Pediatric Orthoses—Part II

The prescription of custom foot orthoses in children utilizes growth and skeletal maturation to produce improvement in structure and function.

BY JOSEPH C. D'AMICO, DPM

Goals and Objectives

To discuss the unique characteristics of pediatric orthoses

To present a historical perspective on their design

To enumerate their benefits

To review their indications and types

To introduce the functional UCBL orthotic

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*Following this article, an answer sheet and full set of instructions are provided (pg. 156).—**Editor***

Historical Perspective

In 1845, Durlacher, an English chiropodist, used built-up leather in an attempt to support the arch of a flatfoot deformity by altering its position within the shoe.[54] In 1874, an English orthopedist, Hugh Owen Thomas, employed a lateral sole wedge and medial heel extension to the navicular for flatfoot conditions.[21] Dr. Thomas was the first to teach a conservative philosophy for the management of orthopedic foot problems. The Thomas heel is still in use to this day.

In 1896, Royal Whitman, MD devised the Whitman plate to address mechanical dysfunction in flatfoot conditions, especially those in the pediatric population, which he classified as weak foot or flatfoot. Whitman demonstrated that the term "flatfoot" was misleading "for the symptoms of flatfoot do not result because the foot is flat, but because it is becoming flat" and will eventually end in progressive subtalar joint dislocation.[55]

The cast was taken in an off-weight-bearing supinated position. This steel device possessed a medial and lateral flange and a narrow forefoot but did not have a heel cup. Otto F. Schuster, a German-trained orthopedic brace maker who later became a podiatrist, fabricated Dr. Whitman's devices. Since these devices originally caused pain in the navicular region, Schuster modified the plate by dimpling the navicular region to make it more tolerable.[2]

In 1917, Dr. Otto Schuster authored the first book on mechanical dysfunction of the foot entitled *Foot Orthopedics*.[2] It is interesting to note that as a boy, Richard O. Schuster, DPM, while working in his uncle Otto's brace-making laboratory, used to deliver Dr. Whitman's braces to his Manhattan office.

Dr. Whitman may have been the first practitioner to note the relationship between flatfoot pathomechanics and postural problems.[55] In 1897, N.M. Shaffer, MD designed a metal sole plate that functioned as a true arch support and was therefore more tolerable than that of Whitman.[21]

In 1912, Percy Roberts, MD designed a steel plate similar to the Whitman model. Roberts' version had an inverted heel and medial and lateral clips to hold the calcaneus in a more vertical position.[21] In the 1920s, Otto F. Schuster redesigned the Whitman plate with Roberts' modifications for a more efficient and better tolerated Roberts-Whitman device. During the 1920s, podiatry-designed orthoses incorporated deepened heel seats for improved rear foot control.

In the late 1920s, '30s and '40s, Dudley J. Morton, MD published and lectured on the role of atavism regarding a short first metatarsal segment and its role in the production of foot pathomechanics.[57-59] The Morton's extension was designed to functionally lengthen the first metatarsal segment and is still in widespread use today. Morton was also the first to discuss hypermobility of the first ray as an accompanying finding in the pathologically functioning foot of modern man.

Figure 1: Original Root type thermoplastic device with butadiene rear foot posts instead of acrylic.

In 1948, two chiropodists, Schreiber and Weinerman, proposed the concept of medial (varus) and lateral (valgus) imbalance of the forefoot.[60,61] They also stated that in order to mechanically manage the foot, the position of the forefoot must be accurately and precisely measured and then "balanced". To obtain this measurement, the rear foot was aligned perpendicular to the leg. This technique was re-introduced 10 years later with forefoot varus and valgus posting by Merton Root, DPM.[62]

Figure 2 a,b: Non-compressible graphite composite device with flexural forgiveness and resistance to shell fracture.

In 1956, an orthopedic surgeon Arthur Helfet, MD designed a heel stabilizer to limit calcaneal eversion in an attempt to control the marked valgus that accompanies the excessively pronated pediatric flatfoot.[63] Dr. Helfet noted that if the calcaneus is held in a vertical position, there is the creation of a normal arch, and since the growing foot would develop and function according to the shape in which it was held over time, a normal arch would develop.[64] In essence, heel stabilizers are only one segment of pediatric foot orthoses since they only address the rear foot component of the condition. Heel stabilizers are better tolerated in younger age groups and should employ rigid materials such as graphite composites, fiberglass, polypropylene, Ortholon, et al.

