EVOLUTION OF FOOT ORTHOTICS—PART 1: COHERENT THEORY OR COHERENT PRACTICE?

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ABSTRACT

Objective: To present a critical review of the evolution of foot orthotics theory and clinical practice.

Data Sources: Several classic publications were consulted because of their overwhelming influence. The work of Merton L. Root and his colleagues in the 1970s was carefully examined. Careful evaluations were performed to determine how faithfully Root's central concepts were subsequently followed. Studies attempting to validate this and other orthotic paradigms were also reviewed.

Results: Epidemiologic studies provide strong support for the clinical advantages of orthoses, yet explanations of foot orthotic mechanisms remain elusive. Considerable variability has crept into the literature with respect to Root's core theoretical concepts of how and why to determine the neutral position of the subtalar joint (weight-bearing vs non–weight-bearing, palpation vs range-checking). Numerous studies document poor clinical reliability and validity; indeed, this paradigm appears to favor supination, thereby violating its "neutral" premise. Mechanisms other than those of the classic Root theory must be at work. Accordingly, successes have been achieved with alternate paradigms that use much simpler casting techniques. Although less frequently cited, successes have been gained with various viscoelastic materials that enhance shock-absorption and proprioception, as well as custom-made flexible orthotic designs that emphasize the 3 natural arches of the foot.

Conclusions: The use of foot orthoses is well documented for the treatment of many maladies, yet clinical successes have been achieved both inside and outside of the classic Root paradigm. Clearly, a more complete theoretical understanding of the mechanisms of foot orthotics awaits discovery. (J Manipulative Physiol Ther 2002;25:116-24)

Key Indexing Terms: *Biomechanics; Orthotics; Foot; Ankle; Subtalar Joint*

INTRODUCTION

After the ground-breaking work of Inman et al,[1] Root et al,[2,3] and others, foot care professionals today have a detailed yet seemingly practical set of techniques for classifying joint disorders and directing treatment approaches. Increasingly, foot orthoses are a successful adjunct to such treatments.[4,5] Of 465 podiatric patients reporting various maladies, 62% acknowledged complete resolution after orthotic treatment, whereas an additional 33% gained partial resolution of their chief complaint as measured after 14 weeks of follow-up.[6] Similarly, in a retrospective study with both soft temporary orthoses and permanent rigid orthoses, 96% of patients experienced pain relief, and 70% were able to return to previous activity levels.[7] In a survey of 347 long-distance runners, 76% benefited from the use of orthoses.[8] Additionally, both Nawoczenski et al[9] and Nigg et al[10] concur that at least 70% of runners who experience lower-extremity symptoms (including knee pain, plantar fasciitis, shin splints, or iliotibial band tendinitis) will show a reduction in symptoms with the use of orthoses. Low back pain has also been successfully treated with foot orthoses.[11] If we seek objective proof for the theoretical principles on which such clinical techniques are based, however, we may be surprised to find that this base of knowledge has been poorly validated.[12] Furthermore, despite such benefits, the mechanisms of cause and

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effect that actually permit orthotic interventions to improve patient health remain elusive.[9,10,13]

Certainly, the clinical solutions and requisite theoretical explanations that fall under the rubric of orthotic treatment are various and manifold. Although podiatrists, chiropodists, orthotists, and pedorthotists often focus on more severe disorders of the foot and ankle, chiropractors and physical therapists tend to use foot orthoses for the treatment of milder cases of lower-extremity malalignment and overuse injuries. Similarly, if one looks at the approaches used to assess, fabricate, and fit such orthoses, great variety exists both within and between the various health care professions. Clinical traditionalists who use custom-fitted, rigid, or semi-rigid Root-style orthoses[14] believe that a detailed classification system should be used to individually diagnose disorders of the foot and ankle. Such practitioners hypothesize that, to be corrective, orthoses must produce functional changes in bony alignment[15]; therefore, a rigid construction is favored.[5,16] In contrast, similar clinical success rates have been reported with the use of soft or flexible orthoses,[8,10,17-21] yet these devices vary widely in sophistication of construction and subject-specificity of design. Furthermore, although clinical traditionalists often believe that orthoses constructed with softer materials are merely accommodative,[15] Nigg et al[10] recently challenged this concept, proposing that the shock-absorbing effects of orthoses, and not the ability to realign bone position, may be their most useful asset. Specifically, Nigg et al[10] suggest that appropriate shock attenuation may result in successful neuromuscular interaction. This suggests that orthoses designed of compliant, flexible materials may play much more than an accommodative role in aiding human performance. Nevertheless, at this time one can only conclude that the literature is resplendent with competing yet unproven theories regarding orthotic mechanisms.

