CONTINUING EDUCATION
for Physical Therapists

THE PEDIATRIC FOOT:
Anatomical Development, Clinical Assessment, and Considerations for Intervention
PDH Academy Course #PT-1703 | 3 CE HOURS

Course Abstract

This course counters the erroneous belief that poor pediatric foot development is of no concern. It begins by reviewing ideal anatomical development. Next, it presents orthopedic development in relation to appropriate development of an adequate base of support, and the subsequent functional assessment of the pediatric lower quarter. Finally, it addresses the negative effects of abnormal development on gait and posture, and presents suggestions for proactive and preventative intervention.

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Target Audience & Prerequisites

PT, PTA – no prerequisites

Learning Objectives

By the end of this course, learners will:

- ❏ Recognize aspects of appropriate anatomical development of the body and foot
- ❏ Recall the impact of shoes on ossification, arch development, and gait
- ❏ Identify considerations pertaining to "flatfoot"
- ❏ Distinguish between gait assessments
- ❏ Recognize elements of evidence-based interventions for pediatric flatfoot

Timed Topic Outline

I. The Skeleton and Alignment (20 minutes)
II. The Significance of the Alignment of the Arches of the Foot (5 minutes)
III. A Developmental Review (20 minutes)
IV. Longitudinal Arch Height Does Matter (20 minutes)
V. Treating Pediatric Flexible Flatfoot (40 minutes)
Gait Assessment; The Influence of Footwear on Gait, Postural Control, and Proprioception; Intervention
VI. References and Exam (15 minutes)

Delivery Method

Correspondence/internet self-study with interactivity, including a provider-graded final exam. *To earn continuing education credit for this course, you must achieve a passing score of 80% on the final exam.*

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Course Author Bio and Disclosure

Liesa M. Persaud, PT, DPT, PCS, CKTP, is a licensed physical therapist with 23 years experience in the field of adult and pediatric therapy. Ms. Persaud is the lead physical therapist at Tulsa Sunshine Center in Oklahoma, where she provides Animal Assisted Therapy with her Border Collie, Serendipity. Additionally, Liesa is owner of Know to Change, PLLC in Skiatook, Oklahoma, and has educated health care professionals, both nationally and internationally, in advanced treatment techniques, specialized practical training and consultative services. She has worked in a variety of settings, including private pediatric and adult clinics, schools, private homes, hospitals and long-term care facilities. Ms. Persaud is a Credentialed Clinical Instructor and also teaches human anatomy, physiology and nutrition at Tulsa Community College.

She received her Associate's Degree in 1993 from Tulsa Junior College and worked as a physical therapist assistant while completing her Bachelor of Science Degree in Organizational Leadership from Southern Nazarene University in Tulsa, Oklahoma. Ms. Persaud earned her Master's Degree in Physical Therapy from the University of Findlay in Findlay, Ohio in 2003 and continued to expand her expertise in the field. She received her post-graduate Doctorate from Rocky Mountain University of Health Professions and is a Board Certified Specialist in Pediatric Physical Therapy. In 2007, Ms. Persaud served as Treasurer for the Oklahoma Physical Therapy Association and has been a member of the Oklahoma Foundation for Physical Therapy since 2004.

Ms. Persaud's passion for helping others extends into her private life. She volunteers as a Call Rape Advocate and a Salvation Army Volunteer, and is a member of the Fraternal Order of Police Auxiliary.

DISCLOSURE: Financial – Liesa M. Persaud received a stipend as the author of this course. Nonfinancial – No relevant nonfinancial relationship exists.

INTRODUCTION

Families and therapists are often told that poor foot development is of no concern. Among other generic statements, we hear that the child will "outgrow" it, they will "walk when they are ready," or "the foot needs more time to develop."

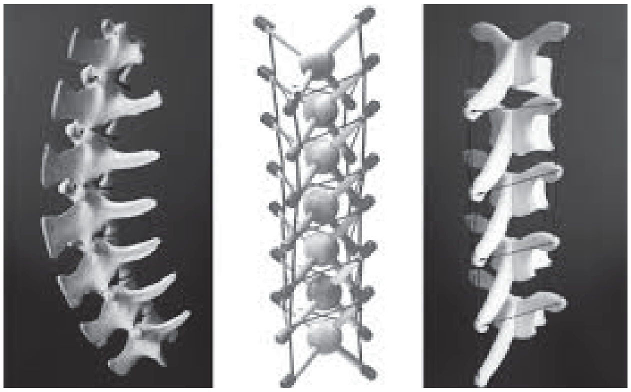
This course addresses ideal anatomical development, so as to assist the clinician in identifying when development is abnormal. Further, the negative effects of abnormal development on gait and posture are addressed, as are suggestions for proactive and preventative intervention. In addition, orthopedic development is presented in relation to appropriate development of an adequate base of support, and the subsequent functional assessment of the pediatric lower quarter.