Schreiber and Weinerman first proposed the concept of medial (varus) and later (valgus) imbalance of the forefoot.

Acrylics

Beginning with the Root functional orthotic and for years to come, almost every biomechanical device was fabricated from an orange-colored, inflexible thermoplastic called Rohadur™. Virtually overnight, replacing steel acrylics offered a durable, non-deforming alternative to leather and its laminates. Acrylic devices such as those made of polydur (Rigidur™), a polymer of methyl methacrylate, are not as popular as they once were since newer materials such as graphite composites and polyethylene have been introduced. Orthotics made from acrylics are lightweight, surprisingly well tolerated, and offer a high degree of control (Figure 1). Although acrylic devices are prone to fracture when their elastic limit is exceeded, they are still useful in children from 9 months to 3 1/2 years of age.

Graphite Composites

Carbon graphite composites along with the polypropylenes have all but replaced acrylics as some of the most popular, versatile and durable materials to be employed in the fabrication of functional foot orthoses. Besides their ability to offer a high degree of control, graphite modules offer many characteristics that are useful in the pediatric population. These devices are well-tolerated, lightweight, streamlined, semi-rigid, non-compressible, and virtually indestructible (Figure 2). Because of their low profile carbon graphite, orthoses fit well in most school and dress shoes. Control may be enhanced by the addition of medial and lateral flanges as well as deepened heel seats. Their prescription can be modified to fit and function well in limited-space sports footwear such as soccer cleats or hockey skates (Figure 3).

HDPE

High-density polyethylene (HDPE) belongs to the polyolefin plastic group and is widely used as a module material for pediatric foot orthoses. HDPE has several characteristics that make it desirable, including: resistant to deformation, torsionally flexible, light in weight, semi-rigid, and non-compressible. When stress is applied to the HDPE shell beyond its elastic limits, it will not fracture as will the acrylic device such as Polydor.

Most pediatric patients can be viewed as mini-Olympians, always ready to start the next event. It is because of this high level of sport-type activity coupled with the fact that most children wear athletic type footwear that the prescription of sport-type orthoses is very fitting. Pediatric sports orthoses should have characteristics similar to those prescribed for adults. These modifications include deepened heel seats averaging 3/4 inch or greater, compressive butadiene rubber rear foot post system, forefoot posting extended to the sulcus, and soft tissue extension to the toes (Figure 4). Using forefoot posting extended to the sulcus is an extremely beneficial modification in the child's foot with forefoot imperfections. Since a large number of the child's weight-bearing activities require on-forefoot action, the extended forefoot post correction continues to control the foot even when the rearfoot is not in contact with the weight-bearing surface. In equinus situations, a more flexible module may be employed, such as Toprelle™, a hybrid HDPE plus rubber material (Figure 5).

Figure 4: HDPE full-foot device with extrinsic rear and forefoot posts extended to the sulcus for maximum control.

The Root Biomechanical Orthotic

The first true functional foot orthosis was developed in 1958 by Merton Root DPM and is the model from which all other modern-day functional foot orthoses have been derived.[62] Root's initial devices were modifications of the Levy mould, a sulcus length device with a digital crest which incorporated balanced correction in the forefoot. The problem with these early devices was that they tended to continue to mold to the foot as they were worn, thereby diminishing their originally intended function.

With the advent of thermoplastic materials, Root began fabricating his devices from Rohadur™, a non-deforming German-made shell material with methyl methacrylate angular rear and forefoot post corrections and a mild to deepened heel seat. The mechanism of action was in direct contrast to that provided by previously prescribed arch supports. As noted, the function of an arch support was to empirically buttress the longitudinal arch, utilizing various materials in order to support the entire weight of the superstructure. Unfortunately, these devices produced random supination of the entire foot, with unlocking of the longitudinal axis of the midtarsal joint and additional dysfunction.

The original Root orthotic was fabricated from Rohadur.