Certainly, when one contrasts the theoretical inconsistencies of the literature with the obvious clinical successes that have been reported for the use of foot orthoses, the clinical pragmatists among us might ask, "Why should researchers continue to pursue a better understanding of the mechanisms of the foot and ankle when there is already a high probability of success associated with the use of foot orthoses?" Although it is likely that human curiosity alone plays an important role in driving research, knowledge gained in the basic sciences can lead to significant advances in clinical practice. It is universally hoped that future treatment protocols can be made both more effective and more efficient. It should also be noted that significant financial considerations now drive the quest for improved foot orthoses. As of 1997, sales in the foot orthotics industry were expected to exceed $4 billion.[22] It seems clear that significant advances will be made as new insight is gained about the biomechanical mechanisms that evoke positive changes within the human body.

To that end, we examine the support, or lack thereof, for some of the common theoretical principles of orthotics practice that are currently relied on, in clinical settings, indeed, often without question.

Discussion

In the classic works on human gait by Inman and colleagues[1] numerous references are made to the functional importance of the subtalar (talocalcaneal) joint within the foot and ankle. Although their peers Manter,[25] Hicks,[26] and Wright et al[27] focused explicitly on examining subtalar and talocrural motion,[28] Inman and colleagues[1,23,24] conducted complementary experimentation to establish the principle that supination of the foot causes external rotation of the tibia and, conversely, that tibial internal rotation accompanies pronation. Inman and colleagues[1] hypothesized that these relationships also affect the motion patterns at the knee and hip. The exact nature of these effects, however, was less well explained. Although these researchers went so far as to monitor the motion of surgically inserted pins to determine the longitudinal rotations of the bones of the lower extremity,[24] several factors still conspired to prevent them from achieving a full understanding of the intrinsic biomechanical interactions of the human body. Although it is likely that limitations in the 3-dimensional (3-D) measurement techniques of that era[29] reduced the interpretability of these data, the delicate complexity of the human body must not be underestimated. Our inability to clearly understand the body's multijoint relationships continues, even today, to provide a significant focus for the many theoretical discussions conducted on gait and lower-extremity function.

In the late 1960s and early 1970s, Root et al[2,3] followed up the efforts of Inman et al[1] by developing a system for the clinical prescription and fabrication of rigid and semi-rigid foot orthoses. In Root's work, detailed consideration of the function of the subtalar joint played a major role. To this end, Root et al[2,3] dramatically revolutionized the manner in which foot and ankle problems were clinically managed.[30] As McPoil and Hunt[30] have noted, before that time foot orthoses were constructed primarily to fortify the medial longitudinal arch of each patient in static posture. Root criticized this static approach, noting that the foot is truly a dynamic load-bearing structure. Reasoning that it was important to classify each individual's foot type, they proposed that it might also be necessary to manage each foot type in a different way. Thus, Root et al[2,3] founded the conceptual classification schemes for the foot and ankle that are still commonly used in clinical practice today.

A Clinical Classification Scheme for the Foot

In the scheme established by Root et al,[2,3] clinical judgments characterize the various intrinsic deformities that may be present within a foot. Essentially, these descriptions characterize the physical relationships that exist between the forefoot, rearfoot, and tibia. Additionally, the entire foot is assessed with respect to its flexibility or rigidity. Estimates of forefoot varus (inverted relative to the rearfoot), forefoot valgus, rearfoot varus (inverted relative to the tibia), and rearfoot valgus are made from within the frontal plane.[30,31]

Forefoot equinus is the name given to the deformity in which the forefoot appears to be structurally more plantarflexed than the rearfoot, as viewed from the sagittal plane.[31] The terms, *pes planus, pes rectus*, and *pes cavus* classify foot types that possess a medial longitudinal arch that is either low (flat foot), normal, or high.[32] The terms, *hallux rigidus* and *hallux limitus* refer to severe and limited restrictions within the dorsiflexion motion of the first metatarsophalangeal joint, respectively.[33] Other terms exist to describe various site-specific pathologic features. With respect to providing detailed descriptions, numerous authors beyond Root et al[3] have since done a masterful job of presenting the various characterizations.[4,5,31,34] Michaud's text,[4] in particular, stands out for its thoroughness and the detail of its accompanying figures. Nevertheless, it is Merton L. Root and his colleagues who can be credited with having originated the comprehensive system that clinicians presently use for the treatment of foot and ankle problems.[30]