In Imperial China, it was the custom for respectable women to have their feet tightly bound with bandages between the ages of five and seven years in order to produce tiny feet. The purpose of this practice was to induce deformities that facilitated increasingly small shoes. Obviously, this ever decreasing base of support had a profound effect on their stability and resultant gait pattern. The consequential swaying "lotus gait" was considered attractive by Chinese men and was therefore thought to make the girls more appealing for marriage.

This practice, as barbaric as it was, was highly effective in changing foot shape and size, and also had a significant effect on gait. Consider for a moment, how similar effects on form and function may be achieved by applying appropriate (or inappropriate?) forces to the child's foot in order to change skeletal relationships and alignment.

THE SKELETON AND ALIGNMENT

The mature human body exists as a tensegrity system (48). Such a system is based upon the architectural principle of the operation of isolated components within a system, components that are compressed in a state of continuous tension.



With regards to the human body, the bones function as tense, staff-like structures and are supported by ligaments (connect bone to bone), tendons (connect bone to muscle) and fascia (supports & reduces friction). The bones are therefore in a state of compression, which reduces potential damage to their integrity as a result of tensile stress, resulting from external load.

When considering a child's skeleton, it is imperative to consider the stage of ossification, use history, current AND future (or anticipated) pattern of use.

In-utero position & its effect on postural development

The in-utero position is crucial for optimum newborn musculoskeletal alignment and consistency of soft tissue. Further, Lois Bly describes how newborn posture influences movement skills in early infancy (6). Premature babies, infants with low birth weight, and/or babies with a pathology are at a significant disadvantage with regards to skeletal alignment and soft tissue competency, and their effect on functional potential.

Likewise, the development of children's feet begins in-utero, being mainly derived from basic embryological tissue called mesenchyme (16).

At full term gestation, in the presence of ideal positioning, the leg and foot are medially rotated.

As the child begins to gain upright mobility, they perform trunk rotation and weight shifts in the frontal plane. Therefore, the leg rotates laterally and the foot sustains load on the lateral borders. Consequently, since these movements are imposed upon an immature skeleton, the boney alignment, and related joint relationships, undergo reorientation.

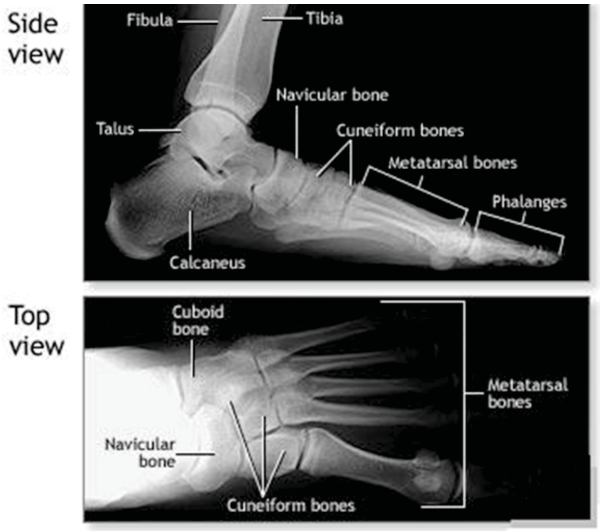
Ossification

Ossification is the natural process of bone formation as it undergoes hardening into a rigid state. The bones of an infant are not completely ossified at the time of birth; in fact, they are mostly water and have a high collagen content. Because the bones have not assumed their final shape and density, the immature skeleton is extremely susceptible to the influences to which it is subjected.

During development, the skeletal system ossifies at dissimilar ages and rates. The purpose of this is to transform the human body from the necessary in-utero position, to the position that is required for decades of functional, upright stable mobility and body:ground interface.

Wolff's Law is the process by which skeletal modeling occurs. Wolff's Law specifies that a bone will adapt to the mechanical stress (load) under which it is placed (41). Such mechanical stress is created by muscle force at the attachment sites and the action of gravity or impact. Bone architecture, position and relationships are thus affected by these stresses, forces and loads. Therefore, the history of use of the human body during the years of ossification influences musculoskeletal anatomy, physiology, alignment, and functional ability – and so, potentially, can therapeutic intervention.

The ossification of the cuboid occurs reliably at thirty seven weeks gestation and its appearance is often used as a marker of fetal maturity. In contrast, the navicular is the final bone to ossify, and this occurs between two and five years of age. Interestingly, at full term birth, the average foot length is 7.6 cms (2.99 inches) (42, 37).