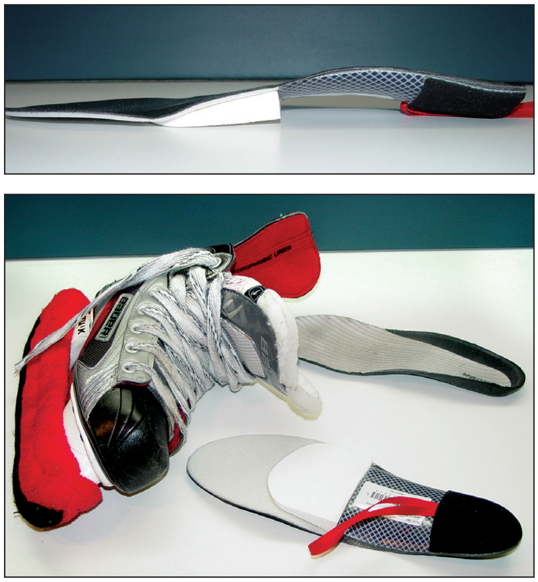

Figure 3 a,b: Full foot, low-profile carbon fiber orthoses with intrinsic rearfoot posting for use in sports such as skating and soccer.

Adjustments to this type of device usually consisted of increasing the height of the arch, resulting in further lateral instability and accompanying first ray hypermobility. The Root device repositioned the rear foot and forefoot in its correct anatomic alignment, thereby allowing optimum foot function to take place. The arch region of this device may be lower than the observed arch morphology off-weight-bearing. This is due to the fact that the Root device functions by re-aligning the rear foot and forefoot in its appropriate anatomic alignment with the arch region; it merely serves as a "connector" from the rear foot to the forefoot post angulations.

Perhaps the most efficient orthotic device would be a rear foot post surgically adhered to the calcaneus and a forefoot post, if indicated, attached just proximal to the metatarsal heads. The problem is finding patients willing to test the theory. In any event, the modern foot orthosis functions by re-aligning the osseous and soft tissue structures in such a manner as to enable an interlocking structural framework to allow the longitudinal arch to support itself during stance or ambulation.

The absence of wear patterns on the arch region of a functional device versus the excessive wear noted on a supportive or accommodative type insert in this same region exemplifies this fact (Figure 6). The functional foot orthosis acts as a guide from which the foot may function, not as a supportive crutch for the superstructure to lean on. The effectiveness of the Root functional device may be supplemented with the addition of medial and or lateral flanges and markedly deepened heel seats. The resulting orthosis will resemble a modified Roberts-Whitman type device.

UCBL

In 1967, the University of California Biomechanics Laboratory at Berkeley designed and introduced a thin, lightweight, semi-rigid, polypropylene deep heel seat device with high medial and lateral flanges ending at the first and fifth metatarsal heads for the control of excessive pronation (Figure 7).[65,66] Due to its bulk design, it is difficult to fit into most non-athletic type footwear. This classic device has been documented to be effective in the management of pediatric flexible flatfoot disorders.[67,68]

The UCBL device functions by blocking all abnormal subtalar and midtarsal joint motion.

The UCBL differs from the Root-type device in that it depends on contouring to resist abnormal motion, rather than by encouraging normal foot mechanics.[65-70] It is intended to block forefoot abduction and talar adduction associated with increased pronation. It has been frequently employed in individuals with talar declination greater than 45˚, Down's syndrome, and cerebral palsy equinovalgus patients.[67]

Essentially, the UCBL is a Roberts-Whitman plate with medial and lateral flanges. This device is not tolerated in the presence of oblique midtarsal joint axis equinus compensation.[69,70]

Figure 5a,b: Flexible shell device to accommodate compensatory sagittal plane forces while still providing motion control and guidance.

Functional UCBL

The most widely prescribed pediatric orthotic in my practice is a device referred to as a functional UCBL (Figure 8). This is a highly controlling device with a subortholene shell composed of an ultra-high molecular weight polyethylene which is thinner than that used in current conventional UCBL prescriptions. The functional UCBL was originally derived from a device designed for aerobic dance participants and is a non-compressible, semi-rigid, lightweight device with some degree of flexural forgiveness and a high degree of control.

Modifications incorporated include a deepened heel seat, reduced or absent undercuts (tapering of the rear foot posts), medial and lateral flanges, rear and forefoot posts extended to the sulcus, medial and lateral longitudinal arch fills, 1/8" heel raises, and a 4 degree medial grind-off to allow for normal motion.

