BAREFOOT™ SCIENCE

Foot Strengthening System™

Foot Care Steps in a New Direction

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For A Healthy ®S

Foot Care Steps in a New Direction

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Barefoot Science Inc. was incorporated in 1997 to market foot care technologies developed after over fourteen years of research on foot function and related pathologies. Our research has focused on four key areas:

- review of relevant studies (global and multi-disciplinary in scope),
- analysis of current philosophies and treatment methods,
- the development of a more accurate method of measuring the three-dimensional musculoskeletal dynamics of the foot structure during full weight bearing, in both static and dynamic environments, and
- the effects of various environmental influences on foot function (i.e., shod and barefoot).

Our findings in these key areas contradicted many of the currently accepted theories of foot function and relevant treatment methods.

Specifically, there is sufficient scientific evidence to prove that, aside from trauma, footwear is the leading cause of the vast majority of foot-related pathologies, and that the majority of these pathologies can be both prevented and effectively treated.

The majority of foot care professionals and footwear companies promote technologies that support and cushion the foot as a means to address most foot-related pathologies and discomfort. These treatment methodologies are based on theories incorporating foot function NORMS that have not changed in over 100 years and are supported by published articles that, for the most part, simply rehash these dated hypotheses. One study, cited in the Journal of the American Podiatric Medical Association, examined the reliability of information found in articles in podiatric medical journals. The study determined that only1% of the 322 articles reviewed displayed consistent, reputable, and scientific evidence-based information. The authors concluded that the majority of these published articles focused on generating, rather than testing hypotheses. [1] The majority of existing research is more aptly viewed as a circumvolution of thought, composed of the repetition and validation of each previous body of research (hypotheses). It is disturbing that the protocols and hypotheses were never tested for their validity, reliability, or applicability, yet these hypotheses are commonly stated as fact and have led to a plethora of myths surrounding foot function and health.

In order to advance more applicable and quantifiable science, Barefoot Science, in consultation with a growing number of medical professionals, has developed and continues to develop new hypotheses, state-of-the-art assessment protocols, and educational tools that clearly illustrate:

- ideal gait biomechanics,

- the biomechanical causes of most foot-related pathologies, and
- the pros, cons, and effectiveness of various treatment methods.

The combining of existing research in the fields of foot function, mechanical physics, bone remodeling physics, neurology, and rehabilitative medicine has led to new hypotheses on ideal foot function. These concepts have been applied to the design of a dynamic device—rather than a static orthotic—that would promote optimal structural integrity of the foot through all ranges of three-dimensional movement. The testing of these new hypotheses and this dynamic device has lead to the creation of the "Barefoot Science Arch Activation Foot Strengthening System™"—a technology that represents a significant advancement in foot care management and treatment.

Based on the principles of rehabilitative medicine, the Arch Activation Foot Strengthening System™ stimulates and retrains the appropriate muscle-firing sequences necessary to dynamically stabilize the foot's arch system as it responds to a multitude of three-dimensional movements. This provides both preventative and rehabilitative benefits. This safe, cost effective, and easy-to-use technology has been tested in numerous clinical, medical, and retail settings with over 90% effectiveness. The technology is used internationally by world class and professional athletes for its rehabilitative and injury prevention benefits, as well as for performance enhancement.

"Barefoot Science technolgies clearly offer the most effective preventative and rehabilitative treatment option available today to address poor structural integrity of the foot's arch system."

Thomas McClain, M.D., F.A.B.O.S., F.A.A.O.S

New technologies that introduce innovative concepts and methodologies invariably must address concerns raised about the validity of their claims. We believe that the existing research and the development of new protocols scientifically and quantifiably validates a revolutionary "new science" (re: foot function).

The following monograph is an update and expansion of our 2001 publication and it presents a more comprehensive overview of our research findings with relevant supporting science that clearly advances theories on foot function and dysfunction, resulting pathologies, and appropriate treatment options. We are confident that you will join the increasing number of medical professionals that recognize the value of the science and technology presented, and we welcome you to contribute to the ongoing exploration and validation of the concepts contained herein.

Sincerely,

Roy Gardiner
President, CEO

Impairments to the musculoskeletal system are the leading cause of limitations in activity for people of all ages. [2, 3, 4] They can affect not only an individual's general health and quality of life, but are also responsible for a substantial portion of health care costs. Considerable research has shown that the maintenance of a healthy musculoskeletal system is usually simpler and less expensive than repair after injury or disease. [5, 6, 7] Therefore, a better understanding of the development and function of the musculoskeletal system in the non-diseased state is crucial in the prevention and treatment of related pathologies.

The feet, as with any other musculoskeletal structure in the body, are positively or negatively affected by environmental stresses. For example, it is commonly accepted that exercising through a full range of motion promotes a balance of strength and flexibility in opposing muscle groups. [8, 9] It also encourages optimum bone density and ideal alignment at the joints. The net result is a stronger, more dynamically efficient musculoskeletal structure that exhibits little or no degenerative stress and that is capable of optimal performance with the lowest risk of injury.

Conversely, it is also commonly understood that, chronic restriction or bracing of the musculoskeletal structure leads to muscle atrophy, loss of bone mass, and joint stiffness—the net result being a weaker, less efficient structure—predisposed to degenerative stress and injury due to poor structural alignment/function. Over time, the impaired musculoskeletal function becomes the conditioned or trained "norm" via desensitization, habituation, and adaptation. Therefore the body is no longer capable of effectively responding to the ever changing environment. and aside from trauma, the resulting degenerative stresses can cause, or contribute to, the majority of musculoskeletal pathologies. Common symptoms include pain, stiffness, and swelling in joints and other supporting structures of the body such as muscles, tendons, ligaments, and bones, along with muscle atrophy (underuse), muscle hypertropathy (overuse), tissue damage, fibrosis/scar tissue, and loss of bone density. This dysfunctional norm can only be reversed through rehabilitative therapies (conditioning) that retrain the optimal musculoskeletal function.

These concepts are not new to medical science. They are the foundation of most current rehabilitative and sports performance programs. The question is: How do they apply to the feet—the musculoskeletal structures that are comprised of nearly one-third of the bones in the human body?

Eighty-five percent of Americans will see a medical professional for some type of foot-related pathology at some point in their lifetime, according to the American Orthopedic Foot and Ankle Society. In staggering contrast, habitually barefoot populations develop virtually no few debilitating foot-related problems. [10, 11, 12]

"...an estimated eight out of ten people in the U.S. have undetected gait problems that cause sore feet, aching backs and hips, and pains in the leg and neck."

Gait Analysis Steps Into New Fields, Mechanical Engineering

"All writers who have reported their observations of barefooted people agree that the untrammeled feet of natural men are free from the disabilities commonly noted among shod people – hallux valgus, bunions, hammer toes, and painful feet."

Stewart SF. Footgear—Its History, Uses and Abuses, Clinical Orthopaedics and Related Research, 88, 1972

"In unshod communities the foot muscles get freedom for exercise and the joints remain supple. This is why functional disorders of the foot are so rarely seen in such people."

"I sometimes like to look upon closed shoes as braces ...which takes up the work of muscles causing them to atrophy from disuse and make the joints stiff."

Sethi PK. The Foot and Footwear. Prosthetics and Orthotics International, Vol. 1, 1977

The structure of the foot and its biomechanical function have been commonly referred to in medical journals, studies, and in consumer publications as being of poor design and function, therefore susceptible to injury. [13, 14] Another common statement is that most foot dysfunctions and resulting pathologies are hereditary. These two myths have been perpetuated within the medical community simply by their repeated exposure in these mediums, not withstanding the fact that there are very few scientific studies to support these hypotheses—in fact, an abundance of research demonstrates otherwise. [15, 16, 17]

There is much debate about what constitutes normal foot function and how "NORMS" are determined. It is important to note that the currently accepted "NORMS," as defined in most medical literature, were derived from studies on foot function and gait conducted mainly on sample populations that have worn shoes since childhood. For the most part, these NORMS have been one of the "tools" used to identify the causes of various pathologies and have traditionally formed the foundation of associated treatment options. Furthermore, they have played an integral role in the development of footwear designs and orthotic devices.

Significantly, the NORMS derived from studies on predominantly unshod populations show drastically different trends with respect to foot function. [9, 14] The difference between NORMS derived from shod vs. unshod populations is similar to comparing function and range-of-motion between:

- a limb that has been immobilized by a splint or cast for several years, and
- a limb that has experienced unfettered movement over the same period of time.

It is obvious even to a lay person, that the chronically restricted limb would be weaker and exhibit joint stiffness with an associated limited range-of-motion. In addition, the restricted limb would also be incapable of many of the tasks that would be easily managed by an unfettered limb.

Therefore NORMS, with respect to foot function and upon which the efficacy of standard therapeutic practice is based, are themselves subjective. Furthermore, the accuracy and applicability of a majority of current foot care research is questionable. [15, 16, 17, 18, 19, 20, 21, 22, 23]

"Typical foot motion does not obey descriptions of triplanar motion such as 'pronation' and 'supination'."

Hunt A, Smith R, Torode M, Keenan A. Inter-segment Foot Motion and Ground Reaction Forces Over the Stance Phase of Walking. Clinical Biomechanics 16 (2001) 592-600

For example, most text books, journals, and studies refer to the terms "pronation" (a composite of dorsiflexion, eversion, and abduction) and "supination" (a composite of plantarflexion, inversion, and adduction) when describing foot function NORMS. The foot's weight bearing or stance phase of motion is most commonly described as consisting of pronation in early stance in association with lowering of the medial longitudinal arch, followed by a progressive supination in association with arch raising. [24, 25, 26, 27] The foot has been described as behaving much like a twisted plate, in that the arch rises or lowers according to counter motions of the rearfoot and forefoot segments. [26,28, 29] According to Hunt, et. al., "...these commonly defined NORMS are largely speculative, as they are based on the application of static experiments or unquantified observations. Furthermore, they have been applied to the motion of foot segments and bones, although no data yet exists to provide a description of typical inter-bone motion during walking." [26]

Lundberg and colleagues' series of in vivo, quasi-static experiments investigating inter-bone motion provide new insights into weight bearing foot function. For example, they found that between 10% and 41% of total foot plantarflexion occurred in the bones of the medial longitudinal arch, and that the talonavicular joint contributed the most. [30, 31, 32] In addition, they found that frontal plane motion occurred primarily at the talonavicular joint, rather than at the talocalcaneal joint [30, 31, 32] as commonly reported. These findings suggest that the midfoot region would contribute more to the overall foot motion during walking than is commonly believed, and should therefore be a focus of research into normal foot function. [26]

To better understand foot function, we must first examine how the feet should *ideally* function from a biomechanical perspective. Once this is clearly understood, the negative environmental influences that lead to a disproportionate number of pathologies in the shod population can be examined in context. Preventative measures can then be developed and new, more effective treatment options can be implemented.

3.0 Lower Limb - Musculoskeletal Mechanics

During natural healthy foot function, optimal musculoskeletal mechanics/alignment is ideally a dynamic response to activity levels and terrain. That is, the muscles of the foot should act to optimally align the bones to most effectively manage the forces generated during varying activities and terrain. Thus, the dynamic stable arch system would provide a capable foundation for the lower limbs and body (kinetic chain) while promoting optimal musculoskeletal alignment/function/performance and little or no degenerative stress throughout.

Fig re 1

From a strictly mechanical perspective, the lower limb structure can be considered to be comprised of a ball and socket joint at the hip, a simple hinge joint at the knee, with the foot and ankle functioning similar to a universal joint, in order to provide an effective interface with the ground. However, closer examination of the skeletal structure of the foot and ankle suggests that, with appropriate muscle contractions, the bones of the foot are capable of aligning to form a dome-like configuration which can act similar to a socket moving around an imaginary ball. (Figure 1)

It is widely accepted that the shape of the interlocking bones and ligament strength maintain the transverse, medial, and lateral longitudinal arches of the foot. [27, 33, 34, 35] This established viewpoint, while technically correct, overstates the role that bone shape and ligament strength play in maintaining optimal structural integrity of the foot. For example, if we isolate the bones of the foot from the muscle, tendons, ligaments, etc., and view the structure from a physics perspective, it becomes clear

The foot, "a masterpiece of engineering."

Leonardo da Vinci.

that the relative alignment and positioning of the bones are the primary determining factors in its structural capabilities. [26, 27, 34, 36, 37]

"The bones of different people exhibit considerable anatomical variation. They vary according to age, sex, physical characteristics (body habitus), health, diet, race, and with different endocrinological conditions." "Bones are vital living organs and will change considerably with age." Moore [35] Bones are also in a constant state of change through cellular regeneration (remodeling) or functional adaptation. [38] Functional adaptation in bone is remodeling of structure, geometry, and mechanical properties in response to altered loading. [38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50] The environmental forces of pressure and tension result in surface (external) and internal bone remodeling as the structure attempts to produce the same maximum normal stress (in brittle material: outer shell) or shear stress (in ductile material: spongy inner core) throughout the body for a specific load. [46] Although the adult skeleton is less versatile than that of maturing children, it is still capable of responding in an adaptive manner to strain and stress. [6]

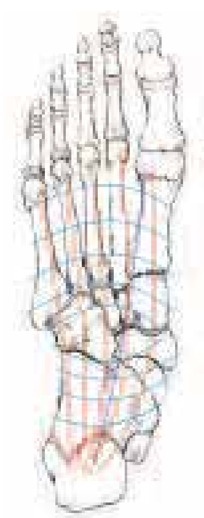


Fig re

Therefore, regardless of age or genetic predisposition, the relative shape and strength of bone is significantly influenced by the pressures and tensions of bone-to-bone contact, their geometric alignment, and muscular forces. These dynamics are often ignored when investigating and defining the foot's structural function, pathologies, and treatment methods.

3.1 Theoretical Ideal Structural Physics Model of the Foot

As Wolfe identified in his "law of bone transformation" (1884): "...there is a perfect mathematical correspondence between the structure of cancellous bone in the proximal femur and Culmann's trajectories." [50] This principle (i.e., cancellous bone patterns directly follow the lines of force that act upon that bone) is obvioiusly applicable to every bone - not just the proximal femur. In fact, this is fundamental to the understanding of the mathematical relationship (mechanical physics) of the bones and the forces involved, as a means to developing an ideal mechanical model for foot function. In essence, bone struture, bone shape, and bone alignment must *ALL* correlate with the forces that will be required to fit the "dome-like" foot functions suggested by Figure 1.

Within the medical community, the foot is commonly described as consisting of the medial, lateral, and transverse arches. [35, 51] This view, from a physics perspective, is inordinately simplified and ignores the complexity of the structure, as a whole. The structural physics of the foot more accurately demonstrates a series of intersecting arches that run medially to laterally and posteriorly to anteriorly from the calcaneus to the metatarsal heads. (Figure 2) To better understand both the simplicity and complexity of this arch system, it is important to indentify the dynamics of a single arch and its intrinsic relationship within a system of arches.

In the foot, the structural mechanics of a single arch (Figure 3) are determined by its components:

- the material composition of the arch: interlocking bone structure and ligaments—their relative strengths (tensile, compressive, etc.) and elasticity, and
- a tie beam: soft tissue, i.e., tendons, muscles, fascia, etc.,—their relative strengths (tensile and elastic).

Within the material composition of any given arch structure, there exists a central "keystone" about which opposing forces must equalize as a means of maintaining the arch integrity. When force is applied to an arch structure, the stronger and more stable the material composition, the lower the degree of tensile (or pulling) force produced on the tie beam.

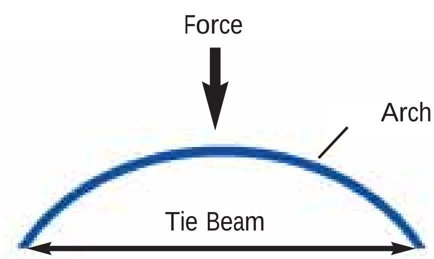


Fig re 3

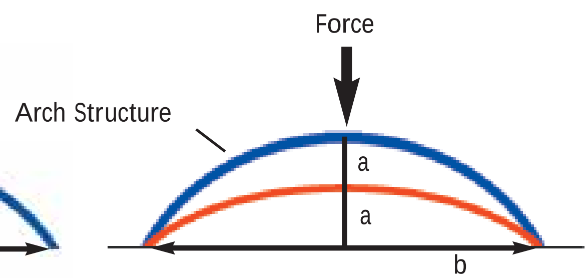


Fig re 4

When comparing arches of identical composition with equivalent tie beam lengths, a higher arch is stronger and more stable and therefore generates less tensile stress (pulling force) on the tie beam. (Figure 4) The blue arch is twice as high (2a) as the red arch (a), therefore the relative traction (tensile) force of the blue arch is "a/2a" (or one half of the applied vertical Force at the arch apex). Mathematically, if the tie beam length was 10 units, and the height of the red arch was 2.5 units vs. 5 units for the blue arch, then the relative horizontal (tensile) stress component on the red arch tie beam would be 10/2.5 or 4 vs. 10/5 or 2 for the blue arch.

"A normal arch is very important... ...very little muscular activity is necessary to support the body"

Subotnick SI. The Flat Foot. The Physician and Sports Medicine. 9(78): p.85, August 1981

When this formula is applied to a single arch structure as seen in an individual foot with a fixed arch length (along the curve of the arch structure), it is clear that there is a direct relationship between a higher arch structure and a shorter tie beam. (Figure 5)

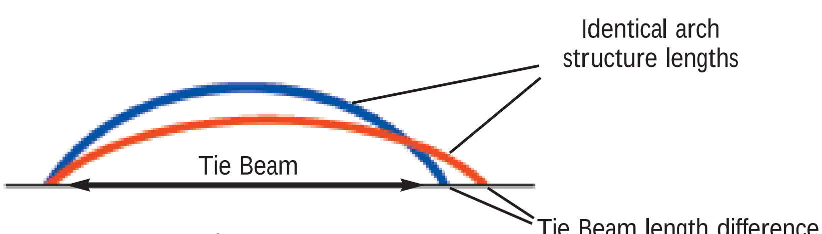


Fig re 5

Despite their identical arch structure and tie beam components, the blue arch structure is not only proportionally stronger than the red arch structure (due to the increased height)—its strength is further accentuated by a decrease in its tie beam length. The increase in height, in combination with a decrease in tie beam length, is reflected in a significantly decreased tensile (pulling) force on the tie beam.

When combined in a multi-arch system, such as the foot, these singular arch dynamics work synergistically to maximize relative strength and stability while greatly minimizing stress, and are more effective collectively than individually.

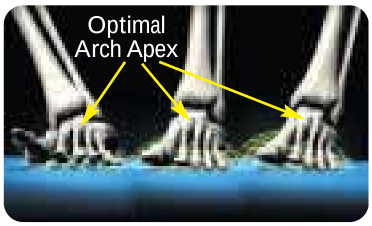


Fig re 6

Therefore, from a physics perspective, the most inherently sound structural mechanics would be achieved if the bones of the foot could interlock and maintain the multi-arch functional dynamics of a *dome* shape. Such a dynamic could manage greater loads with minimal contribution from, or stress on, the ligaments and extrinsic/intrinsic musculature. The interlocking bones' dome shape would function much like a socket, capable of rotating around an imaginary ball. (Figures 1 & 6) The dome's level of functional stability would be determined by the "Ideal" or "Optimal Arch Apex" height necessary to most effectively maintain structural integrity in the interlocking bones as they manage the forces generated throughout three-dimensional activity.

Further, the location of the "Optimal Arch Apex" would ideally correlate to the location of the "conceptual" arch keystone, for optimal force management.

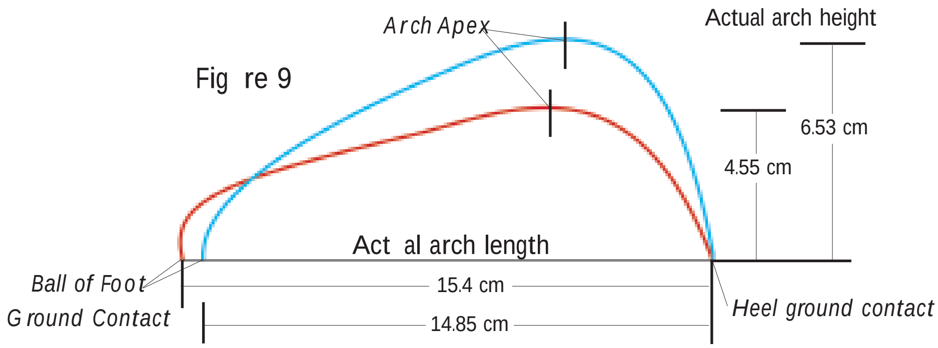
The relative positioning of the midfoot joints (re: the Optimal Arch Apex) is significant to the degree and pattern of forefoot segment motion, which in turn, is indicative of the foot's stability. [7, 19, 26, 27]

As is evident from the x-rays, the foot is capable of this functional dome-like alignment. (Figures 7 and 8) Both x-rays are of the same subject's right foot, during full weight bearing. Traditional analysis of the subject's foot indicated typical hypermobility that in a relaxed stance (Figure 7) would be inclined to excessively pronate (as commonly described). The x-ray in Figure 8 was taken approximately ten minutes after the x-ray in Figure 7, with the great toe dorsiflexed (minimal effort).

Fig re

Fig re 8

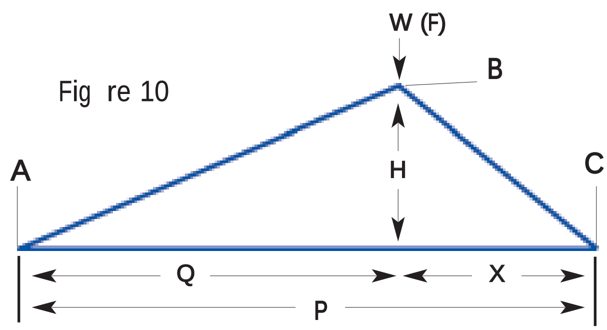
Fig re 9



The structural integrity of the arch system is determined by the arc created through the structure's center of mass. Figure 9 illustrates the actual differences in arch length and height.The length of the blue arch in Figure 8 is only 3.25% shorter than the red arch in Figure 7, with a relative 43% increase in height.

Figures 10 and 11 illustrate the geometry and mathematical equations for measuring: (a) the relative strength or vertical Force (F) capabilities of the arch, and (b) the

Fig re 10



A = ball of foot ground contact

B = arch apex

C = heel ground contact

a) RELATIVE ARCH STRENGTH

F = THP/QX

T = tensile strength of tie beam (100 ft. lbs.)

F = **W**

b) RELATIVE TIE BEAM TENSION

T = W(Q/H) (X/P)

W = weight (170 lbs.)

Foot in Fig re (red arch)

a) F = (100 x 4.55 x 15.4)/(10.8 x 4.6)
F = 141.0

b) T = (170) (10.8/4.55) (4.6/15.4)
T = 120.5

Foot in Fig re 8 (l e arch)

a) F = (100 x 6.53 x 14.85)/(10.45 x 4.4)
F = 210.9

b) T = (170) (10.45/6.53) (4.4/14.85)
T = 80.5

Fig re 11

Tension (T) in the tie beam during the single support phase, up to the point where the heel leaves the ground.

Consequently, the foot's structural alignment (single arch) in Figure 8 is capable of managing 50% (i.e., 210.9 vs. 141.0) greater weight or vertical force while generating 34.8% (i.e., 80.5 vs. 120.5) less tension on the tie beam as determined by the equation for calculating plantar tension). [52]

Throughout the kinetic chain, the integrity of the foot's structural alignment plays a significant role in managing the forces and stresses generated during gait. [27, 34, 53, 54] It is clear that an ideal, dome-like structural alignment in the foot is possible, and that there is an inverse relationship between the structural integrity of the foot and the muscular effort required to facilitate and manage its relative alignment. The *more* structurally sound the arch, the *less* muscular effort is required to manage alignment.

In addition, it is clear that the relative geometry of the bone-to-bone contact is significantly different. (Figure 7 compared to 8) Over time, habitual alignment in either scenario would result in bone remodeling in response to the forces and stresses generated. This dynamic will be more fully explored in Section 4.2.1, Unhealthy Bone Remodeling.

3.2 The Foot - Muscle Function and Ideal Mechanical Physics During the Gait Cycle

3.2.1 Overview

The musculature of the foot is comprised of both extrinsic and intrinsic muscle groups. These muscle groups play varying and complementary roles relative to the alignment and stabilization of bone structure, in propulsion, in the management of forces during standing and gait, and in other non-gait related tasks, such as grasping, climbing trees, etc. As with any other muscles in the body, the muscles of the foot are influenced by both nociceptive and proprioceptive stimuli and can be positively or negatively conditioned by training or environmental influences. [5, 8, 9, 13, 33, 56, 57]

"... the high arch foot is a better shock abosrber with regards to the low back level than the low arch foot."

Ogon M, Alekesiev A, Pope M, Wimmer C, Saltzman C. Does Height Affect Impact Loading at the Lower Back in Running? Foot and Ankle International 20(4): p. 263, April 1999

As indicated earlier, ideally during natural healthy foot function, optimal musculoskeletal mechanics (alignment) is a dynamic response to activity levels and terrain. That is, the muscles of the foot act to optimally align the bones to most effectively manage the forces generated during varying activities and terrain. For example, while running, nociceptive and proprioceptive stimuli trigger reflex muscle activations to create a higher (mechanically stronger) and more stable arch system than when walking. Thus, the dynamic stable arch system provides a capable foundation for the lower limbs and body (kinetic chain) while promoting optimal musculoskeletal alignment/function and little or no degenerative stress throughout. {Please see Section 3.2.3 Neurologic Mechanisms (Somatosensory Feedback) for more information on nociceptive and proprioceptive mechanisims.}

An excellent example of conditioning potential can be found in individuals that have lost their arms, yet developed the dexterity of their feet to the extent that they function as "hands"—still capable of performing many complex tasks, all with a considerable degree of finesse and precision. Therefore, there is no reason that the muscles of the feet cannot be conditioned to achieve ideal, dynamic domed, structural alignment as described in the previous Section.

It would be virtually impossible to quantify the roll of specific muscles throughout such a multiplicity of activities. We can, however, examine the relative roles (primary and supporting) that muscles are ideally capable of performing throughout the gait cycle, from a mechanical perspective.

The extrinsic muscles of the foot are comprised of the extensors (originating in the lateral aspect of the shin), the flexors (originating in the posterior side of the lower leg)—both groups are connected to the foot via long tendons—and the ankle plantar flexors (i.e., the calf muscles). The intrinsic muscles of the foot (located primarily in the plantar region of the foot) are comprised of flexors, adductors, and abductors.

From an ideal mechanical perspective, the following muscles are grouped according to their gait-related roles:

- Alignment of the foot and ankle structure: -

- Stabilization of the foot and ankle structure: via active (re - foot), active (re - ankle), in concert with passive extrinsics - , and passive intrinsics -

- Stabilization of the foot and ankle structure:

, in addition to the

- Stabilization of the foot structure: via active Groups , , , and and active to passive and
- Propulsion: via active and active extrinsics - gastrocnemius and soleus. (See Figures 12 to15)

Fig re 1

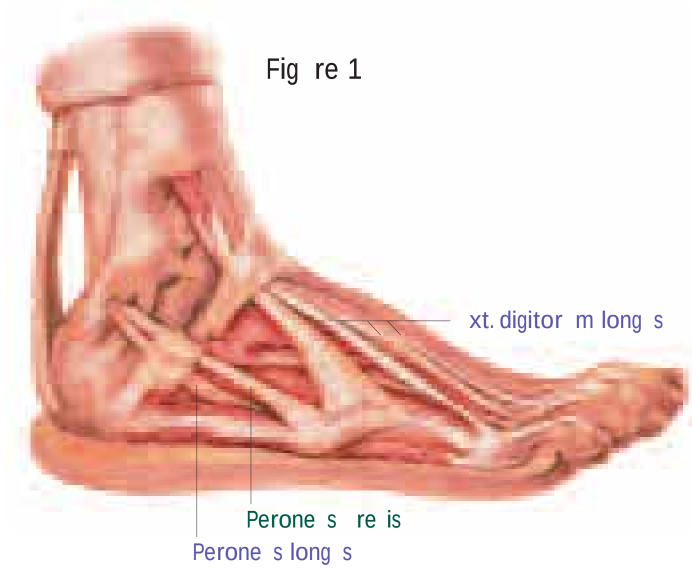


Fig re 13

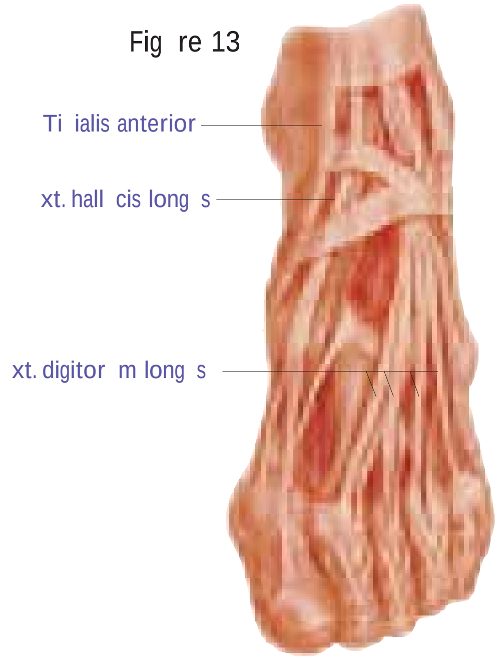


Fig re 14

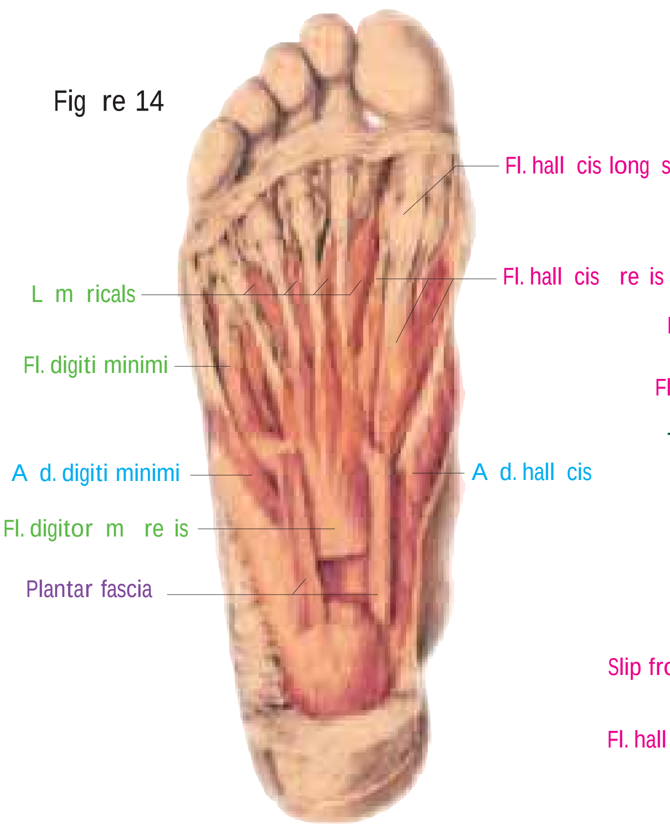
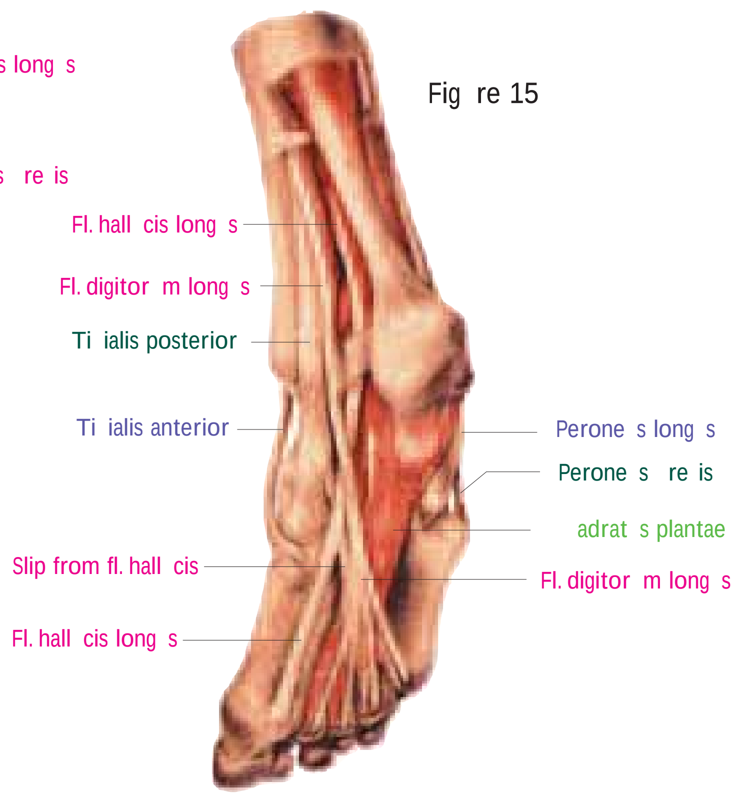


Fig re 15



If the foot's supporting musculature aligned and stabilized its interlocking bones into a functionally dynamic dome shape *prior* to weight bearing, the structure would be inherently strong and resilient. This would provide the most stable and stress free foundation for the rest of the body, requiring the lowest degree of muscular effort during the weight bearing and propulsion phases of gait. [19] This alignment and stabilization process is exhibited in barefoot gait, [14, 35, 58] and is easily achieved during the swing phase as the foot moves from the muscle-firing sequences of propulsion to the extensor muscle-firing sequences of dorsiflexion. (Figure 16)

Fig re 16

When examining the muscle-firing sequences of the lower leg extensors during the gait cycle, EMG analysis shows a co-contraction of the peroneus longus and tibialis anterior, prior to heel strike. [59, 60, 61] Coupling this information with their respective origins and insertions, these opposing contractions cause a transverse pulling or cinching action that essentially aligns the bones of the foot's mid tarsal region into a dome-like position with an ideal (maximum) transverse arch apex height. (Figure 17) This is further supported by the fact that the main actions of the tibialis anterior are dorsiflexion and inversion, while the main actions of the peroneus longus are dorsiflexion and eversion. [34, 35]

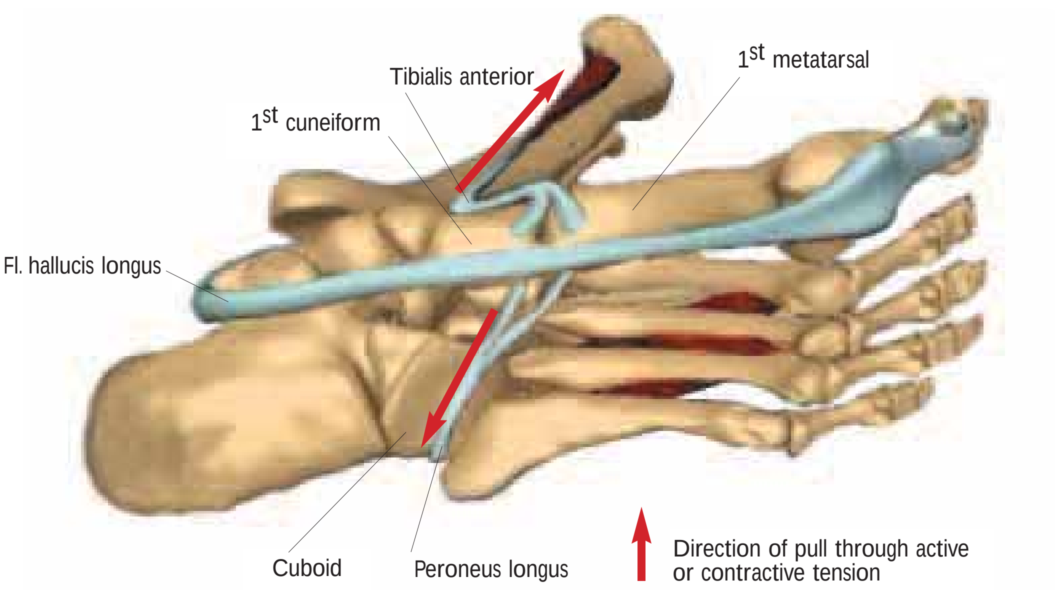


Fig re 1 Active or contractive tension on peroneus longus creates a pulley effect around the cuboid, cinching the 1st cuneiform and 1st metatarsal together.