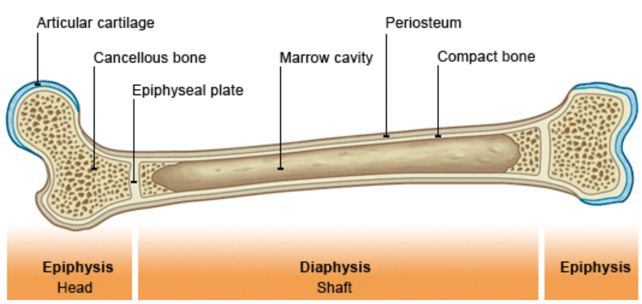
The fusion of secondary ossification centers follows a predictable pattern. For example, the ossification center of the greater trochanter appears at the age of three in girls and six in boys, whereas that of the lesser trochanter appears at the age of six in both girls and boys. The secondary ossification centers for the pubis appear at nine to eleven years in girls and at thirteen to sixteen years in boys (37).

Foot growth is rapid during the first five years of life, and then slows until skeletal maturity. This is approximately thirteen years of age for girls and fifteen years of age for boys. Final foot length is achieved before maximum height is reached in both genders (37).

Ossification of the bones in the feet, which takes place over many years, generally is complete by the age of eighteen to twenty.

Microscopic Anatomy (37)

The epiphysis is the end of the long bone, where growth occurs, and it is responsible for increasing the length of the long bones. Epiphyseal structure is crucial for long bone lengthening.



Bones develop by either endochondral or membranous ossification. Endochondral ossification is bone formation from cartilage. Long bones are primarily formed by endochondral ossification. The cartilaginous phase is usually absent in membranous ossification, as with flat bones.

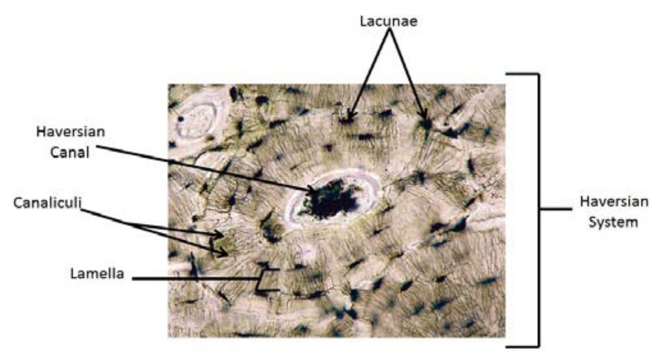
Bones show many layers that demonstrate the process of bone formation. A basal layer consists of resting cartilage cells that multiply into "rounded cells". These rounded cells are arranged in rows and mature into a loose cartilaginous matrix. Blood vessels then insert minerals into the matrix, and form loose woven bone that begins to calcify. Mature bone is finally deposited. This process is repeated as causes the long bone to lengthen.

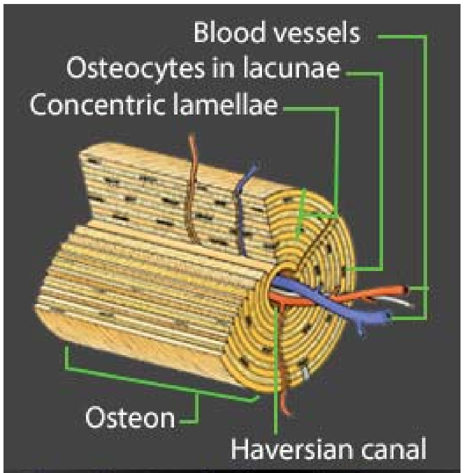
The anatomical regions of a long bone are the epiphysis & the metaphysis. The epiphysis, or "tip", and the metaphysis ("end") are connected by mammillary processes (internal) and tough fibrous periosteum (external). Both these structures are rigid in order to be able to resist displacement forces. However, they are also flexible enough in order to allow microscopic translation forces, and thus provide protection to the bone from injury.

Bone Remodeling

The developing skeleton of a child, which is more porous than that of an adult, responds to injury and infection differently from the adult skeleton.

Mature compact, or cortical, bone (as opposed to cancellous, trabecular or spongey bone) is comprised of haversian canals. Haversian canals are a series of microscopic tubes in the outermost region of bone (cortical bone) that permit the passage of blood vessels and nerves through concentric, layered channels called lamellae. Bone cells are contained in spaces (lacunae) within the dense bone matrix, and communicate with the haversian canals through connections, called canaliculi. This distinctive composition is beneficial for mineral salt deposits and storage, ultimately yielding the impressive strength of bone (37).





Cross Section of a Haversian System

The haversian system is underdeveloped in the child's skeletal system, and so the canals are wider than that of an adult's. Therefore, a child's skeleton is more plastic, and has a significant capacity for being molded or altered. Also, a child's bones are more elastic, and, as such, are more equipped to resume their normal shape after deformation or pressure. For example, they may deform but not fracture, which is a condition often described as a "plastic deformation." Alternatively, the bone may not fully deform, but may become distorted, and result in a "torus (or "buckle") fracture." These structural results do not occur in adults, because their bones' resistance and elasticity to deformation is significantly less (37).