Except for its increased length due to extended forefoot posts, the resulting orthotic outwardly resembles the original UCBL; functionally, however, there is a distinct and crucial difference. The original UCBL functions by blocking all abnormal motion, whereas the functional UCBL acts as a true Root-type functional orthosis to optimally re-align the osseous and soft tissue segments of the foot and ankle, thereby promoting normal function.

Blake Orthosis

In 1986, Richard Blake, DPM published a paper describing a technique to improve orthotic control and function.[51] The Blake inverted orthosis is an aggressive varus correction of the standard off-weight-bearing subtalar neutral position cast. This is achieved by plaster correction of the positive in the rear and forefoot regions. The usual correction is 25˚, but up to 75˚ may be achieved by this method. Since the device contours well to the longitudinal arch, there is minimal tendency for lateral instability. As a rule-of-thumb, each 25˚ of cast correction will produce up to 5˚ of calcaneal eversion neutraliza-

The Blake inverted cast correction is a method of significantly improving orthotic control and function in the pediatric patient.

tion. If above the 5° eversion, a 7:1 ratio may be more appropriate.[51]

Additional modifications may include a plantar fascial groove, a deepened heel-seat, as well as flattened rear foot posts. The typical foot orthosis for the pediatric patient usually requires a new prescription every one to two years or with a change of two shoe sizes. Owing to its inverted heel-cup rather than relying exclusively on forefoot or rearfoot post corrections, along with its deepened, inverted heel contouring, the Blake orthosis will accommodate the child's foot for over three years before a new prescription is necessary.

DSIS

The DSIS or dynamic stabilizing innersole system was podiatry-designed in 1992 by Drs. Harold Schoenhaus and Richard Jay to neutralize hyperpronation in the pediatric patient.[73] This device is better tolerated than its predecessor the Roberts-Whitman device, even in equinus situations. This semi-rigid, lightweight subortholene device possesses a deep, off-set heel seat to cup the calcaneus in 5° of varus with high medial and lateral flanges, which prevent lateral and medial drift of the fifth and first metatarsal, thereby enhancing transverse plane control (Figure 9). A central slit in the shell creates two independent control arms, allowing the device to be more readily tolerated.

Figure 8: Functional UCBL with medial grind-off promoting normal function along with ultra-high control, medial and lateral flanges, heel raises, deep heel seats, butadiene posts, and reduced undercuts.

The DSIS allows normal pronation to occur during early stance. A medial arch cushion may be added if necessary. For heavier children or where additional forces are being directed through this device, the arch region may be buttressed to prevent deformation. Extrinsic and/or intrinsic forefoot varus or valgus tip posting as well as first or fifth metatarsal head cutouts may be incorporated.

Figure 6: Absence of medial longitudinal arch wear patterns indicating effective orthotic functioning.

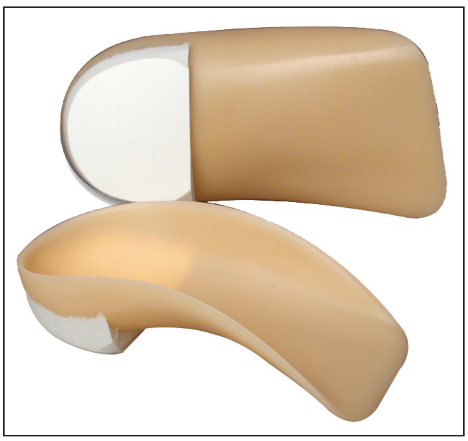

Figure 7: UCBL device deepened heel seat and medial and lateral flanges providing control and blockage of motion.

The gait plate is a device to alter the angle of gait in the pediatric patient and was designed by Richard O. Schuster.

Gait Plates

The gait plate device was designed by Richard O. Schuster, DPM in 1967 to alter the angle of gait in the developing child.[22] Since this device functions at the propulsive phase of gait, the child must possess an adult gait pattern with an active propulsive phase in order for the device to be effective. This usually occurs from three to three and a half years of age.