Fig re 18

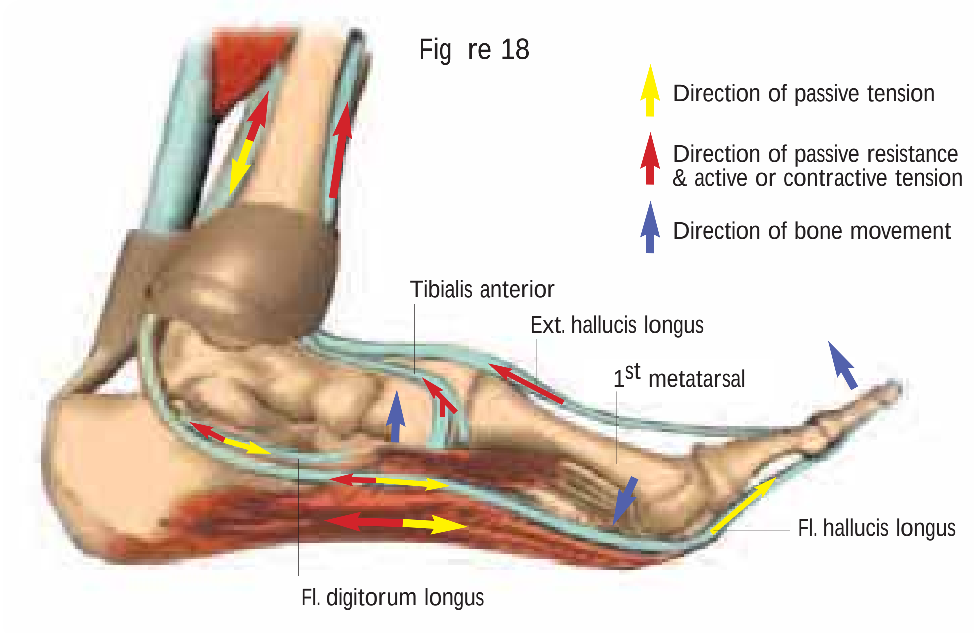
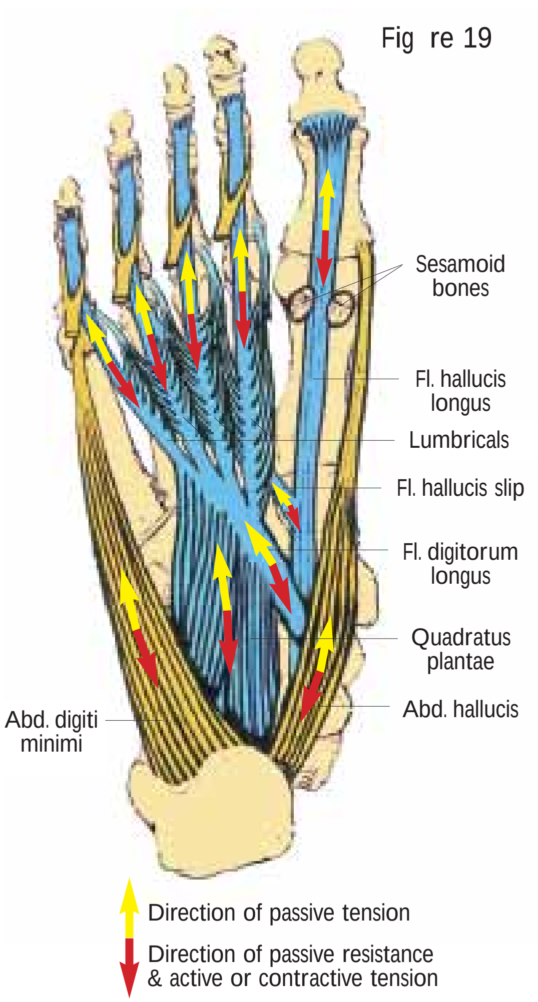


Fig re 19



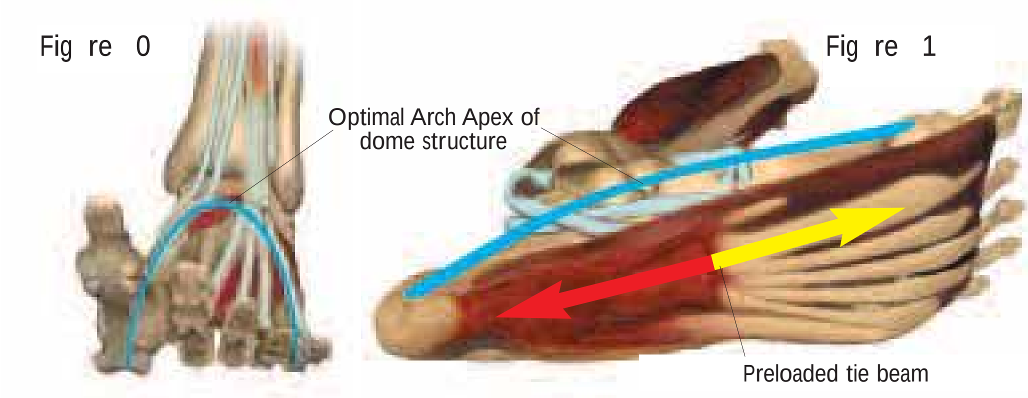
The cinching action of the peroneus longus tendon around the cuboid is essential to the control of the transverse arch's feature of stability with adaptability. This process, with the antagonistic activity of the tibialis anterior, establishes the 1st metatarsal/1st cuneiform joint, not only as the "conceptual" transverse arch keystone, but as the foundation of the entire kinetic chain, regardless of activity levels and terrain.

The function of the interosseous muscles (i.e., adduction of the 3rd to 5th toes toward the 2nd toe, and abduction of the 2nd to 4th toes) establishes the 2nd ray as the longitudinal axis of the foot's dome-like functional configuration.

Another important contribution to the dome-like alignment and ideal longitudinal arch apex in the pre-contact phase is contraction of the extensor hallucis longus; this results in the "Windlass Effect" (dorsiflexion of the great toe and plantarflexion of the first metatarsal). (Figure 18)[62, 63, 64, 65, 66] In addition, simultaneous contraction of the extensor digitorum longus causes dorsiflexion of the corresponding digits, and plantarflexion of the related metatarsals. The "Windlass Effect" is further enhanced, regarding the 2nd to 5th digits, by passive to active tension within the lumbricals which (via their dorsal insertion points) also contribute to dorsiflexion of the interphalangeal joints.

Fig re 0

Fig re 1



As the digits dorsiflex, the mechanical dynamic that causes plantar-flexion of the metatarsals corresponds to a passive tension or preloading of the following:

- the tendons of flexors hallucis longus (and slip) and digitorum longus, muscle body of quadratus plantae and the lumbricals —the second layer muscles (Figure 19)
- abductor hallucis, flexor digitorum brevis, and abductor digiti minimi—the intrinsic first layer muscles, and
- the plantar fascia.

The opposing active tension created between the extrinsic extensors and 1st & 2nd layer muscles cinches the interlocking bones into a dynamic dome-like structure that is capable of handling enormous force with minimal muscular contribution. (Figures 20 & 21) The pre-loaded intrinsic 1st & 2nd layer muscles and plantar fascia provide a resilient tie beam of optimal tensile strength. [65] (Figure 21)

Additionally, the great toe and the sesamoid bones play a significant role in this stabilization and locking process. [65] As the great toe dorsiflexes, the sesamoids

Fig re

"...sensory-induced behavior associated with the physical interaction of the plantar surface with the ground (in the unshod), or the footwear and underlying surface (in shod), is considered unimportant to the traditional thesis. This omission is astounding because logically, the plantar surface, being a highly sensitive layer, would produce significant sensations in either state, and it is common knowledge that noxious plantar skin sensation can easily induce avoidance behavior..."

Robbins SE, Hanna AM, Gouw GJ. Overload Protection: Avoidance Response to Heavy Plantar Surface Loading. Medicine and Science in Sports and Exercise 20(1): p. 85, February 1988.

move forward and up around the first metatarsal head, maximizing the tension on the flexor hallucis longus. (Figure 22) The synergistic effects of these dynamics are significantly greater than their individual additive benefits and create the structure's Ideal or Optimal Arch Apex—the arch system mechanics that are capable of effectively and efficiently managing the greatest loads with the lowest degree of unhealthy stress. The arch system's contribution to load management has been demonstrated mathematically in earlier work by Henning, et al. [67]

3.2.3 Neurologic Mechanisms (Somatosensory Feedback)

To appreciate the importance of somatosensory feedback in the creation of optimal function and allignment and in the prevention of injury, an understanding of the following neurophysiological concepts is required. (Figure 23)

Neurologically speaking the cortex decides what the body will do and the cerebellum decides how it will do it. In the absense of ascending sensory input (via external stimuli) the cerebellum becomes inefficient at influencing the cortical descending pathways.

Specifically, from a musculoskeletal perspective, nociceptive and proprioceptive stimuli play a central role in providing information input to the physiologic loop that controls and influences bodily movement. In addition, nociceptive and proprioceptive sensory receptors play an important role in the body's natural reflex response to protect it from harm {i.e., pulling your hand away when touching a hot object (Nociceptive Withdrawal Reflex) or reaching out with your hands and arms to catch yourself in a fall (Proprioceptive Reflex)}.

Nociceptive neuroreceptors are a peripheral nerve organ or mechanism for the reception and transmission of painful or injurious stimuli. Mechanical nociceptors (mechanoreceptors) respond to small discrete displacements, to directionally applied force (shearing), and to low intensity repetitive force (vibration). Mechanoreceptors have a relatively low threshold. Nociceptive sensory input activates reflex muscle activity relative to pain or excessive mechanical pressure caused by potentially damaging external stimulus. [14, 70]

Proprioceptive neuroreceptors are one of a variety of sensory end organs (such as the muscle spindle and Golgi tendon organ) in muscles, tendons, and joint capsules. Proprioceptive sensory input provides feedback solely on the status of the body internally (indicates whether the body is moving with required effort, as well as where the various parts of the body are located in relation to each other). Further, proprioception is a key component in muscle memory and hand-eye coordination and training can improve this sense. Proprioceptive muscle activity can be influenced by both nociceptive stimuli and the body's interaction with the three dimensional environment.

Proprioceptive learning allows us to master new skills or improve old ones.

Proprioceptive impairments can occur due to habituation, desensitization, or adaptation. This can occur when conscious proprioceptive sensory impressions disappear, just as a scent can disappear from awareness over time. One practical advantage of this is that unnoticed actions or sensations are still functionally active in the background while individual moves on to other concerns. However, external environmental influences that inhibit sensory input or impair musculoskeletal movement can, over time, result in the desensitization, adaptation and habituation of poor proprioceptive function which continues without conscious awareness.

Proprioceptive sense can be sharpened by removing the external environmental influences that inhibit sensory input or impair musculoskeletal movement, and by introducing activities that sharpen and condition, it is possible to train optimal musculskeletal function. In sports this is often called training with "Proper Technique."

Musculoskeletal Feedback Loop

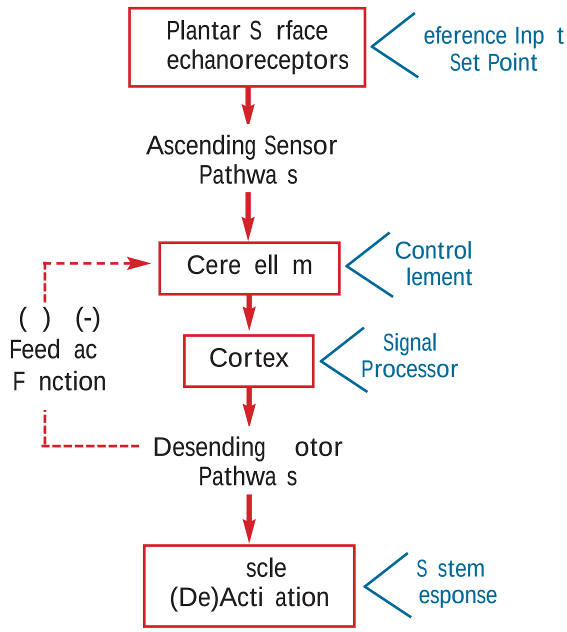


Fig re 3

Training with "poor technique" conditions inefficient musculoskeletal mechanics (poor structural alignment and unbalanced muscle use). Inefficient mechanics increases both degenerative stresses and the risk of injury.

On the other hand, "Proper Technique," conditions efficient musculoskeletal mechanics (optimal structural alignment and balanced muscle use). Efficient mechanics increases the healthy stresses that safely strengthen the structure, significantly decreases or eliminates degenerative stress, reduces the risk of injury, and enhances performance capabilities.

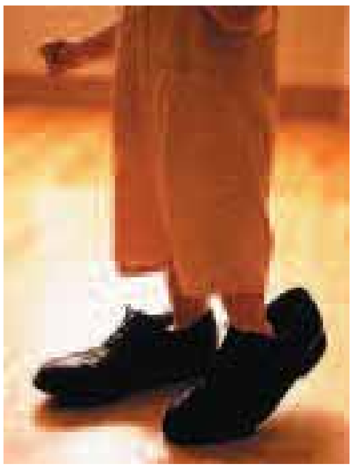
The plantar and palmar epithelia share the unique characteristic of an extremely high density of nociceptors/mechanoreceptors. The plantar surface of the foot is highly sensitive and it is common knowledge that noxious plantar skin sensation contributes to intrinsic foot muscular activation. [9, 68] One common example of a nociceptive reflex mechanism is the involuntary muscular response known as the Babinski Reflex. Research data supports the notion that somatosensory plantar feedback plays a central role in safe and effective locomotion and has demonstrated a relationship between increased arch height and barefoot activity; the greatest increases were found in subjects who performed barefoot activities outdoors. [13, 69]

From a mechanical perspective, increased arch height can only be achieved by the muscle-firing sequences described earlier or by contractions of the foot's intrinsic first layer musculature, which is accompanied by curling of the toes. However, the latter provides no benefit during the gait cycle (prior to, or at weight bearing) since

"The barefoot walker receives a continuous stream of information about the ground and about his relationship to it, while a shod foot sleeps inside an unchanging environment. Sensations that are not listened to become decayed and atrophy."

Platte B. San Francisco Chronicle Interview with Dr. P.W. Brand. Medical Research. www.unshod.org/pfbc/pfmedresearch.html: 1976 the resulting structural alignment effectively prohibits natural gait. It is logical to assume that the foot's nociceptive/proprioceptive feedback mechanisms play an integral role (as a protective reflex catalyst) in stimulating the necessary muscle-firing sequences that contribute to the foot's ideal structural mechanics, prior to heel strike. [9, 13]

Therefore, the digits' degree of dorsiflexion and resulting variable (dynamic) Optimal Arch Apex are precipitated by the body's natural nociceptive/proprioceptive response to terrain and activity levels.The greater the demands, the greater the dorsiflexion, and the higher the arch apex must rise to effectively manage the increased loads.



"...the arch develops during the first decade of life..."

"... shoes increase the frequency of flat feet (studies from India suggest that shoes actually cause flat feet)..."

Dr. James G. Wright, Assistant Professor, Department of Surgery, University of Toronto Faculty. The Hospital for Sick Children. Foot and Ankle Symposium Co-sponsored by the Canadian Orthopaedic Association and the Department of Surgery, Orthopaedic Division University of Toronto, held at Sunnybrook Hospital, April 1996

The fine motor control, of which the opposing, intrinsic muscle groups (i.e., the abductors vs the adductors, in harmony with the flexors vs the extrinsic extensors) are capable, during active gait, confers the following features to the foot's dynamic dome-like alignment:

1. adaptable relative rigidity
2. adaptable distal transverse arch width
3. adaptable ground contact angles of the 2nd to 5th metatarsal heads and thus
4. the ability to "fine tune" the dome's size and postion, which ensures optimal shock management and the most ideal propulsion leverage through the first ray.

All of these features are reflexively maintained in response to nociceptive and proprioceptive stimuli to both protect from, and react to, the environment and the loads generated (i.e., varying terrain and activity demands), while optimizing propulsion.

Ideal propulsion, from the weight-bearing phase to the toe-off phase of gait requires :

1. a rigid (1st class) lever (i.e., the 1st ray)
2. the vector of force for foot plantar flexion to fall perpendicular to the point of ground contact (the 1st metatarsal head).

Optimal mechanics suggests that a rigid propulsive lever is created and maintained by:

- the Windlass Effect concurrant with the cinched up mid-tarsal region (with both of these actions created by the proprioceptive reflex catalyst), while
- the perpendicular vector of the plantar flexion force is provided by the adaptive, fine motor control of the intrinisc foot muscles, after an antagonistic balance has been achieved between the flexor hallucis longus and the extensor hallucis longus muscles.

This biomechanical efficiency decreases the incidence of stress and fatigue-related injuries at the muscle, tendon, and ligament junctions throughout the kinetic chain.

3.2.4 Schematic Model of Ideal, Dome-like Foot Function in Gait

The human foot, in a gross generalization, is capable of two categories of function:

1. gait-related and
2. non gait-related.

The second category includes activities such as tree climbing, swimming, and acting as ersatz hands for individuals who lack hands. It is primarily the adaptability of the instrinsic muscles that convey such versatility.

Alternatively, during gait-related activity, the foot must serve the seemingly disparate functions of propulsion (requiring rigidity), and balance (requiring supple adaptablility). The features of foot function, as discussed in previous sections, indicate that this apparent contradiction is not only present but elegantly utilized within the unshod population. This capacity is essentially “switched-on” via somatosensory stimuli received by the plantar surface mechanoreceptors. The following is a schematic model of ideal foot funciton (as deduced from the information thus far presented) that accomplishes these roles. (Figure 24)

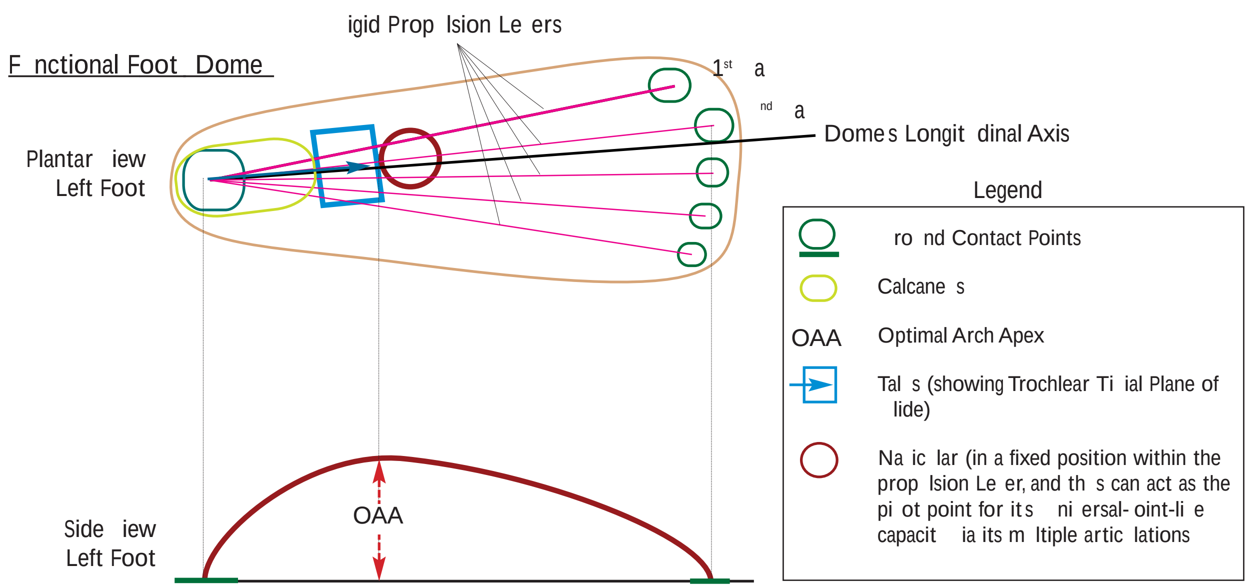


Fig re 4

The following table delineates the specific role(s) played by each component of the foot in the creation of the above model.

PA T	OL
CALCAN S	1. Weight-bearing ground contact at heel strike; 2. Posterior end of rigid propulsion lever; 3. Posterior end of dome-like, functional configuration; 4. Posterior sulcus acts as pulley for FHL tendon which establishes the line of pull for the FHL which establishes the longitudinal axis of the propulsion lever; 5. Articulates with talus in lever formation; 6. Articulates with cuboid for mid-foot cinching; 7. Round inferior surface for efficient ground contact adaptability.

PA T	OL
TAL S	1. Articulate with calcaneus + navicular in rigid lever formation; 2. Articulates with cuboid for mid-foot cinching; 3. Controls plane of tibial glide over the trochlea – creating the ideal axis for the rigid propulsion lever.
NA IC LA	1. Keystone of longitudinal arch/point of Optimal Arch Apex; 2. Articulates with talus and 1st cuneiform in rigid lever formation; 3. Articulates with 2nd + 3rd cuneiforms and cuboid to enable ground contact + activity level adaptability.
1ST C N IFO	1. Articulates with navicular + 1st metatarsal in rigid lever formation; 2. Acts as the base of the kinetic chain via insertions of tib. ant. + per long and thus is part of the keystone of the transverse arch.
1ST TATA SAL	1. Articulates with navicular + 1st phalange in rigid lever formation; 2. Acts as the base of the kinetic chain via insertions of tib. ant. + per long and thus, is part of the keystone of the transverse arch; 3. Plantarflexes in creation of the windlass effect; 4. Primary weight-bearing ground contact for propulsion at the anterior end of rigid propulsion lever; 5. Antero-medial end of dome-like, functional configuration.
S SA OIDS	1. Increases leverage of flexor hallucis longus 2. Lock 1st phalange in dorsiflexion to maintain the windlass effect throughout weight-bearing.
ND C N IFO	1. Articulates with navicular, 1st cuneiform, 3rd cuneiform and 2nd metatarsal to enable ground contact + activity level adaptability.
3 D C N IFO	1. Articulates with navicular, 2nd cuneiform, 3rd metatarsal and cuboid to enable ground contact + activity level adaptability.
ND 5T TATA SALS	1. All articulations, at their bases, enable ground contact + activity level adaptability; 2. Secondary weight-bearing ground contact at their heads contributes to balance and adaptability; 3. They plantarflex in the Windlass Effect, and are secondary propulsion levers; 4. Anterior end of dome-like configuration.

PA T	OL
P ALAN S	1. Articulate with heads of metatarsals and are dorsiflexed to create the windlass effect; 2. Can plantarflex to aid propulsion and/or ground adaptability.
FL O ALL CIS LON S	1. Its tendon pathway around the posterior calcaneal sulcus + its plantar insertion at the 1st metatarsal head indicate the ideal axis for the rigid propulsion lever; 2. Its active-passive tension, in opposition to, but "in line" with the extensor hallucis longus activity, creates the 1st ray windlass effect.
T IO ALL CIS LON S	1. Creates the 1st ray windlass effect via antagonistic balance with tension of flexor hallucis longus; 2. Creates the rigidity of the propulsion lever; 3. Its action shifts the sesamoids into their "locked" position, ensuring lever rigidity.
TIBIALIS ANT IO	1. Cinches the mid-tarsal region into an Optimal Arch Apex, in conjunction with the peroneus longus; 2. Secondarily, the cinching effect adds rigidity to the propulsion lever; 3. Its activity establishes the base of the kinetic chain, with the per. long.
P ON S LON S	1. Cinches the mid-tarsal region into an Optimal Arch Apex, in conjunction with the tibialis anterior; 2. Secondarily, the cinching effect adds rigidity to the propulsive lever; 3. Its activity establishes the base of the kinetic chain, with the tib. ant.
INT INSIC FOOT SCL S	1. Create adaptable relative rigidity of foot; 2. Create adaptable distal transverse arch width; 3. Create adaptable ground contact angles of 2nd – 5th metatarsal heads; 4. Create the ability to "fine tune" the dome's size and position, which ensures the most ideal propulsion leverage through the 1st ray.

3.2.5 Ideal Gait Mechanics

As already described, natural healthy foot function and ideal gait mechanics should demonstrate optimal musculoskeletal mechanics (alignment) throughout the kinetic chain as a dynamic response to activity levels and terrain. That is:

- nociceptive reflex activations of the foot and ankle related muscles,
- proprioceptive reflex activations in the muscles throughout the kinetic chain,

together, optimally align the bones to most effectively manage the forces generated during varying activities and terrain—while promoting optimal musculoskeletal alignment/function and little or no degenerative stress. Nociceptive and propriocaptive sensory stimuli of the first step, and/or optimal proprioceptive conditioning, triggers a protective reflex response during the swing phase of gait prior to the second step ground contact. This continuous, step by step, nociceptive/proprioceptive reflex activity results in the preground contact cinching of the foot and ankle's interlocking bones to:

1. form a strong yet adaptable dome-like shape in the foot (i.e., Optimal Arch Apex)
2. lock the foot and ankle to inhibit eversion or inversion at ground contact (i.e., stabilize the subtalar joint for optimal mechanical positioning of the knee in line with the Arch Apex).

The reflexive preground contact musculoskeletal cinching is a dynamic response to activity levels and terrain. Functioning in this ideal manner, the foot's musculoskeletal structure is capable of providing optimal structural integrity, alignment, and shock management throughout multi-directional ground contact, weight-bearing, and toe off, while forming a spring-loaded rigid lever when in the propulsion mode.

When the ankle is locked against eversion and inversion at heel contact, the roundness of the heel initiates a smooth, stress-free transition, naturally aligning the forefoot to the ground. This is consistent in multi-directional activity through varying angles of impact. The pivot point for this movement is located in the calcaneus' mass, centered at the radius of the curve created by the fleshy surface of the heel. (Figures 25 & 26)

Fig re 5

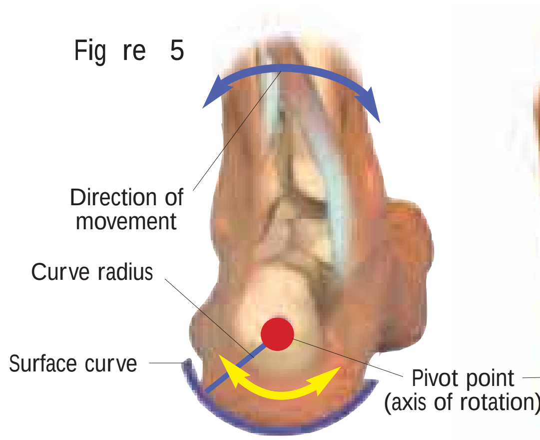
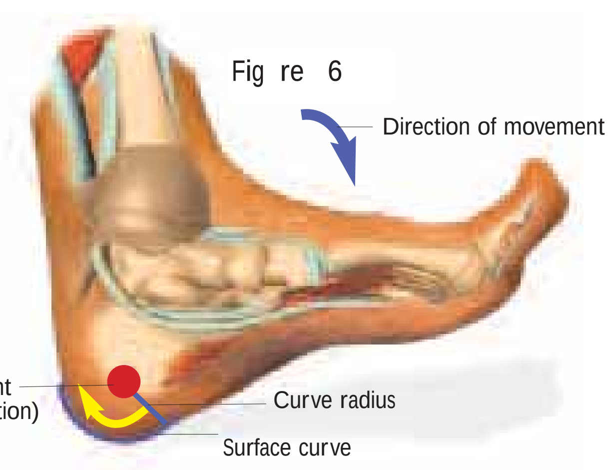


Fig re 6



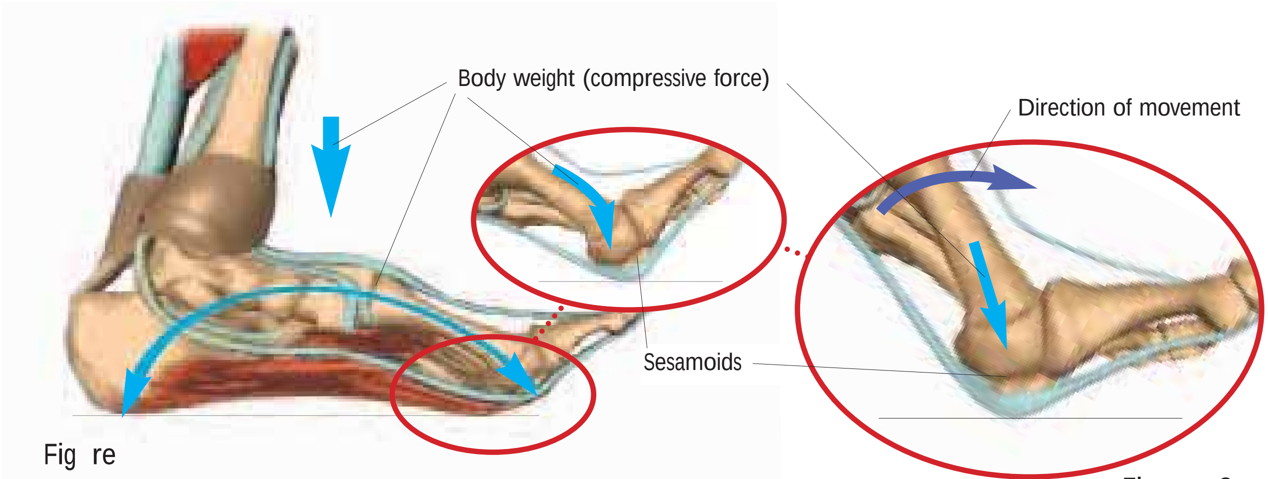


Fig re

Fig re 8

Once the forefoot contacts the ground, the compressive force created by the body's weight restricts the sesamoids from moving backward, effectively locking the structure into a functional dome shape. (Figure 27)

As the foot moves into the propulsion phase of gait and the extensors ease their contractions, the "locked" sesamoids ensure that the structure maintains this most stable position (i.e., rigid lever). (Figure 28)

Sub-talar neutral (the mechanical relationship between the talas and navicular) is often thought of as the "key" to "proper" structural alignment in the foot. Contrary to the conventional view, this mechanical relationship is dynamic in nature rather than static. That is, the relative positioning of the "subtalar joint" is determined by the nociceptive and proprioceptive reflex muscle activations (or lack thereof) in response to activity levels and terrain.

