). Dorsiflexion with eversion of the first ray is seen until its end-range of mobility is achieved, at which point it begins to invert from its markedly everted position.[17]

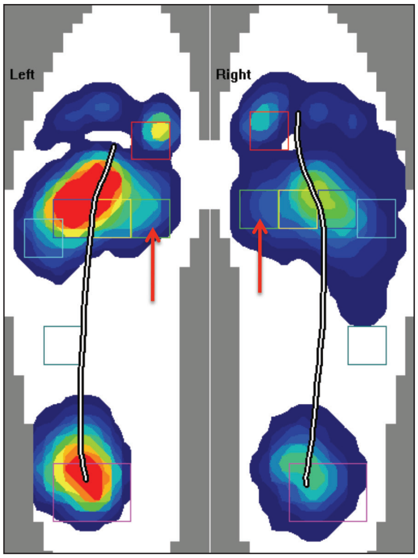

Figure 11a: LW barefoot averaged stance pressure patterns with center of force (COF) pathways Note absence of pressure sub first met heads and significant increased pressure sub 2,3,4 met heads left foot.

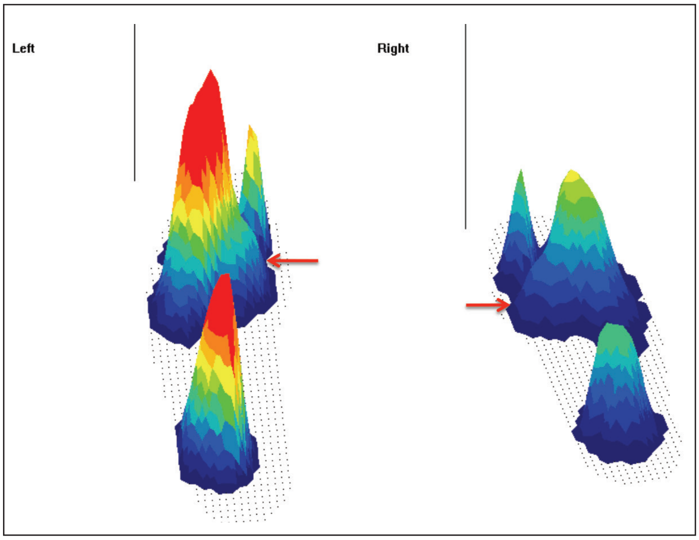

Figure 11b: LW 3-D view depicting reduced to absent first ray loading.

Additionally, it has been shown that there is a relationship between generalized ligamentous laxity and first ray hypermobility.[39, 70] Fritz and Preskorn demonstrated 6.93 degrees of sagittal plane first ray motion in individuals with a hyperextensible thumb with only 3.95 degrees of motion in a control group.[55]

### First Ray Hypermobility and Hallux Valgus

As early as 1925, surgeons such as Truslow recognized that first metatarsocuneiform stabilization was required to treat hypermobility associated with hallux valgus.[74] Lapidus popularized the closing wedge first metatarsocuneiform arthrodesis, however it is Truslow who is credited with the term metatarsus primus varus. Lapidus believed that hypermobility of the first metatarsal may represent an atavistic finding.[19, 67, 68]

**Hypermobility of the first ray has been implicated in the production of hallux valgus, metatarsus primus varus and acquired flatfoot deformities.**

Hypermobility of the first ray has been implicated in the production of hallux valgus, metatarsus primus varus, and acquired flatfoot deformities.[13, 23-25, 27, 31, 42, 60, 62, 64, 75-78] Since first metatarsocuneiform instability or first ray hypermobility is seen with hallux abducto valgus deformity and since this is a three-dimensional pathology, patients often have an associated flatfoot deformity.[8, 71] Eustace, et al. radiographically analyzed 100 feet and demonstrated not only a significant relationship between first metatarsal pronation and the height of the medial longitudinal arch, but also found that it was the most dominant single variable.[50]