The original gait plate was a flat acrylic or steel plate but as the heel seat was deepened and the device fabricated from a neutral subtalar plaster model of the patient's foot, it became known as a Shaffer gait plate. The better the orthotic segment of the gait plate controls abnormal pronation, the less apparent is the benefit of the gait plate extension. For each degree of calcaneal eversion controlled, there is a 1° increase in forefoot adduction.[21,22] It is important to make parents aware of this apparent treatment "failure" situation prior to dispensing it.[5]

The distal edge of the device is angled perpendicular to the desired direction of correction. To correct an in-toe gait, the distal aspect would extend from proximal to the head of the first metatarsal to the sulcus of the fifth digit (Figure 10). To correct an out-toe gait disorder, the device would be angled proximally from the fifth metatarsal head and extend distally and medially to the sulcus of the hallux.

During propulsion, the child is unable to continue forward motion over the angular correction unless the extremity is rotated internally or externally to become perpendicular with the device angle. This is exhibited by an observable adductory or abductory twist

By necessity, the device must be inflexible; and in order to be effective, it must be worn in a shoe with a flexible forefoot. Additionally, to correct an in-toe gait, at least 25° of external hip rotation must be available in order for the gait plate to be effective.[22] Depending on the child's weight and intensity of activity, materials such as a thicker shell high density polyethylene (HDPE), graphite composites, and acrylics work well.

Gait plates may improve gait angles by 5-20˚.[5,21] Enhancement of correction for an in-toe gait may be achieved by adding a similarly angled valgus forefoot post extension to the distal tip of the device. Enhancement of gait-plate correction for an out-toe gait may be achieved by adding a varus forefoot post extension to the distal aspect of the device. Of course, it is difficult to rationalize adding these corrections if

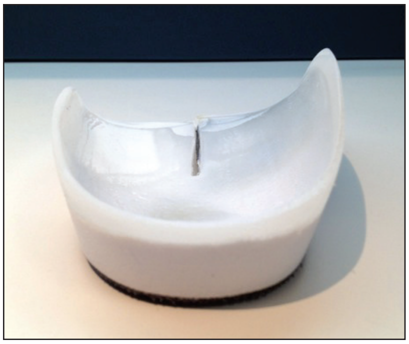

Figure 9: DSIS device with high medial and lateral flanges and central slit to allow tolerance in severe hyper-pronation syndromes as well as equinus compensation.

the corresponding underlying frontal plane deficiencies are not inherently present in the foot.

Reduced Profile Devices

There are circumstances where the bulk of conventional pediatric foot orthoses make them unable to be worn in a particular shoe or during a specific activity. In these instances, a reduced profile device is particularly useful and effective (Figures 11 a,b). Because of their decreased bulk, these devices are approximately 20% less efficient than their full-size counterpart; however, they are still able to significantly affect foot and limb function in a positive manner and obviously are significantly more effective than no device at all.

Situations in children where a reduced profile device would be indicated include dress and fashion shoes, dance and martial arts footwear, and some slip-ons.

Many martial arts instructors will allow a child to wear a dance-type shoe or sneakers, if physician-requested. These devices also conform well to girls' dress and party shoes as well as stylish winter boots. The limited space available in some soccer and skate footwear makes these situations ideal for reduced bulk devices. Especially useful in this regard are those devices fabricated of graphite composites. These orthoses may have a hollowed-out heel cup with intrinsic rear foot posting to allow for better foot seating in the shoe (Figure 11).

Monitoring Effectiveness

At the time of dispensing the orthotic, devices should be checked against the child's foot off-weight-bearing to ensure conformity. The child is then asked to stand, and the subtalar neutral position is assessed without orthoses. This can be observed indirectly by observation and measurement of the relaxed calcaneal stance position, or directly by measuring the angular frontal plane relationship of the forefoot on weight-bearing and comparing it with its position when in subtalar neutral alignment (Figure 12a,b).

The difference between the two readings, i.e., the subtalar neutral value minus the at rest value will give you the 'total varus' or total degree of compensation that is taking place in the child's foot.[74,76] This measurement captures the sum total of all frontal plane varus influences into the foot from the head to the toe.