Likewise, the process of the "*re*-modeling" of a fracture or deformity is more effective and has better efficiency in a child than in an adult. To further explain, a skeletal deformity (or break) undergoes correction by unequal, but parallel, development of new bone. Remodeling is influenced by many contributing characteristics, but the primary components are as follows (37):

1. Age: remodeling potential is greater at younger ages.
2. Proximity to the physis: remodeling has greater potential when the site is located close to the physis.
3. Relation to the axis of joint motion: inside the axis of joint motion has better remodeling results than outside the axis of joint motion.
4. Rotational versus non-rotational deformity: rotational deformities do not remodel.

Ossification and the Impact of Shoes

In relation to the immaturity of ossification, shoes can have a significant effect of the development of a child's foot, and ultimate functional ability.

At the crawling stage (3-6 months), the bones of the foot are protected by a layer of subcutaneous tissue.

At the cruising stage (6-9 months), there are proportionally large spaces between the tarsal bones, and so the foot is susceptible to deformation. Therefore, the shoe style should have a protective toe and heel with a firm top cover and textured side patterns to aid in gripping the foot.

At the onset of independent gait (9-18 months), the foot grows rapidly (up to two sizes/16mm per year), and the twenty-five bones of the foot are separated by large spaces to allow for this growth. However, this orientation lends itself to high risk for deformity at this time. For example, the navicular bone (whose precursor is a fat pad) is far from fully ossified, and therefore highly susceptible to external forces – and it is situated where shoes are usually fastened.

At the pre-school stage (2-4 years), the navicular bone begins to ossify and areas of protective fat reduce. At this time there are forty-five separate bone genesis centers, some of which will fuse during the following fifteen years. Shoe style should have a highly flexible forefoot that bends in congruency with the anatomical foot, and a firm rear foot to provide stability on uneven ground.

At the age of four, the arch of the foot will be more visible and functional. Foot growth will reduce to approximately one shoe size per year. The foot will continue to develop into the mid to late teens; however, the potential for change is now significantly less.

THE SIGNIFICANCE OF THE ALIGNMENT OF THE ARCHES OF THE FOOT

By approximately 12 months of age, ideal positioning of the foot should allow loading of the entire foot, with more weight through the forefoot as compared to the hindfoot. For further stability & appropriate recruitment of posterior muscle groups, foot length is about 50% of the mature foot. This proportionally large length resists an anterior center of mass, which creates additional stability in the upright posture (14).

Aharonson et al (1980) (2) and Cavanagh, Rodgers, and Liboshi (1987) (11) illustrated this relationship between ideal foot load distribution and postural control by use of a weight-calibrated force plate in forty-eight typically developing children aged four and five years. In standing, all demonstrated vertical heels and mature weight distribution as follows:

- 61% at the heel (majority of weight)
- 35% at the forefoot
- 4% at the mid foot (minimal weight)

Per Aharonson et al, "Relative to the skeletally mature foot structure, it is expected that an infant and young child should display a flat foot posture…. paediatric flat foot posture has been found to reduce with age (2)."

It must be noted, though, that the foot posture does not change merely through development in isolation, or solely due to chronological age. This "reduction with age" is actually a result of ideal function along the kinetic chain, which consists of anatomical segments that affect one another during movement.

Gould et al (18) describe how an ideally functioning medial longitudinal arch requires a well-developed sustentaculum tali, an appropriate tibialis posterior tendon, an adequate deltoid ligament, a non-restricted Achilles tendon, and a correctly located inferior calcaneonavicular ligament. These authors state that successful development of the medial longitudinal arch is not complete until approximately eight years of age, and that hyperpronation is possibly the norm for five-year-old children. However, it must be reiterated that ideal and functional maturity requires appropriate movement that arises from correct positioning, and resultant muscle recruitment and balance is crucial during the earlier, foundational years.

Their study showed how arch height increases with age. For example, 14.9% of children aged 6 years had low arches, while only 5.3% of 9-year-olds, 3.3% of 11-year-olds, and 2.2% of 12-year-olds presented with low arches. Because of the higher prevalence of low arches among children aged 6 years who wore shoes compared with those who did not, the authors concluded that the critical period for arch development is before age 6.

In addition, the contributions of the somatosensory systems must be considered. For example, the sensory stimulation associated with barefoot activity may produce an increase in muscle activity and tone, which causes additional longitudinal arch development.

Also demonstrated by Gould et al (18), excessive pronation before the age of seven years may consequently form the sustentaculum tali at an inferior angle, due to its immaturity of ossification. This could result in inadequate support of the talus. Development of the sustentaculum tali is essential for the formation of a functional medial longitudinal arch because it allows the bony architecture to control motion, thereby lessening muscular/ ligamentous strain during stance.

Arch Development and the Impact of Shoes

The suggestion that barefoot activity facilitates arch development is worth further consideration.