The Neutral Position of the Subtalar Joint

Root thought that it was necessary to define a consistent starting position for the foot and ankle to permit clinicians to conduct repeatable examinations and make discrete measurements of clinical entities, such as rearfoot varus, and to conduct natural examinations of the foot and ankle. To match the foot's plantar surface with the contours of the ground, the subtalar joint typically provides a subtle range of pronatory or supinatory movements about its obliquely yet somewhat anteriorly directed axis.[1,2,23] Root reasoned that this same functional accommodation also extended to cases in which various foot deformities were thought to exist. In this way, alterations in the foot's subtalar motion were thought to mask various pathologic conditions.[31] Recognition of the compensatory abilities of the subtalar joint therefore led Root to propose the concept of locating its neutral position. Unfortunately, the enclosed location of the talus within the ankle mortise made this a difficult task.

Original Definition

In the original definition from their 1971 text, Root et al[2] stated, "The subtalar joint is in the *neutral position* when the foot is neither supinated nor pronated." Fortunately, they also realized that it was necessary to operationalize a specific definition for this premise. Under the heading "Neutral Subtalar Joint Position," Root et al[2] described a detailed series of measurements that were to be performed on subjects while they remained in a non–weight-bearing position. These methods are described as follows.

The subject lies prone, and a bisecting line is drawn on the skin overlying the distal ⅓ of the tibia; the rearfoot is moved into full inversion, and a bisecting line is drawn on the skin overlying the posterior surface of the calcaneus; the rearfoot is moved into full eversion, and a second bisecting line is drawn on the skin overlying the posterior surface of the calcaneus. These 2 bisectors often appear to provide a Y or V shape. The use of 2 bisectors is meant to avoid the problem of skin and soft-tissue shifts over the full range of calcaneal positioning. A goniometer is used to determine the total inversion/eversion range of the subtalar joint. The rearfoot is then placed into a position that corresponds to ⅔ of the subtalar joint's full range as measured relative to the full inversion position. This position is the neutral position of the subtalar joint. A new "neutral" calcaneal line can then be drawn. This line should fall within the V or Y configuration.

Root et al[2] actually described the use of a mathematical formula to quantify the angular alignment of the subject's rearfoot (varus or valgus) angle. This same measure can be easily attained, however, by using a protractor to quantify the orientation of the "neutral" calcaneal line relative to the tibial bisector. This angle can then be assessed to determine the level of pathologic features within the individual's foot.

Second Definition?

Having described a clear methodology with which to determine the subtalar neutral position, Root et al[2] went on to describe an additional method to determine the subject's "neutral calcaneal stance position." The intent of this second procedure was to define the relationship of the calcaneus to the floor when the subtalar joint is held in its neutral position. Unfortunately, within this description Root et al[2] introduced the opportunity for great controversy. Their instructions state, "The subtalar joint is placed in the neutral position. . . .Three criteria are used to define this position. . . ," yet strangely, the 3 criteria listed are completely unlike those previously described.[2] Hence, by making such statements, they essentially ignored their own precise definition of the subtalar neutral position.

This apparent second definition of the subtalar neutral position was based on the ability of clinicians to use palpation of the talocrural joint, along with qualitative observations of the foot and ankle, to make judgments of standing subjects. We contend that although Root et al[2] unfortunately used familiar terminology to define their concept of the "neutral" position of the weight-bearing calcaneus, it is unlikely that they actually intended to use this description to redefine their original definition of the subtalar neutral position. In their original text, they did not comment on whether both methods could be used to arrive at the same answer or appear to even acknowledge the existence of 2 competing methods (range-checking non–weight-bearing vs palpation during weight-bearing).[2] By the time their 1977 text appeared,[3] they referred to the palpation technique (apparent second technique) as if it were to be used as a clinical screening tool. In this context Root et al[3] stated, "Any clinical determination of the neutral subtalar joint position can, and should, be confirmed by a range of motion study of the subtalar joint (See Vol. I)." Note that the volume referred to in this quote is the 1971 text.[2]