Elevation of the first ray due to first ray hypermobility leads to

*Continued on page 118*

*First Ray* *(from page 117)*

transfer loading of the second metatarsal with radiographic hypertrophy and is frequently seen with hallux abducto valgus.[32, 71]

Carl, et al. demonstrated a correlation between generalized ligamentous laxity and hallux valgus versus a control group.[35] Coughlin, et al. performed a cadaver study to determine the degree of hypermobility pre- and post- crescentic osteotomy correction of hallux valgus deformity. They found first ray stability restored with a procedure that does not sacrifice the first metatarsocuneiform articulation. As a result of their findings, the authors suggested that extrinsic anatomic features may play a role in first ray mobility.[79]

**Clinical Identification**

In the past, identification has been derivatively determined by subjective complaints and clinical findings. Subjective complaints include first metatarsocuneiform joint pain, metatarsalgia, painful hyperkeratoses sub second or third metatarsal heads and/or medial IPJ of the hallux, hallux interphalangeal joint pain associated with compensatory hyperextension, first MPJ pain with or without accompanying shoe irritation, etc. Clinical findings may include a “dropped” transverse metatarsal arch and increased dorsal mobility of the first ray. Radiographically, a thickening of the medial and lateral cortices of the second metatarsal shaft, metatarsal cuneiform split, posteriorly displaced sesamoids, metatarsus primus elevatus, short first metatarsal, metatarsocuneiform osteophytes or dorsal lipping, etc. may be observed.

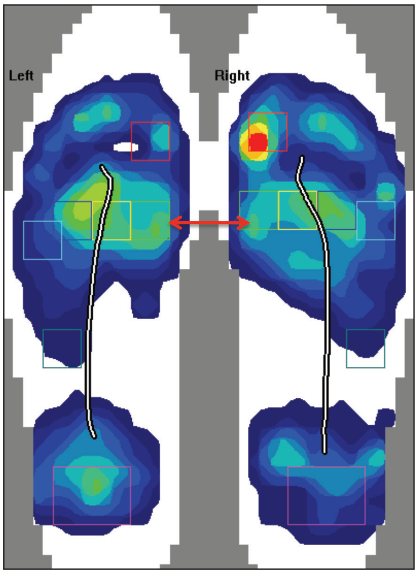

Figure 12a: LW sneakers with orthoses averaged stance Note improved weight distribution patterns bilaterally especially sub first met heads.

**The Coleman block test is another clinical test that may be employed to assess first ray sagittal plane motion on weight-bearing.**