In a study of 2,300 children aged four to thirteen years, and raised in rural India, Rao and Joseph evaluated the influence of footwear on medial arch development (38). It was found that children who were raised barefoot rarely displayed low arches. At 13 years old, 2.8% had pes planus, as compared to 8.6% of children who were raised wearing shoes. Further, the prevalence of low arches also correlated with shoe type: closed-toe shoes (as compared to sandals) were associated with lower arches. It was evident that arch development progressed with age, and the authors proposed that pre-six years old is the crucial time for foot development.

Michaud (34) suggests that the specific somatosensory stimulation provided by being barefoot increases muscle tone in order to raise the arches of the foot as a protective measure. Such a measure serves a valuable purpose in that it influences skeletal development and relationships with regards to appropriate, and functional, foot structure. His view is supported by other research (39) that showed increases in adult arch height (evidenced by x-rays) due to barefoot activity.

Therefore, it is suggested that when either:

- Barefoot activity is not possible (e.g. due to environmental conditions)
- Adequate time in weight bearing is not achievable (e.g. as with disabilities)
- Poor alignment and/or muscle dysfunction is present
- The child is significantly overweight

…implementing appropriate foot orthoses may be indicated in order to facilitate optimum development in the absence of ideal developmental opportunities. Orthoses improve the medial arch by lifting the talus off the sustentaculum tali, allowing for normal development of the talus (7). We will discuss this intervention in greater detail later in the course.

A DEVELOPMENTAL REVIEW

During the first three years of life, a child goes through a significant amount of changes in anatomy and functional movement skills.

A toddler has a relatively large head and feet in relation to the rest of its body. Toddlers also have vertical tibias and flexed hips. This posture serves to keep the weight lines posterior and helps develop posterior balance reactions.

The characteristics of early gait include a wide base of support, high arm guard, footflat at initial contact, high variability, short step lengths, no reciprocal arm swing and everted heels.

However, the first 5 months of walking practice serve to integrate postural control into dynamic movement. Soon after, balance and more precise adjustments emerge. After approximately 5 months of walking experience, the child's gait matures to demonstrate initial heel contact, lateral weight shift stability, and transverse plane motion (19).

The segments of the human body are anatomically linked in a biomechanical chain. Therefore, changes in foot position will alter leg and hip position, pelvic tilt, spinal alignment, and the orientation of body weight on the foot.

At ages 2 to 3 years, the following characteristics are evident (14):

1. Body weight is carried on the whole foot, with occasional toe flexion used for balance.
2. The lateral column of each foot is load-bearing, and in full contact with the floor.
3. Footprints show that the medial longitudinal arch is forming. Weight is lifting off the medial arch area in girls earlier than boys.
4. The shape of the foot is rectangular at 2, and widens at the forefoot at age 3 years.
5. The medial and lateral borders are straight.
6. The heels, when viewed posteriorly (relaxed calcaneal stance), demonstrate valgus positioning: the legs progress from varum to valgum prior to mature development of the foot muscles and ligaments. Valmassy (50) proposed a guideline of (7-8 minus the child's age) as ideal for age relaxed calcaneal stance. Of principal significance, however, is that the body weight is carried on the full foot, with frequent shifts to heel and lateral surfaces, as opposed to primarily on the medial forefoot.
7. The toes align parallel with each other and with the metatarsal shafts.
8. The medial longitudinal arch is increasing in height.
9. The foot shape is more triangular than rectangular.

Postural Control

The lower extremities must support the weight of the body weight in motion for five thousand steps per day (each foot) for seventy years. Therefore, to assure structural longevity, acquisition and maintenance of postural control is crucial. To accomplish this, by four years of age, body weight is greater posteriorly, with a ratio of 2:1 (heels:metatarsals) (14).

At birth the ideal position of the hips is flexion, abduction and lateral rotation. This positioning is sustained ex-utero by the shortened anterior and inferior capsules and iliopsoas muscles. The knees are aligned in flexion and medial rotation, and are maintained in that position by the restraints of ligaments, tendons and soft tissue. During the process of ideal development, appropriate mobility and adequate weight bearing, these postures will re-model over several years (14).

In the twelve months after birth, the child's feet are soft and flexible, with plentiful fat pads on the plantar surface. These fat pads fulfill a purpose. They protect bones, tendons, ligaments, blood vessels and nerves. They provide this protection by absorbing the impact, shear, force & pressure that are involved in the upright activities, such as standing, walking, running & climbing, in which the child will now participate. The plantar fat pads are composed of many microchambers that contain fatty tissue. These chambers are formed by walls of elastin (mainly collagen) that are extremely pliable. The qualities of stretch and rebound absorb and dissipate activity induced force, pressure, shock and vibration.

As the child progresses to accomplish antigravity movement skills and improved postural control, they will establish mature skeletal alignment & balanced muscle function (14).