Although it seems odd that Root and his colleagues would provide 2 distinct definitions for the same clinical entity, on reviewing the literature some 30 years later, it seems even more unusual that virtually all authors who have since quoted Root et al[2] have simply ignored the differences between these 2 techniques. Indeed, the literature contains numerous instances in which authors[35-39] have used variations of Root's second method (palpation while weight-bearing) rather than their original method (range-checking while non–weight-bearing). Despite these variations, most authors have simply and incorrectly referenced Root et al[2] as the source of their technique.[37-39] The palpation criteria that is most commonly quoted is, "The congruity of the medial and lateral edges of the talus to the calcaneus at the subtalar joint."[2] Some authors have actually misquoted Root et al,[2] referring instead to palpation of the talonavicular joint.[15,37-39] The palpation approach for determining the subtalar neutral position has also received common use in making non–weight-bearing assessments,[34-36,38-40] yet Root had only used this technique to assess the qualities of the weight-bearing calcaneal stance position. Finally, despite clear recommendations that range checking should always be performed, recent literature shows that the use of Root's original range checking method is all but ignored. We contend that this situation has caused much confusion within the literature.

Practical Justification?

If we accept that Root intended to define just one method for the purpose of determining the subtalar neutral position (joint range, non–weight-bearing), then we must ask what use there could be in conducting non–weight-bearing examinations of the subtalar joint when the primary function of the foot and the ankle is to enable weight-bearing activities? There are at least 2 reasons. First, Root et al[2] based their original non–weight-bearing technique on passive examination of the subject. Presumably, this approach provided consistent results during clinical examinations. Second, this non–weight-bearing pose permitted the characteristics of the forefoot to be measured relative to the rearfoot.[4] Conceptually, this approach was consistent with Root's belief that the practice of accepting loads (bearing weight) had the potential to alter the foot's intrinsic relationships. Root suspected that accommodations to load (such as subtalar motion) could mask pathologic conditions.[31]

To further justify the need to locate the neutral position of the subtalar joint, Root et al[2] also put their faith into one additional factor. They believed that the subtalar neutral position held a special functional significance during gait. Specifically, in subjects with normal feet, this pose was thought to correspond to the correct position of the subtalar joint as it occurs functionally at both heel strike and at the 50% position of mid stance. Root et al[2] set forth this principle on the basis of subjective observations of so-called "normal" subjects. In doing so, they referenced the findings of an earlier study on subtalar motion that had been performed by Wright et al.[27] Unfortunately, as several inquisitive researchers have since pointed out,[28] Root actually interpreted Wright's findings incorrectly.[30] Wright et al[27] used a relaxed standing posture, not the subtalar neutral position, as the basis from which to conduct their original study. Thus, Root et al[2] offered no validation of their original premise for the functional importance of the subtalar neutral position.[28,30,41]

Having established both a novel (but perhaps not unique) starting position from which to assess the foot and ankle, as well as a relatively comprehensive classification scheme with which to denote pathologic features, Root et al[42] went on to redefine the way that foot orthoses were custom designed. Given their belief in the functional significance of the subtalar neutral position, Root et al[42] stipulated that each patient's foot was to be routinely cast in this position as measured when not bearing weight. Similarly each orthotic device was to be custom fabricated from its own cast. This was done with the intention of causing the foot to work through the subtalar neutral position during the weight-bearing activities of both natural standing and the stance phase of gait.

Having created methods that were said to consider the "dynamic" qualities of the foot and ankle, Root et al[3] appeared to have advanced the state of the art. Indeed, Root et al stated in the introduction to one of their texts, "The truth of this text is based primarily on coherence. . . . Each explanation must be consistent with the known facts of every applicable basic science. No fact of any basic science must conflict with the logic leading to a conclusion, or else that conclusion cannot meet the standards of coherence and must be discarded as incoherent and, therefore, unreliable."

There is no doubt that Root and his colleagues set out to achieve lofty goals that, to their credit, seem to have been met. As McPoil and Hunt[30] have noted, Root's influence on the clinical community continued to grow, so much so that between 1988 and 1993, a full 70% of the articles published in physical therapy journals on the topic of foot orthoses directly referenced the writings of Root and his colleagues.[30] No doubt, a similarly high rate of referencing also occurred in other health care disciplines. At the same time, researchers began to question the very underpinnings of Root's approach. This questioning has continued, and today one must conclude that several emerging facts now challenge the "truth" of Root's paradigms.

To Subtalar Neutral or Not to Subtalar Neutral, That is the Question ...

The criticisms directed at Root's paradigm can be divided into at least 3 areas. First, the reliability of the non–weight-bearing subtalar neutral approach is now considered suspect. Second, Root's definition of the subtalar neutral position as measured when not bearing weight is possibly not representative of the manner in which the foot and ankle deal with loads. Third, it is likely that Root's subtalar neutral position does not have the functional significance that it is purported to have during the motion patterns of normal gait.