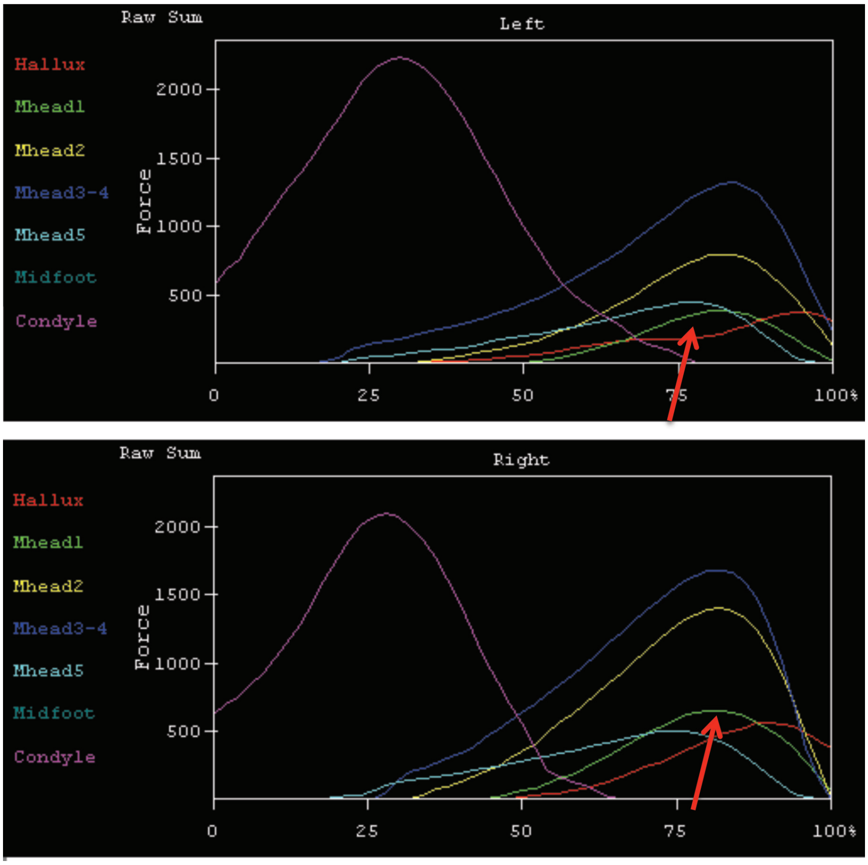

Figure 11c: LW barefoot waveform analysis force vs. time Note decreased first met pressure (green wave) and increased second (yellow) and third (blue) met head pressure.

Various devices have been designed to measure first ray motion, some more accurate than others.[80–85] The value of instrumented assessment of first ray motion has yet to be determined.[71]

First described by Morton in 1928 and reintroduced by Root, et al. in 1971, the first ray clinical mobility test may be utilized to assess first ray motion.[13, 23, 25] It is performed using one hand to sandwich the lesser metatarsals, and applying a dorsiflexory force to stabilize the ankle at 90 degrees, then using he opposite hand to dorsi and plantarflex the first ray. (Figures 8a, b, c) The amount of movement is noted by the end position of the examiner’s fingernails in relationship to the head of the second metatarsal. Normal motion

*Continued on page 118*

*First Ray* *(from page 118)*

consists of 5mm dorsally and 5mm plantarward for a total of 10 mm.[13] Again, findings should be compared with the contralateral foot.

Bednarz and Manoli suggested that one full thumb breadth of movement in a dorsalward direction indicates hypermobility.[86] Radiographs may be compared with and without strapping (radiographic squeeze test) to note changes in first ray alignment.[11, 87] Roukis discusses a "dynamic Hicks test" initially described by Roy and Scherer to assess first ray motion. Similar to the sandwich technique test, however, in this instance it is the hallux that is dorsiflexed and plantarflexed with the examiner noting dorsal and plantarward movement of the first ray.[88, 89]

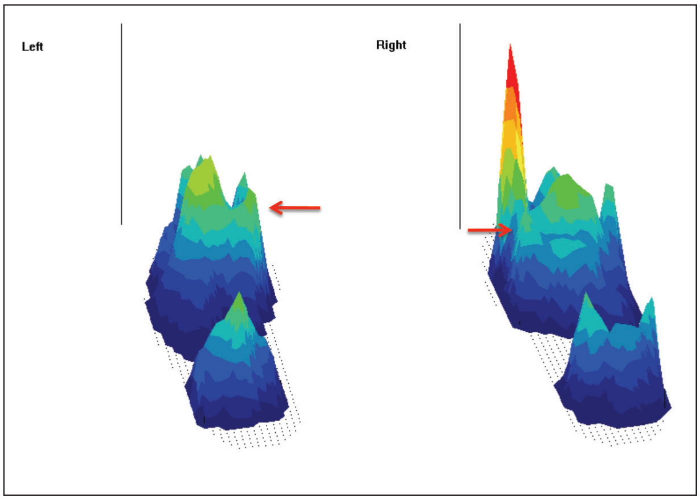

Figure 12b: LW 3-D view sneakers with orthoses Note markedly improved first met head weight-bearing function.