While the extrinsic musculature of the foot plays the predominant role in the alignment and maintenance of the arch system's optimal structural integrity, the intrinsic musculature of the foot plays only a minimal role, therefore, they are used more effectively in the fine-tuning of balance and ground interface interaction.

Functioning as described, the optimal structural integrity of the foot's domed arch system is maintained throughout the weight bearing and propulsion phases of a wide range of three-dimensional movements, facilitating superior natural shock management throughout.

When the interlocking bones of the feet are optimally aligned and stabilized, the longitudinal axis of the rigid first ray propulsion lever parallels the tibia/trochlea axis of glide, thus ensuring a torsion free, strictly frontal plane of knee motion (thus fulfulling the ideal as set out in Figure 1). Just as significantly, this ideal alignment is

"The non-neutral foot allows for instability, and the muscles work out of phase and inefficiently to maintain balance ."

Subotnick SI. The Flat Foot. The Physician and Sports Medicine 9(78): p. 85, August 1981

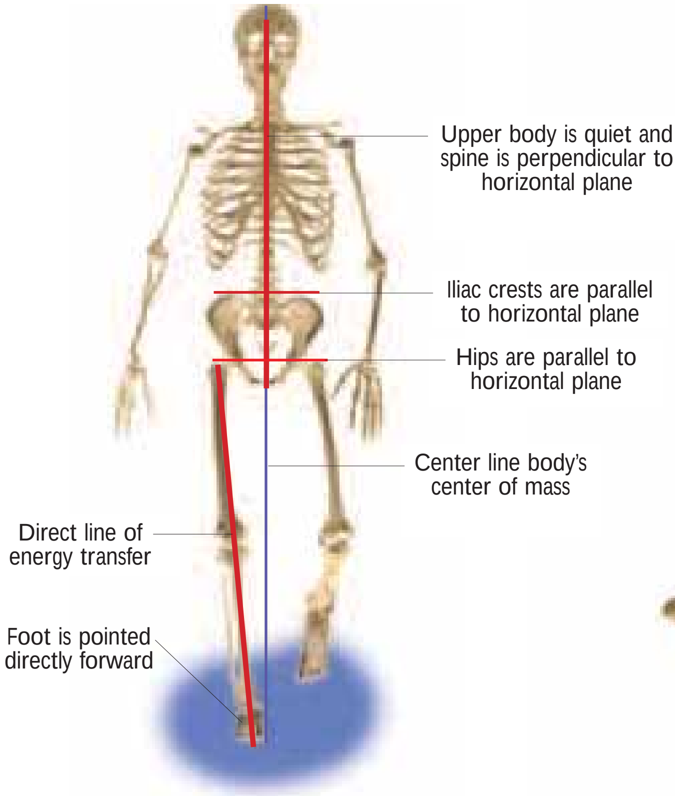


Fig re 9

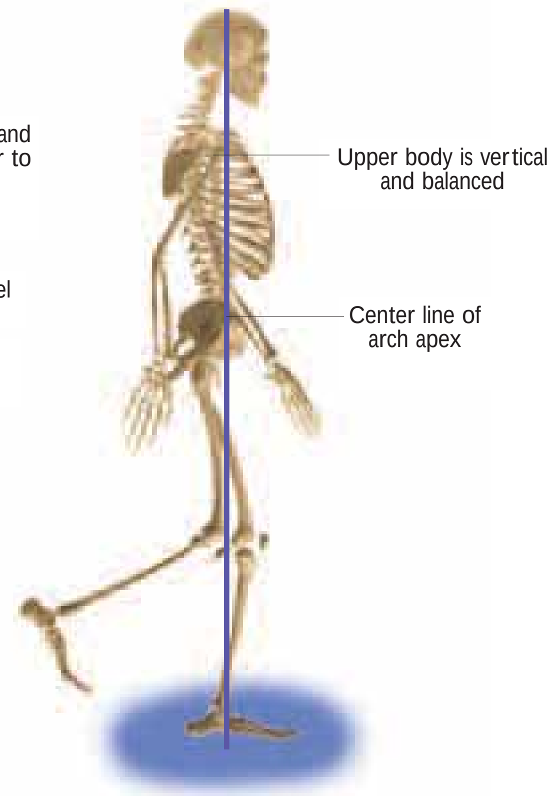


Fig re 30

capable of being maintained regardless of terrain or activitiy levels via the round nature of the inferior calcaneus surface and the adaptable nature of the instrinsic foot musculature. The feet thus provide an extremely effective, stress-free platform for the rest of the body. Consequently, the entire kinetic chain's musculoskeletal structure demonstrates:

- optimal energy efficiency,
- a greater capacity to safely manage increased activity levels,
- little or no degenerative stress, and
- a significantly reduced propensity to injury.

Ideally, the consequence of a stable arch is that the foot points directly forward through weight bearing and there is a direct line of force through the arch apex, the center of the knee, and at a midpoint between the greater trochanter and lesser trochanter of the femur. (Figure 29) The hips and iliac crests are parallel and the spine is perpendicular to a horizontal plane. Viewed from the side, the upper body remains balanced and vertical as the body's center of mass moves over the arch apex. (Figure 30)

4.0 Footwear's Relationship to Lower Limb Biomechanics and Resulting Pathologies

It is commonly accepted that poor foot biomechanics play a significant role in the development of pathologies such as metatarsalgia, plantar fasciitis, hallux valgus, heel spurs, neuromas, Achilles tendonitis, shin splints, patello-femoral problems, hip and back pain, etc. It is often argued that genetics play a leading role in dysfunctional foot biomechanics, yet little science exists to support this hypothesis. There is, however, an abundance of scientific evidence that points to "footwear" as the leading cause of foot dysfunction and the majority of associated foot-related pathologies. [13, 14, 58, 71, 72, 73, 74, 75, 76, 77, 78]

It is more likely that foot pathology trends in families are the result of footwear buying patterns, as opposed to genetic predisposition. From an early age, children's footwear is selected by parents whose own choices closely reflect their socio-economic values. Considering the rate (and amount) of bone development throughout childhood, along with the bone remodeling principles previously identified, it would seem obvious that footwear environments would impact significantly on structural development. An abundance of research indicates that children's feet are negatively affected by footwear by the age of six, and that optimum foot development occurs in the barefoot environment. [72, 74]

Furthermore, studies on predominantly shod populations presenting some type of pathology have demonstrated a reversal of symptoms through increased barefoot activity. [11, 76] It has also been widely reported that predominantly unshod populations develop a paradoxically low incidence of foot-related problems, and that there is a direct relationship between related pathologies proportionate to footwear use, to a level equal to habitually shod populations. [10, 11, 12, 17, 80]

Most conventional footwear designs affect the feet much like a cast or splint would affect an arm or leg. Specifically, the chronic restrictions imposed by footwear account for muscle atrophy, loss of bone mass, less than ideal bone geometry (through remodeling) and joint stiffness. Wearing shoes can actually weaken the feet and legs, increasing their susceptibility to injury. [9, 13, 14, 17, 35, 71, 81, 82]

Shoes both dampen nociceptive stimuli and impair optimal proprioceptive muscle activity by inhibiting/restricting the foot's natural musculoskeletal mechanics, effectively destabilizing (impairing) its dynamic load-bearing and propulsion capabilities [i.e., the foot's dynamic mechanical (alignment) capabilities are impaired]. This instability (impaired dynamic structural alignment) results in degenerative stresses in the muscles and at joints that cause or contribute to various "arthritic-like" problems (pathologies) in the feet, legs, hips, and back.

Aside from improper sizing, the numerous footwear design characteristics (Figures 31 & 32) and their contribution to poor foot function are:

◆ CA S rigid soles • cushioning properties (underfoot) • arch supports

FF CT inhibits the sensory stimulus (on the sole of the foot) needed to trigger the proper muscle function required to align the bones for optimal stability. Both nociceptive and proprioceptive reflex musculoskeletal activity are inhibited.

◆ CA S restrictive toe box height/width and/or rigid soles that prevent dorsiflexion of great toe • restrictions over arch area (by design or via tight lacing) that prevent optimal arch apex height • narrow width through metatarsal area

FF CT act like a brace on the feet by restricting the natural dynamic nature of the foot (i.e., full foot flexion involving the natural raising of the arch and dorsiflexion of the toes) that is necessary to effectively manage varying loads (impact stresses), and terrain changes. Rigid soles inhibit natural walking and running dynamics and increase the forces the foot must manage. Shallow rigid toe boxes restrict the natural toe movement required to form a strong stable arch. Tight lacing inhibits the natural raising of the arch in response to increased loads, causing the foot to flatten (promoting inefficient bone alignment and structural instability), which weakens the restricted muscles and causes others to fatigue from overwork. Enclosed footwear with rigid soles and tight lacing will condition "poor" proprioceptive reflex muscle activity.

◆ CA S wide or flared heels or mid-soles • rigid soles or mid-soles • stiff uppers

FF CT increases lever arm mechanics and accelerate forces during gait—premature plantar flexion and excessive pronation

◆ CA S increased heel height

FF CT inhibits balanced stance and equal distribution of weight during walking or standing—poor structural alignment through feet and entire kinetic chain

Fig re 31

Fig re 3

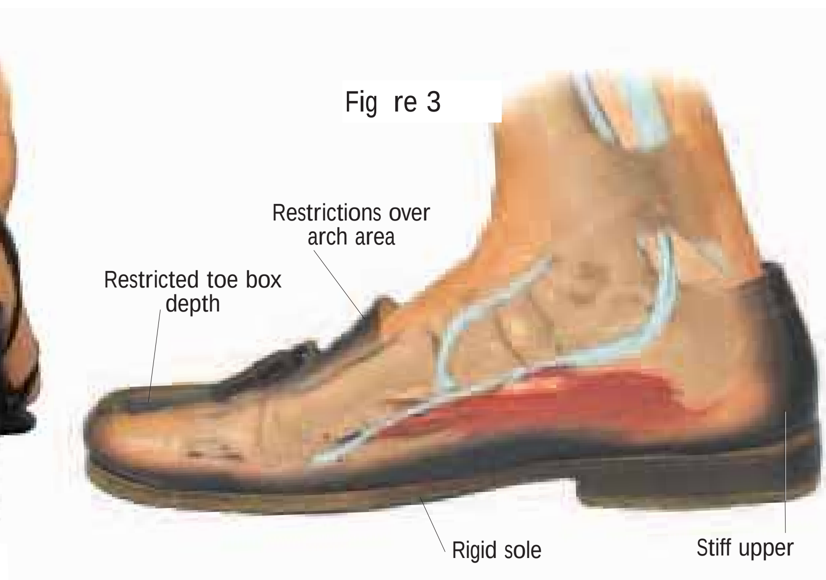


Fig re 33

Each of these design characteristics impose singular negative effects on foot function; in combination, their negative effects are magnified significantly. It is apparent that the majority of footwear on the market today features a number of these characteristics, many of which are ironically promoted as beneficial for the user. In all instances, damaging degenerative stresses increase relative to the amount of cushioning, support, and restrictiveness of the footwear.

4.1 Lack of Nociceptive and Proprioceptive Sensory Feedback

A shoe that is rigid and supportive or one that features abundant cushioning (Figures 31, 32, & 33) greatly diminishes the sensory feedback required for optimal "natural" nociceptive and proprioceptive reflex muscle-firing sequences that stabilize the arch. [82] According to Robbins, "Wearers of expensive running shoes that are promoted as having additional features that protect (e.g., more cushioning, 'pronation correction,' etc.), are injured significantly more frequently than runners employing inexpensive shoes." [80]

Footwear in general, specifically the modern running shoe, substantially diminishes sensory feedback but does not diminish injury-inducing impact—a dangerous situation. [11, 55, 65, 68]

Supportive cushioning features are widely promoted to be essential for safety when walking or running in order to mitigate chronic overload on the lower extremities, due to modern man's purported inherent fragility. However, this supposition is inconsistent with reports that indicate habitually unshod humans are not subject to chronic overloading when running and are virtually free of foot-related pathologies. [9,10,11] Considerable research indicates that the lower extremities of predominantly barefoot populations are inherently durable and that chronic overloading is a consequence of wearing footwear. [9,10, 65, 66, 80, 81]

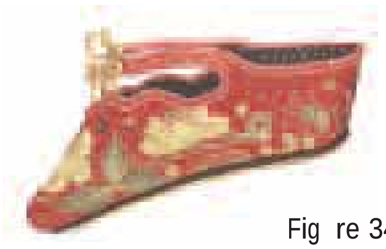


Fig re 34

Fig re 35

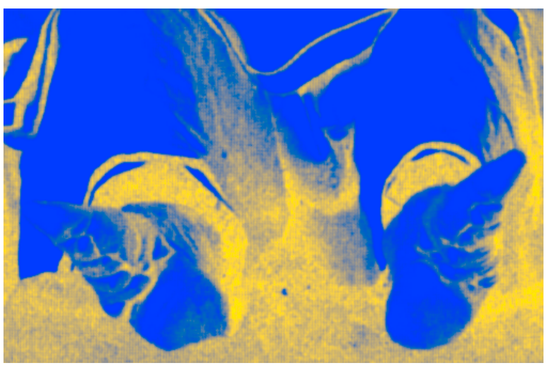


Fig re 36

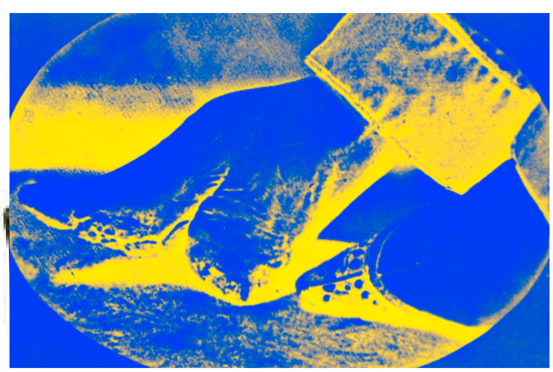


Fig re 3

Over time, the impaired propriocetive muscle activity becomes "static" as it is conditioned or trained via desensitization, habituation, and adaptation therefore the body is no longer capable of effectively responding to the ever changing environment. In other words, the unhealthy degenerative stress generating proprioceptive muscle function becomes a conditioned response (i.e., the dys-"functional" norm). The degenerative stresses cause or contribute to the majority of foot-related pathologies. Common symptoms include pain, stiffness, and swelling in joints and other supporting structures of the body such as muscles, tendons, ligaments, and bones, along with muscle atrophy (underuse), muscle hypertropathy (overuse), tissue damage, fibrosis/scar tissue, and loss of bone density. This dysfunctional norm can only be reversed through rehabilitative therapies (conditioning) that retrain the optimal proprioceptive muscle activity.

"Technique" training is proprioceptive training and this conditioning concept is the foundation of most modern sport training. That is, "Proper Technique" is fundamental for conditioning optimal musculoskeletal function. It promotes little or no degenerative stress, reduces risk of injury, and enhances performance capabilities. "Poor Technique, on the other hand, conditions less than optimal musculoskeletal function, increases degenerative stress, increases risk of injury, and hampers performance capabilities.

Studies on barefoot populations indicate that the intrinsic properties of a biomechanically sound foot, unfettered by the constrictions of footwear, can effectively manage the forces and stresses generated during the most rigorous activities on the hardest surfaces. [9, 11, 14, 68] Man-made cushioning and motion control designs pale in comparison.

4.2 Restrictions in Structural Alignment

Footwear for women that features narrow pointed toe boxes and high heels has generated ample criticism from foot care professionals. It is commonly understood that improper footwear (by design or size) contributes to a host of foot pathologies, yet opinions are conflicting about what constitutes appropriate footwear and the effect it actually has on the foot's structure and the dynamics of gait. [83]

4.2.1 Unhealthy Bone Remodeling

The ancient Chinese custom of foot binding and the use of Lotus shoes (Figure 34) is an excellent example of how negative environmental influences can restructure the foot. Chinese foot-binding spanned over a thousand years—approximately a billion women endured this extremely painful process. It was banned in 1911, yet continued until the New China was founded in 1949. This wide-spread practice has caused severe life-long disability for millions of elderly women. [84]

Fig re 38

In early childhood, a girl's feet were bound with meters of cloth to inhibit growth so that they would resemble the most desired "three inch golden lotus"—a size no larger than 10 centimeters, or 3.9 inches. [85] (Figure 35) The practice would cause the soles of their feet to bend in extreme concavity. (Figures 36 & 37)

Fig re 39

A bandage, ten feet long and two inches wide, was wrapped tightly around each foot, forcing the four small toes under the soles. This made the feet narrower and at the same time shortened them because it forced the big toe and the heel closer together, bowing the arches. The bandages were tightened each day and the girl's feet were put into progressively smaller and smaller sized shoes. (Figure 34) The entire process usually took about two years, at the end of which, the feet were rendered essentially "dead" and utterly useless.

Fig re 40

As the practice waned, some girls' feet were released soon after their initial binding, leaving less severe deformities. However, the legacy of foot binding is that the deformities linger on as a common cause of disability in elderly Chinese women. [84, 86]

Similar deformities are also common in today's modern society. (Figures 38, 39 & 40) The environmental influences of the toe box design characteristics clearly demonstrate the negative physiological impact of restrictive footwear. (Figure 38) Not only does footwear impede healthy optimal muscle function; it actually contributes to unhealthy bone remodeling. [87, 88] (Figure 40)

As implied by Wolfe's Law, bone is living tissue and is consistently undergoing cellular regeneration and, as such, possesses the ability to change and adapt. [44, 89, 90] In fact, bone constantly changes in response to many varied influences; some of which are mechanical, others are hormonal, some are genetic, etc. [3, 38, 43, 44, 49, 89, 90, 91]

Casting an arm or leg ensures that the bones are "at rest" and protected from mechanical stresses. In the absence of normal "healthy" stress, even normal bones remodel, becoming weaker (exhibiting reduced bone mass). [49, 91] Immediately upon removal of the cast, the weakened bones are more prone to fracture but will respond to the resumption of moderate "healthy" mechanical stress by reversing the process—building greater density and strength.

Even though bone is in a constant state of change, it requires time to adapt to environmental influences. With increased activity and exercise, bones hypertrophy (become thicker and stronger) to more effectively manage new levels of stress without the risk of fracturing. [3, 43, 45, 50, 89, 92]

There is an optimum range of "healthy" stress for maximum strength—when understressed or overstressed, bone can actually weaken. Stress is generated through repetitive or constant tension and/or pressure and may exert a healthy or unhealthy "degenerative" influence depending on the mechanical action it generates, coupled with the inherent characteristics of the bone.

For example, unhealthy repetitive stress can be demonstrated in the formation of heel spurs at the insertion of the plantar fascia to the calcaneus. In this case, the bone remodels toward the source of repetitive tension as a means of mitigating the stress. (Figure 39) Bunions and "pump bumps" provide similar examples of how unhealthy repetitive stress affects bone. (Figure 40) Healthy repetitive stress that is generated through moderate exercise, such as running or lifting weights, helps build and maintain bone density.

It is clear that mechanical factors are the one constant in this remodeling process and act on bone in concert with hormonal, metabolic, and genetic influences. Therefore, understanding musculoskeletal mechanical physics and its effects on the skeletal structure's remodeling process is essential to understanding the cause of related pathologies and their prevention and treatment.

These concepts, while relatively new to foot care, are widely accepted in other medical disciplines and are regularly integrated into treatment methodologies. For example, orthodontists use braces on individuals of all ages to remodel the bone anchoring the teeth (alveolus socket in the alveolar process). Constant pressure is exerted on the bone through the roots of the braced teeth by rubber bands connected to the braces. These mechanics cause the teeth to act as lever arms, with the bone remodeling *away* from the constant pressure. Once the braces have been removed, the new alignment is maintained through a diversity of forces (healthy stresses generated through chewing) that sustain the integrity and density of the bone. Failure to maintain this healthy stress can result in loss of bone mass and a subsequent loosening of the teeth, as witnessed in those who are unable to chew solid food.

"The inescapable conclusion is that footwear use is ultimately responsible for ankle injury."

Robbins SE, Waked E, Rappel R. Taping Improves Proprioception Before and After Exercise in Young Men. British Journal of Sports Medicine 29(4): p. 242,1995

These dynamics (the alveolus' remodeling in reaction to braces) are demonstrated in bone throughout the body as it responds to the forces exerted by muscle tension and the related mechanics of structural alignment.

A Stanford University study examined how loads applied to the calcaneus influence the bony architecture. [67] The study's findings suggest that there is a strong relationship between bone structure and loading history. Mechanically favourable bone remodeling has also been documented on other areas of the body, [38, 93, 94, 95] with demonstrated changes in bone shape geometry at bone-to-bone contact.

4.2.2 Unhealthy Musculoskeletal Mechanics

The most damaging footwear design characteristics are those that prevent structural integrity of the domed arch dynamic and, those that increase the forces and stresses on the musculoskeletal structure.

In additon to dampening sensory feedback, rigid soles and restrictive toe box areas exert the most damaging influence by inhibiting dorsiflexion of the toes, which is necessary for alignment and stabilization of the strong, functional dome-like dynamic of the interlocking bones in the foot and ankle. Chronic interruption of this dome-like dynamic can actually condition improper muscle-firing sequences and result in either compensatory overuse or a failure to fire at all. The dynamic is further hampered by restrictions over the arch area that prevent the formation of the optimal arch apex, which is necessary for efficiently managing specific loads. These restrictions may be inherent to the footwear design, and may result from improper shoe size or from overtight lacing. These dampening and restrictive influences negatively impact all types of developed foot function, however in slightly differet ways.

A rigid high arch is structurally capable of managing greater loads initially, but without appropriate muscular activity to maintain the arch systems' domed integrity the arch system suddenly fails mechanically when loads exceed the structural capacity. This results in more "acute-like" degenerative stresses and a diminished capacity to effectively manage "shock."

A hypermobile or flat foot is structurally capable of managing lesser loads. In both instances, the load bearing capacity is notably diminished without appropriate muscular activity to maintain the arch systems' domed integrity. A functional arch system is either not present (flat) or fails immedialtely (hypermobile) upon forefoot/ground contact and results in more "chronic-like" degenerative stresses and compensatory muscle imbalances throughout the closed kinetic chain.

X-rays graphically illustrate the limitations of structural alignment between the fully mobile unshod foot (Figure 41) and the restricted shod foot (Figure 42) during full weight bearing. The x-rays are of the same subject, taken approximately 10 minutes apart.

Fig re 41

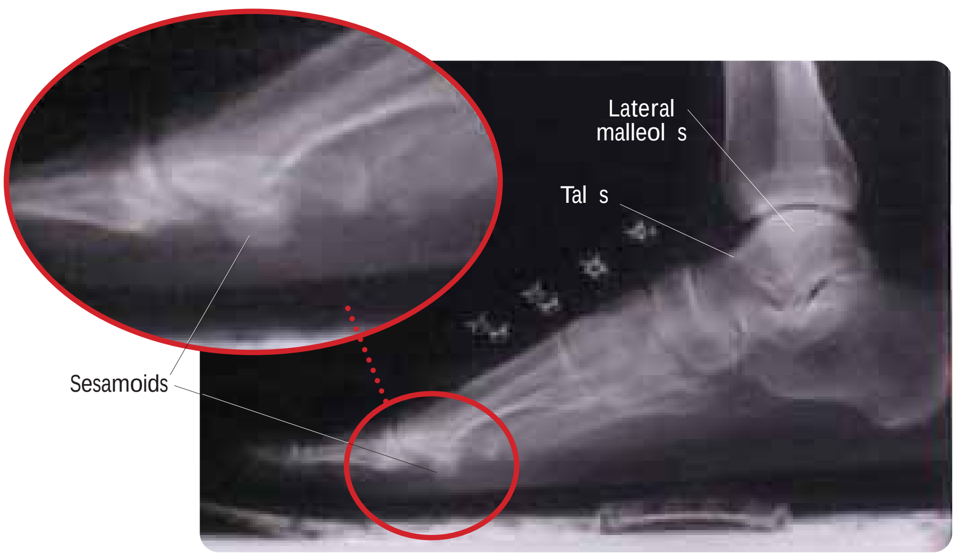


Fig re 4

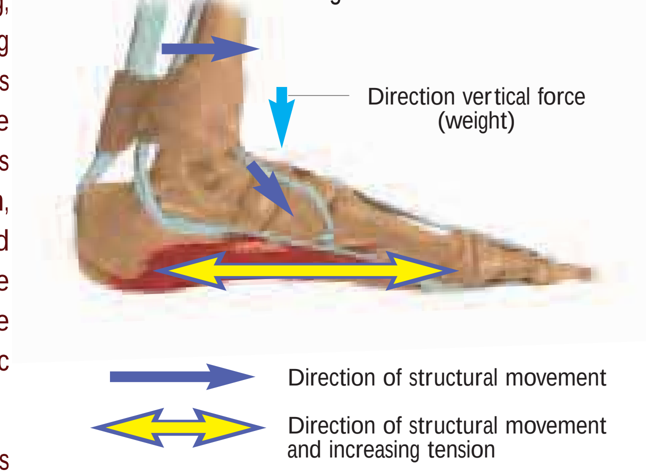
Note the differences in the relative positioning and alignment of the interlocking bones. In the unrestricted foot with the great toe dorsiflexed, the interlocking bones are cinched tightly together, forming a stable dome-like dynamic. (Figure 41) The metatarsals are plantarflexed relative to the midfoot, the midfoot is inverted and plantarflexed relative to the rearfoot, and the talus and calcaneus are dorsiflexed and inverted.

When the great toe is restricted and unable to dorsiflex, or when restrictions or lacing prevent raising of the mid-foot, the interlocking bones are unable to achieve this stable dynamic. (Figure 42) Instead they are loosely aligned and demonstrate poor structural integrity. The metatarsals are dorsiflexed relative to the midfoot, the midfoot is dorsiflexed and everted relative to the rearfoot, and the talus and calcaneus are plantarflexed and everted. The sesamoids remain *behind* the 1^{st} metatarsal head, which prevents them from locking the structure throughout the weight bearing and propulsion phases of gait. Upon weight bearing, this positioning can actually restrict dorsiflexion of the great toe—an action that is necessary for effective dynamics through the propulsion phase of gait.

Note also, the relative position of the lateral malleolus to the talus, and the degree of medial tibial rotation demonstrated in Figure 42 when compared to the relative positioning in Figure 41. From a physics perspective, the alignment, structural integrity and height of the foot's arch system corresponds directly to the degree of tibial rotation and inefficient alignment at the knee.

As the foot moves from heel strike to full weight bearing, loads increase over the arch area in response to varying activity levels. When running, loads can reach up to 2.5 times body weight. [53, 96, 97] As these loads increase, the unlocked arch system progressively destabilizes, losing its structural integrity and strength, collapsing the arch system, and accelerating tension on the tie beam (intrinsic first and second layer muscles and plantar fascia). (Figure 45) These accelerating horizontal forces can stress the integrity of the tie beam components beyond their tensile or elastic capabilities, leading to plantar fasciitis or "heel spurs." [51]

Fig re 43



In addition, the relative geometry of compressive forces through the arch system generates stresses that will affect adaptive bone remodeling. In external (shape) and internal (density) bone remodeling, the rate of change at a location is a function of surface strain, stress, or strain energy at that point. [50]

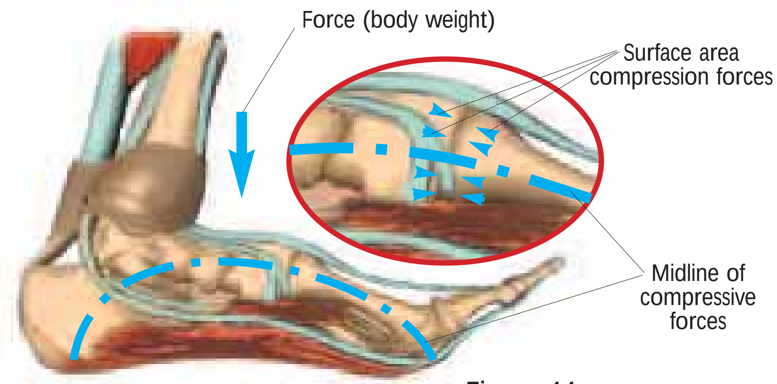


Fig re 44

The mechanical physics of the high stable arch system (Figures 41 & 44) by necessity, means that the compressive forces generated by the body's weight are evenly distributed at bone-to-bone articulations, most particularly through the midfoot as it articulates with the forefoot and rearfoot. A consistently smooth tendon/muscle pull facilitates healthier bone stress/remodeling vs. inconsistent/jerking/jarring actions that may cause unhealthy stress/remodeling at the tendon-bone junction. These balanced forces promote optimal bone shape and geometry during the ongoing process of remodeling.

The mechanical physics of the unstable collapsing arch system subject the dorsal surface area of the bone-to-bone articulations in the midfoot to greater compressive forces. (Figure 42 & 45) These forces are also seen in the relative articulations between the midfoot and the fore and rearfoot. When standing, these forces are constant, but increase progressively as the arch collapses due to fatigue, footwear restrictions (such as tight lacing), or the increased loads generated during gait.

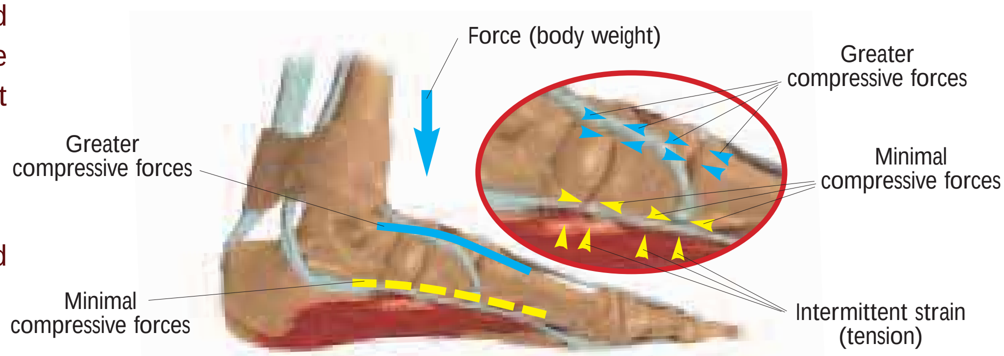


Fig re 45

The plantar surface area of the corresponding bone-to-bone articulations is subject to a much lower degree of compressive force and greater tensile force at the insertion points of ligaments and muscle. These tensile stresses tend to be intermittent and accelerating in nature, and increase significantly as the arch system collapses under increasing loads. Unbalanced stresses promote poor bone shape and geometry as the bone remodels in an attempt to equalize the stress throughout the structure. [50, 89] The bone remodels *away* from the constant compressive forces on the dorsal surface areas of the bone-to-bone articulation and *toward* the intermittent tensile stresses on tendon and ligament attachment points in the plantar region, until these forces are balanced throughout the structure. [50]

With the great toe unable to dorsiflex, the foot follows a number of dysfunctional paths, depending upon activity and predilection (pes planus or pes cavus). Pes planus individuals typically excessively "pronate" and pes cavus individuals typically excessively "supinate." Two of the most common pes planus [54, 65, 98, 99] dysfunctional paths are detailed below:

1) In normal walking gait, at heel contact, the foot and leg are abducted excessively. (Figure 46) As the body's center of mass moves forward over the foot, the foot's arch system collapses as the forefoot and midfoot increasingly dorsiflex, while the rearfoot plantarflexes and everts. The tibia and knee rotate medially (adduct) as a result. Through propulsion and toe off, the abducted foot and adducting leg cause a diagonal rolling, about and over the medial side of the first metatarsal head. The propulsion stride directs the body's mass medially and forward, relative to the foot's positioning.