Mary Weck, PT at the Children's Hospital of Chicago (47) describes how vertical tibias are a significant phase during the process of ideal development. At the onset of independent ambulation, the triceps surae (gastrocnemius and soleus functional group) demonstrate amplified negative activity, which presents as eccentric contraction. Eccentric muscle activity is the situation of muscle activation that increases tension on as it lengthens. Eccentric contractions typically occur when a muscle opposes a stronger force. In this situation, the forces are inertia, gravity & momentum. This eccentric action results in the muscle lengthening as it contracts.

Further, tibial inclination is restrained in order to assist the child during the acquisition of skilled balance in the sagittal plane. Mature tibial inclination in the stance phrase of gait is 7-10 degrees. As a result of this tibial restraint, the child presents with two ankle dorsiflexion range of motion values, R1 and R2. R1 values are developmental.

Let's look more closely at this point: R1 is the initial point of resistance to the light, rapid, passive lengthening of a muscle; R2 is maximum joint range of motion. If R1 is pathologically decreased, then the normal alignment of collagen fibers and sarcomere elasticity is interrupted as a result of muscular imbalance. R1, then, indicates the position of primary function. For example, a child may present with adequate range of motion (R2 value within normal limits), but does not demonstrate dorsiflexion at heel strike. This is because their R1 has developed into inadequate range of motion. This is a result of decreased muscle length in gastrocnemius (and possibly soleus) from a pathological history of use. The ultimate imbalance of the muscle force couple creates an abnormal movement pattern, even though the child "has the range."

Therefore, singular, isolated developmental skills are less functional as primary goals of achievement. Instead, emphasis on the development of a stable base, competent postural control and a wide repertoire of movement patterns and skill are better options for functional performance.

Children's motor development generally follows the pattern of sitting (at approximately six months), crawling (at approximately nine months) and walking (at approximately ten to sixteen months). However, there is high normal variability in the ages at which various milestones are reached (1).

The early gait of new-walkers is different from that of an older child or adult in the following ways: shortened stride, feet wide apart, high guard posture for balance, frontal plane sway, and high cadence. The toddler (two to three years of age) has an unsteady bipedal gait with a narrow base of support, with foot placement and progression angles of approximately 6 degrees. By contrast, in order to increase speed and energy efficiency, mature gait includes the following: transverse plane motion, greater stride length, and lowered arm swing. Due to rapid skill progression and neurological maturity, the gait of a three year old child is stable, efficient and reliable. Mature gait is seen at approximately three years of age, with a range of normal variation from two to six years.

Therefore, postural control begins to develop in infancy and continues into adolescence, at approximately eleven to fourteen years of age.

Functional responses to lateral tilting were consistent in children aged three and older. That is, repeated movement patterns move from higher cortical functions to more easily reproducible cerebellar motor maps: per Schumway-Cook & Woollacott (2001), "As development proceeds, the preferred solutions to the task will come to dominate the repertoire. They will more frequently be used and will become accurate and efficient. Thus, they become a skilled activity (44)." In other words, although the neurological system is plastic and still able to be changed, the potential for change is less after this age.

Balance, Proprioception, and Gross Motor Skill Development

The human environment is not static and so it is necessary for us to develop an adequate range of flexible movement solutions to environmental changes in order to move with successful efficiency and adaptability. The function of postural control is to sustain balance by keeping the body's center of gravity within its base of support. Through the development of postural control, variability of movement & ability is crucial. As the child develops and perfects a new motor skill, they ideally utilize a range of motor strategies.

As a common example, children with hypotonia often lack variability of, or high level, motor strategies. The result is a decreased ability to adapt to the environment. Children with low tone often pronate. A child who is significantly pronated is unable to supinate during the stance phase of gait. Therefore, they have inadequate variability of foot position. This results in difficulty walking on uneven surfaces and is interpreted as poor balance and instability. Alternatively, another child may have excessive movement variability and so is unable to react to the environment with the appropriate motor strategy (3, 13, 51).

Hypotonia often co-exists with poor body position awareness. The term "proprioception" is used to describe a person's ability to know their body's position without actually seeing it. A person who has difficulty with proprioception may appear clumsy or uncoordinated. They may overcompensate by looking down at their feet because they cannot effectively sense where their feet are. The combination of poor foot position, lower extremity malalignment, plus incorrect muscle timing and imbalance leads to significant developmental delays.

Delays develop, in part, due to ligament laxity being associated with poor proprioception: information from the mechanoreceptors to the central nervous system (when the foot is weight bearing) is negatively affected in the poorly aligned foot. This inadequate somatosensory information results in postural abnormalities such as a wide base of support, hyperlordosis, anterior pelvic tilt, knee hyperextension, and foot pronation. Over time, these abnormalities create permanent foot deformities that limit functional ability and cause pain. In addition, gait is less efficient as the child compensates for their lack of stability by over-using muscles to resist gravity.

Such developmental delay can be evident in the early stages, such as floor mobility and stability; it may become more obvious with the challenges of upright mobility. Delayed onset of walking is further complicated by obstacles such as an inadequate base of support, poor postural control and impaired proprioception.