The higher the number, the more compensation that is taking place. Next, the child is placed on the orthotic device. The subtalar neutral position is palpated and, if necessary, the foot re-positioned and another measurement taken (Figure 13). If the orthotic device is positioning the foot and ankle properly, this reading in most cases should be 0˚-5˚. In no case should the total varus measurement with orthoses be similar to that obtained without the devices.

Progress can be monitored objectively by means of periodic clinical examination, radiographic assessment, and in the case of children over three years of age, by computer-assisted gait

Figure 10: Acrylic gait plate for the right foot designed to encourage out-toe. The distal edge of the device is angled in the direction of desired correction.

analysis.[4] Orthoses will need replacement with foot growth as well as structural changes that are taking place. This will be necessary at least every two years or two shoe sizes although if a growth spurt has taken place, the orthotic may have to be changed as early as one year.

Sometimes, the child does not change shoe size but the foot becomes more adult-like, increasing in girth and form, so the original orthotic is not

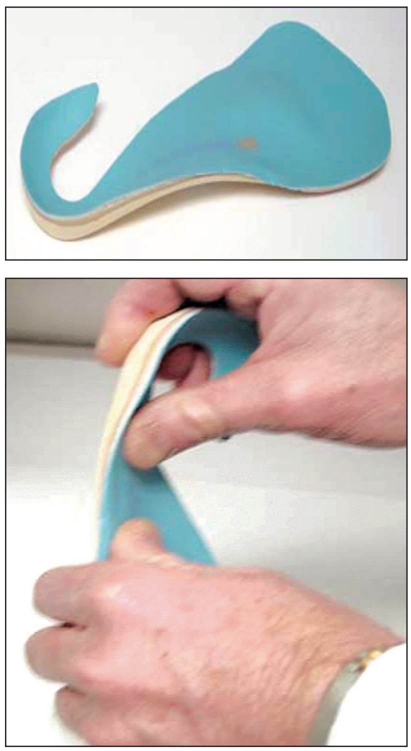

Figure 11a,b: Reduced profile device with flexural forgiveness useful in dress footwear as well as in martial arts and dance activities.

able to control the foot as well as it did when it was initially dispensed. As an aside, in cases where the orthotic seems just marginally small and it is late spring or early summer, it is helpful to wait until the end of the summer before recasting due to the possibility that the child may experience a growth spurt over that time. Additionally, and on a practical note, kids virtually destroy otherwise indestructible devices while away at camp!

Each child's foot requires an individual amount of correction to be applied in order to achieve the optimum outcome.

Duration of Treatment

The goal of orthotic intervention is to achieve normal foot structure and function during stance and ambulation, with all visible signs of pronation neutralized.[8] Remission of symptomatology, when present, is not a criterion of optimum function nor is it a determinant for cessation of therapy. Since most lower extremity musculoskeletal parameters have achieved the majority of their adult values by seven to eight years of age, this is the earliest time that cessation of therapy should be considered, regardless of the age at which treatment was instituted. Furthermore, since complete skeletal maturity does not occur until 13 years of age in girls and 15 years of age in boys, it is prudent to maintain correction to at least this point in development. Existing observable structural deficiencies retained beyond this point require continuing care. Progress should be monitored throughout life.

Pre-fabricated Orthoses

Pre-fabricated orthoses in the child have been used for many years ranging from shoe store dispensed "cookies" to professionally prescribed arch supports. Herman R. Tax, DPM, the "Father of Podopediatrics", routinely dispensed pre-fabricated, flexible rubber orthoses with the first metatarsal head cut-out for use in rigid-soled orthopedic type footwear.[9]

Today, there are a number of excellent pre-fabricated children's devices available in all shapes, sizes, and materials. They can be purchased with flexible, semi-rigid or rigid shells with deepened heel seats, medial and or lateral flanges, 4˚ rear foot posts, 4mm medial skive, etc. These devices offer excellent control for many individuals. No matter what device is chosen, whenever possible it should be capable of being modified by the addition or deletion of materials or by shape alteration to provide as close a match to the child's foot as would be provided by a custom device while at the same time providing neutral subtalar joint position function.