Reliability of Clinical Findings

Unfortunately, conflicting results abound within the literature that examines the clinical reliability of locating the subtalar neutral position. Likewise, even the early literature that instructs students and clinicians on these techniques appears confusing. In a 1977 instructional text entitled *Practical Podiatric Orthopedic Procedures*, 6 different methods were described for locating the subtalar neutral position,[15] yet there was no mention of whether each technique arrived at the same physical position. Furthermore, although this text referenced Root's work,[2] only 1 of the 6 methods listed was similar (not identical) to Root's original range-checking, non–weight-bearing methodology. In further work, although Cook et al[35] reported that 2 clinicians who trained together could locate the subtalar neutral position to within 2 degrees 95% of the time, Elveru et al[43] found that 14 experienced clinicians could not achieve a statistically significant measure of inter-rater reliability. All of the angular measurements taken in these studies were performed with a goniometer, a simple device of poor measurement accuracy and precision. Perhaps the most telling criticism of the reliability of clinicians to locate Root's subtalar neutral position, however, comes from the work of Pierrynowski et al.[44] By using a high precision, 3-D measurement system, they found that 8 experienced clinicians could locate the subtalar neutral position to within only ±3 degrees 90% of the time. Because clinical judgments for classifying Root's pathologic foot types are routinely based on deviations of only ±5 degrees,[44] it seems that such findings do not bode well for the routine correct treatment of patients through the fabrication of Root-type custom-posted orthoses. In partial defense of Root, however, it should be noted that the study of Pierrynowski et al[44] did not actually test Root's original subtalar neutral methodology. Rather, a modified non–weight-bearing palpation technique was used, whereby the examiners altered the foot's position "until the palpated head of the talus projected equally on both sides of the navicular."[15] Although this technique was listed as 1 of the 6 in the *Practical Podiatric Orthopedic Procedures* manual mentioned previously, it should be noted that Pierrynowski and his colleages actually attributed the creation of this method to Root.[3]

Weight-Bearing Versus Non–Weight-Bearing Assessments

In citing obvious concerns for both the reliability of Root's subtalar neutral position (non–weight-bearing) and its relevance to joint function during weight-bearing, numerous authors have since chosen to modify the subtalar neutral technique to incorporate either a partial loading or a weight-bearing component.[45,46] Today, this practice is so prevalent that in discussions held at a recent meeting of the Foot and Ankle Special Interest Group of the American Physical Therapy Association, attendees representing various health professions concurred that they rarely use an unloaded approach to determine the subtalar neutral position. Instead, more typically, the clinician applies a superiorly directed force to the fourth and fifth metatarsal heads of the patient's foot in an effort to load the foot's lateral border.[38] This is done because the foot is believed to be composed of 2 columns.[4,5] The medial, more flexible column consists of the talus, navicular, 3 cunieforms, and first 3 metatarsal heads. The lateral, stiffer column is composed of the calcaneus, cuboid, and the fourth and fifth metatarsal heads. By loading the lateral border of the foot, the mid-tarsal joint (the interface between the forefoot and rearfoot) is stiffened. The intent of this practice is to reduce variability while assessing the patient's foot. These actions, in effect, also reduce the amount of forefoot varus that each patient exhibits. It should be noted, however, that the concept of locking out the mid-tarsal joint is not new. Root et al[2] actually described this phenomenon with respect to the functional relationships between the mid-tarsal and subtalar joint. What is new, however, is the idea that locking out the mid-tarsal joint, combined with palpation of 2 vague bony surfaces (listed varyingly as the talonavicular or talocalcaneal joint[15]), provides a better clinical guide for locating the neutral position of the subtalar joint. Finally, with respect to the use of a full or partial weight-bearing approach to examining the subtalar joint, some researchers have simply substituted the joint's resting standing position as its so-called "neutral" position.[27,37,38] Others have required individuals to forcibly attain a desired position while a trained clinician provides feedback through direct palpation.[37,45] In any case, the various approaches to this task in the literature seem to suggest that, although often quoted, Root's original premise to locate the neutral position of the uncompensated subtalar joint has been lost over time.