Fig re 46 Normal ait

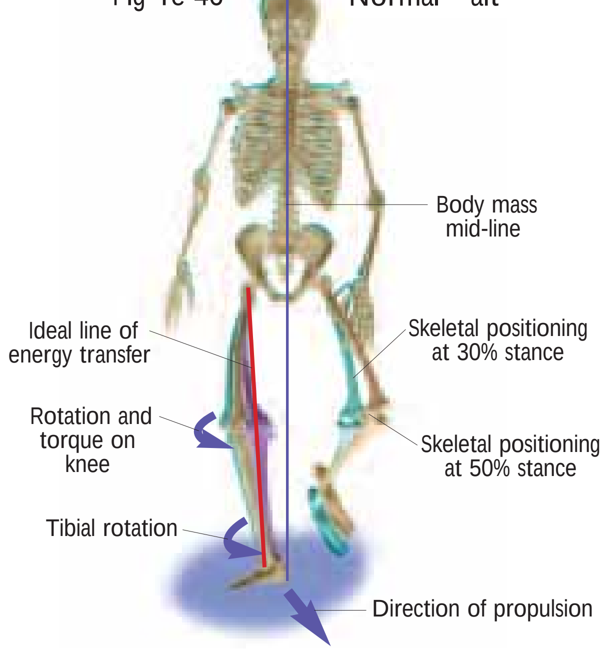
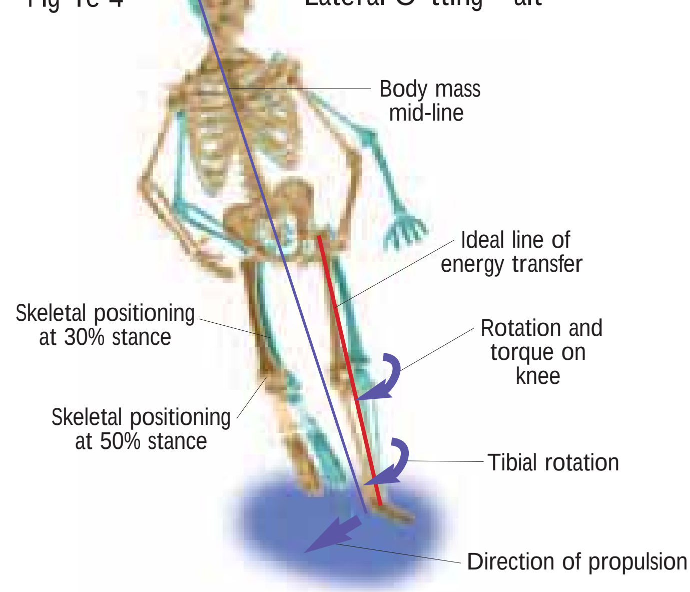
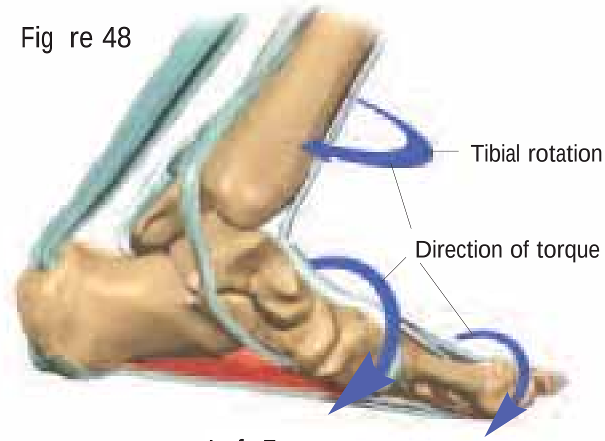


Fig re 4 Lateral C tting ait



2) During lateral cutting movements, at contact, the foot is abducted slightly but is more in line with the body. (Figure 47) At initial ground contact, the knee is abducted slightly but is predominantly pointing forward. As the force generated by the body's center of mass is absorbed by the lower limb, the foot's arch system collapses, as described above, causing a progressive acceleration of medial tibial rotation and adduction at the knee. These accelerating collapsing and torsional forces are maximized as propulsion is initiated. The propulsion stride is therefore inefficient because poor foot and knee alignment result in significant energy loss.

Fig re 48

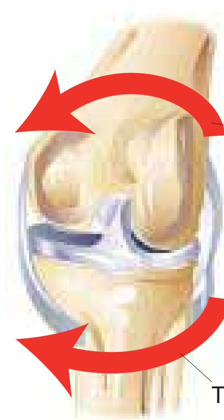


Left Foot

In both instances, tremendous torsional stresses are generated on the joint of the first metatarsal head and great toe. (Figure 48) These stresses contribute directly to pathologies such as hallux valgus and turf toe. In addition, the foot generates a tremendous amount of torque and friction within the shoe and depending on the shoe design, these stresses often result in excessive calluses, bunions, bunionettes, metatarsalgia, Morton's Neuroma, and "pump bumps" at the heel. Accelerating torsional stresses are also generated at the knee, contributing to ligament and cartilage damage, chondromalacia, patello-femoral syndrome, illiotibial band syndrome (ITBS), etc. (Figure 49)

Individuals exhibiting pes cavus feet typically demonstrate less mid-foot flexibility and excessively supinate, invert, and toe-in through heel strike to toe off, thus rolling off the 4th and 5th metatarsal heads during propulsion. During normal walking gait, at heel contact, the foot and leg are abducted excessively. As the body's center of mass moves forward over the foot, through heel strike, full weight bearing, propulsion, and toe off, the abducted foot and abducting leg cause a diagonal rolling, about and over the lateral side of the 4th and 5th metatarsal heads. The propulsion stride is inefficient, directing the body's mass laterally and forward, relative to the foot's positioning, generating tremendous torsional stresses on the 4th and 5th metatarsal heads.

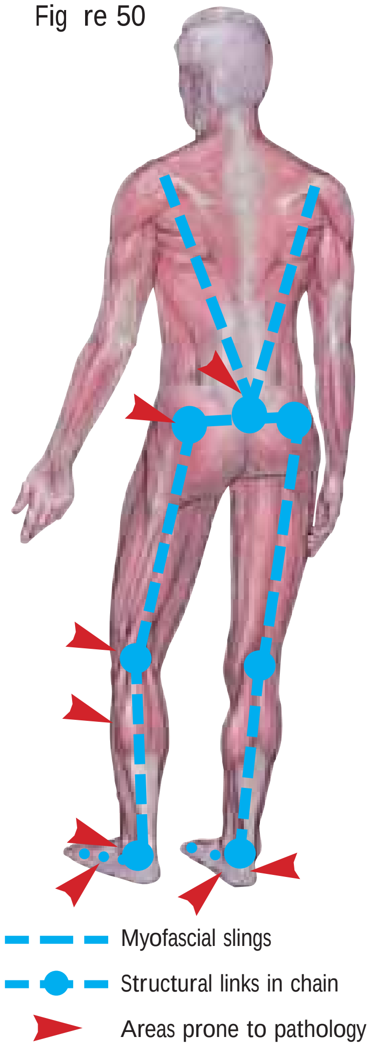
Fig re 49



Left nee

While the high rigid arch is structurally capable of managing greater loads, when compared to the hypermobile foot, its load bearing capacity is exceeded (without appropriate nociceptive and proproceptive muscle activity) the structural integrity fails more acutely, resulting in more traumatic (sudden) degenerative stress. In addition, the foot generates a tremendous amount of torque and friction within the shoe and depending on the shoe design, these stresses often result in excessive calluses, bunions, bunionettes, and metatarsalgia. Accelerating torsional stresses are also generated at the knee, contributing to ligament and cartilage damage, chondromalacia, patello-femoral syndrome, etc.

Fig re 50



The inetic Chain

Regardless of foot type, the habitual use of footwear that dampens somatosensory stimulus and/or creates a restrictive environment will condition improper muscle-firing sequences of the foot's supporting musculature—they cease to fire completely or at inappropriate intervals. [14] This can lead to muscle atrophy (from lack of use) or hypertrophy (from overwork) and to muscles becoming easily fatigued. [9] Pathologies such as plantar fasciitis, heel spurs, or shin splints typically develop when these dynamics are present.

When the foot's supporting musculature fails to provide structural stabilization, the resulting inefficient alignment negatively affects the mechanical geometry of the smaller and deeper levels of intrinsic musculature. Poor mechanical geometry leads to compensatory and inefficient (over-worked) muscle function, increased stress, and fatigue. These smaller muscles are best suited for fine motor control and dexterity, and are not able to effectively manage the forces generated by an unstable and poorly aligned structure.

As the unstable structure enters into, first the weight bearing, then propulsion phase of gait, the poorly aligned and unlocked bones are unable to effectively manage the forces and stress generated. These forces/stresses magnify as they migrate up through the musculoskeletal structure and can lead to chronic or acute pathologies at the sites of the weakest links in the kinetic chain, depending on activity levels. (Figure 50) Conditions such as Achilles tendonitis, patello-femoral syndrome, knee, hip, and back problems are commonly associated with these poor structural dynamics. [100]

Unfortunately, the stresses generated by poor structural dynamics are further exacerbated by footwear design characteristics—some of which were engineered to stabilize the unstable foot.

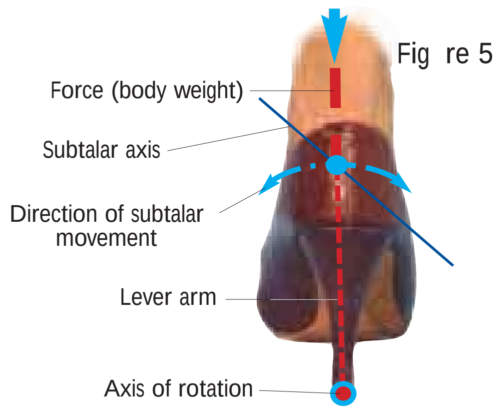
4.3 Increased Lever Arm Mechanics (Heel Height and Width)

It is commonly accepted that women's high heels negatively affect balance and posture, not only while walking, but while standing as well. It is also commonly accepted that there is a relationship between the height of the heel and its negative effects on the body. [73, 101] What isn't generally under-stood, however, is how heel height, regardless of footwear type, affects mechanical physics while standing, walking, or participating in any other gait-related activity.

Fig re 51

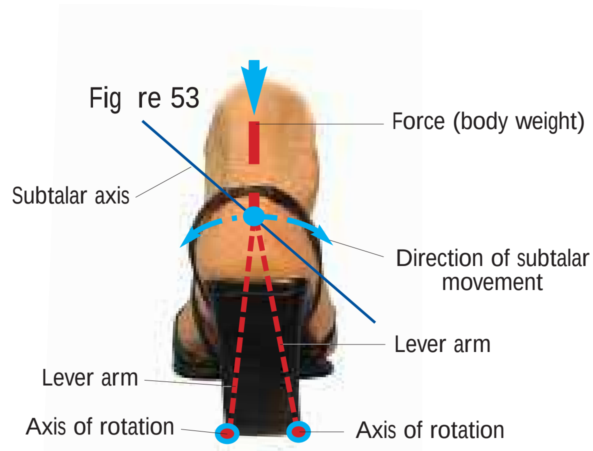
There is a corresponding relationship between heel height and the transfer of increased weight to the metatarsal heads during weight bearing. (Figure 51) In order to keep from falling forward, the body attempts to compensate by shifting upper body mass further back—arching the lower back and

Fig re 5



ight foot

Fig re 53



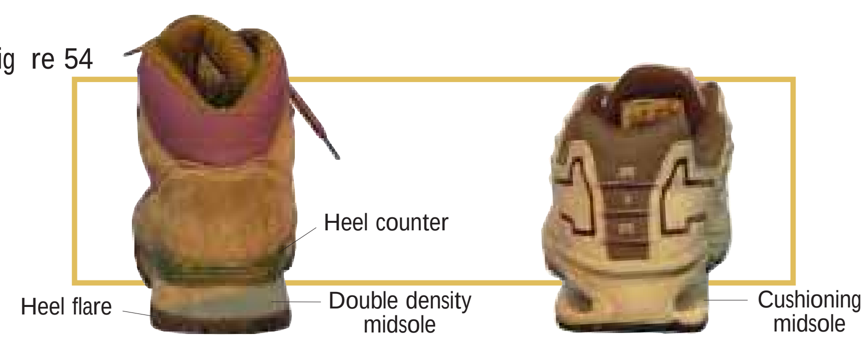
ight foot

altering the mechanics at the hips. The associated muscles are then forced to compensate, increasing stress to these areas.

Heel height also dictates the degree of transverse lever arm forces that are generated through the midfoot and at the ankle. A narrow pointed heel will create a single pivot point at ground contact, centered under the calcaneus. (Figure 52) As the body's weight shifts away from midline balance, movement increases about the subtalar joint and stress is generated either medially or laterally at the ankle, depending on the direction of movement. (Figure 52) Heels with wider bases provide a more stable platform while standing, but create two pivot points that increase the lever arm forces about the midfoot and ankle during gait. (Figure 53)

Many shoe manufacturers incorporate designs that attempt to stabilize the foot (motion control) and reduce shock (thicker midsoles) during the gait cycle. (Figure 54) Unfortunately, at best, these design characteristics function one-dimensionally when standing or when straight-line walking on a horizontally flat surface.

Fig re 54



These design characteristics actually accelerate the negative forces generated by the unstable structure, during gait over uneven terrain or in multi-directional activities, as described above. Increasing degrees of heel height and heel flare create pivot points (axes of rotation) and lever/moment arms that dramatically increase the speed of pronation and plantarflexion (of the shoe and foot). [73, 102, 103] In fact, heel height and the degree of posterior heel flare directly correspond to the speed and degree of acceleration that starts at heel strike and continues through to weight-bearing forefoot contact. This significantly increases the load at midstance on the arch system, particularly on the mid and forefoot. [103]

For the unshod foot, with a given amount of force (i.e., gait momentum and body weight), the speed at which the centers of mass - for each of the arch apex and metatarsal heads - rotate about the pivot point is directly proportionate to their distance from the pivot point. This is clearly a fixed variable for a given unshod foot, but when considering the shod foot the pivot location changes from the calcaneus' center of mass to the shoe/ground interface. This increases the distance between the pivot point and the center of mass for each of the arch apex and the metarsal heads. As a result, footwear magnifies the vertical and horizontal forces that are generated during weight-bearing. [103] (Figures 55 - 57) Further, the shod foot, when compared to the barefoot:

1. strikes the ground earlier,
2. strikes the ground further from the body's center of mass,
3. has a greater plantar surface angle, and
4. has a greater angle of lower leg to contact surface, at heel strike.

As either heel height or posterior flare increases, the vector forces become correspondingly greater as their distance from the axis of rotation increases. At full weight-bearing, the accelerating vertical forces are directed forward over the forefoot/midfoot rather than being centered over the arch apex (forefoot/midfoot/rearfoot). In additon, both the calcaneus' and foot's center of

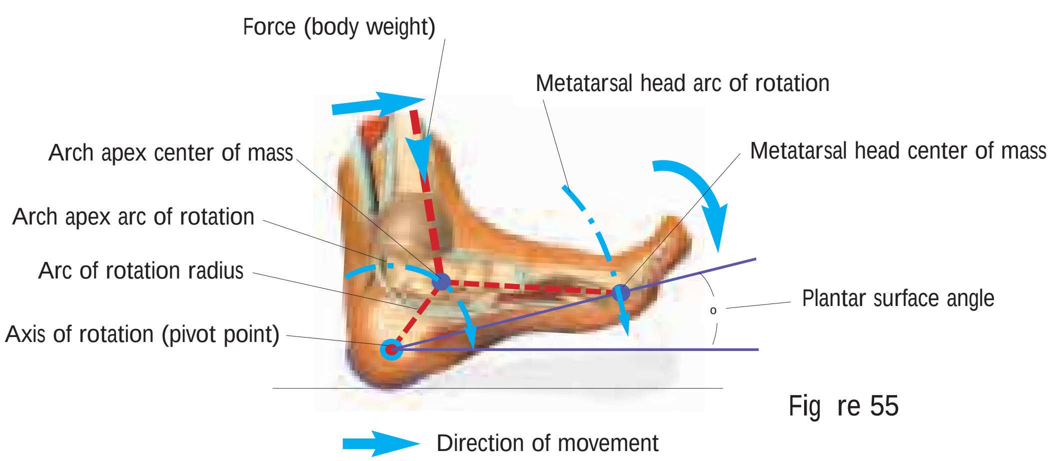


Fig re 55

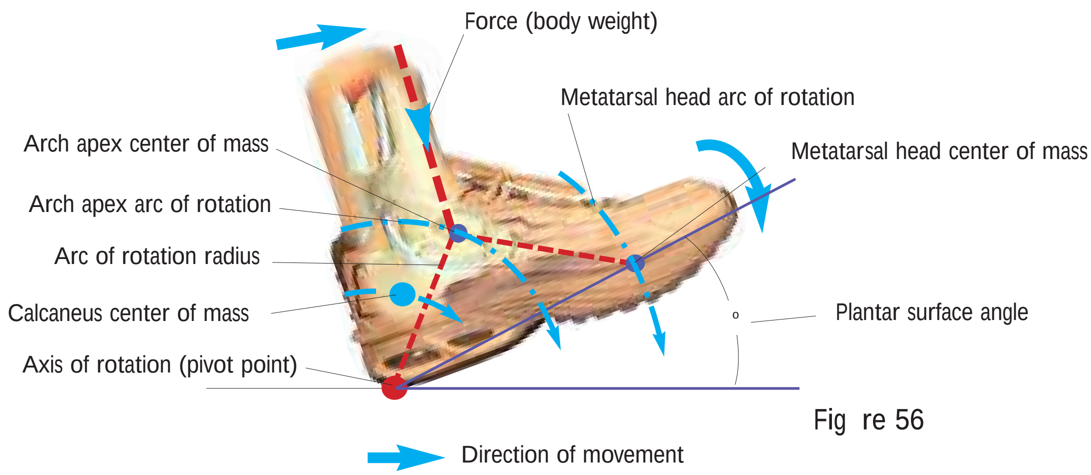
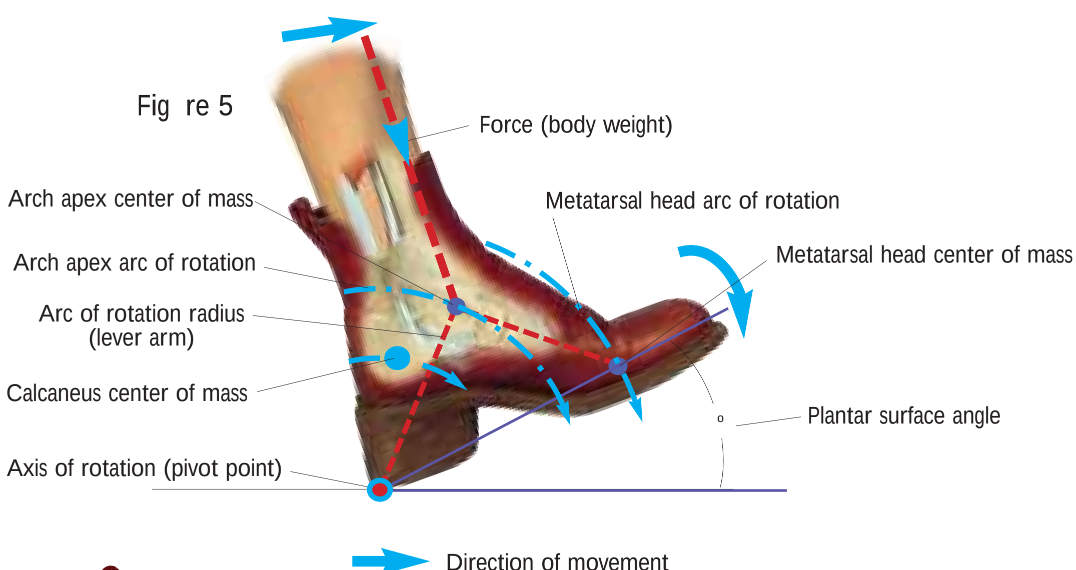


Fig re 56

mass gain velocity as they rotate about the axis, generating horizontal momentum upon weight-bearing contact. This leads to friction on the plantar surfaces of the heel and forefoot that can contribute to excessive calluses.

Heel counters, heel height, and degree of heel flare (width) directly correspond to the acceleration and velocities of pronation and eversion at lateral heel strike, and to supination and inversion at medial heel strike. [97, 103, 104] These accelerating velocities produce structural load increases of up to 200%. [105] Increases in midsole thickness and flare are also directly related to the acceleration and velocity of both forefoot eversion at lateral forefoot strike, and forefoot inversion at medial forefoot strike. [104]

Fig re 5



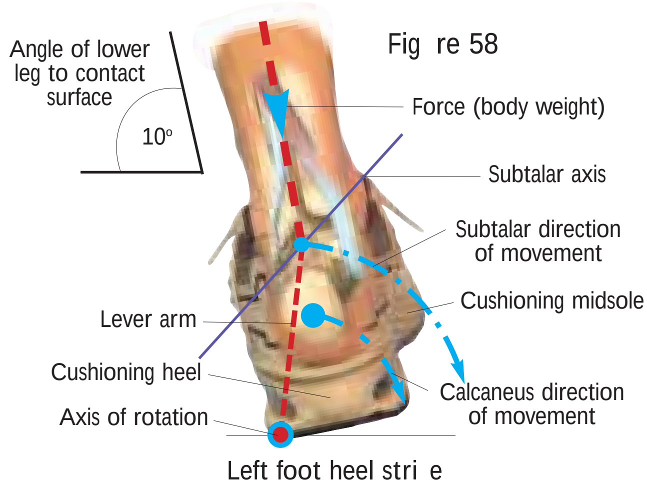


Fig re 58

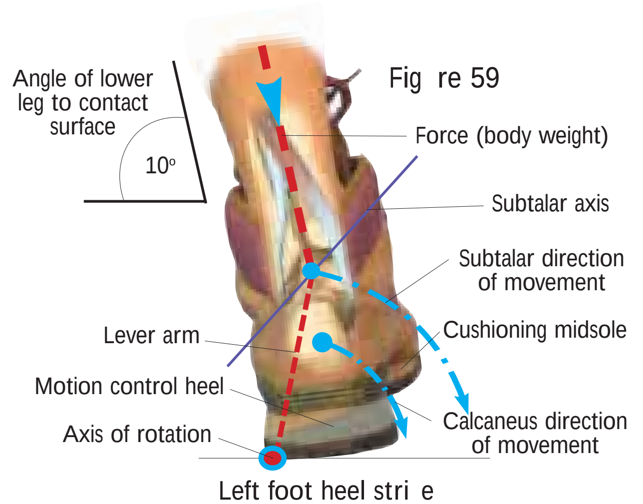


Fig re 59

Regardless of shoe midsole type, during normal shod gait on a predominantly flat surface, the lateral rear area of the heel first contacts the ground and creates a pivot point, or axis of rotation, about which the rest of the foot moves until the forefoot attains maximum weight bearing contact. (Figures 58 & 59) [104] This creates a lever or "moment" arm, whose length determines the acceleration and velocity of pronation—proportionally increasing the vertical and horizontal forces (stresses) on the forefoot. These accelerating dynamics are not present in barefoot gait.

During normal barefoot gait on a predominantly flat surface, the heel contacts the ground later in the swing phase, reducing the angle of lower leg to contact surface and making contact closer to the body's center of mass. Heel contact is slightly lateral to the calcaneus' center of mass (axis of rotation). The curvature of its plantar surface facilitates a smooth roll about the axis of rotation, allowing an efficient transition to, and alignment of, the forefoot parallel to the ground at full weight bearing contact. (Figure 60)

This naturally efficient dynamic is also demonstrated while walking or running barefoot on varied terrain and in multi-directional (i.e., lateral sideways cutting) movements. (Figure 61) In instances of initial forefoot ground contact on varied terrain or during multi-directional movements, the forefoot proprioceptively aligns itself parallel to the surface area prior to contact. [105] This alignment produces the lowest torsional and torque forces through the subtalar joint, throughout the foot, and up through the kinetic chain.

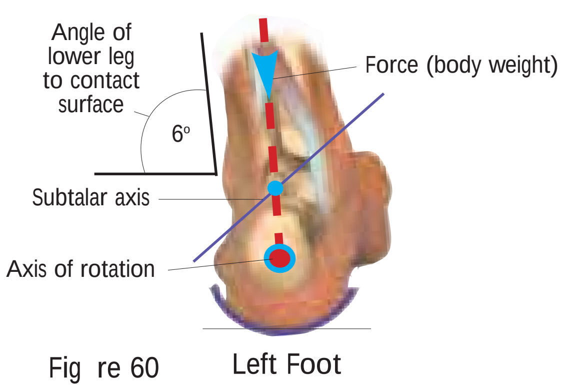


Fig re 60

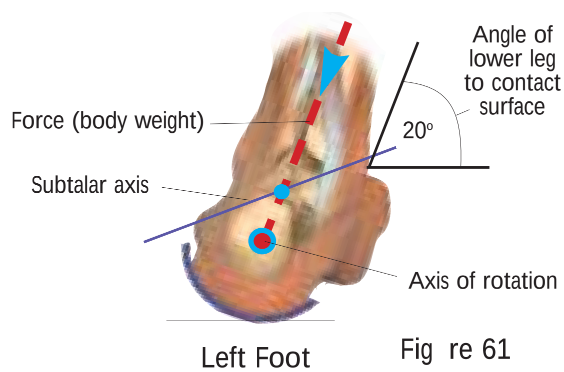
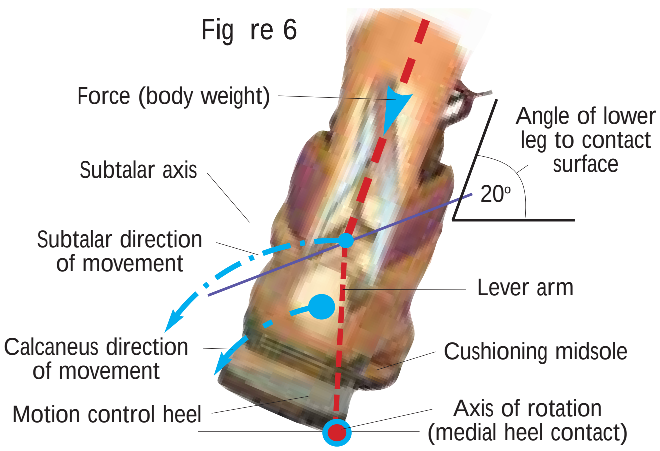


Fig re 61

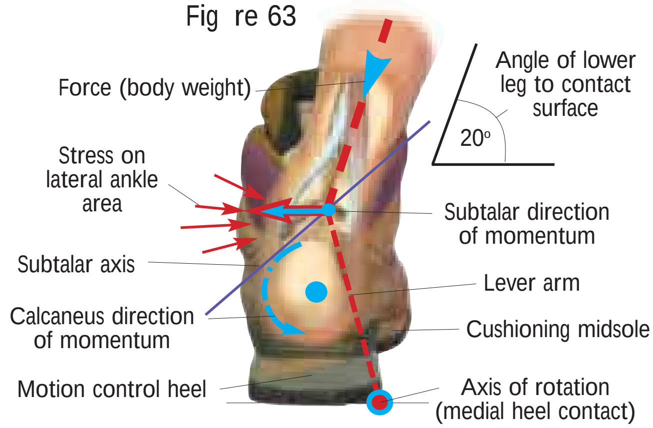
The barefoot condition also provides superior natural lateral stability during sideward cutting movements and during multi-directional activities, when compared to the shod condition. [103] (Figure 61) Shoes increase the lever arm length and, consequently, increases the movement around the subtalar joint. [103] (Figures 62 & 64) Given similar angles, torsion is increased from contact to full weight-bearing, which is equivalent to an inversion movement of the rearfoot relative to the forefoot. [103] The degree of stress on the ligaments of the lateral aspect of the foot and ankle is directly proportional to the velocity of inversion. (Figures 63 & 65) Heel counters are designed to stabilize the shoe relative to the heel to ensure that they follow the same motion. Unfortunately, by locking the heel in place (forcing it to follow the movement of the shoe), heel counters contribute to the forces generated by heel height and width.

Fig re 6



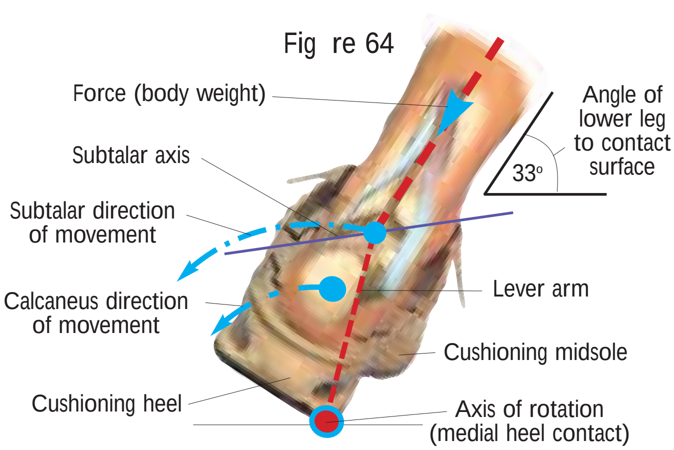
Left foot at gro nd contact

Fig re 63



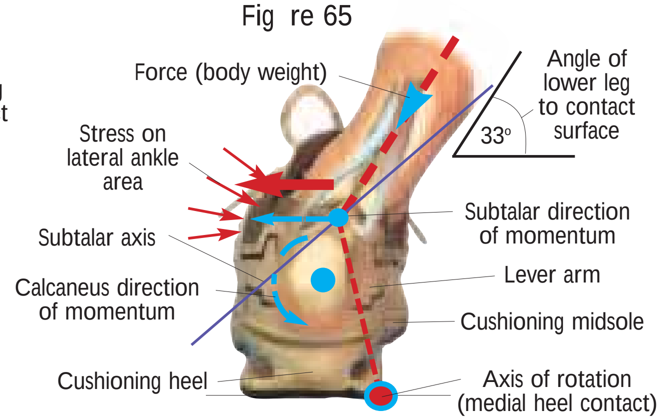
Left foot at f ll weight- earing

Fig re 64



Left foot at gro nd contact

Fig re 65



Left foot at f ll weight- earing

From a mechanical perspective, the effects of varying footwear charateristics (midsole and heel height/flare) are synergistic in their resultant accelerating velocities of plantarflexion, pronation, supination, inversion, and eversion. In varying combinations (due to design geometry), they impact significantly on structural loads, magnify the horizontal tie beam and torsional stresses throughout the foot and ankle, and negatively affect structural integrity. [104] These design geometries directly influence the location and degree of poor structural alignment and the relative increase in degenerative stress at the joints throughout the kinetic chain, particularly the knees, hips, and lower back. Clearly, footwear design characteristics play a major role in the development and exacerbation of musculoskeletal pathologies throughout the gait-related kinetic chain. [14, 58, 83, 87, 88, 101, 106]

5.0 Conventional Treatments for Foot-Related Pathologies

"...current treatment of foot disorders is limited..."

Dr. Roger A. Mann, Associate Clinical Professor, Department of Surgery, University of California at San Francisco. Foot and Ankle Symposium Co-sponsored by the Canadian Orthopaedic Association and the Department of Surgery, Orthopaedic Division, University of Toronto, held at Sunnybrook Hospital, April 1996

The most common treatments for the host of pathologies that result from poor foot biomechanics focus on cushioning, supporting, or bracing the foot and ankle–often in combination. Whlle exercise and rehabilitation programs are sometimes recommended—the focus is usually on the flexors as opposed to the extensors and compliance is usually poor. More aggressive treatments, such as surgical intervention, may be necessary in certain instances when other treatment methods prove unsuccessful, however, surgical intervention is beyond the scope of this monograph and will not be addressed.

5.1 Cushioning

Cushioning treatment options include foam, gel, and felt-based insole products, and footwear that incorporates cushioning midsoles. Cushioning often presents a "comfortable" feeling initially, but it provides a false sense of security by offering benefits that are superficial, at best.

"...consistent use of (shock absorbing) orthotic inserts did not prevent lower limb pain among healthy soldiers in basic training..."