Another method of clinically determining the presence of first ray hypermobility is to grasp and stabilize the foot proximally with the opposite hand, then move the first ray in the sagittal plane (clinical squeeze test) (Figure 9).[90] Since talar position influences first ray mobility, dorsiflexing the ankle reduces first ray mobility while plantarflexion increases it; therefore, all testing should be done with the ankle in neutral position.[16] The examiner notes the amount of motion present and compares it to contralateral foot. Normal first ray sagittal plane range of motion is 4.3-6.5mm. Findings greater than 7–10 degrees with a firm endpoint indicate hypermobility.[27, 31, 77, 86]

The Coleman block test is another clinical test that may be employed to assess first ray sagittal plane motion on weight-bearing. A patient stands on a 1.5mm wooden block supporting the second through fifth metatarsals, allowing unopposed plantarflexion of the first ray. The block is then shifted to support the first ray, allowing the lateral metatarsal to plantarflex while allowing first ray dorsiflexory capacity to be observed.[88]

Richard O Schuster, DPM always had a penlight handy to examine the innersole wear of the patient's shoe, thus revealing a dynamic record of their weight distribution patterns. In essence, this is a simplistic, realistic, and reliable method of assessing in-shoe forces, based on sub hallux, first and second met head pressure markings capable of indicating first ray function or dysfunction during gait (Figures 10a, b). Since many types of daily and sport footwear today have removable insoles, this assessment is even easier to perform.

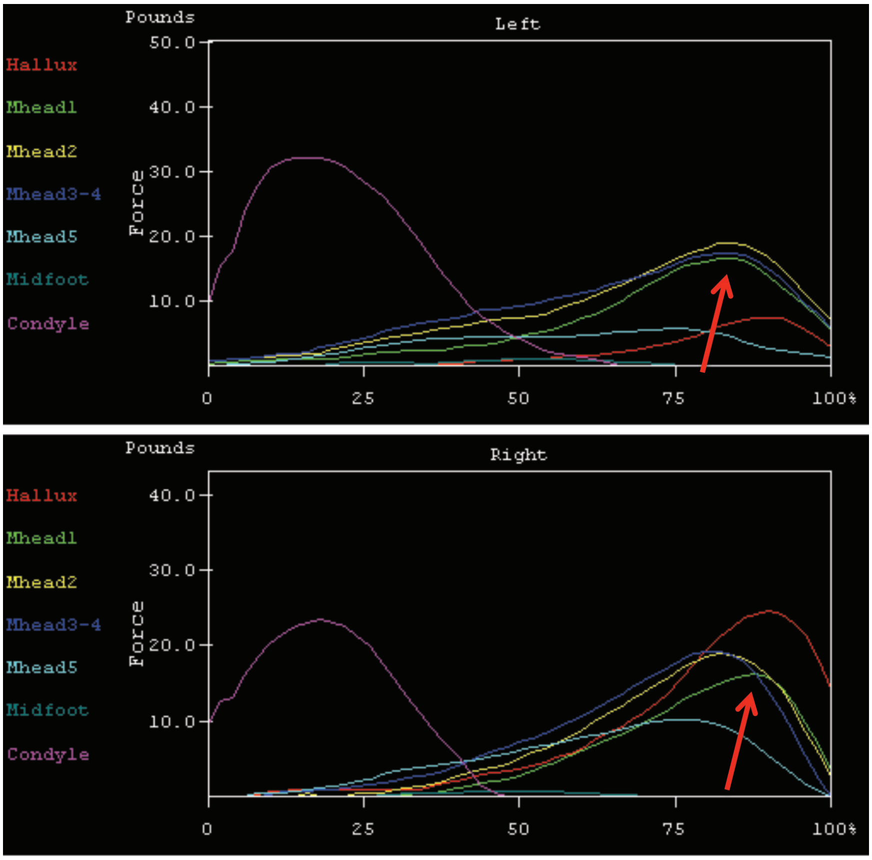

Figure 12c: LW shoes plus orthoses. Note the markedly improved stabilized first metatarsal function during propulsion.

## Dynamic Quantitative Assessment of First Ray Function

Hypermobility of the first ray is a condition that occurs under the foot and inside the shoe while the patient is ambulating. It cannot be seen with the naked eye, nor timed with a stopwatch. In-shoe pressure analysis via a computer-assisted gait system (CAGA) allows the ob-

*Continued on page 120*

*First Ray* (from page 119)

jective, realistic assessment and quantification of first ray function during ambulation.