Functional Significance

Finally, in what may be the most poignant area of criticism, both McPoil and Cornwall[37] and Pierrnowski and Smith[38] have found that, in normal subjects, the motion of the subtalar joint rarely even reaches the subtalar neutral position during the stance phase of gait. Specifically, McPoil and Cornwall[37] made these observations for just the first 60% of the stance phase. Unfortunately, their results were limited on 2 particular counts: their 2-dimensional study of rearfoot motion relied on the use of just a single camera; additionally, only 1 experienced clinician performed all of the subtalar neutral assessments. Pierrynowski and Smith[38] subsequently used a more sophisticated measurement technology. Their 3-D study reported valid results for the entire gait cycle. These authors also ensured the reliability of their subtalar neutral estimates by having 6 to 7 experienced clinicians examine each subject. The results for each subject were then averaged. With respect to findings, both studies reported that the natural gait orientation of the rearfoot was everted (pronated) relative to the theoretical subtalar neutral position. Conversely, these results demonstrated that to match the predicted subtalar neutral position, it would be necessary to apply a significant amount of inversion (subtalar supination) to the typical foot during gait. In McPoil and Cornwall's[37] study, a difference of approximately 4° to 6° was reported, whereas in Pierrynowski and Smith's[38] study a discrepancy of 7.2° ± 1.2° was found. Pierrynowski and Smith[38] also noted that "inversion/eversion orientation during swing was characterized by 1° to 2° of eversion, with a small amount of inversion in early swing." Obviously, such values match the subtalar neutral position more closely, but because these results were measured during the non–weight-bearing phase of gait (swing phase), they do not appear to have any practical significance. However, in defense of Root it should be noted that neither study actually used Root's original method (joint-range, non–weight-bearing) to determine the neutral position of the subtalar joint. McPoil and Cornwall[37] conducted palpation measurements on weight-bearing subjects, whereas Pierrynowski and Smith's[38] clinicians performed palpation assessments of non–weight-bearing volunteers. These considerations aside, however, it appears from these findings that the so-called neutral position of the subtalar joint does not actually have a functional significance within the normal patterns of gait.

One additional, but no less interesting conclusion can also be drawn from the studies of McPoil and Cornwall[37] and Pierrynowski and Smith.[38] Both groups found the "resting standing foot posture" rather than the "subtalar neutral position" to be closer to the true "neutral" position of the rearfoot during the walking cycle. Intuitively, this seems comforting because it suggests that a given amount of posting (inversion/eversion) applied to one's resting standing posture has the potential to directly modify one's gait performance. Unfortunately, because the previously mentioned studies did not actually examine the use of orthotics, the possible relationships between orthotic interventions, the subtalar neutral position, and standing and walking foot postures remains unclear. Nevertheless, it is interesting to note that if use of a Root-style orthotic device truly alters "resting standing foot posture," then routine fabrication of a "neutral" Root-style orthoses is likely to result in a device that intrinsically causes supination. Additionally, because it is common within the Root paradigm to apply corrective posting to a supposedly "neutral" cast, these findings also suggest that it is likely that supination has been intrinsically yet unknowingly favored in virtually all of the Root-style orthoses that have been fabricated over the past 30 years. Perhaps surprisingly then, it is interesting to note that Root et al[3] actually cautioned against such simplicity in thinking. Michaud[4] agreed that although the practice of posting orthotics to correct for static alignment often results in pain reduction, such an approach may also lead to over-correction and, hence, the development of osseous deformations in response to altered forces. In retrospect, given the aforementioned challenges to the validity of the subtalar neutral position, the practitioners of classic Root orthotics theory may have arrived at such conclusions as a direct result of the paradigm's hidden supinatory characteristics.

Alternative Orthotics Paradigms

Although over the past 30 years the content of the orthotics literature has predominantly reflected the features of Root's classic orthotics paradigm, various approaches to orthotics management have also been developed and found to succeed.[10] Certainly, within the classic orthotics paradigm, great variation exists. The deviations within the subtalar neutral concept are obvious; however, casting practices have been conducted with weight-bearing techniques,[47] and softer materials have been used in place of rigid ones to construct orthoses that dimensionally match their rigid counterparts.[7,48] Nevertheless, the features that generally set the alternative orthotic paradigms apart are the following: (1) casting is conducted in a relaxed standing posture (weight-bearing) or not at all; (2) soft or flexible materials are used; and (3) the supporting theory for the alternative paradigm does not depend on the concept of rigid realignment. In general, much less has been written to support the alternative orthotic theories. Nevertheless, research evidence shows that successes have been obtained with the use of orthotic designs (or shoe inserts) that differ greatly from the classic paradigm.[10]