Sherman RA, Karstetter KW, May H, Woerman AL. Prevention of Lower Limb Pain in Soldiers Using Shock-Absorbing Orthotic Inserts. Journal of the American Podiatric Medical Association, Volume 86, No. 3, March 1996

Cushioning products are purported to dissipate the vertical shock that results from chronic overloading, thereby reducing the stress to the foot. Contrary to common perceptions, cushioning products mitigate vertical shock by less than 10%, at best. [105, 107, 108] Unfortunately, studies show that horizontal forces—rather than vertical forces—contribute most significantly to foot pathologies. [107, 109, 110] Research demonstrates that the control of initial pronation is of greater importance than shock absorption. [7, 109, 110] Studies indicate that cushioning the foot isolates the plantar surface from the sensory feedback it requires to induce its protective adaptations—essential for effectively managing the forces generated at impact. [80, 108, 111, 112] It has been demonstrated, in vivo, that impact remains unchanged whether the runner uses soft running shoes, hard running shoes, or is barefoot (without a barefoot adaptation period). [110, 113]

A study on U.S. Army trainees examined the prevention of lower limb pain using shock-absorbing orthotic inserts. The relatively large study tested the most effective shock absorbing insert (as per clinical comparison trials) [114, 115] and concluded that consistent use of this insert did not prevent lower limb pain among healthy soldiers in basic training, and in fact, suggested that the insert actually caused some injuries—the insert group (vs. the non-insert group) presented a slightly higher rate of several problems. [114]

5.2 Support (bracing)

5.2.1 Orthotics

Custom orthotics and similar products attempt to stabilize the subtalar joint by supporting the arch, claiming to "correct" the poor biomechanics of the foot. [17, 18, 116, 117, 118, 119, 120] This claim of correction is misleading.

Subtalar neutral (the mechanical relationship between the talas and navicular) is often thought of as the "key" to "proper" structural alignment in the foot. Contrary to the conventional view, this mechanical relationship is dynamic in nature rather than static. That is, the relative positioning of the "subtalar joint" is determined by the nociceptive and proprioceptive reflex muscle activations (or lack thereof) in response to activity levels and terrain.

Aside from acute trauma, it is commonly accepted that most foot-related pathologies arise from unhealthy stresses generated by a biomechanically unsound structure that has been subjected to excessive repetitive activity.

Acute or chronic symptoms manifest as a result of varying levels of intensity. These symptoms impact at the most structurally unstable locations or the "weakest links" in the individual's kinetic chain relative to the repetitive activity. For example, poor structural mechanics, along with increased lever arm forces inherent in footwear design, promote excessive pronation that can lead to plantar fasciitis, shin splints, or knee problems. [99] All too often, excessive pronation is incorrectly identified as the cause of these problems when it has been demonstrated herein to be merely a clinical sign.

Clearly, the real *cause* of the above noted foot-related problems is the foot's inability to align, stabilize, and lock the arch structure prior to heel strike, as influenced by restrictive footwear. These poor structural dynamics of the collapsing arch system are further exacerbated by rigid soles and by increased heel height and flare. [103, 104] It is also clear that the relative positioning of the bones of the midfoot significantly affects the foot's ability to manage the forces generated by gait. [26]

"Shock absorbing materials in the shoe are not required if subtalar joint function is normal."

Tiberio D. The Effect of Excessive Subtalar Joint Pronation on Patellofemoral Mechanics: A Theoretical Model. Journal of Orthopedic & Sports Physical Therapy 9(4): p. 160, 1987.

"We shoud have a clear body of evidence that orthoses actually work. Unfortunately we don't."

Hamill J, Derrrick TR. Orthoses: Foot/Custom: The Mechanics of Foot Orthoses for Runners. Biomechanics: February 1996

"...the results of a two-year prospective randomized national study on the treatment of heel pain. The study found inexpensive off-the-shelf shoe inserts to be more effective than plastic custom arch supports in the initial treatment of heel pain (plantar fasciitis)."

Glenn Pfeffer, M.D., San Francisco,
Chairman of the AOFAS Heel Pain Study Group,
American Orthopedic Foot and Ankle Society (AOFAS)
1996

Fig re 66

Orthotics "mask" symptoms by artificially supporting or bracing a dysfunctional structure (i.e., exhibiting poor bone alignment) along with its inherent muscle imbalances, by simply introducing a new angle of ground interface to the foot. [116]

A variety of "measuring processes" are used to develop orthotic prescriptions. Older methods involve taking a foam or plaster impression of the foot's plantar surface. (Figure 66) "Corrective" posting angles for the rearfoot and forefoot are often dependent on the practitioner's expertise. [117] (Figures 67) These methods are subjective at best.

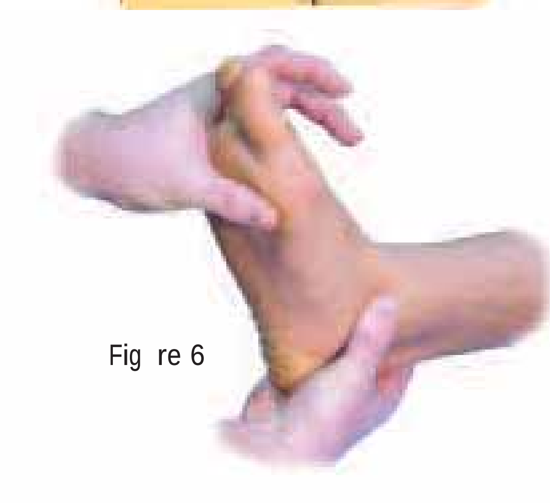


Fig re 6

Newer methods involve force plate measuring systems that produce recommended forefoot and rearfoot posting through comparison of database NORMS. (Figures 68 & 69) Force plate measurement systems make inferences about foot shape through pressure distributions —measuring vertical forces on the foot's plantar surface through one step of the gait cycle, specifically heel strike to toe off. The final "custom" orthotic is usually chosen from a pre-fabricated inventory of varying sizes and postings. (Figure 70) Unfortunately, this type of measurement system does not take into account the relative three-dimensional geometry of bone alignment, which has proven essential for normal foot function. [26]

Fig re 68

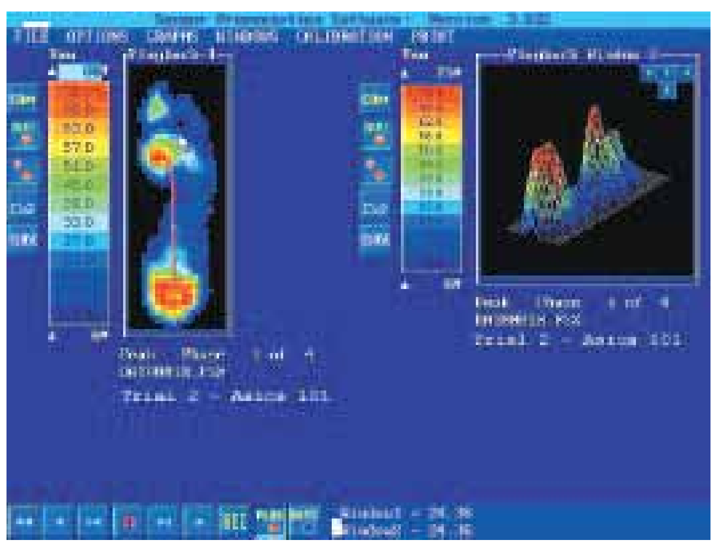


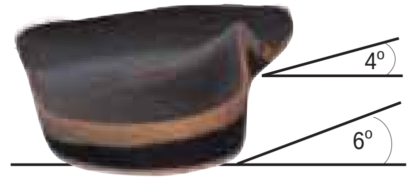
Fig re 69

Fig re 0

Fig re 1

Initial gro nd
inteface angle

Fig re



Corrected gro nd
inteface angle

In addition, impressions and measurements are commonly taken shortly after the patient removes his or her footwear. Poor structural alignment and inherent compensatory muscle imbalances resulting from the footwear are therefore reflected in the impressions and measurements.

The supportive bodies of the more state-of-the-art custom orthotics are manufactured from a rigid plastic or composite material; older technologies incorporate cork, foams, and leathers that are layered alone or in combination. (Figure 70) There are a wide range of surface coverings available that include a variety of fabrics and leathers––some bonded to thin layers of foam. These materials insulate the foot's plantar surface from the sensory feedback required to induce protective adaptations necessary for healthy foot function.

Without the "corrective" postings, the orthotic body mirrors the casting impression of the dysfunctional structure (with its inherent compensatory imbalance) as it interacts with the ground—the initial ground interface angle. (Figure 71) Varus or valgus wedges post the rearfoot and/or forefoot as a means to support or brace the arch. (Figure 72) Contrary to claims of correcting biomechanical alignment commonly made by those who support orthotic use, the relative change in structural alignment is minimal. [18, 25] (Figures 73 & 74) More accurately, the orthotic simply introduces a new ground interface angle to the plantar surface of the foot.

Fig re 3

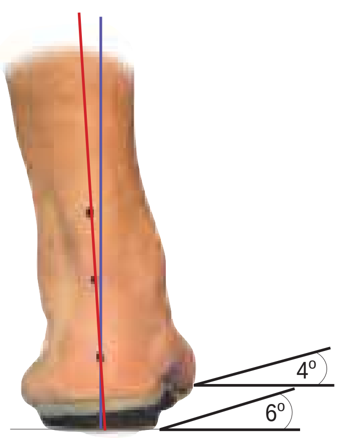


Fig re 4

To clearly identify the effects of orthotics on structural alignment in the foot, x-rays were taken of three subjects' feet—with and without orthotics in their shoes. (Figures 75 & 76) This was done during full weight bearing and within a ten minute time period. The orthotics used were a commonly prescribed type—"corrective" postings for the forefoot and rearfoot ranged from 4-6 degrees. A medical professional had previously determined that all three subjects required orthotics. In every instance, the orthotics had little or no effect on the relative alignment or structural integrity of the interlocking bones, specifically in the midfoot—an area identified as significant to normal (healthy) foot function. [26] The only appreciable change in relative alignment was strictly a result of the increased heel height. (Figure 77) The structures remained "unlocked," dysfunctional, and unstable.

Viewing the x-rays and comparing the arcs created by the structures' center of bone mass reveals little, if any, difference in their relative geometry. (Figure 77) When the arcs are rotated and placed on a horizontal plane, they are virtually identical. (Figure 78)

Fig re 5 Shod with orthotic

Fig re 6 Shod witho t orthotic

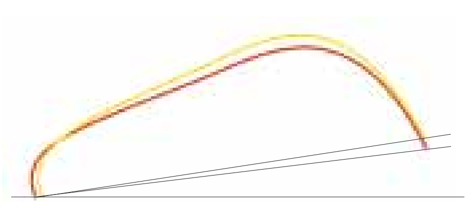


Fig re

Fig re 8

By bracing (supporting) the foot with "corrective" postings, the orthotic is purported to "force" the foot to follow a more biomechanically sound pattern of movement throughout the gait cycle.

"No one method for measuring STJ neutral has been proven accurate and reproducible by different testers."

Miller M, McGuire J. Literature Reveals No Consensus on Subtalar Neutral. Biomechanics: p. 63, August 2000

The claims and benefits of foot orthotic therapy have generated controversy amongst researchers and foot care practitioners. [1,18, 103, 106, 117, 121, 122, 123]

Researchers have gathered qualitative data from patient surveys to offer proof of orthotic efficacy. [106] Several quantitative studies have demonstrated that orthotics affect both the kinetics and kinematics of gait when used by pronated subjects. Unfortunately, repeating quantitative results has proven difficult, with many researchers unable to confirm the quantitative effects of orthotics or find significant variations in their effects. [18, 106, 119, 120, 121]

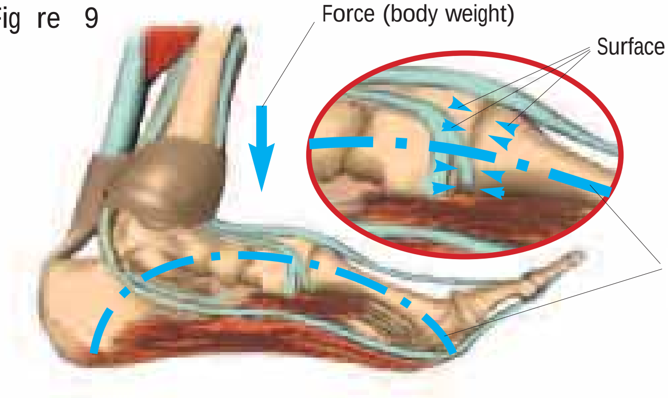
From a mechanical perspective, orthotics simply cause a shift in the dynamics of repetitive movement by introducing a new angle of ground interface. The symptoms resulting from the old dynamic disappear and the problem seems to be corrected, but this effect is temporary. Unfortunately, over time or with increased activity levels at the new ground interface angle, the repetitive movement often results in the appearance of new symptoms at different locations. A repetitive cycle emerges as new orthotics are prescribed to compensate for ever-migrating symptoms and pathologies. Current practice is to recommend new orthotics approximately every two years, generally with increases in the forefoot and rearfoot postings.

A study on the effects of shoe insert construction (orthotics) found that the most common harder inserts allowed for more individual variation of foot and leg movement and did not force the foot into preset movement patterns. [120] The individual results showed substantial differences between subjects and, therefore, did not indicate a trend.

Medial wedges (postings) alter the angles of the weight bearing surface that affect tension on the plantar fascia. [53, 123] Medial wedges or postings are commonly incorporated into orthotics with a view that they will reduce this tension. Contrary to conventional teachings, an in vitro study found that medial wedges (postings) on the forefoot significantly increased the strain on the plantar aponeurosis; lateral wedges reduced the tension; and heel wedges had no significant effect. [123]

From a bone remodeling perspective, orthotics change the manner in which forces are managed throughout the structure. In a foot with a dynamically controlled arch, the vertical forces generated by body weight result in horizontal compressive forces through the foot's arch system. (Figure 79) By supporting the medial side of the foot, the orthotic manages the vertical loads in place of the arch system. (Figure 80) The forces remain vertical throughout the bones of the foot's arch system and the structure remodels in response, leading to a weakened structure and an increased dependency on the artificial support. [56]

Fig re 9



Rearfoot posting of orthotics increases the relative lever arm forces associated with footwear heel height and width. (Figures 80, 81 & 82) This proportionately increases the acceleration and velocities associated with plantarflexion, pronation, inversion, and eversion, and the loads on the structure. [104] Therefore, the risk of lateral foot and ankle injury increases with orthotic use, most particularly in side to side cutting movements as the forces increase through the unlocked and misaligned structure.

There is no evidence that orthotics rehabilitate the functional dynamics of the foot, and thus, claims of correction have no actual scientific basis. [119, 120] It is important to note that in virtually all areas of musculoskeletal medicine, long-term bracing is not the recommended treatment of choice. Orthotics may be lucrative for those who are dispensing them, but from the user's perspective, it is clear that a more effective rehabilitative treatment and preventative methodology is preferred.

Fig re 80

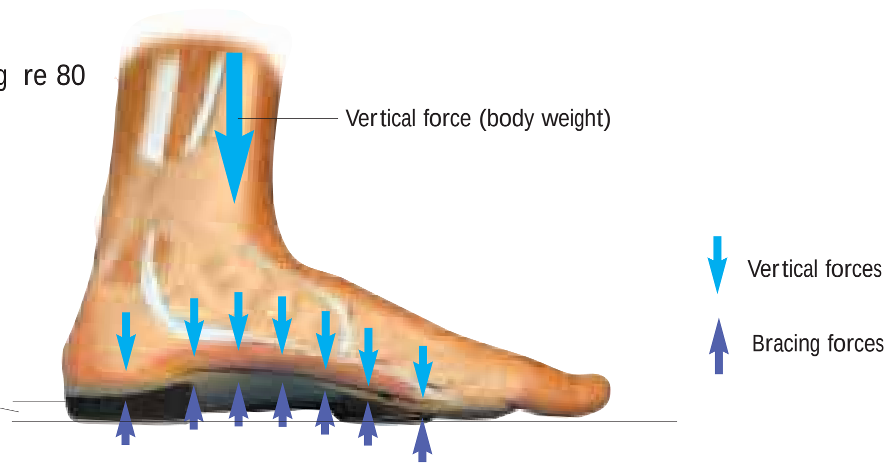
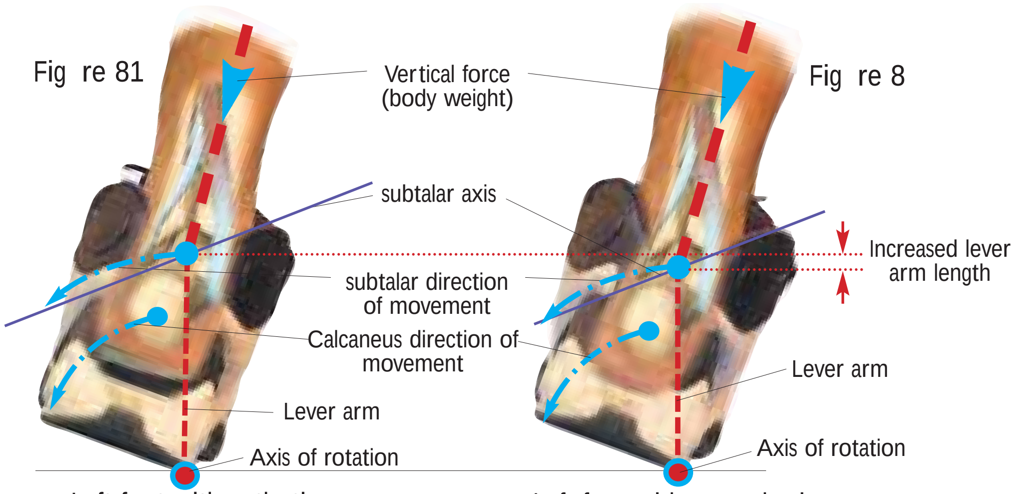


Fig re 81

Fig re 8



Left foot with orthotic

Left foot witho t orthotic

5.2.2 Taping and Ankle Braces

Foot and ankle taping or ankle braces are commonly used to support an injured area or to prevent injury from occurring. (Figure 83) Ankle taping is commonly used by both professional and amateur athletes as a preventative measure.

As demonstrated, restrictions inherent in footwear design destabilize the structural integrity of the foot and ankle. In addition, athletic footwear manufacturers incorporate stabilization or motion control features in an attempt to stabilize the structure. Unfortunately, these design characteristics actually increase the stresses on the ankle. Ankle taping and braces are used in an attempt to protect the foot and ankle from these stresses, but conversely result in structural atrophy and an increased dependence on the artificial support.

Studies on external ankle supports (braces) suggest that they negatively affect balance. [58, 124, 125, 126] Athletes wearing them showed greater fluctuations in ground reaction force and touched down more frequently with the non-supporting foot. The researchers believed that posture control and balance were adversely affected by the supports due to restriction of normal ankle movement. They indicated that braces may provide a false sense of security and would not endorse them for prevention purposes, cautioning that even during rehabilitation, they should not be used for prolonged periods. [124, 125, 126]

While ankle taping improves foot position perception for people wearing athletic footwear, foot position awareness remains poor when compared to the barefoot condition—with taped and un-taped subjects wearing athletic footwear demonstrating 58.1% and 107.5% poorer foot position awareness respectively. [58]

Fig re 83

5.3 Exercise (rehabilitation)

Exercise as a means of rehabilitation is a common therapy throughout musculoskeletal medicine. In fact, exercise, where appropriate, is usually the first treatment of choice, prior to more radical options, such as surgery. Many orthopedic surgeons recommend a regimen of exercise, both before and after surgery, as a means to speed recovery times. Mobility braces are commonly used after reconstructive ligament surgeries (i.e., at the knee) to reduce scar tissue formation and maintain mobility at the joint.

The most commonly recommended exercises for foot pathologies focus on rolling a ball or cylinder with the sole of the foot, plantarflexing the toes, or using them to grasp an object. These exercises may provide some benefit, but the muscular sequences involved have very little relevance to gait mechanics.

The most benefical foot exercise would involve multi-directional barefoot activity on diversified terrain to develop a balance of strength and flexibility, however, this type of activity is impractical for most individuals. [9, 14, 71]

Regardless of the exercises involved, the amount of time spent to achieve some positive benefit would be in direct proportion to the amount of time the person wore restrictive footwear. While exercise is promising for most individuals, it is limited by time constraints, hence the typically poor compliance.

6.0 Foot Care Steps in a New Direction

The abundance of research, mechanical physics models, and quantitative evidence presented herein clearly demonstrates the negative environmental influences associated with footwear use and its correlation to poor foot function, increased stresses, and resulting pathologies. It is also clear that conventional theories and treatment methods are founded on erroneous assumptions regarding foot function—that the foot structure is inherently weak and as such, requires artificial support and cushioning.

In essence, footwear weakens the structure by impairing the foot's sensory response to the ground, while also restricting both movement and optimal structural alignment. These factors, alone or collectively, can lead to structural instability. Conventional treatment methods attempt to mitigate instability by incorporating additional restrictions through support/bracing or cushioning areas of peak pressure, but inadvertantly create a never ending cycle and an ever-increasing dependence on the artificial support.

Conversely, research has demonstrated that the unfettered dynamic of barefoot gait, whether habitually unshod, or through increased barefoot activity, leads to optimal foot development, a significant reduction of structural loading, optimal stability, and the fewest incidences of pathologies. [9, 11, 12, 13, 14, 127]

This should not be surprising given that the health benefits of exercise, which promotes a balance of strength and flexibility (full range of motion) in opposing muscle groups, is universally considered important for normal, if not optimal, musculoskeletal function. It is also widely accepted that the application of moderate exercise to a weakened (injured) area of the musculoskeletal system will lead to improved strength, mobility, and structural integrity of the affected area.

It would seem self-evident that these principles are equally applicable to the foot and lower limb.

Clearly, footwear provides protection from the elements and from hazardous environments, and for some individuals affords socio-economic status through fashion appeal or perceived athletic performance. "Going barefoot" is not a practical solution in today's modern world.

It follows that the development and incorporation of footwear design characteristics that facilitate the dynamics of barefoot gait should be a priority in the prevention and rehabilitation of foot-related pathologies. These characteristics can be separated into three different categories:

1) the introduction of proprioceptive feedback stimulus to facilitate the protective adaptive response necessary for optimal structural alignment and reduced stress,
2) the elimination of restrictions that inhibit dorsiflexion of the digits, allowing optimal structural alignment,
3) midsole and outsole geometry and material properties that incorporate ground contact angles to promote rotational axes through the bone structures' center of mass.

Footwear incorporating these design characteristics would actually facilitate the development and maintenance of optimal stability and structural integrity of the foot's arch system. Regular use of such footwear would encourage optimal foot health, optimal athletic performance, and would significantly reduce risk of injury and pathology.

6.1 Barefoot Science

Barefoot Science has developed revolutionary new technologies that are based on the principles of rehabilitative medicine to not only rehabilitate the foot's dysfunctional structure, but to actually prevent problems from occurring in the first place. The technologies and patented or patent-pending products are designed to facilitate the dynamics of barefoot gait while using footwear. These technologies overcome the disadvantages of current footwear design by:

"...the development of a prophylactic orthotic would be of great benefit in the prevention and treatment of foot disorders."

Dr. Roger A. Mann, Associate Clinical Professor, Department of Surgery, University of California at San Francisco. Foot and Ankle Symposium Co-sponsored by the Canadian Orthopaedic Association and the Department of Surgery, Orthopaedic Division, University of Toronto, held at Sunnybrook Hospital, April 1996

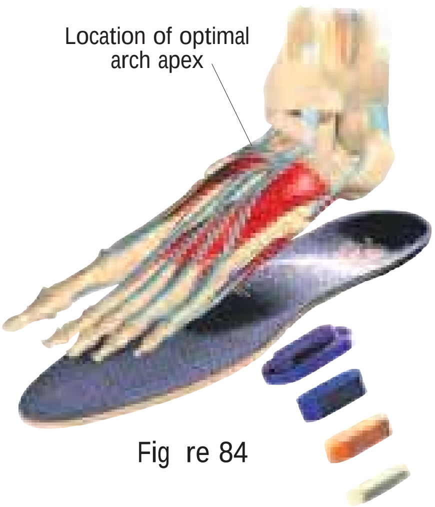


Fig re 84

Fig re 85

Fig re 86

- introducing a nociceptive/proprioceptive response stimulus—the Barefoot Science Arch Activation Foot Strengthening System™, (currently avialable)
- introducing midsole and upper design characteristics that promote dorsiflexion of the digits and optimal arch apex heights, (available soon)
- introducing midsole and outsole geometries and characteristics featuring ground contact angles that promote rotational axes through the bone structure's center of mass thus a reduction of acceleration and velocities. (available soon)

6.1.1 Foot Strengthening System

6.1.1.1 The Mechanical Physics

As identified in Section 4.2.2, Unhealthy Musculoskeletal Mechanics, the mechanical physics of the arch system dictate that as the structure collapses, the vertical forces of body weight result in greater tensile loads on the plantar aponeurosis. In the case of orthotics, vertical loads are borne by the orthotic rather than the skeletal structure. (Section 5.2.1, Orthotics) This leads to an increase of degenerative stress and/or atrophy, and an increased dependence on the artificial support. In such instances, the body is naturally responding (via modeling or conditioning) to the inhibiting/restriciting environmental influences of conventinal footwear.

This modeling or conditioning process, however, can also be used to advantage by incorporating into footwear/insole design a safe nociceptive/proprioceptive response stimulus to the foot's sensitive plantar surface.

The Arch Activation Foot Strengthening System™ takes advantage of these mechanical dynamics to stimulate a nociceptive/proprioceptive (reflex) response, which safely initiates and retrains the muscle-firing sequences that align, stabilize, and lock the foot's interlocking bones. The shape and unique dome design (Figure 84) generates a gentle recoil pressure on the foot's sensitive plantar surface area at a location directly beneath the midfoot that corresponds to the Optimal Arch Apex (height) during weight bearing. (Figures 85 & 86)

The System incorporates a series of resilient and progressively firmer/higher interchangeable inserts that act as nociceptive/proprioceptive catalysts to stimulate an involuntary adaptive sensory response. (Figure 84)

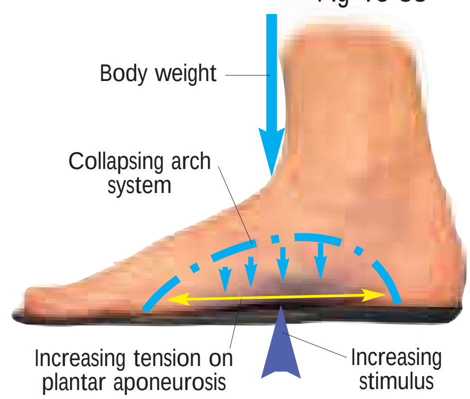
Typically, the user starts with the softest/lowest insert and progresses steadily through to the highest/firmest insert as the structure adjusts to the stimulus. The degree of stimulus generated is inversely proportional to the structural integrity of the foot's arch system; the higher and more stable the arch, the less stimulus generated.

With an unstable arch structure, the System produces a noticeable but not uncomfortable pressure (noxious stimulus) on the foot's plantar surface (activating the nociceptors/mechanoreceptors). (Figure 85) Due to the mechanical physics, the stimulus increases progressively as the arch system collapses (i.e., the forefoot and midfoot increasingly dorsiflex and evert while the rearfoot plantarflexes and everts). The pressure generated triggers a withdrawal reflex. By the nature of their design and materials, the dome and insert flatten out with increased loads and therefore do not brace or support the foot, nor do they mechanically manage the vertical loads.

Fig re 8

The shape, positioning, and resiliency of the dome and inserts allows the foot an uninhibited full range of motion through three-dimensional movement, (regardless of terrain geography or activity—standing, walking, running, diagonal cutting movements, etc.). The dome's shape and positioning directs the stimulus to a precise and consistant location on the plantar surface, ensuring that an appropriate protective adaptation response is initiated for optimal structural integrity in the foot's arch system, regardless of activity. (Figure 87)

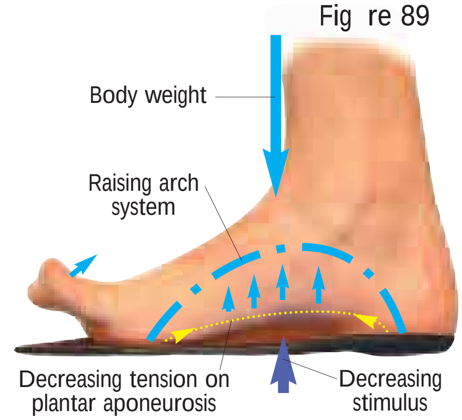
Fig re 88



The Arch Activation Foot Strengthening System™ stimulus affects the structure in two similar yet distinct ways—when (1) standing and (2) during gait.

1. When standing, as the arch system collapses, a constant increasing pressure is generated on the sensitive plantar surface. (Figure 88) The involuntary neuromuscular response (i.e., withdrawal reflex) is to retract the midfoot up and away from the pressure, plantarflexing and inverting the forefoot and midfoot, while dorsiflexing and inverting the rearfoot. (Figures 87 & 89) Every time the arch collapses, the foot is automatically "reminded" to stabilize itself, or "pull away" from the stimulus. Therefore, over time, the muscles are conditioned to maintain the Optimal Arch Apex necessary to effectively manage loads through the arch system. When standing for long periods, this repetitive action encourages the foot to "move," counteracting the lethargy propigated by footwear's restrictive nature and insulation from plantar surface stimuli.

Fig re 89



2. During gait, the Arch Activation Foot Strengthening System™ generates little or no pressure (noxious stimulus) while the foot is off the ground, however, as the arch system collapses upon weight-bearing, (Figure 88) the pressure (noxious stimulus) generated on the sensitive plantar surface increases proportionately to the intensity of activity (i.e., running will generate greater forces than walking). In these instances, the body's protective adaptive response to the noxious stimulus is an involuntary neuromuscular response (i.e., proprioceptive reflex) that

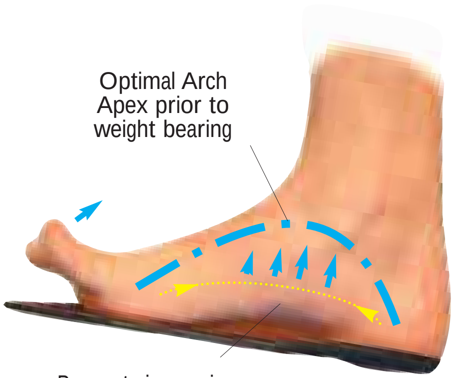


Fig re 90

attempts to pre-align the structure to its most stable position prior to weight-bearing as a means to mitigate the intensity of the noxious stimulus (relative to the activity levels). (Figure 90) Therefore, a higher arch dynamic is triggered when running compared to when walking. With each weight-bearing step, the foot is "reminded" to pre-stabilize itself to prevent the pressure from occurring. Over time, this conditions the appropriate muscle-firing sequences necessary to maintain the Optimal Arch Apex, prior to and during weight-bearing.

While standing or during gait, the nociecptive/proprioceptive reflex triggers contractions of the tibialis anterior, anterior extensors, and peroneals—the only muscles that can efficiently create and stabilize the arch apex and effectively raise the sensitive plantar surface area up and away from the noxius stimulus.

With sufficient ongoing use of the Arch Activation Foot Strengthening System™ the foot is safely and progressively conditioned to function as described in Section 3.2.2, Ideal Muscle Mechanics. Contraction of the tibialis anterior and peroneus brevis raises the medial and lateral aspects of the arch system, contraction of the peroneus longus "cinches" the mid-foot transverely, contraction of the extensor hallucis longus creates the "Windlass Effect" (i.e., dorsiflexion of the great toe and plantarflexion of the first metatarsal). The remaining extensors dorsiflex the associated digits and plantarflex the metatarsals. These muscle-firing sequences align the interlocking bones of the foot into the most structurally sound dome-like dynamic or Optimal Arch Apex. (Figures 88 & 89) The intrinsic musculature of the foot then fulfills its primary role—fine-tuning both balance and the structure's interaction with the ground.

The foot and kinetic chain are now capable of functioning as described in Section 3.2.5, Ideal Gait Mechanics, with optimal structural integrity and alignment maintained up throughout the body through a wide range of three-dimensional movements. The entire structure is mechanically capable of safely managing greater loads, is more energy efficient, demonstrates optimal natural shock management, and is capable of superior performance with the lowest risk of injury.

Through the continuous stimulation of neuromuscular responses, the Arch Activation Foot Strengthening System™ effectively counteracts the restrictive environmental influences of most footwear that lead to muscle atrophy and structural instability. However, excessively rigid or restrictive footwear can, to a relative degree, impede optimal structural alignment and mechanical function. Optimal results are achieved with soft flexible footwear that allow uninhibited dorsiflexion of the great toes and raising of the optimal arch apex.

6.1.1.2 Testing

The Arch Activation Foot Strengthening System™ has undergone extensive testing over its twenty plus years of development, with both quantitative and qualitative data acquired.