The above sequelae often contribute to persistent pronation throughout the gait cycle because the child is unable to appropriately re-align the foot when required. This impedes knee extension, further contributing to pronation at initial contact. Therefore, gait is no longer ideal, stable, skeletally safe or efficient.

Foot Maturation

And so… let's revisit feet. The biomechanics (the mechanical laws relating to the movement or structure of living organisms) and physiology (the normal functions of living organisms and their parts) of the foot are designed to support the entire body, adapt to uneven surfaces and absorb shock with each step.

Foot development is highly relative to maturation of the nervous system and growth of related structures such as bones, ligaments and tendons.

The foot grows at a faster rate than height. For example, it is 75% of its full length at seven years of age. Also, at seven years old, the medial arch is well developed, although it may continue to change for another two to three years.

Following are the growth characteristics of feet in children from ages one to five:

- Under 15 months: a child's footwear increased by half a size about every two months.
- From 15 months to two years: 1/2 size increase occurred every two to three months.
- From two to three years: a 1/2 size increase occurred every three to four months.
- From three to five years: a 1/2 size increase occurred every four months.
- Boys' feet tended to average one size longer and one size wider than those of girls.
- Width growth remained proportional to length growth throughout the study.

By twelve years of age, the feet are 90% of their adult size and width.

The congruent foot ("full congruity" = neither pronated nor supinated) is one of optimum stability. When congruent at terminal stance, the foot is physiologically prepared to advance.

Foot Function & Postural Control

The relationship between foot function and postural control was studied in ten toddlers periodically (at 1, 2, 3, 4, 6, 8, 10, 12, 16 and 20 weeks) after the onset of independent gait. The authors noted improvements in balance (as evidenced by decreased oscillations of the center of pressure) that coincided with changes in foot roll-over. There were no changes in load distribution through the plantar foot. They concluded that maturation of foot loading develops at a slower pace (19).

Joint moments and power for gait in both children and adults was analyzed in 3D. The goal was to investigate strategies of stability and mobility. The authors found that the children utilized primarily ankle stabilization and hip propulsion. In contrast, the adults predominantly used hip stabilization, plus ankle resistance and propulsion. These findings suggest that foot maturation during gait is achieved at five years of age (43).

LONGITUDINAL ARCH HEIGHT DOES MATTER!

The Significance of Longitudinal Arch Development

Contrary to the conclusions of early research, recent studies suggest that arch height does indeed affect lower extremity function. Knowledge of the biomechanics associated with arch height enables clinicians to provide specific, and proactive, intervention for both optimum functional development and injury prevention and management (54).

Initially, the foot was classified by the height of the medial longitudinal arch. Historically, it was assumed that low-arches are hypermobile (susceptible to pronation-related injuries), and high-arches are hypomobile (related to high-impact injuries). Studies of injuries do support this correlation between arch height and function: low arches are related to medial knee and ankle injuries, and individuals with high arches are more likely to experience stress fractures.

Confusingly, when Nigg et al (35) investigated the relationship between arch height and 3D motion, they disputed the suggestion that the height of the medial longitudinal arch has an effect on foot function. They stated that individuals with high arches frequently presented with increased calcaneal eversion while low-arched individuals often possessed rigid, less mobile feet. Unfortunately, this study was flawed due to the use of calipers to measure arch height. This method of measurement has a high margin of error because caliper measurements are easily distorted by hypertrophy of the arch muscles and/or adipose tissue, both of which significantly alter arch height and shape. As such, the results of this study provide poor accuracy and therefore the findings are of limited objective value. This is misleading information and contributes to the assumption that height of the medial longitudinal arch does not have an effect on foot function.

However, Williams and McClay (54) demonstrated conclusively that arch height and function are indeed correlated: people with low arches have greater rearfoot eversion excursions and velocities than people with high arches, who present with increased vertical loading rates.

Of great importance to pediatric clinicians is the increased potential for pes planus in children who are obese (15). Therefore, vigilant assessment of foot development is necessary for young children who are overweight.

The Etiology of "Flatfoot"

A hypermobile "flatfoot" or pes planus does not often result from a genetic cause. It is more often due to other conditions, such as an unstable first ray, a malformed midtarsal joint, muscle weakness, gross or fine motor skill inadequacy, or a short, restricted Achilles tendon. More importantly than the etiology, is the fact that once a poor longitudinal has formed, it significantly, and negatively, affects kinetics within the complete kinetic chain.

When the talus is excessively plantar flexed, the foot is more unstable since the talus then further separates the sustentaculum tali from the navicular bone.

As this situation progresses, the plantar ligaments are unable to contain the head of the talus and so the medial arch collapses, and the talar head migrates towards the ground. In severe cases, especially in conjunction with muscular pathologies, it may actually make contact with the ground.

Unfortunately, this situation may be defined as "asymptomatic" because there is no pain. This is an incorrect description.