Enhanced Shock Absorption and Proprioception

The term *accommodative* is often used to describe the intentions of clinical traditionalists to use soft or flexible materials for the purposes of providing padding or increasing comfort. As Nawoczenski[5] notes, "Although the softer materials typically are not used when control of motion is the primary goal, they may be used in combination with other materials for control of mild biomechanical imbalances." Alternatively, the use of compliant or flexible materials in an orthoses has also been seen as part of the continuum of conventional orthotic design. For example, in an effort to test their clinical intentions, Donatelli et al[7] describe the use of soft materials to construct temporary orthoses. As well, in the successful treatment of patellofemoral pain in adolescent girls, Eng and Pierrynowski[20,21] used soft orthoses to demonstrate small yet seemingly important changes in the frontal plane alignment of both the ankle and the knee.

Because soft or flexible orthoses typically have not fit well in the Root-style paradigms of orthotics treatment, it is not surprising to note that much less research has been performed on them. In general, many designs of soft orthoses (or shoe inserts) forgo the need to cast the individual's foot shape. Sizing is typically based on shoe size. Often, the emphasis is placed on the use of specialized viscoeleastic materials to provide cushioning. The actual designs of such orthoses vary quite widely, from simple off-the-shelf neoprene inserts to orthoses shaped with an orthopedically restorative intent. It is for these reasons that the findings gained in one study are often unlikely to relate across the entire class of devices. Nevertheless, a scan of the literature suggests that orthoses designed from soft or flexible materials can offer unique benefits.

Recently, in an orthotics review article devoted to sports applications, Nigg et al[10] summarized several of the successes that have been gained with the use of soft orthoses. They noted that simple neoprene insoles,[17] as well as the use of basketball shoes in place of hard combat boots,[18] have been shown to reduce impact injuries in the training of military personnel. Nigg et al caution, however, that variations in the viscoelastic properties of orthoses generate changes in human response that vary more than would be expected if alterations in shock absorption (typically

<10%-20%) were the only acting factor. This phenomenon has led Nigg et al[10] to propose that improvements in the quality of the subject's compensatory neuromuscular responses may be the most important criteria in defining the success of an orthotics application. It should also be noted that such compensations are no less conceivable for the use of rigid orthoses. Within the human body, peak forces and rates of loading may be reduced as pressure is dispersed across the greater contact surfaces that a custom-fitted device provides. Certainly, in the future, the neuromuscular paradigm of Nigg et al[10] will be expected to receive greater attention from both researchers and clinicians alike.

Flexible Support of the 3 Arches in the Foot

In 1967, 4 years before the publication of Root's landmark texts,[2,42] Monty Greenawalt patented the use of a simple box filled with crushable foam to obtain a detailed impression of the foot.[49] Choosing to cast his patients in the relaxed standing position, Greenawalt hypothesized that this technique could be performed reliably. Greenawalt further postulated that precise measurements could be made directly from the foam cast, thereby permitting custom orthotic devices to be designed and fabricated without requiring the common yet time-consuming practice of creating a plaster cast. With respect to orthotic design, Greenawalt theorized that all 3 arches of the foot should function together dynamically to maintain proper biomechanical and neuromuscular performance of the foot and ankle. In support of this theory, a unique orthotic design was developed to provide individualized flexible support for all 3 natural arches[50] of the foot (medial longitudinal, lateral longitudinal, and transverse). This design can be contrasted with the classic orthotic paradigm that emphasizes the need to provide rigid control to the bones of the foot wherein primary support is concentrated only on the medial longitudinal arch.

Having created a unique orthotics paradigm, Greenawalt founded a commercial venture, Foot Levelers, Inc (Roanoke, Va). A few central tenets govern the design, creation, and fitting of this company's orthoses. First, the foam-impression casting technique is used to capture the characteristics of the individual weight-bearing foot. Second, 16 measurements are made from each cast. Third, this information is used to create a custom-made flexible orthosis for each foot. Given the commercial nature of this paradigm, the knowledge of the extent to which each arch receives support remains proprietary.