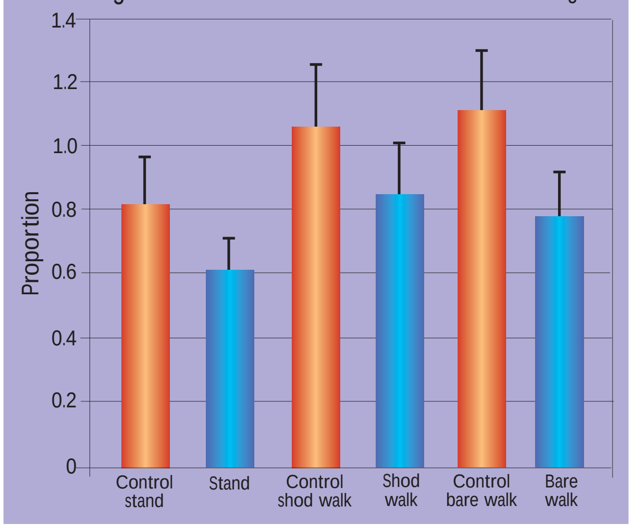
6.1.1.2.1 Changes in Foot Length

A six week pilot study on the effects of Arch Activation Foot Strengthening System™ prototypes, conducted at the University of Huddersfield in the UK, concluded that the technology appears to be affecting foot shape and, therefore, may affect foot function. A slight reduction in foot length, along with a shortening of the medial, lateral, and transverse arches, and reductions in the valgus index were observed in the test group. The results show trends as opposed to statistical significance due to the small sample numbers and lack of a control group. [129] The observations were similar to those found in a study on increased barefoot activity in the habitually shod.

6.1.1.2.2 Changes in Plantar Surface Area Due to Proprioceptive Response

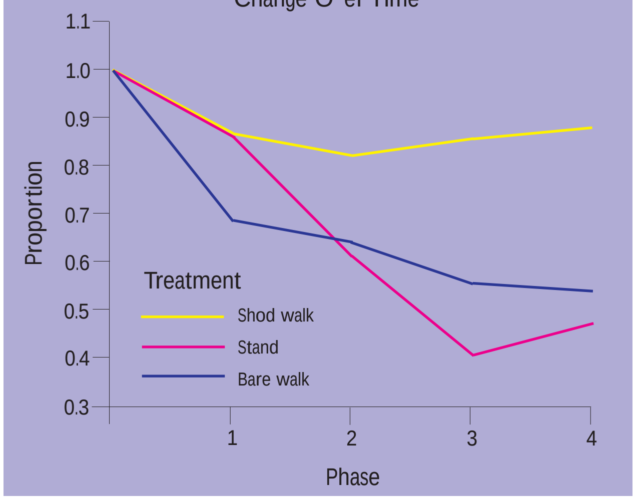
An eight week study on the effects of the Arch Activation Foot Strengthening System on weight bearing plantar surface area reinforced the Huddersfield findings. Test subjects consisted of a control group and an experimental group. All experimental group subjects used the Arch Activation Foot Strengthening System™ in their regular footwear over the duration of the study. [130] F-Scan weight bearing surface area measurements were taken of all subjects prior to their use of the System and changes in both groups were monitored every two weeks over the duration of the study. Three tests were conducted on both test groups: static unshod standing, dynamic unshod walking, and dynamic shod walking. The test subjects did not use the System in their footwear during the measurement process. Data was collected for two experiments: experiment one assessed the relative plantar surface change over the duration of the study between the experimental group and control group, and experiment two measured the proportional plantar surface area change in the experimental group over time.

Fig re 91 elati e Plantar S rface Area Change



xperiment One res lts A significant difference between the test and control groups was observed for the barefoot walking condition. After eight weeks, the test group showed an average 15% decrease in plantar surface area, while the control group did not change. No significant differences were observed among the test and control group for the standing and the shod walking conditions, however, a general trend was observed, indicating a decrease in surface area over time for the standing (averaged 11%) and shod walking conditions (averaged 10%). (Figure 91)

Fig re 9 Proportional Plantar S rface Area Change O er Time



xperiment Two res lts An interaction was observed between treatment type and phase. Both standing and barefoot walking showed a marked decrease in plantar surface area over time, while shod walking decreased only slightly. (Figure 92)

The smaller decrease of plantar surface area observed in the unshod standing results vs. the unshod walking results is attributed to the reduced loads while standing (lower proprioceptive stimulus) and the increased loads while walking (greater proprioceptive stimulus). In the shod walking condition, the initial decrease, followed by a leveling off, is attributed to the constricting effect of footwear.

The study concluded that the decrease in weight bearing plantar surface area was attributed to an anatomical restructuring of the foot in response to the gradual biofeedback created by the Arch Activation Foot Strengthening System™. It also concluded that the System stimulated the foot's supporting musculature to fire in sequences similar to those attained in barefoot gait.

Although the limitations of F-Scan measurement protocols prevented plantar surface area measurements while the Arch Activation Foot Strengthening System™ was in use, the above noted studies clearly demonstrate a relationship between the System's use and a decrease in weight-bearing plantar surface area and foot length, over time. As identified in Section 3.2.2, Ideal Structural Mechanics, a reduction of arch (tie beam) length corresponds to an increase in arch height in the same foot. In addition, there is a direct relationship between the length and height of a foot's arch system and the structure's load bearing capabilities. During weight bearing gait, a decrease in arch (tie beam) length can only be achieved by the muscle-firing sequences that raise the midfoot and create the Windlass Effect, [64, 65, 66] {i.e., contraction of the tibialis anterior and peroneus brevis raises the medial and lateral aspects of the arch system, contraction of the peroneus longus "cinches" the mid-foot transverely, contraction of the extensor hallucis longus creates the "Windlass Effect"(i.e., dorsiflexion of the great toe and plantarflexion of the first metatarsal)}. (Section 3.2.4, Ideal Gait Mechanics).

6.1.1.2.3 Motion Capture Gait Analysis

Two motion capture studies were undertaken to determine the Arch Activation Foot Strengthening System™'s effect on the foot's structural mechanics.

6.1.1.2.3.1 Study One

The test protocol involved videotaping the medial sides of both subjects' feet (barefoot) prior to the start of the study, then every two weeks thereafter, over an eight week period. A digital video camera was set one meter away from and perpendicular to a reference mark placed on the ground, indicating exact positioning of the medial side of the foot. Once in position, all subjects were asked to raise their great toe as high as possible during stationary full weight bearing. The subjects then made a number of walking passes (with full weight bearing contact on or near the reference mark) through the camera's viewing range. (Figure 93)


Fig re 93

The test group subjects consisted of twelve police officers that walked for the majority of their eight hour shift. During work hours they wore regulation footwear (same style and design). All subjects used the Arch Activation Foot Strengthening System™ in all their footwear over an eight week study period, and made no other changes in their regular activities.

At the end of the study, the video data was analyzed in freeze frame (at 30 frames per second). Angular measurements were taken on the degree of great toe dorsiflexion, frame by frame, during:

- full weight bearing (maximum possible while standing),
- at heel strike (walking gait),
- immediately prior to forefoot contact (walking gait), and
- at toe off (walking gait).

The averaged results indicate substantial increases in great toe dorsiflexion over the duration of the study. (Figure 94) Great toe dorsiflexion increased by 26.45% for maximum weight bearing (while standing), 34.29% at heel strike, 51.43% at pre-forefoot contact, and 15.9% at toe off. These results clearly indicate that the Arch Activation Foot Strengthening System™ made a significant beneficial impact on the muscle-firing sequences required to stabilize the foot structure prior to full weight bearing.

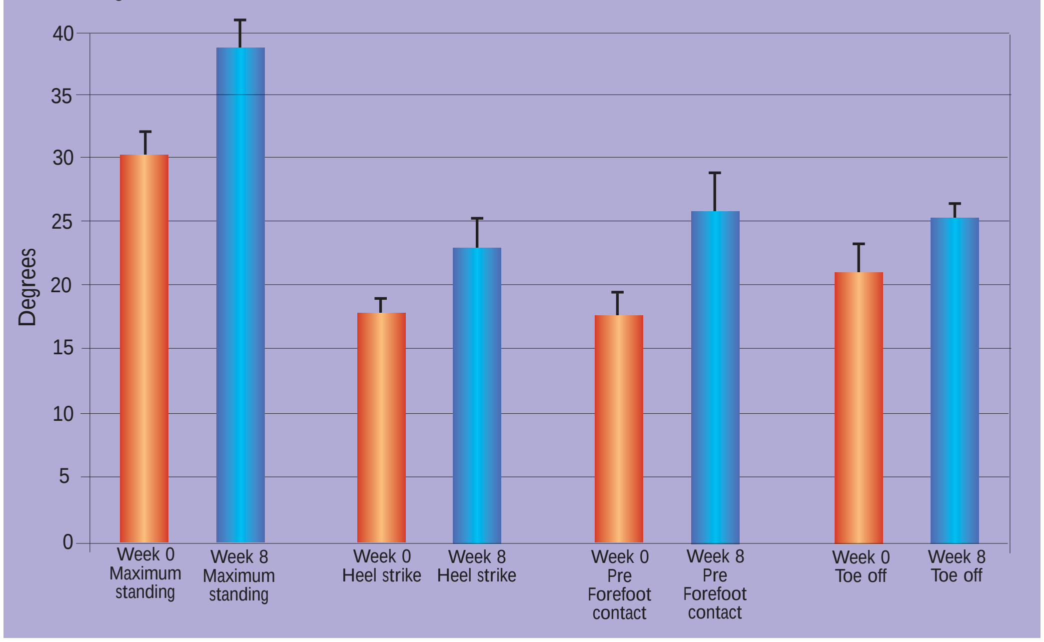
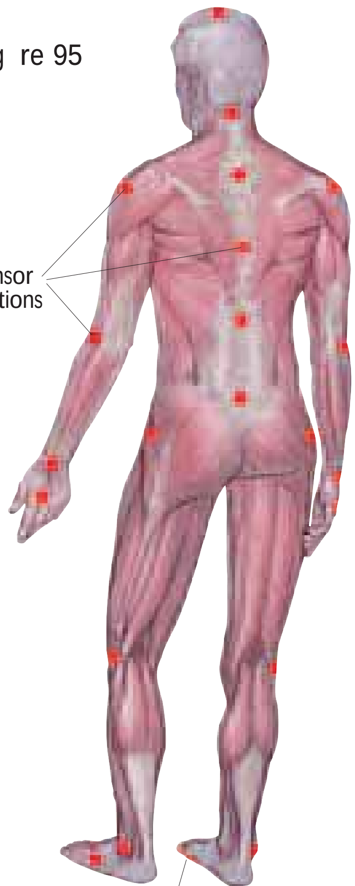


Fig re 94 Change in reat Toe Dorsiflexion - O er ight ee s

6.1.1.2.3.2 Study Two

Motion capture analysis was undertaken to determine the Arch Activation Foot Strengthening System™'s effect on structural mechanics during its actual use. Data was collected using the protocols outlined in Study One (above) to determine angles of great toe dorsiflexion for the barefoot condition during the walking gait cycle. This information was then used as a baseline for data collected during repetitive gait cycles using a strain gauge (timing and degree of great toe dorsiflexion) and magnetic positioning sensors (relative joint alignment positioning).

Fig re 95



The study monitored the musculoskeletal function and alignment of three test subjects that had used the Arch Activation Foot Strengthening System™ for at least two months, and one control subject with no previous orthotic or shoe insert experience. The control subject was a twenty-six year old male with no history of foot problems—demonstrating "normal" foot function. The demographics of the test group were as follows:

- Subject one: male, age 37, presented a rigid pes cavus (high arched) foot with a history of foot-related pathologies including hallux limitus. (System use: Level 6-7)
- Subject two: male, age 47, presented a hypermobile normal foot with a history of foot-related pathologies including excessive callousing, bunionette, ankle sprains, and knee problems (two minimal incision surgeries for medial meniscus, MCL & ACL repairs, and one complete ACL reconstruction). (System use: Level 6-7)
- Subject three: male, age 26, presented an inflexible pes planus (flat) foot with a history of repeated ankle sprains. (System use: Level 3)

All subjects were fit, in good health, and participated in regular athletic activities and the test subjects had been free of injury since using the System.

Each subject was fitted with magnetic positioning sensors at each joint and a strain gauge underneath the first metatarsal and great toe. (Figure 95) The sensors' 3D positioning (motion capture) was monitored through a sensory field (8' x 8' x 8') created by an overhead sensory grid. The strain gauge measured timing and degree of dorsiflexion of the great toe. Each subject undertook a number of activities: walking, running, and diagonal cutting movements through the sensory field; and walking and running (jog and sprint) on a treadmill. The test group first performed these activities barefoot, then in at least two types of regular footwear (casual and athletic), first without, then with the Arch Activation Foot Strengthening System. In both instances, the control subject performed the activities barefoot, and then shod, without the System.

The data for the three test subjects was collected in three classifications: barefoot gait, regular shod gait without the Arch Activation Foot Strengthening System™, and shod gait with the System. The control subject's data was also classified in the same manner, but without the System. The motion capture data from the sensors was digitized, time code synchronized, and line graphed.

During barefoot gait, all subjects demonstrated a significant degree of nocicepetive/proprioceptive dorsiflexion of the great toe that began during the swing phase and increased at heel strike to maximum, immediately prior to forefoot contact. (Figure 96 & 97) The degree of nocicepetive/proprioceptive dorsiflexion pior to forefoot contact was directly proportionate to the activity levels. Progressively

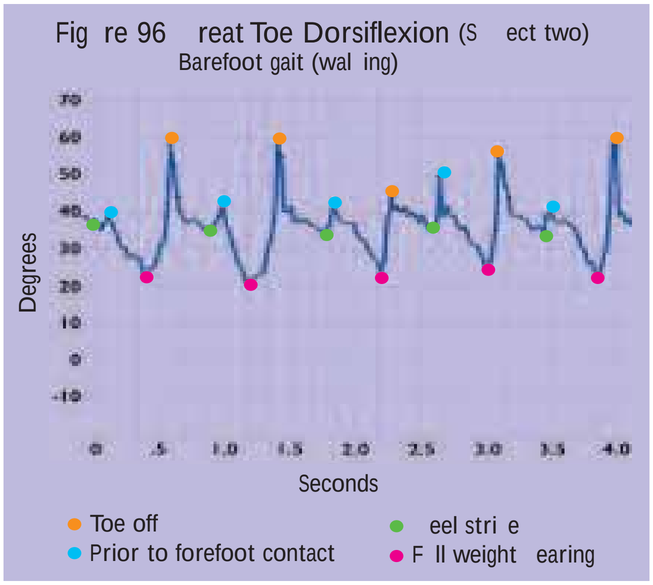


Fig re 96 reat Toe Dorsiflexion (S ect two)
Barefoot gait (wal ing)

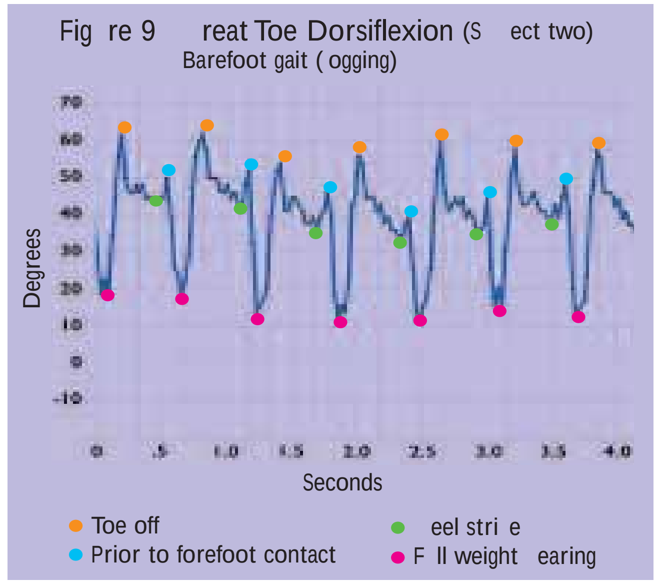


Fig re 9 reat Toe Dorsiflexion (S ect two)
Barefoot gait (ogging)

greater degrees of nocicepetive/proprioceptive great toe dorsiflexion were observed between walking, a light jog, and a brisk jog. The highest degree of great toe dorsiflexion occurred at toe off in the barefoot condition.

During regular shod gait (walking or running), all subjects demonstrated no appreciable nocicepetive/proprioceptive great toe dorsiflexion prior to heel or forefoot contact. (Figures 98 & 99)

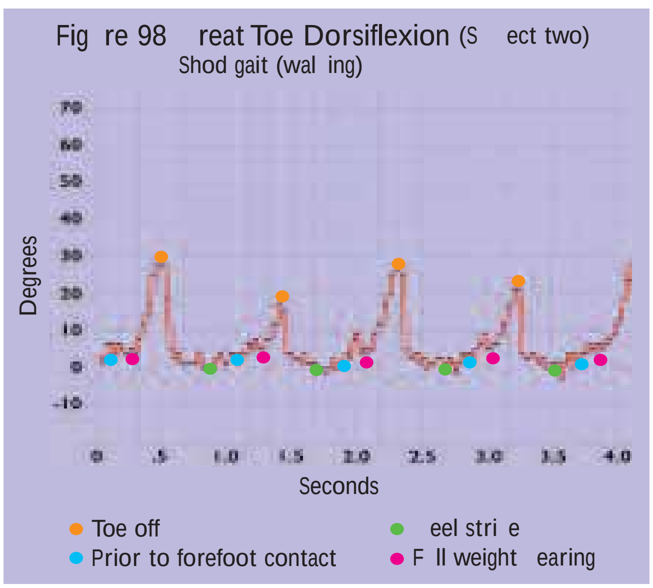


Fig re 98 reat Toe Dorsiflexion (S ect two)
Shod gait (wal ing)

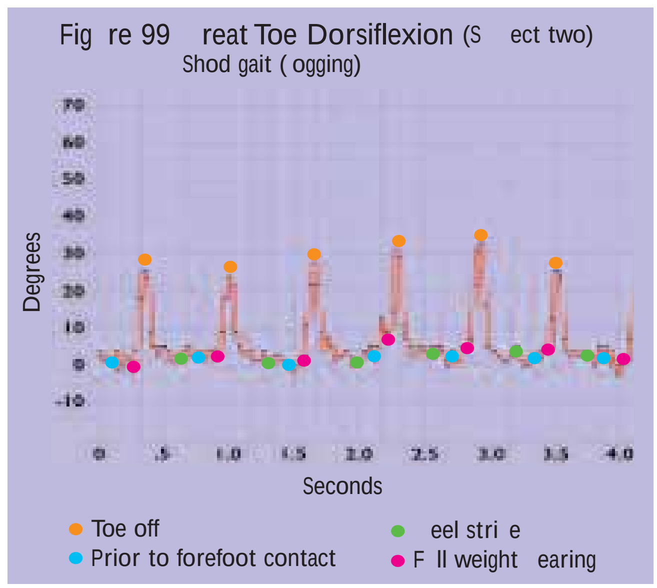


Fig re 99 reat Toe Dorsiflexion (S ect two)
Shod gait (ogging)

During shod gait with the Arch Activation Foot Strengthening System™, the test subjects demonstrated a significant degree of nocicepetive/proprioceptive great toe dorsiflexion during all activities. (Figures 100 & 101) The timing and trends of great toe dorsiflexion mirrored those observed during barefoot gait. (Figures 96 & 97)

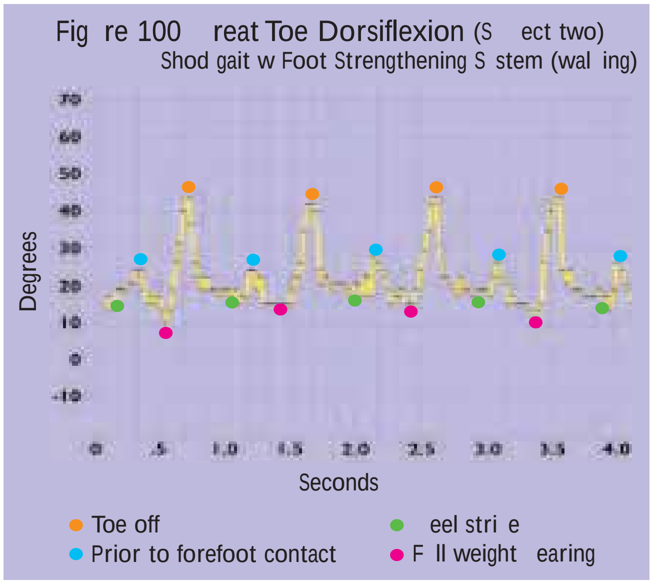


Fig re 100 reat Toe Dorsiflexion (S ect two)
Shod gait w Foot Strengthening S stem (wal ing)


Fig re 101 reat Toe Dorsiflexion (S ect two)
Shod gait w Foot Strengthening S stem (ogging)

Footwear design characteristics (restrictions of toe box depth and midsole /outsole rigidity) contributed to a 10 degree reduction in great toe dorsiflexion immediately prior to forefoot contact and toe off when compared to the barefoot condition.

The study results clearly demonstrate that during barefoot gait, adaptive (i.e., protective) nociceptive/proprioceptive muscle-firing sequences (re: dorsiflexion of the great toe) occur in corresponding degrees in response to activity levels. The results also indicate that footwear inhibits these natural proprioceptive adaptive (i.e., protective) muscle-firing sequences, which are required for optimal stuctural alignment and stability. (Figure 102) It was also clearly demonstrated that regardless of foot type, the Arch Activation Foot Strengthening System™ stimulated these necessary nociceptive/proprioceptive muscle-firing sequences in the same footwear that had previously prevented them. These observations, while remarkable, suggest that the Arch Activation Foot Strengthening System™'s results could be further improved with footwear designed to facilitate the great toe's dorsiflexion and the formation of the Optimal Arch Apex.

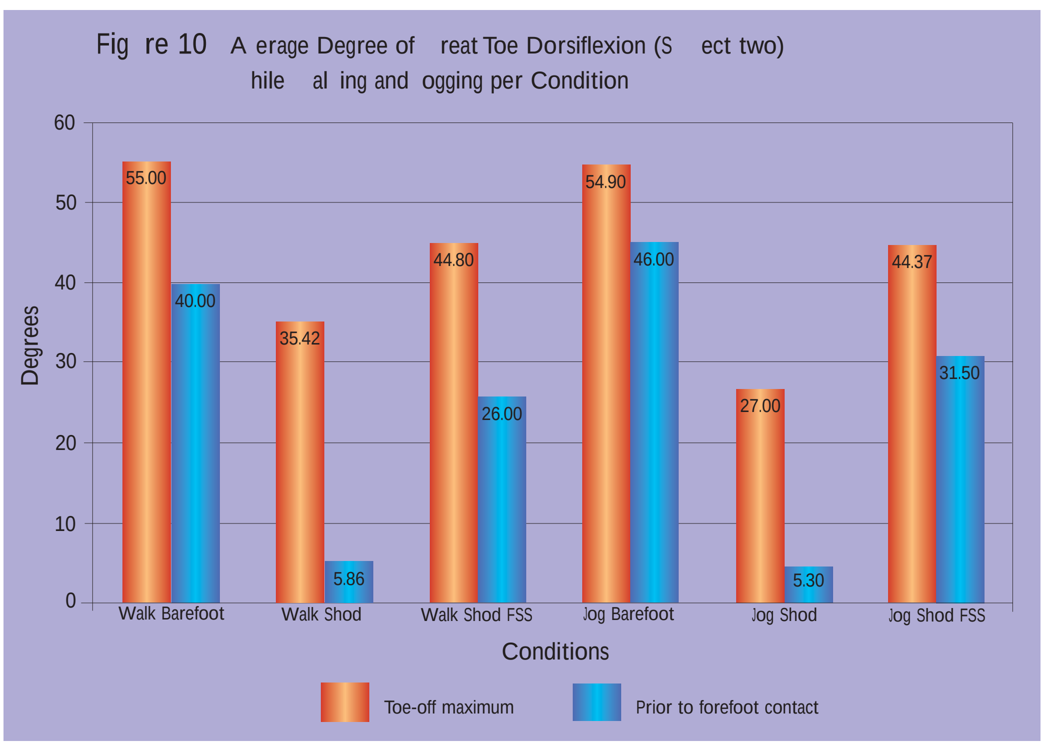


Fig re 10 A erage Degree of reat Toe Dorsiflexion (S ect two)
hile al ing and ogging per Condition

The motion capture data was used in the development of an animated 3D skeletal model of the human body. (Figures 103-106:

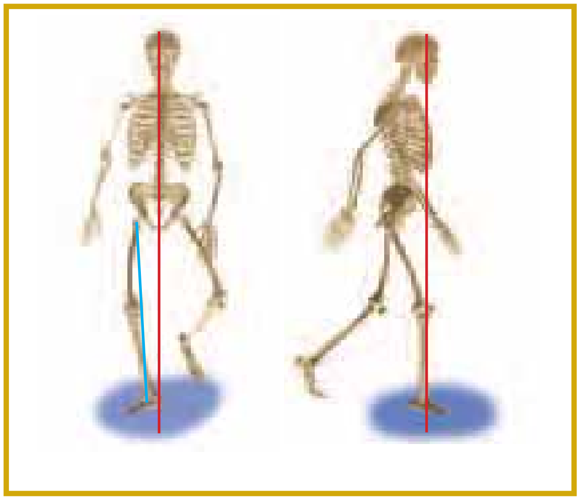


Fig re 103 Shod gait witho t Foot Strengthening S stem (ogging)

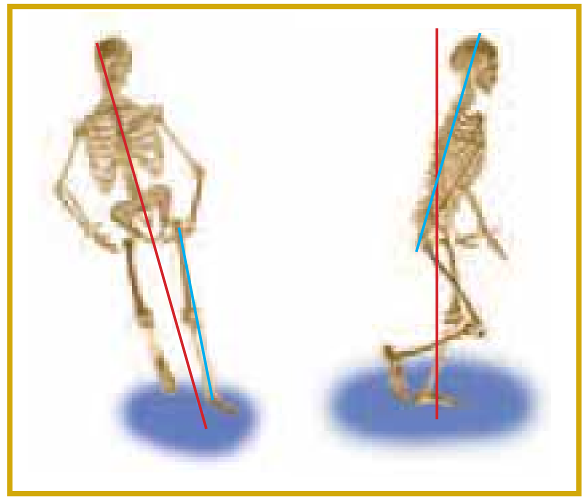


Fig re 104 Shod gait witho t Foot Strengthening S stem (diagonal c tting mo ements)

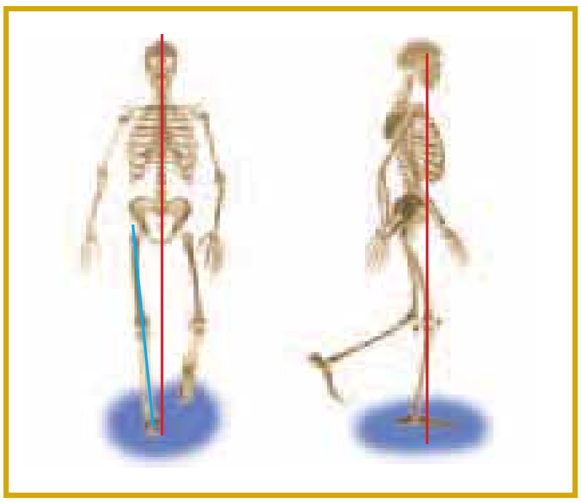


Fig re 105 Shod gait with Foot Strengthening S stem (ogging)

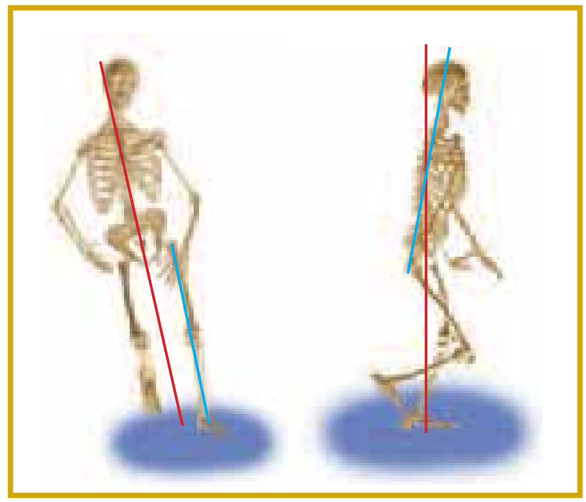


Fig re 106 Shod gait with Foot Strengthening S stem (diagonal c tting mo ements)

still captures of animation sequences) This animated skeletal model demonstrates the relative structural alignment during various movements. The viewer is able to isolate areas of interest by being able to enlarge their view of a specific joint movement, or can observe the model as a whole in “real time” slow motion and freeze frame throughout the animation sequences. An infinite number of camera (viewing) angles is possible.

The variances in structural alignment and function, relative to the degree of dorsiflexion of the great toe during ground contact, are clearly demonstrated in Figures 103 to 106. These freeze frame images illustrate comparative skeletal alignment during jogging and side to side cutting movements (at the identical point in time during the gait cycle) while shod with the Arch Activation Foot Strengthening System™, and while shod without the System.

A direct relationship is demonstrated throughout the gait cycle between the degree of great toe dorsiflexion and the efficiency of alignment at the ankle and knee. A higher degree of great toe dorsiflexion, prior to forefoot contact, corresponded to an increased efficiency in structural alignment. As identified earlier, optimized alignment correlates to increased stability and less degenerative stress throughout the kinetic chain.

6.1.1.2.4 Structural Relationship Between Arch Length and Height

Photographic measurement and X-ray protocols were developed to determine the changes in structural alignment due to increased dorsiflexion of the great toe and the mechanical relationship between reduced foot length and arch height. These protocols were also used in identifying and comparing the relative structural changes caused by footwear, orthotics, and other insole products.

A pilot study was undertaken to examine the relationship between arch height and length relative to dorsiflexion of the great toe during full weight bearing. The study consisted of twelve subjects that had used the Foot Strengthening System™ for at least two months (to allow for a soft tissue adaptation period). The subjects presented foot types in the following proportions: three flat (inflexible, pes planus), seven normal (two hypermobile), and two high arch (rigid, pes cavus). Reference points were marked on the subjects' skin surface, and relative distances were measured between points. Arch length and height were measured externally, both with the foot relaxed, and with the great toe dorsiflexed. The averaged results show a 2.88% decrease in arch length with the great toes dorsiflexed.

A fixed camera position was used to take multi-angle photographs of structural positioning changes in the subjects' feet and lower legs during full weight bearing. (Figures 107 & 108)

Fig re 10 elaxed

Fig re 108 reat toe dorsiflexed (s ect two)

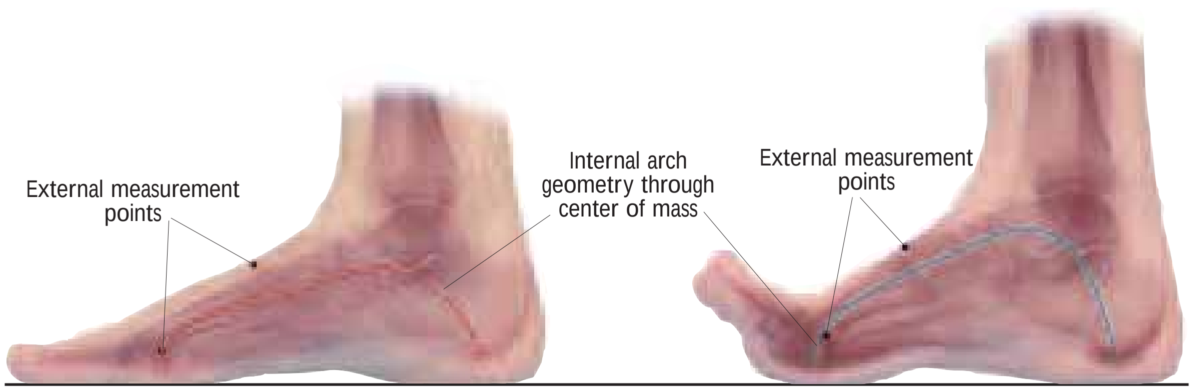


Fig re 109 Arches created thro gh center of mass (s ect two)

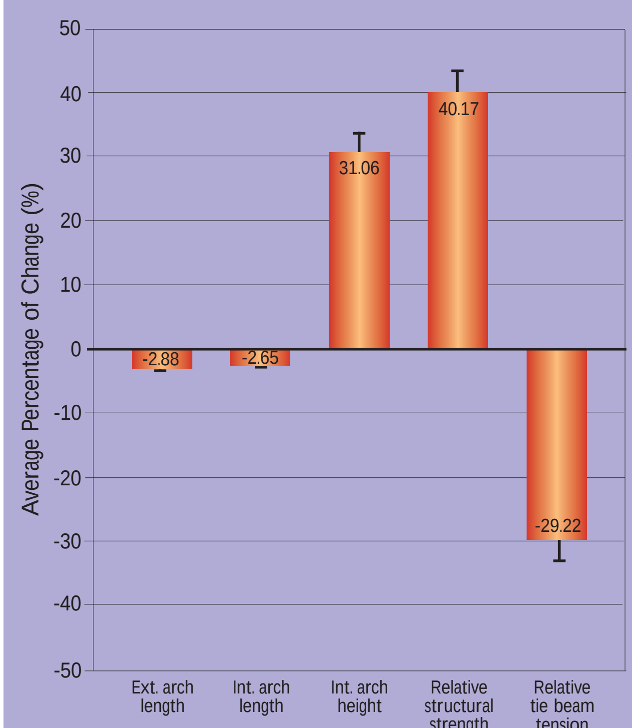
In all instances, alignment improved when the great toes were dorsiflexed as evidenced below.