Each child's foot requires an individual amount of correction to be applied in order to achieve the optimum outcome. Furthermore, over 90% of all pediatric foot pathology differs in degree from right to left, and since all pre-fabricated devices are symmetrically corrected, I do not prescribe these mass-produced devices. With that being said, the pre-fabricated device does not require an impression. In children where a subtalar neutral position plaster impression cast cannot be performed or a foam impression is not able to be obtained, the pre-fabricated orthotic may be a satisfactory temporary solution. Additionally, if cost is a major concern, the pre-fabricated devices will offer the family some economic benefit as well.

Summary

Prescription foot orthoses in the pediatric patient have myriad beneficial applications. When employed appropriately and judiciously, they

Figure 12a: With the foot in its relaxed weight-bearing position, the angular frontal plane deviation of the forefoot is measured.

Figure 12b: The foot is then placed in subtalar neutral position and the angular frontal plane deviation of the forefoot is measured. The difference between the two numbers is the sum total of all super-structural and intrinsic frontal plane influences into the foot. The higher the number, the more severe the compensatory pathomechanical dysfunction.

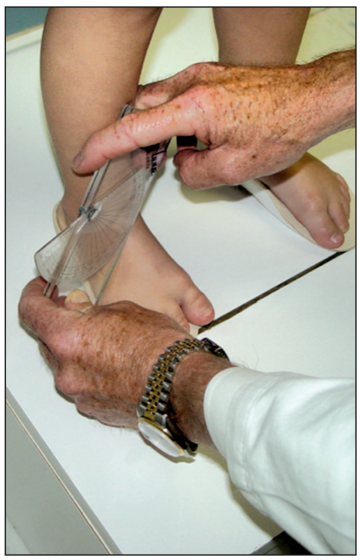

Figure 13: The foot is placed in the orthotics and the angular frontal plane is again measured and compared with the palpated subtalar neutral position measured. If the orthotic is properly positioning the foot and ankle, there should be little or no difference between the two measurements.

mold and guide the developing foot into a more structurally balanced base of support, thereby improving function and preventing deformity in a child whose feet may have to last 100 years or more. **PM**

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

CME **EXAMINATION**

1) Which one of the following describes Morton's syndrome?
- A) short first metatarsal
- B) accessory navicular
- C) plantarflexed first ray
- D) metatarsus primus adductus

2) Which one of the following individuals first proposed the concept of medial (varus) and later (valgus) imbalance of the forefoot?
- A) Morton
- B) Schreiber and Weinerman
- C) Root
- D) Schuster

3) The original Root orthotic was fabricated from which one of the following materials?
- A) Rohadur
- B) Leather
- C) Graphite composite
- D) Steel

4) Which one of the following materials has replaced thermoplastics in the fabrication of foot orthoses?
- A) leather
- B) Plastazote
- C) cellular rubbers
- D) high-density polyethylene (HDPE)

5) Due to the increased activity level in the young child, prescription foot orthoses should possess which one of the following characteristics?
- A) rearfoot post
- B) forefoot post extended to the sulcus
- C) rigid shell
- D) soft tissue supplement top cover

6) The UCBL device functions by which one of the following methods?
- A) blocking all abnormal subtalar and midtarsal joint motion

B) realignment of rearfoot and forefoot osseous segments
C) encouraging adaptive phase pronation
D) encouraging normal function

7) Characteristics of the functional UCBL are represented by which one of the following?
A) medial grind-off
B) reduced or absent undercuts
C) appropriate rear and forefoot posting extended to the sulcus
D) all of the above

8) A method of significantly improving orthotic control and function in the pediatric patient may be achieved by which one of the following?
A) Blake inverted cast correction
B) Morton's extension
C) Increased shell flexibility
D) Metatarsal pad

9) A particularly valuable, highly controlling pediatric orthotic device with medial and lateral control arms is referred to as:
A) Whitman plate
B) Levy mould
C) Helfet heel cup
D) DSIS (Dynamic Stabilizing Innersole System)

10) The gait plate is a device to alter the angle of gait in the pediatric patient and was designed by which one of the following?
A) Richard O. Schuster
B) Dudley Morton
C) Merton Root
D) Kevin Kirby

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2.	**A**	**B**	**C**	**D**	**7.**	**A**	**B**	**C**	**D**
3.	**A**	**B**	**C**	**D**	**8.**	**A**	**B**	**C**	**D**
4.	**A**	**B**	**C**	**D**	**9.**	**A**	**B**	**C**	**D**
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