Citing the principles of the kinetic chain, Foot Levelers orthoses have been tested and found to provide various benefits. These include improved maintenance of skeletal alignment within the foot and ankle[50] as well as enhancements in balance performance and fatigue.[51] Although further study is needed, historically, even the classic orthotics paradigm has relied heavily on face validity. Although the present review cites several studies that cast considerable doubt on the significance of the subtalar neutral position, through inference the functional validity of casting the foot in the relaxed standing position appears supportable. Although Greenawalt's concept of fortifying the 3 arches of the foot also appears theoretically sound, it is noted that the validity of this concept requires careful study. Certainly, the choice of whether an orthosis should be rigid or flexible remains under debate.[10] A flexible design, however, does appear to offer greater potential in terms of permitting alterations in shock absorption and proprioceptive characteristics across the foot's plantar surface. Indeed, in spite of Root's original objectives to carefully consider the foot's "dynamic" qualities, it is the classic Root orthotics paradigm that actually appears to rely more heavily on the concept of static intervention.

Conclusion

The clinical literature contains a broad scope of information covering variations in techniques for the clinical assessment of the foot and ankle. Numerous studies have also reported on the successful treatment of various pathologic conditions as well as the avoidance of repetitive injuries with the use of various orthotic designs. It is within this academic environment that several practical texts, including those by Michaud[4] and Nawoczenski and Epler[5] have been written to provide useful information on numerous topics related to foot care. Obviously, the present review, which focuses on the theoretical principles of foot and ankle assessment and orthotic interventions, has only scratched the surface of such a knowledge base. Nevertheless, having reviewed this subset of the foot orthotics literature, we can draw a few conclusions with which to reflect on the validity of the past 30 years of orthotics theory and clinical practice.

First, although the success of an academic paradigm is often measured in terms of how frequently its works are cited, it seems reasonable to conclude that the true value of the contributions of Root and his colleagues remain under debate. Certainly, they can be richly credited with having set the tone for the development of a comprehensive clinical classification scheme that permits categorization of various pathologic features of the foot and ankle. Root and his colleagues also initiated major changes in the way that orthoses are prescribed, fabricated, and fitted. In both of these contexts, they used the neutral position of the subtalar joint as the central concept from which to make clinical decisions. However, given the empirical controversies surrounding each of these issues and the fact that considerable clinical successes have been gained outside of Root's paradigms, we must now conclude that other under-appreciated biomechanical or neurologic factors of sizable importance must be stealthily at work in the treatment of pathologic conditions of the foot and ankle. Although the general practice of prescribing orthoses does appear wholly coherent, the current theory does not.

Second, given the considerable weight the past literature has placed on locating the subtalar neutral position and the fact that uncertainties exist within this paradigm, it seems likely that these uncertainties have also had a significant effect on orthotics practice. One example is the possibly dubious functional significance of the subtalar neutral position. The findings of McPoil and Cornwall[37] and Pierrynowski and Smith,[38] suggest that whenever Root-style orthoses have been fabricated they have tended to be biased toward supination, independent of the amount of corrective varus or valgus posting that was clinically intended. If this is true, this tendency may have been fortunate, because excessive pronation is the diagnosis that is most commonly quoted with respect to overuse injuries of the foot, ankle, and lower extremities.[13] Unfortunately, such a possibility could also explain the relatively high number of patients who have tended to require modifications or reductions to the postings of their "custom-fitted" Root-style orthoses. In a survey of 130 podiatrists, 88% reported having to recast or make cast modifications for 25% or fewer of their patients, yet 10% of these podiatric clinicians reported making such modifications 25% or more of the time.[52] Although it seems possible that the refined clinical art of a skilled practitioner could intrinsically yet unknowingly permit the avoidance of such biases, it seems just as likely that not all practitioners would be capable of achieving such refined compensation.

We have presented an evolutionary view of the past 30 years of foot orthotics theory and practice. Paradoxically, although the classic works of Root and his colleagues have historically set the standard in many fields of practice, researchers have now assembled strong evidence with which to question the validity of these techniques. The use of the neutral position of the subtalar joint remains one of the key controversial issues within current orthotics practice. The validity of the functional significance of this reference position has been clearly challenged. Additionally, although numerous definitions of the subtalar neutral position have been proffered (even by Root and colleagues), the distinctions between these variations and their possible ramifications have often been overlooked. The clinician is now challenged to look beyond the status quo of the classic orthotic paradigm. In future studies, recent advances in measurement and computer modeling techniques will add greater clarity to the orthotics literature. In turn, this should result in the creation of new or revised theoretical paradigms. Clearly, the clinical world and thousands of satisfied patients owe a debt of gratitude to the pioneers and contributors of modern orthotics practice. From a scientific point of view, however, it seems equally clear that, although the challenges are significant, the best is yet to come.

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