Three subjects were selected, from the group of twelve, for a series of foot x-rays—one from each of the following foot types: high arch (Subject one—rigid, pes cavus), normal (Subject two—hypermobile) and flat (Subject three—inflexible, pes planus). Images were taken of their feet when relaxed, and with the great toe dorsiflexed—barefoot and shod—with and without the Foot Strengthening System™. X-rays were also taken of their feet, barefoot and shod, with and without custom orthotics and other insole devices.

To determine the relative structural positioning mechanics from the reference point measurements, the x-ray and photographic images of the medial side of the foot were digitized, combined, and scaled to actual size using Adobe Photoshop software. (Figure 109) Accurate internal structural measurements were then taken of the skeletal arch geometry (through the center of bone mass) and were compared to the external arch height and length measurements.

The data for the three x-ray test subjects was averaged into percentiles of internal and external structural change and factored into data collected from each of the foot type groups. (Figure 110) The averaged results indicated that for each 1% decrease in arch length, the internal arch height correspondingly increased by 10.78%. The internal structural geometry changes of the x-ray group were also averaged into the Relative Arch Strength and Relative Tie Beam Tension equations (see Section 3.1, Theoretical Ideal Structural Physics Model of the Foot). The results indicate a 1.2% increase in arch strength for every 1% increase in internal arch height.

Fig re 110 A erage Arch Length and eight Changes in elation to elati e Foot Str ct re Strength



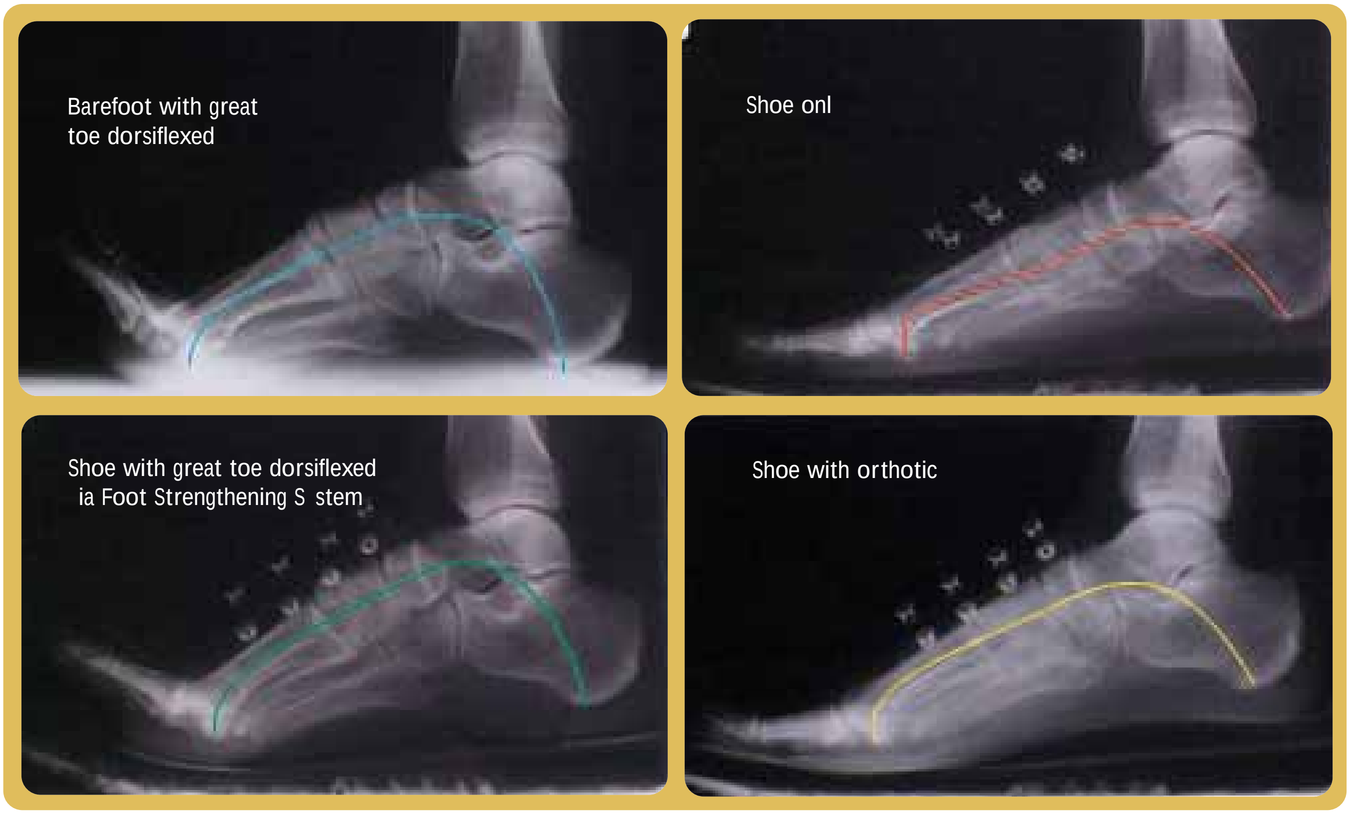


Fig re 111 S ect two

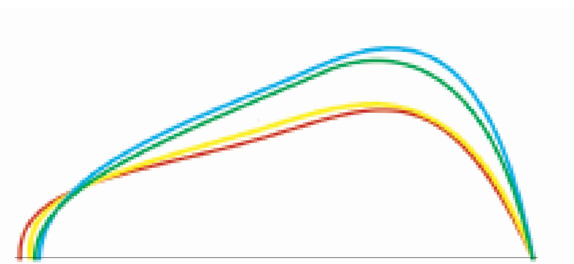


Fig re 11

Given the same loads, with the great toe dorsiflexed, the test group's structural geometry averaged a 40.17% increase in relative arch strength, and tension in the plantar fascia decreased by 29.22%.

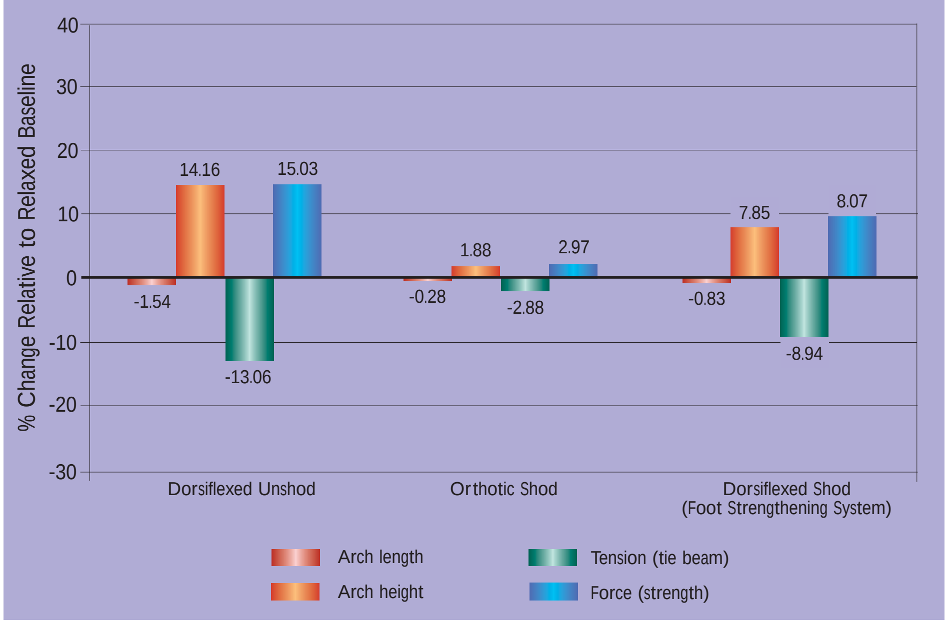
The structural alignment of the three x-ray subjects' arches through center of bone mass (Figure 111) were compared for four conditions:

1) barefoot—with the great toe dorsiflexed,
2) shod—regular footwear only,
3) shod—with the great toe dorsiflexed, via the Arch Activation Foot Strengthening System (as per Study Two 6.1.1.2.3.2), and
4) shod—with a custom orthotic (posted to four degrees at rearfoot and six degrees at forefoot).

The resulting arch profiles were then grouped (Figure 112) and their geometric measurements entered into the Relative Arch Strength and Relative Tie Beam Tension equations. (See Section 3.1, Theoretical Ideal Structural Physics Model of the Foot) The percentage of change demonstrated in each condition, compared to the regular shod condition, is reflected in the accompanying graphs. (Figures 113, 114 & 119)

Subject one (rigid pes cavus foot) demonstrated the lowest degree of change in all conditions. (Figure 113) The "barefoot—with the great toe dorsiflexed" condition demonstrated an improvement in relative structural strength of 15.03%, and tie beam tension was reduced by 13.06%. The "shod—with the Foot Strengthening System™" condition demonstrated an improvement in relative structural strength of 8.07%, and tie beam tension was reduced by 8.94%.

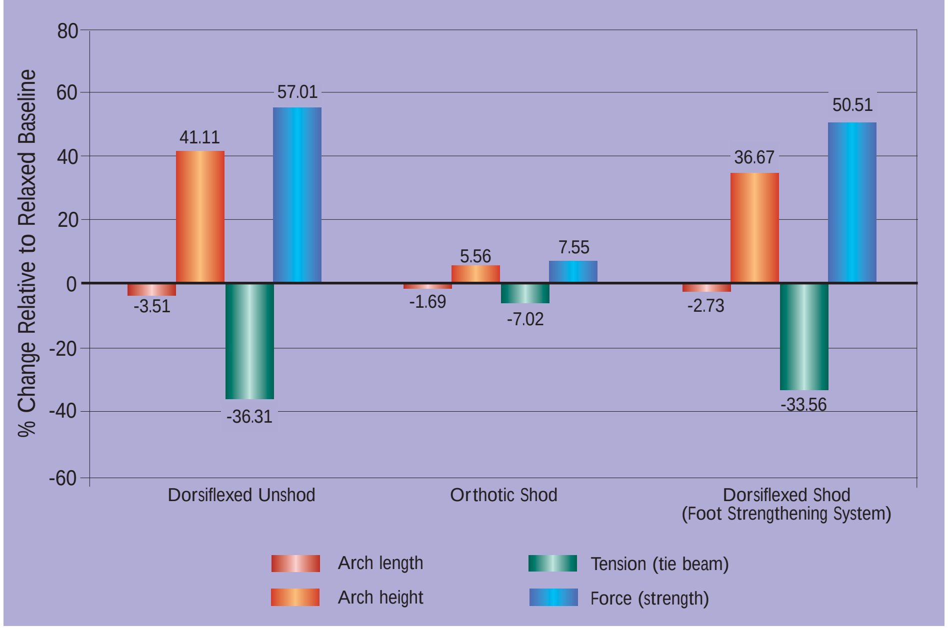
Fig re 113 Arch Length, eight, Tension, and Force Change elationships Condition (S ect one - rigid pes ca s foot)



In identical footwear, this condition demonstrated a 4.2 times greater improvement in structural alignment, 2.72 times greater structural strength, and 3.1 times less tie beam tension when compared to the "shod —with custom orthotics" condition, which demonstrated structural alignment changes (arch height increases) of 1.88%, structural strength increases of only 2.97%, and tie beam tension decreases of 2.88%.

Subject two (normal hypermobile foot) demonstrated the greatest degree of change in the "barefoot—with the great toe dorsiflexed" and "shod—with the Foot Strengthening System" conditions. (Figure 114)

Fig re 114 Arch Length, eight, Tension, and Force Change elationships Condition (S ect two - normal h permo ile foot)



The "barefoot—great toe dorsiflexed" condition's relative structural strength improved by 57% and tie beam tension was reduced by 36.31%. The "shod—with the Foot Strengthening System™" condition's structural strength improved by 50.5% and tie beam tension was reduced by 33.6%. In identical footwear, this condition demonstrated a 6.6 times greater improvement in

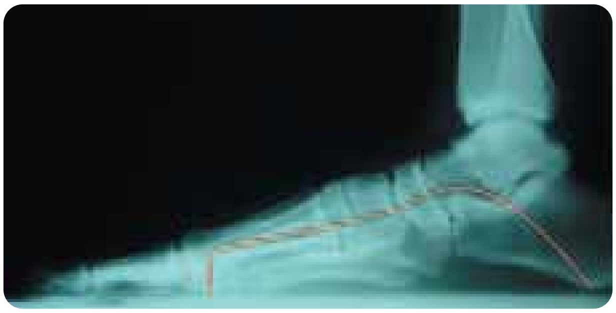


Fig re 115 S ect three (0 001)

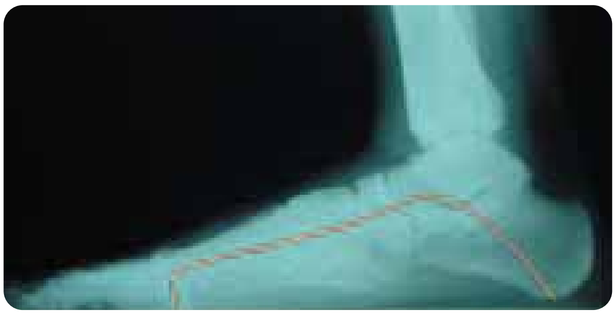


Fig re 116 S ect three (0 00)

Fig re 11 S ect three (0 001)

Fig re 118 S ect three (0 00)

structural alignment (arch height), 6.7 times greater structural strength, and 4.8 times less tie beam tension, when compared to the "shod—with custom orthotics" condition, which demonstrated structural alignment (arch height) improvements of 5.56%, structural strength increases of only 7.55%, and tie beam tension decreases of 7.02%.

Subject three (inflexible pes planus foot) did not demonstrate a functional arch geometry through center of bone mass in either the relaxed barefoot or shod conditions. (Figure 115)

In order to compare structural strength and tie beam tension changes, a stable arch was assumed and relative geometric measurements were taken and incorporated into the Relative Strength and Tie Beam Tension equations. (Figure 119) With this considered, the "barefoot—great toe dorsiflexed" condition's relative structural strength improved by 21.75% and tie beam tension was reduced by 17.86%. The "shod—with the Foot Strengthening System™" condition's structural strength improved by 15.22% and tie beam tension was reduced by 13.21%. In identical footwear, this condition demonstrated a 1.6 times greater improvement in structural alignment (arch height), 2.23 times greater structural strength, and 2 times less tie beam tension when compared to the "shod—with custom orthotics" condition, which demonstrated structural alignment improvements (arch height) of 6.14%, structural strength increases of 6.82%, and tie beam tension decreases of 6.38%.

Subject three had used the Foot Strengthening System™ for the least amount of time and was still progressing though the System's insert stages, therefore, follow-up x-rays and measurements were taken approximately six months later. (Figures 116 & 118)

These later x-rays, when compared to those initially taken, clearly illustrate improved structural alignment and mobility. The structural alignment in the later weight bearing unshod condition (Figure 116) reflects an improved functional arch geometry (note 5th metatarsal and cuboid positioning). Great toe dorsiflexion improved from 33° (Figure 117) to 71° (Figure 118).

New structural geometry measurements were taken and incorporated into the Relative Strength and Tie Beam Tension equations. Significant improvements in structural strength, and reduced tie beam tension, are demonstrated. (Figure 120) The "barefoot—great toe dorsiflexed" condition's relative structural strength improved to 35% and tie beam tension was reduced by an additional 8.17%, to a total reduction of 26.03%. The "shod—with the Foot Strengthening System™" condition's structural alignment (arch height) improved from 10% to 17.05%, structural strength improved from 15.22% to 21.16%, and tie beam tension was further reduced to 17.47%. In identical footwear, this new condition demonstrated a 2.8 times improvement in structural alignment (arch height), 3.1 times greater structural strength, and 2.7 times less tie beam tension when compared to the "shod—with custom orthotics" condition.

The above six studies clearly demonstrate a relationship between the use of the Foot Strengthening System™ in footwear, and the nociceptive/proprioceptive muscle activation necessary to optimally align and stabilize the foot, prior to and during weight bearing ground contact. It is also clear that this muscle activation is a natural adaptive response to activity levels during barefoot gait, and is virtually eliminated during regular footwear use.

Fig re 119 Arch Length, eight, Tension, and Force Change elationships Condition (S ect three - inflexi le pes plan s foot)(0 001)

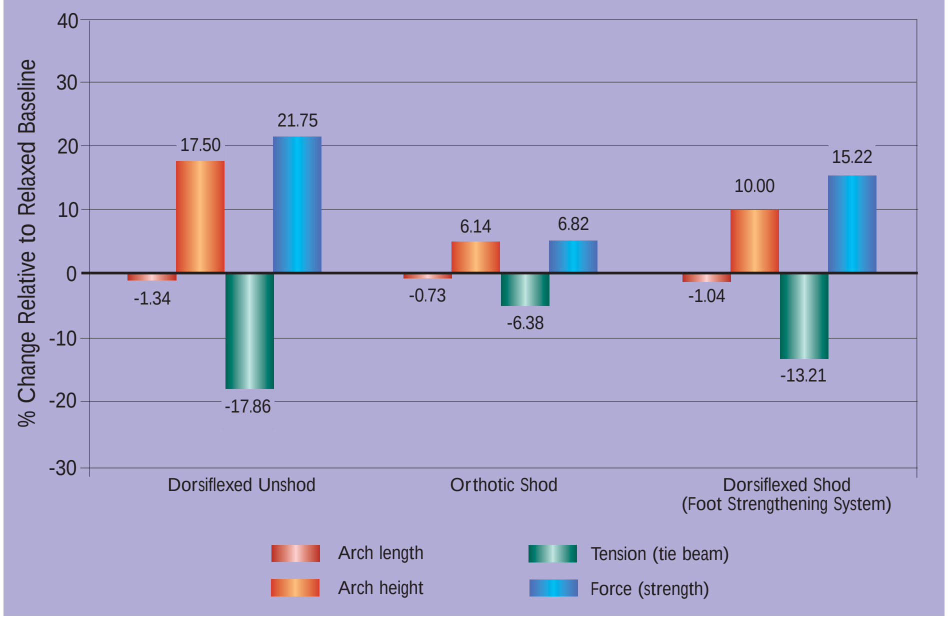


Fig re 1 0 Arch Length, eight, Tension and Force Change elationships Condition (S ect three - inflexi le pes plan s foot)(0 00)

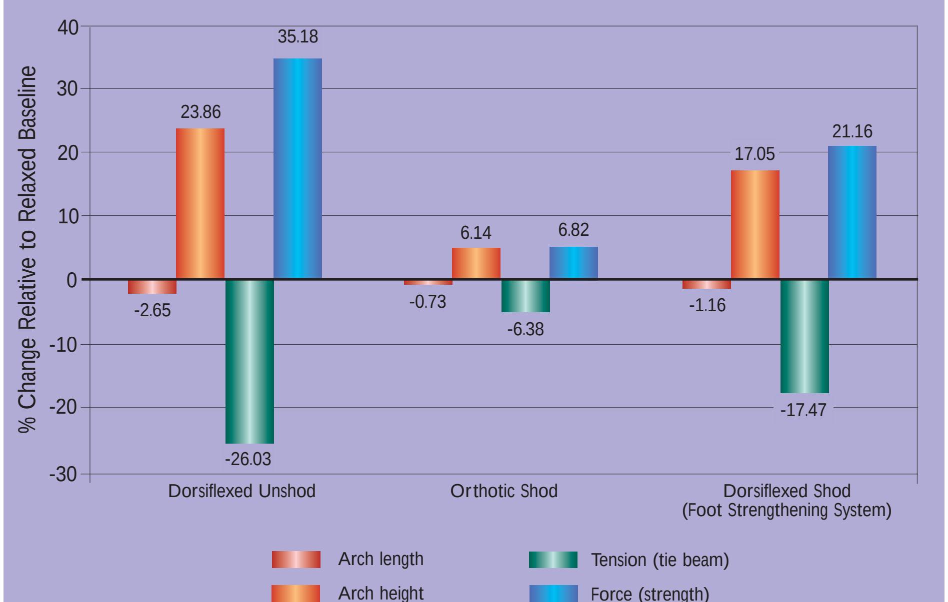


Fig re 1 1 Degree of Bac Pain Normali ed

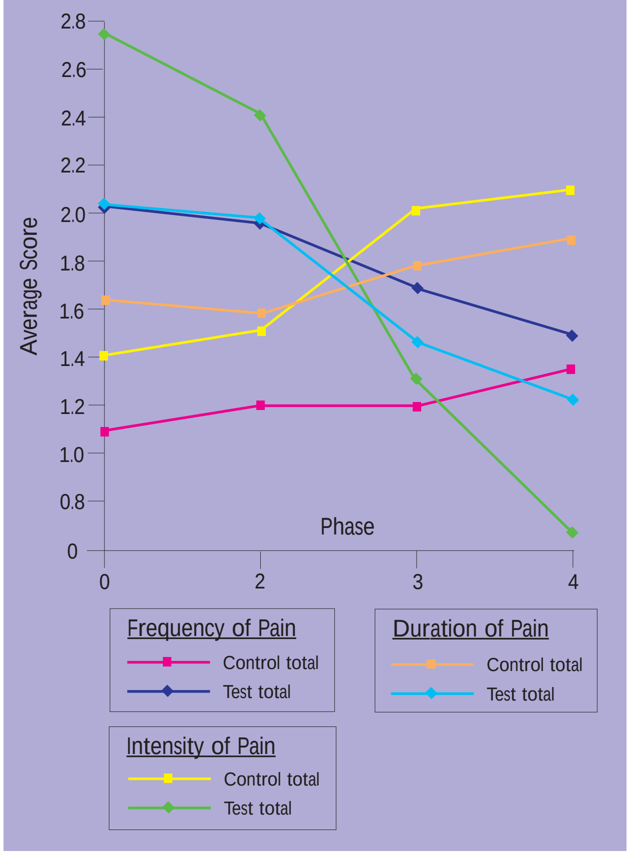
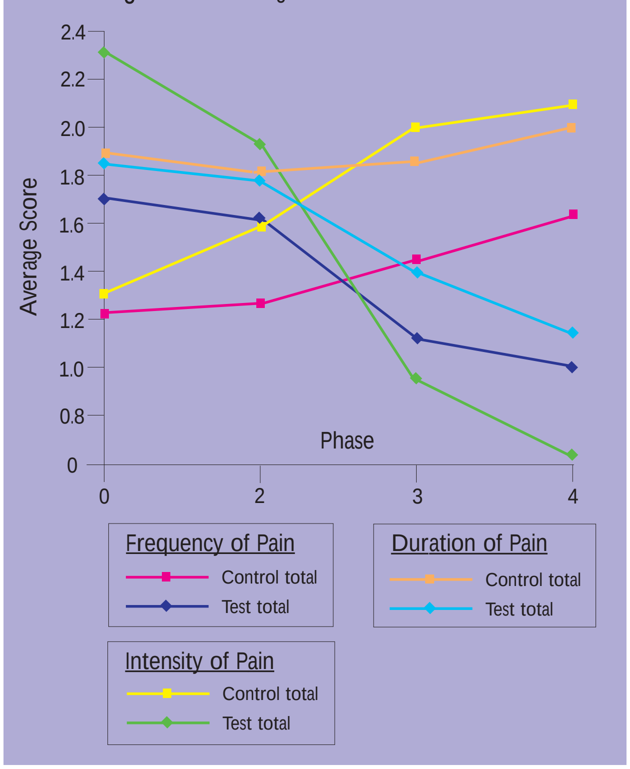


Fig re 1 Degree of Foot Pain Normali ed



It has also been demonstrated that pre-forefoot contact muscle activation significantly improves the foot's structural alignment and strength, which dramatically reduces the damaging horizontal (tie beam) forces (tensions). In footwear, this improved muscle activation and structural stability increases circulation to the muscles of the foot and improves the balance of strength and flexibility—all of which are necessary for optimal foot health.

In addition, the foot's improved structural alignment and functional dynamics clearly demonstrate the greatest degree of benefical change (when compared to orthotics) in structural alignment through the lower leg. There is a significant improvement in structural efficiency (performance) and a reduction of unhealthy stress in the muscles and at joints. This data provides compelling evidence that the benefits of the Arch Activation Foot Strengthening System™ are vastly superior to those of conventional orthotics.

6.1.1.2.5 The Foot Strengthening System's Effect on Foot and Back Pain

In a 12 week pilot study conducted for Scholl PLC, a test group of sixty-five foot and back pain sufferers used a developmental prototype of the Arch Activation Foot Strengthening System in their regular footwear. Their results were compared to those of a control group, consisting of twenty-two foot and back pain sufferers, who were not users of any insole or orthotic product. A Mankoski Pain Scale questionaire was used to monitor both groups bi-weekly. All subjects' lifestyles required that footwear be worn in an accumulated weight bearing manner for a minimum of six, but not more than nine, hours per day. All subjects were asked to maintain their regular pre-study lifestyle. Neither group used any pain medication during the test period. The study results indicated that the System users demonstrated a significant reduction of intensity, duration, and frequency of foot and back pain, while the control group demonstrated an increase of intensity, duration, and frequency of foot and back pain. (Figures 121 & 122) [128]

6.1.1.3 Clinical Observations

The Foot Strengthening System™ has also been tested in hospital and clinical settings, and by a number of medical professionals in their clinical practices. Their observations support the System's positive effect on foot shape and function, and its alleviation of various foot-related pathologies.

One of the most commonly reported advantages is high patient compliance with the Foot Strengthening System™, especially when compared to alternative treatment methods.

- Thomas McClain, MD, A.B.O.S., F.A.A.O.S., "I am convinced that the concepts presented by Barefoot Science offer a new, revolutionary approach to understanding, diagnosing and treating the vast majority of foot-related pathologies. Barefoot Science™ philosophies provide a vastly superior understanding of foot function when compared to conventional views and clearly offer the most effective preventative and rehabilitative treatment option available today to address poor structural integrity of the foot's arch system.

  I have personally used this device and have recommended it to numerous family members, friends, acquaintances and patients—many having previously used custom orthotics without success in alleviating their symptoms.

  Invariably, patients are reporting definite satisfaction with their introduction to the use of Barefoot Science™ technology and are noting noted positive benefits. I have seen a number of cases where there was significant relief of symptoms of tarsal tunnel syndrome, plantar fasciitis, intermetatarsal neuroma, tendonitis of the peroneal and posterior tibial tendons, and definite decrease in pain associated with halux valgus, hammer toes, pes planus, and hind foot pronation. I have seen patients report improvement in illiotibial band syndrome, trochanteric bursitis of the hip, and low back pain due to chronic lumbar strain."

- Donna Lawrenson, B.Sc., O.T., director, Foot Care Centre, Women's College Hospital Foot Care Clinic (noted teaching hospital, associated with the University of Toronto), "The most common symptoms expressed by the patients referred to our Centre are arch pain, medial knee pain, heel pain and tired/fatigued feet.

  In reviewing the results of approximately 200 patients we have treated with the (Barefoot Science technology), 95% have expressed satisfactory relief of symptoms and the remaining 5% at least partial relief of symptoms."

- J. Kahn, M.D., F.R.C.S., F.C.C.S., "…a unique, simple and effective therapy that could be of immeasurable benefit to the multitudes suffering from foot disorders and related secondary effects…" "…both static and functional abnormalities have been studied and corrective measures addressed…"

"The experimental changes of shortening of the medial arch and load redistribution to the digits can only be explained by an activation of this normally inactive musculature associated with increased barefoot weight-bearing activity.

The data clearly demonstrates that the normally shod foot is capable of rehabilitation of foot musculature."

Robbins SE, Gouw JG, Hanna AM. Running Related Injury Prevention Through Innate Impact-Moderating Behaviour. Medicine and Science in Sports and Exercise 21(2): p. 1390, 1987 (American College of Sports Medicine).

- Bruce Comstock, B.Sc., D.C., "I have been using your product on my patients for two years now, in approximately 900 cases with spectacular results.

  The list of conditions that I have seen alleviated by Barefoot Science™ includes: bunions, metatarsalgia, claw toes, hammer toes, corns, plantar fasciitis, patellar malalignment, chondromalacia patellae, illiotibial band syndrome, recurrent low back pain of mechanical origin, recurring mid back pain, headaches, and TMJ syndrome. I have witnessed an 11 year old girl's lifelong 'pigeon toed gait' disappear in just four steps and I have seen claw toes of a 60 year old man become normal within a month using Barefoot Science™ insoles. I believe the most powerful evidence for the efficacy and uniqueness of Barefoot Science™ technology comes from the pleasure and gratitude expressed by individuals who, due to many years use of 'custom fitted' rigid orthotics, suffered severe and relentless pain, until Barefoot Science™ insoles completely ameliorated their symptoms—in most cases, taking less than three weeks to do so.

  Patients who accept my advice, to implement daily use of Barefoot Science™ insoles, have been approximately 95% compliant in their usage. Of these compliant users, I estimate the success rate (symptom eradication) to be 90-95%."

- Daniel Perlitz, M.D., "…the insoles have been effective in dramatically reducing, or eliminating my chronic symptoms of achilles tendonitis and plantar fasciitis. This has allowed me to take up new sporting activities, and pursue some which I was forced to abandon. I have found these insoles to be very comfortable after a short adjustment period, and have found the holistic benefits to be far greater than any other insoles I have used. I would strongly recommend the use of these insoles to any person pursuing any active lifestyle, or would like to. The concept of stimulating the foot such that it becomes independent makes perfect sense to me…"

6.1.1.4 Supplementary Treatments

While the majority of patients progress through the Arch Activation Foot Strengthening System™ without the need for any additional treatment, a relatively small number will require some extra attention. In most instances, these patients will have an earlier injury to the lower extremity that will have appeared to have healed, or that exhibits no symptoms. As "ideal foot function," muscle activation, and body alignment are restored through the use of the System, symptoms relating to the old injury may reappear. Recurrence of these symptoms may temporarily prevent initial or progressive use of the System until the injured site(s) are effectively treated. (Figure 123)

Most commonly, these symptoms arise from tension on the scar tissue and fibrosis formed during the old injury's healing process while the structure was poorly aligned. In effect, the scar tissue and fibrosis prevent the structure from achieving optimal alignment. In virtually all cases, these sites can be effectively treated through the modern methods of physiotherapy (to break down the scar tissue and fibrosis). The following patient case study [131] is provided as an example:

Fig re 1 3 Sites of istorical In r e iring Additional Treatment and Appropriate emedies

Common Symptomatic and Non-symptomatic Sites	Recommended Treatments
• Plantar fascia damage and scar tissue	- deep massage, ultrasound, electrotherapy
• Lateral ankle ligament fibrosis / old sprain	- ultrasound, manipulation of talus, calcaneus, & navicular
• Peroneii muscle and tendon fibrosis / old strain	- ultrasound, electrotherapy, cuboid, navicular & talus manipulation
• "Shin splints" micro tear and fibrosis of muscle fibers	- ultrasound, electrotherapy
• Peripatellar fascial fibrosis	- ultrasound, electrotherapy
• Fibrosis of erector spinales insertion at iliac crests	- ultrasound, electrotherapy & spinal manipulation
• Gluteal muscle insertion/IT band fibrosis	- ultrasound, electrotherapy, & massage
• Fibrosis of lateral calf region (gastrocnemious and soleus)	- ultrasound, electrotherapy & manipulation of calcaneus and midfoot regions

Thirty-nine year old male—excellent general health and fitness level.

Presentation: (Nov. 2000)

- Two year duration of *severe* foot, leg, and low back pain; most severe in foot/ankle/achilles.
- Quite literally "unable to walk."