CAGA observation of sub first MPJ weight-bearing during the midstance and propulsive phases of gait indicates stability or instability of the first ray. Reduced first MPJ weight-bearing in a pronated foot indicates inactivation of the windlass mechanism and failure of the peroneus longus to stabilize the first ray resulting in hypermobility with secondary transfer of ground reactive forces laterally and/or distally. These forces are depicted and quantified via time and force curves of individual foot segment pressures along with dynamic multiple step analysis of in-shoe or barefoot weight distribution pressures, patterns and pathways (Figures 11a, b, c). CAGA can also be employed to objectively assess success post conservative and/or surgical management (Figures 12a, b, c)

## Summary

Hypermobility of the first ray is a destructive process occurring primarily at the medial cuneiform-navicular articulation, caused by subtalar and midtarsal joint pronation as a result of inherently-induced phylogenic and ontogenic-induced imperfections. These may be exacerbated by acquired co-morbidities. Historically, identification has been determined by subjective complaints and clinical findings. Objective assessment of first ray function via in-shoe pressure analysis offers a realistic quantitative perspective of its performance.

Understanding and utilization of these principles and techniques will allow the astute practitioner to be able to identify and assess first ray hypermobility as well as improve conservative as well as surgical-based management outcomes.

Although the recognition of a major functional fault in the key propulsive phase segment of the foot is a significant finding, it remains of paramount importance that its underlying etiology be identified and addressed. **PM**

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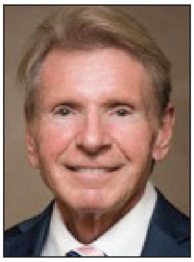

**Dr. D'Amico** is Professor and Former Chair Division of Orthopedics & Pediatrics at the New York College of Podiatric Medicine. He is a Diplomate of the American Board of Orthopedics & Medicine and is in private practice New York, NY.

*CME Exam on page 122*

# CME EXAMINATION

*See instructions and answer sheet on pages 144-146*

1) What percentage of body weight is carried by the first metatarsal during static stance?
   A) 20%
   B) 30%
   C) 40%
   D) 50%

2) In a normal functioning foot, contraction of the peroneus longus results in a
   A) Medial and dorsal pull of the first ray
   B) Medial and plantarward pull of the first ray
   C) Lateral and dorsal pull of the first ray
   D) Lateral and plantarward pull on the first ray.

3) Which one of the following are components of Morton's syndrome?
   A) Short first metatarsal
   B) Hypertrophy of second metatarsal cortices
   C) Posteriorly displaced sesamoids
   D) All of the above

4) Which of the following are responsible for first ray stability?
   A) Peroneus longus
   B) Flexor hallucis longus and brevis
   C) Windlass effect of the plantar fascia
   D) All of the above

5) Which one of the following are example of an evolutionary "scar" or atavistic trait in the human foot?
   A) Forefoot varus
   B) Hypermobility
   C) Metatarsus primus adductus
   D) All of the above

6) Which of the following conditions are capable of producing a hypermobile first ray?
   A) Compensated forefoot varus
   B) Compensated gastroc/soleus equinus
   C) Short first metatarsal
   D) All of the above

7) The net effect of pronation on the first ray is best represented by which one of the following?
   A) Dorsiflexion and inversion
   B) Dorsiflexion and eversion
   C) Plantarflexion and inversion
   D) Plantarflexion and eversion

8) Hypermobility of the first ray may lead to which of the following?
   A) Hallux Valgus
   B) Metatarsalgia
   C) Hallux Extensis
   D) All of the above

9) At what point in the gait cycle does the medial longitudinal arch function as a curved beam?
   A) Swing
   B) Early midstance
   C) Late midstance
   D) Propulsion

10) The inclination angle of the first metatarsal is represented by which one of the following?
   A) 5-15 degrees
   B) 15-25 degrees
   C) 25-35 degrees
   D) 35-45 degrees

**SEE INSTRUCTIONS AND ANSWER SHEET ON PAGES 144-146.**