History:

- October, 1998 via sports; severe twist of right foot/ankle—"hopped about" for three months—symptoms steadily worsening, right and left leg fatigue/ache due to hopping.
- Arose one morning with severely swollen legs and feet and was *unable* to walk or stand.
- Consulted in the following order: M.D.'s, orthopods, vascular specialist, and neurologists—prescribed Prednisone over seven months, which did ease swelling of legs—no diagnosis was offered.
- Attempts at walking steadily created back pain, first in lower and mid areas—complained that, "now everything hurt."
- November 1999—best ease of symptoms via massage, stretching, and swimming.
- The more weight bearing he did, the worse the right heel/achilles/foot pain would be.
- Avoided working and marriage problems—"almost suicidal."
- Conventional orthotics used only briefly, then intermittently, due to severe pain aggravation.
- Last six months or so, prior to presentation, experienced "horrible" pain due to ingrown first toe nails.

Treatment:

- Barefoot Science Arch Activation Foot Strengthening System™ implemented immediately
- Used mobilization and massage of feet.
- Used ultrasound in right lateral ankle ligaments and achilles tendon at calcaneus; low voltage on tender/inflamed areas.
- Phases of pain: "shin splints," under calcaneus, and in medial arch region.
- Primary Rx site(by Feb 01) was lateral region of calf (extensive fibrosis) and mid-region right peroneii muscles.
- By March 2001—only symptom was tenderness in calf.
- Had been reluctant to get "bigger shoes" and was afraid of advancing to higher stages of Arch Activation Foot Strengthening System inserts (being quite demanding/painful at early transitions).
- As shoes were corrected for size and progress was made through higher stages of inserts, symptoms eased steadily.
- Treatment dropped from three times per week to once a week in April 2001.
- July 2001—golf with no pain.
- October 2001—follow-up, no pain (did get toe nail removed).
- No recurrences to date (March 2002).

6.1.1.5 Diagnostic, Rehabilitative, and Preventative Use

There are a host of environmental influences (footwear, activity levels, etc.) that can cause, contribute to, or exacerbate an unstable foot structure and lead to a multitude of foot-related pathologies. From a diagnostic perspective, the mitigation of unhealthy environmental influences and related symptoms would logically provide the best opportunity to identify the more critical pathologies. The Arch Activation Foot Strengthening System™ provides the practitioner with a practical tool during the assessment process. Not only does the System demonstrate improved patient compliance, it also promotes increased awareness of the environmental influences (footwear types, lacing, etc.) that contribute to their symptoms.

Positive results, i.e., reduction or elimination of symptoms, most often indicate that continued use of the System will fully address (rehabilitate) the problem. Persisting symptoms are then addressed as outlined in Section 6.1.1.4, Supplementary Treatments. The small number of patients that do not respond positively to the System are then identified for more aggressive (and costly) treatment methods.

Significant research has been presented herein that provides compelling evidence that footwear use is the leading cause of the majority of foot-related pathologies. Furthermore, research indicates that footwear use has a negative impact on foot development through bone remodeling. The preventative use of the Arch Activation Foot Strengthening System™ counteracts the negative environmental influences of footwear—promoting healthier foot function and optimal remodeling dynamics. While these benefits are available to all ages, they could be greatest for children in their formative growth years.

6.1.1.6 Performance Enhancement

In addition to rehabilitative and preventative benefits, the Foot Strengthening System™ provides considerable benefit for those seeking performance enhancement—particularly athletes. As presented in Section 4.0, Footwear's Relationship to Lower Limb Biomechanics and Resulting Pathologies, from a mechanical perspective, current footwear designs negatively impact optimal structural alignment and related muscle function. The resulting inefficencies lead to compensatory muscle imbalances (overuse and underuse). In other words, when the stucture is poorly aligned, muscular energy is dissipated or lost due to poor mechanical geometry and greater muscular effort is required to obtain a desired performance level. Not only do muscles work longer and harder to achieve performance levels, a significant amount of the muscular energy must also be used to create and maintain optimal structural alignment—this energy is not available for performance.

Therefore, an optimally aligned structure not only generates less unhealthy stress, but a significantly greater degree of muscular energy is available, which can be applied more directly and efficiently to achieving higher levels of performance. Given equal outputs of muscular energy, the optimally aligned structure is more stable, more agile, faster, stronger (better mechanical geometry), and consumes less oxygen, than when it is poorly aligned.

From an athletic perspective, there are two primary footwear and foot function dynamics that must be considered:

- Static function—the foot doesn't follow the typical mechanical patterns of gait. Static function is demonstrated in sports such as skiing, skating, cycling, rowing, etc.,
- Dynamic function—the foot follows the typical mechanical patterns of gait. Dynamic function is demonstrated in sports such as football, track and field, soccer, basketball, baseball, etc., or in activities such as walking.

In both instances, optimal structural alignment contributes to improved performance although it is achieved in slightly different ways.

During static function, the foot's adaptive proprioceptive behaviour is not as prevalent due to the immobilizing effect of the boot or skate, or the fixed foot positioning common to cycling or rowing. Optimal structural alignment is best conditioned outside these sports, in dynamic function activities, then maintained (stabilized) in the static environment. During static function sports, the System is more effective at maintaining, rather than creating optimal structural alignment.

Using the Arch Activation Foot Strengthening System™ during dynamic function sports best facilitates or creates optimal structural alignment. In this dynamic, the System functions much like an exercise program—to retrain and maintain optimal foot function. The best results are achieved when the System is used with all footwear and not only during athletic activities.

Elite athletes may wish to use the System exclusively in their every day footwear *prior* to high levels of competitive use to allow the muscles to adapt—usually not longer than one month. After this adjustment period, the System should be used at all times and in all footwear for optimal benefits.

6.1.1.7 Proper Usage

The Arch Activation Foot Strengthening System™ *must* sit on a flat surface regardless of footwear type and all arch supports and contoured insoles *must* be removed. The System *must* be used exclusively and consistently throughout the day for optimum benefits. Using the System in some shoes while using a rigid orthotic in others is not recommended, and should be avoided.

The System will provide benefit in virtually all footwear with heel heights of two inches or less, however, the greatest benefit is realized when the System is worn in footwear that is soft and flexible with minimal restrictions over the arch area. Ideally, footwear should also provide adequate toe box depth and feature minimal heel flare and height. In all instances, lacing should be very loose (just enough to keep the shoe on).

Current footwear allows 25% to 75% of the Arch Activation Foot Strengthening System™'s optimal benefit, due to the design characteristics described in 4.1.2, Restrictions in Structural Alignment, although even benefits of 25% are considerably greater than those of existing treatment methods. (See Section 6.1.2, Barefoot Science Appropriate Footwear for Healthy Feet)

6.1.1.8 Choosing the Correct Version

The Arch Activation Foot Strengthening System technology is currently incorporated into 3/4 and full length versions and will soon be integrated directly into footwear design. The 3/4 length version is designed to be worn in shoes without removable insoles (i.e., dress shoes), and the full length model is designed for shoes with removable insoles (i.e., athletic shoes).

6.1.1.9 Insert (Stimulus) Progression

After selecting the appropriate size and version (full or 3/4 length), the user begins with the lowest/softest insert in the dome cavity of the insole body. While wearing the System as often as possible, the user continues with this insert level until the foot's arch structure is capable of raising itself away from the stimulus, which is accomplished over the "adjustment period." This is normally completed in two to seven days—when the pressure under the arch area is no longer noticeable. The lowest/softest insert is then replaced by one that is slightly higher/firmer and the process is repeated through a progressive series of stages that incorporate increasing height and firmness.

The adjustment period can vary according to age, activity levels, footwear design, and the percentage of time the Arch Activation Foot Strengthening System™ is used in all footwear. Children typically respond faster than adults, though no age is too advanced—seniors in their 70's and 80's have experienced remarkable results. In general, the more time people spend on their feet, the more active they are, the more accommodating their footwear, and the more frequent the System's use—the faster the adjustment period. (See Section 6.1.2, Barefoot Science Footwear for Healthy Feet)

Ideally, the person will progress through all the stages of inserts until they reach the final level. The height of the final level is determined by a mathematical formula that takes into consideration the relationship between the arch strength, relative to its height and tie beam length. (See Section 3.1, Theoretical Ideal Physics Model of the Foot)

6.1.1.10 Insert (Stimulus) and Footwear Type

Regardless of footwear type, the Arch Activation Foot Strengthening System™ *must* sit on a flat surface––all arch supports and contoured insoles *must* be removed. Footwear characteristics, such as restrictions over the great toe and arch area, will affect not only the adjustment period, but also the level of insert height/firmness. For example, the adjustment period can be prolonged if restrictions over the arch area prevent the arch from raising away from the stimulus. This can also cause uncomfortable pressure under the arch area. In some instances, these restrictions may cause cramping as the muscles overwork in an attempt to lift the structure away from the pressure, therefore, a person may use higher/firmer inserts in less restrictive footwear and lower/softer inserts in more restrictive footwear. The user simply progresses to the highest/firmest insert level that they find comfortable in their respective footwear.

6.1.1.11 Inserts (Stimulus) and Activity Levels

The user may find that varying activity levels also require different levels of insert height/firmness/softness. For example, standing generates significantly less force on the foot's arch system than walking or running. Consequently, someone who spends a considerable amount of time standing will require less stimulus to initiate the Optimal Arch Apex. In this case, a lower/softer insert may be preferred. Again, the user is free to select the highest/ firmest insert level that they find comfortable for each activity.

6.1.1.12 The Arch Activation Foot Strengthening System and Safety

The Arch Activation Foot Strengthening System™ cannot exert mechanical forces on the musculoskeletal structure that can injure the user—individuals that are too sensitive to the plantar stimulus simply reduce the insert level or discontinue use. Footwear restrictions, including lacing that is too tight, and progression through the insert stages faster than recommended, can result in the following discomforts:

- over-stimulation of the plantar surface,
- muscle cramping as muscles overwork, and
- lactic acid build-up as muscles overwork.

These symptoms are similar to those experienced by individuals that exercise too vigorously after an extended period of inactivity. None of these discomforts can result in injury and are easily mitigated by loosening the shoe or returning to a lower/softer insert stage. They are most often experienced by those who start out with higher/firmer insert levels, thinking that they can short-cut the adjustment period. Following the directions that accompany the System should prevent any of these discomforts from occurring.

6.1.2 Barefoot Science Appropriate Footwear for Healthy Feet

While the Arch Activation Foot Strengthening System™ will provide some benefit (25-75%) in most footwear, choosing complementary footwear will optimize the results and promote the healthiest feet.

The softer and more flexible the shoe, the better. This includes uppers, midsoles, and outsoles. Stiffer shoes cause greater friction between the shoe and the foot by resisting the foot's natural movement.

It is most important that the great toe be able to dorsiflex in the shoe. This can be facilitated by footwear with a deep toe box, soft flexible material over the toe box, a pliable midsole and outsole, or a combination of the above.

The shoe should not be tight or snug on the foot and should allow the arch to rise without restriction. Ideally, even when laced, the shoe should be able to be easily removed and placed back on the foot. This is particularly true for athletic footwear where greater Optimal Arch Apexes are required.

A rounded heel is the most beneficial—flared heels should be avoided. Lower heel and midsole heights are recommended as they significantly reduce the unhealthy stresses to the foot, ankle, and knee.

7.0 References

1. Turlik MA, Kushner D. Levels of Evidence of Articles in Podiatric Medical Journals. Journal of the American Podiatric Medical Association 90(6): p. 300, June 2000.

2. O'Driscoll S, Nicholas JG. Continuous Passive Motion (CPM): Theory and Principles of Clinical Application. Journal of Rehabilitation Research and Development 37(2): March / April 2000.

3. Hurwitz DE, Foucher KC, Sumner DR, Andriacchi TP, Rosenberg AG, Galante JO. Hip Motion and Moments During Gait Relate Directly to Proximal Femoral Bone Mineral Density in Patients with Hip Osteoarthritis. Journal of Biomechanics, 31: p. 919, 1998.

4. Gait Analysis Steps Into New Fields. Mechanical Engineering: p. 105, September 1984.

5. Carpenter DM, Nelson BW. Low Back Strengthening for the Prevention and Treatment of Low Back Pain. Medicine and Science in Sports and Exercise 31(1): p. 18, 1999.

6. Layne JE, Nelson ME. The Effects of Progressive Resistance Training on Bone Density: A Review. Medicine and Science in Sports and Exercise 31(1): p. 25, 1999.

7. Tomaro JE, Burdett RG, Chadran AM. Subtalar Joint Motion and the Relationship to Lower Extremity Overuse Injuries. Journal of the American Podiatric Medical Association 86(9): p. 427, September 1996.

8. Rothstein JM. Muscle Biology: Clinical Considerations. Physical Therapy 62(12): p. 1823, December 1982.

9. Yessis M. Explosive Running: Using the Science of Kinesiology to Improve Your Performance. Contemporary Books, a div. of NTC/Contemporary Publishing Group, Inc., 2000.

10. Rao UB, Joseph B. The Influence of Footwear on the Prevalence of Flat Foot. The Journal of Bone and Joint Surgery 74B(4): p. 525, 1992.

11. Shulman S. Survey in China and India of Feet That Have Never Worn Shoes. The Journal of the National Association of Chiropodists 49: p/ 26, 1949.

12. Stewart SF. Footgear - Its History, Uses and Abuses. Clinical Orthopaedics and Related Research 88: pp. 119-130, 1972.

13. Robbins SE, Gouw GJ. Athletic Footwear and Chronic Overloading. Sports Medicine 9(2): p. 76, 1990.

14. Robbins SE, Hanna AM. Running Related Injury Prevention Through Barefoot Adaptations. Medicine and Science in Sports and Exercise 19(2): p. 148, 1999.

15. Nesbitt L. Correcting Overpronation. The Physician and Sports Medicine: May 1999.

16. Pratt DJ. A Critical Review of the Literature on Foot Orthoses. Journal of the American Podiatric Medical Association 90(7): p. 339, July / August 2000.

17. Sethi PK. The Foot and Footwear. Prosthetics and Orthotics International 1: p. 173, 1977.

18. Tis LT, Higbie EJ, Chadwick L, Johnson BF. Put to the Test: Orthoses Reduce Pressure But Fall Short of Biomechanical Correction. Biomechanics.: October 2000.

19. Latanza L, Gray GW, Kantner RM. Closed Versus Open Kinematic Chain Measurements of Subtalar Joint Eversion: Implications for Clinical Practice. The Journal of Orthopaedic and Sports Physical Therapy 9(9): p. 310, 1988.

20. McClay I. The Evolution of the Study of the Mechanics of Running. Journal of the American Podiatric Medical Association 90(3): p. 133, March 2000.

21. Sobel E, and Levitz S. Reappraisal of the Negative Impression Cast and the Subtalar Joint Neutral Position. Journal of the American Podiatric Medical Association 87(1): p. 322, January 1997.

22. Pierrynowski MR, Smith SB, Mlynarczyk JH. Proficiency of Footcare Specialists to Place the Rearfoot at Subtalar Neutral. Journal of the American Podiatric Medical Association 86(5): p. 217, May 1996.

23. Phillips RD. Discourse and Dialogue: Planovalgus Foot Deformity Revisited. Journal of the American Podiatric Medical Association 89(5): p. 265, May 1999.

24. Pribut S. Biomechanics of Foot and Leg Problems. Dr. Stephen M. Pribut's Sport Pages: 1998.

25. Baycroft C. Orthotic Devices and Foot Function. Patient Management: p. 115, June 1987.

26. Hunt A, Smith R, Torode M, Keenen M. Inter-Segment Foot Motion and Ground Reaction Forces Over the Stance Phase of Walking. Clinical Biomechanics 16: p. 592, 2001.

27. Donatelli R. Normal Biomechanics of the Foot and Ankle. The Journal of Orthopaedic and Sports Physical Therapy 94: 1985.

28. Sarrafian SK. Functional Characteristics of the Foot and Plantar Aponeurosis Under Tibiotalar Loading. Foot Ankle 8: p. 4, 1987.

29. Sarrafian SK. Anatomy of the Foot and Ankle; Descriptive, Topographic, Functional - 2nd edition. Lippincott, Philadelphia: 1993.

30. Lundberg A, Goldie I, Kalin B, Selvik G. Kinematics of the Ankle/Foot Complex: Plantarflexion and Dorsiflexion. Foot Ankle 9: p. 194, 1989.

31. Lundberg A, Svendsson OK, Bylund C, Goldie I, Selvik G. Kinematics of the Ankle/Foot Complex-Part 2: Pronation and Supination. Foot Ankle 9: p. 248, 1989.

32. Lundberg A, Svendsson OK, Bylund C, Goldie I, Selvik G. Kinematics of the Ankle/Foot Complex-Part 3: Influence of Leg Rotation. Foot Ankle 9: p. 304, 1989.

33. Subotnick SI. The Flat Foot. The Physician and Sports Medicine. 9(78): p. 85, August 1981.

34. Perry J. Anatomy and Biomechanics of the Hindfoot. Clinical Orthopaedics and Related Research 177: p. 9, July/August 1983.

35. Moore K, Agur A. Essential Clinical Anatomy. Williams and Wilkens, Baltimore, Maryland, U.S.A., p. 254, 1995.

36. Yessis M. Running Barefoot vs. Running in Shoes. AMAA Quarterly Spring 1998: p. 5

37. Doxey G. Calcaneal Pain: A Review of Various Disorders. The Journal of Orthopaedics and Sports Physical Therapy 9(1): p. 25, 1987.

38. Mack PB, Vogt FB. Roentgenographic Bone Density Changes in Astronauts During Representative Apollo Space Flight. Science and Space. 113(4): December 1971.

39. Cowin SC. Mechanical Modeling of the Stress Adaptation in Bone. Calcified Tissue International 36: p. S98, 1984.

40. Meade JB, Cowin SC, Klawitter JJ, Van Buskirk WC, Skinner HB. Bone Remodeling Due to Continuously Applied Loads. Calcified Tissue International 36: p. S25, 1984.

41. Lanyon LE. Functional Strain as a Determinant for Bone Remodeling. Calcified Tissue International 36: p. 56, 1984.

42. Parfitt AM. The Cellular Basis of Bone Remodeling: The Quantum Concept Reexamined in Light of Recent Advances in Cell Biology of the Bone. Calcified Tissue International 36: p. S37, 1984.

43. Katz JL., Yoon HS, Lipson S, Maharidge R, Meunier A, Christel P. The Effects of Remodeling on the Elastic Properties of Bone. Calcified Tissue International 36: p. S31, 1984.

44. LeVeau BF, Bernhardt DB. Developmental Biomechanics - Effect of Forces on the Growth, Development, and Maintenance of the Human Body. Physical Therapy 64(12): p. 1874, December 1984.

45. Currey JD. Can Strains Give Adequate Information for Adaptive Bone Remodeling? Calcified Tissue International 36: p. 118, 1984.

46. Hawkins SA, Scroeder ET, Wiswell RA, Jaque SV, Marcell TJ, Costa K. Eccentric Muscle Action Increases Site-Specific Osteogenic Response. Medicine and Science in Sports and Exercise 31(9): p. 1287, 1999.

47. Bugbee W, Sychterz C, Engh C. Bone Remodeling Around Cementless Hip Implants. Southern Medical Journal: November 1996.

48. Lanyon LE. Control of Bone Architecture by Functional Load Bearing. Journal of Bone Mineral Research 7(Suppl. 2): p. S369-75, 1992.

49. Malka JS. Osteoporosis and Bone Remodeling. Malka Orthopaedics: Osteoporosis Treatment. www.orthohelp.com/osteop.htm: 2001.

50. May-Newman KD. Bone Growth and Remodeling. Mechanical Engineering, San Diego State University Lecture: 24-Jan, 2001.

51. Copeland G. The Foot Doctor: Lifetime Relief For Your Aching Feet. MacMillan Canada, A Div. of Canada Publishing Corp., 1996.

52. Roberts S. Calculating Tension in the Plantar Fascia. www.heelspurs.com: 1998.

53. Donatelli R. Abnormal Biomechanics of the Foot and Ankle. The Journal of Orthopaedic and Sports Physical Therapy 9(1): p. 11, 1987.

54. Harradine PD, Bevan LS. The Effect of Rearfoot Eversion on Maximal Hallux Dorsiflexion. Journal of the American Podiatric Medical Association 90(8): p. 390, September 2000.

55. Ogon M, Aleksiev AR, Pope MH, Wimmer C, Saltzman CL. Does Arch Height Affect Impact Loading at the Lower Back Level in Running? Foot and Ankle International 20(4): p. 263, April 1999.

56. Duchenne GB. Physiology of Motion. Physiology of Motion: 1959.

57. Jones RL. The Human Foot: An Experimental Study of its Mechanics and the Role of Its Muscles and Ligaments in Support of the Arch. American Journal of Anatomy 68: p. 1, 1941.

58. Robbins S, Waked E, Rappel R. Ankle Taping Improves Proprioception Before and After Exercise in Young Men. British Journal of Sports Medicine 29(4): p. 242, 1995.

59. Elliott BC, Blanksky BA. The Synchronization of Muscle Activity and Body Segment Movements During a Running Cycle. Medicine and Science in Sports 11(4): p. 322, 1979.

60. Nilsson J, Thorstensson A, Halbertsma J. Changes in Leg Movements and Muscle Activity With Speed of Locomotion and Mode of Progression in Humans. Acta Physiol Scand 123: p. 457, 1985.

61. Winter DA. The Biomechanics and Motor Control of Human Gait. The Biomechanics and Motor Control of Human Gait.: 1987.

62. Gefen A, Megido-Ravid M, Itzchak Y, Arcan M. Biomechanical Analysis of the Three-Dimensional Foot Structure During Gait: A Basic Tool for Clinical Applications. Journal of Biomedical Engineering 122: p. 630, December 2000.

63. Creighton DS, Olson VL. Evaluation of Range of Motion of the First Metatarsophalangeal Joint in Runners with Plantar Faciitis. The Journal of Orthopaedic and Sports Physical Therapy 8(7): p. 357, 1987.

64. Carlson RE, Fleming LL, Hutton WC. The Biomechanical Relationship Between the Tendonachilles Plantar Fascia and Metarsophalangeal Dorsiflexion Angle. American Academy of Orthopaedic Surgeons 1999 Annual Meeting: Scientific Program, Paper No. 271.

65. Fuller EA. The Windlass Mechanism of the Foot - A Mechanical Model to Explain Pathology. Journal of the American Podiatric Medical Association 90(1): p. 35, January 2000.

66. Dananberg H. Functional Hallux Limitus and Its Relationship to Gait Efficiency. Journal of the American Podiatric Medical Association 76(11): pp. 648-652, November 1986.

67. Henning EM, LaFortune MA, Lake MJ. The Influence of Midsole Material and Knee Flexion on Energy Return in Simulated Running Impacts. International Society of Biomechanics - Second Symposium on Footwear Biomechanics: p. 2, June 1995.

68. Robbins SE, Hanna AM, and Gouw GJ. Overload Protection: Avoidance Response to Heavy Plantar Surface Loading. Medicine and Science in Sport and Exercise 20(1): p. 85, February 1988.

69. Robbins SE, Gouw GJ, McClaran J, Waked E. Protective Sensation of the Plantar Aspect of the Foot. Foot and Ankle International 14(6): p. 347, 1993.

70. Latash ML. Neurophysiological Basis of Human Movement. Human Kinetics, Windsor, Ontario: 1998.

71. Robbins SE, Gouw JG, Hanna AM. Running Related Injury Prevention Through Innate Impact-Moderating Behaviour. Medicine and Science in Sports and Exercise 21(2): p. 130-139, 1987.

72. Staheli LT, Giffin L. Corrective Shoes for Children: A Survey of Current Practice. Pediatrics 65(1): p. 133, January 1980.

73. The Low Down on High Heels. The American Orthopaedic Foot and Ankle Society: www.aofas.org/highheels.html.

74. White J. Cost of Poor Shoe Fit. Biomechanics: December 1997.

75. Footwear Market Insights: If The Shoe Fits, Wear It. American Academy of Orthopaedic Surgeons: www.aofas.org/shoefit.html.

76. Frey CC, Thompson FM, and Smith J. Footwear and Stress Fractures. Clinical Sports Medicine 16(2): p. 249, April 1997.

77. Cooke-Anastasi S. Footwear: Therapeutic Shoe Bill Suffers from Anonymity. Biomechanics: Diabetes Supplement: p. 31, August 1999.

78. Wikler SJ. Take Off Your Shoes and Walk.: www.barefooters.org/pfbc/toysawfl.htm.

79. Sim-Fook L, Hodgson A. A Comparison of Foot Forms Among the Non-Shoe and Shoe Wearing Chinese Population. American Journal of Bone and Joint Surgery 40: p. 1058, 1958.

80. Robbins SE, Gerard GJ. Athletic Footwear: Unsafe Due to Perceptual Illusions. Medicine and Science in Sports and Exercise 23(2): p. 217, 1991.

81. Kennedy T. The Plantar Fasciitis Epidemic. Running Times: October 1996.

82. Jabbour K. Running Barefoot: Merits and Dangers. The Post Standard: October 1998.

83. Soames RW, Clark C. Heel Height-Induced Changes in Metatarsal Loading Patterns During Gait. Biomechanics IX-A, ed. by Winter DA, Norman RW, Wells RP et al, Human Kinetics Publishers: Champaign IL: p. 446, 1985.

84. Chinese Girl with Bound Feet.: www.sfmuseum.org/chin/foot.html.

85. Special Shoes for Bound-feet Women Now a Thing of the Past.: www.sfmuseum.org/chin/foot.html.

86. Crites JA. Chinese Foot Binding.: www.beautyworlds.com/chinesefootbinding.htm.

87. Frey CC, Thompson FM, Smith J. American Orthopaedic Foot and Ankle Society Women's Shoe Survey. Foot Ankle 14: p. 78, 1993.

88. Coughlin MJ, Thompson FM. The Price of High Fashion Footwear. Instructors Course Lecture 44: p. 371, 1995.

89. Currey JD. What Should Bones Be Designed to Do? Calcified Tissue International 36: p. S7, 1984.

90. Herzog CD. Bone Carpenters. Research/Penn State 18(3): September 1997.

91. Whedon GD. Disuse Osteoporosis: Physiological Aspects. Calcified Tissue International 36: p. S146, 1984.

92. Madsen KL, Adams WC, Van Loan MD. Effects of Physical Activity, Body Weight and Composition, and Muscular Strength on Bone Density in Young Women. Medicine and Science in Sports and Exercise 30(4): April 1998.

93. Beaupre G, Carter D, Giddings V, Leong T, Mikic B, Stevens S, Whalen R. Improving Musculoskeletal Function - Understanding Skeletal Development, Adaptation and Aging. www.Stanford.edu, 1996.

94. Lidtke R, Patel D, Muehleman C. Calcaneal Bone Mineral Density and Mechanical Strength of the Metatarsals. Journal of the American Podiatric Medical Association 90(9): October 2000.

95. Klein T, Ebeling P, Anderson D, Buss D. Mechanically Favorable Adaptive Bone Remodeling in Rotator Cuff Arthropathy Patients with Good Function. Biomechanics Laboratory, Minneapolis Sports Medicine Center, Minneapolis, MN: 1999.

96. Hamill J, Derrick TR. Orthoses: Foot/Custom: The Mechanics of Foot Orthoses for Runners. Biomechanics: February 1996.

97. Cavanagh PR, Lafortune MA. Ground Reaction Forces in Distance Running. Journal of Biomechanics, 13: p. 397, 1980.

98. Dananberg H, Guiliano M. Chronic Low-Back Pain and Its Response to Custom-Made Foot Orthoses. Journal of the American Podiatric Medical Association 89(3): pp. 109-117, March 1999.

99. Aquino A, Payne C. Function of the Windlass Mechanism in Excessively Pronated Feet. Journal of the American Podiatric Medical Association 91(5): p. 245, 2001.

100. Harris P. Tracing The Pain. Biomechanics: 1996.

101. Mandato MG, Nester E. The Effects of Increasing Heel Height on Forefoot Peak Pressure. Journal of the American Podiatric Medical Association 89(2): p. 75, February 1999.

102. Nike Inc. Research Newsletter: 1986 NIKE Sport Research Laboratory: Study on Walking: Fall, 1988.

103. Stacoff A, Steger J, Stussi E, Reinscmidt C. Lateral Stability in Sideward Cutting Movements. Medicine and Science in Sports and Exercise 28(3): p. 350, 1996.

104. Nigg B, Morlock M. The Influence of Lateral Heel Flare of Running Shoes on Pronation and Impact Forces. Medicine and Science in Sports and Exercise 19(3): pp. 294-302, 1987.

105. Kalin V, Denoth J, Stacoff A, Stussi E. Possible Relationships Between Shoe Design and Injuries in Running. Sportverletzung-Sportschaden 2(2): p. 80-85, 1988.

106. Staheli LT. Shoes for Children - A Review. Pediatrics 88(2): pp. 371-375, August 1991.

107. McPoil TG, Cornwall MW. The Effect of Foot Orthoses on Transverse Tibial Rotation During Walking. Journal of the American Podiatric Medical Association 20(1): p. 2, January 2000.

108. Liddle D, Rome K, Howe T. Vertical Ground Reactions Forces in Patients with Unilateral Plantar Heel Pain - A Pilot Study. Gait and Posture 11(1): p. 62, February 2000.

109. Tiberio D. The Effect of Excessive Subtalar Joint Pronation on Patellofemoral Mechanics: A Theoretical Model. Journal of Orthopedic & Sports Physical Therapy 9(4): p. 160, 1987.

110. Patritti B, Lake M. In Vivo Assessment of the Shock Absorption Characteristics of Athletic Footwear Insert Materials. Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, U.K.

111. Nigg BM. Biomechanical Analysis of Ankle and Foot Movement. Medicine and Sport Science 23: p. 22, 1987.

112. Fiolkowski P, Bauer J. The Effect of Viscoelastic Insoles on Gait Kinetics. International Society of Biomechanics - Third Symposium on Footwear Biomechanics: p. 24, August 1997.

113. Nigg B, Khan A, Fischer V, Stefanyshyn D. Effect of Shoe Insert Construction on Foot and Leg Movement. Medicine and Science in Sports and Exercise 30(4): April 1998.

114. Sherman RA, Karstetter KW, May H, Woerman AL. Prevention of Lower Limb Pain in Soldiers Using Shock-Absorbing Orthotic Inserts. Journal of the American Podiatric Medical Association 86(3): 1996.

115. Frederick E. Impact Testing of Insoles. Exeter Research: Brentwood, NH: 1985.

116. Fuller EA. Reinventing Biomechanics. Podiatry Today: December 2000.

117. Miller M, McGuire J. Literature Reveals No Consensus on Subtalar Neutral. Biomechanics: p. 63, August 2000.

118. Orthotics - The Miracle Cure-All? Footwear News 51(19): p. 22, May 1995.

119. Nurse MA, Nigg BM, Deazeley S. Effects of Forefoot Posting on the Kinematics of the Lower Extremities During Walking. Human Performance Laboratory, University of Calgary

120. Edwards A. Interview: Foot and Ankle Research Drives Northern Arizona Practitioner. Biomechanics: p. 29, September 2000.

121. Hunter S. Foot Types: Are Foot Types Related to Injury? Biomechanics: Special Report for Physical Therapy: May 1997.

122. Wenger DR, Mauldin D, Speck G, Morgan D, Lieber RL. Corrective Shoe Inserts as Treatment for Flexible Flatfoot in Infants and Children. The Journal of Bone and Joint Surgery 71-A(6): p. 800, July 1989.

123. Kogler GF, Veer FB, Solomonidis SE, Paul JP. The Influence of Medial and Lateral Orthotic Wedges on Loading of the Plantar Aponeurosis, In Vitro Study. International Society of Biomechanics - Third Symposium on Footwear Biomechanics: p. 22, August 1997.

124. Do You Need That Brace? American Running and Fitness Association: www.nbrnetwork.com/brcnogd.htm. Journal of Orthopedic & Sports Physical Therapy 20(6): p. 287, 1994.

125. Yeung MS, Chan K, So CH, Yuan WY. An Epidemiological Survey on Ankle Sprain. British Journal of Sports Medicine 28: p. 112, 1994.

126. Thacker SB, Stroup DF, Branche CM. The Prevention of Ankle Sprains in Sports: A Systematic Review of the Literature. American Journal of Sports Medicine 27: p. 753, 1999.

127. Rossi W. The Arches - Some Controversial Views. Podiatry Management. www. podiatrymgt.com: 1999.

128. Platte B. San Francisco Chronicle: Interview with Dr. P.W. Brand. Medical Research. www.unshod.org/pfbc/pfmedresearch.htm: 1976.

129. West S. Report on Dynapro Insole (Barefoot Science). University of Huddersfield, Podiatric Department, Queensgate, Huddersfield, U.K., 1994.

130. Burke R, Reyes R, Bompa T. Insole System Decreases Plantar Surface Area. BioMechanics 8(10); pp. 85-93, October 2001.

131. Comstock B. In-House Clinical Evaluation: November 2000-March 2002.