The absence of pain is because the ground now supports the talus, thus decreasing strain on the plantar talonavicular ligaments. In essence, the ground is acting as a pseudo-orthosis, and this in itself, although not pain, IS a symptom… one of dysfunction. It is an unfortunate situation because, although joint deformities, skeletal malalignment, pain, and muscle damage are somewhat subject to lifestyle activities, the potential for resolution is much less after advanced ossification and maturity of gait are achieved. In fact, pain and dysfunction that begins in early teenage years and adulthood results from incorrect foot development that is evident in young childhood.

Negative Effects on Gait and Posture

Harris and Beath (21) report that a hypermobile (pes planus or "flat foot") foot is often symptomatic. In addition to an inferior medial longitudinal arch, this presentation is often accompanied by increased forefoot inversion mobility (they found that the midtarsal joint may allow as much as 50° of forefoot inversion). Further, increased rearfoot eversion is often present, with the calcaneus everted greater than 10° during static stance. Most notably, ankle dorsiflexion is dramatically reduced, demonstrating negative 25° of ankle dorsiflexion (measured with the talonavicular joint maintained in a neutral position).

The biomechanical effects of pronation are not isolated to the foot and ankle. Excessive pronation contributes to developmental and gait pathologies.

Because of the relationship between functioning foot alignment and that of the lower limb joints, problems of anterior knee pain, low back pain, and foot pain commonly occur in the presence of chronic foot pronation of moderate to severe degree (15). In a twelve month study in the United States, musculoskeletal disorders were found to account for 67% of medical discharges from the Air Force, with patello-femoral syndrome, pes planus (flexible flat foot), and low back pain occurring most frequently (21).

According to Michaud (33), from a functional perspective, "The most detrimental aspect of excessive talar adduction is that it increases the body's lever arm for maintaining the subtalar joint in a fully pronated position throughout midstance and propulsion. This has significant effects on both the proximal kinetic chain and the medial forefoot. During midstance, because the adducted talus is held in a fixed position by superimposed body weight, the external rotation moment created by the swing limb is unable to generate a force strong enough to abduct the talus. As a result, the torsional forces associated with this external rotation moment must be temporarily stored in the stance limb. The release of these stored torsional forces is occasionally evidenced by a sudden "abductory twist" of the rearfoot as heel lift occurs; i.e., because ground reaction forces no longer maintain the plantar heel, the entire rearfoot is free to snap medially, as though released from a loaded spring. Because a chain is most likely to give at its weakest link, the prolonged application of these forces may produce transverse plane laxity of the lower extremity joint capsules, and the knee is most likely to be affected by these torsional forces."

Coplan (12) agreed, and observed that, "Individuals with excessive ranges of subtalar pronation were more likely to display significantly greater ranges of tibiofemoral rotation than normal controls, particularly as the knee approached full extension (its normal position of function as torsional strains peak during late midstance)."

She reported that the mean range of tibial rotation (when the knee was flexed to five degrees) was seven degrees more in the pronating study group. She suggested that, "The opposing rotary torques present during the late midstance period produced laxity in the tissues that normally limit knee rotation," but continued to state that it is also feasible that overpronators more likely to present with ligamentous laxity, which would result in larger ranges of tibiofemoral rotation.

While relevant to the general population, this information is of great significance to those with physical disabilities. This is because excessive subtalar pronation during midstance pre-disposes a body to cumulative, chronic physical trauma as a result of the conflicting movement patterns between the leg and talus.

Continued subtalar pronation through the propulsive period of gait causes more destruction as the congruency of the foot joints is compromised at a functional moment when maximum stability is required. This results in a shifting of the tarsal bones as ground reaction forces peak during early propulsion. Therefore, the foot is forced to behave as a flexible lever arm rather than provide the necessary rigidity to withstand vertical forces.

Hypotonia negatively affects gait. Out of necessity, children develop a wider base of support and more muscle co-contractions in order to "…artificially create stability… against gravity (9)." As a result, they are less able to adapt to the environment and are required to change their ambulatory strategies when confronted challenges to their mobility.

Low muscle tone is typically accompanied by joint hypermobility, and this further contributes to biomechanical consequences. With prolonged pronation, the peroneal muscle shortens and posterior tibias lengthens; the tibia medially rotates, with subsequent genu valgum and medial hip rotation.

The resultant chronic situation is one of hypermobility, primarily in the foot and ankle. This hyper mobility creates hyper-pronation at initial contact (when supination is ideal) and instability in midstance. As a result, the lever arm (ie. toes) is decreased and so propulsion is much less. Repetition over time contributes to skeletal maladaptation and consequentially greater pronation. Finally, the balance deficits that are due to these poor biomechanics create a compensatory response of a wider base of support and more muscle co-

contractions in order to artificially create stability against gravity.

Poor biomechanical alignment and ligament laxity, in the presence of related muscle weakness, creates the sequelae of delayed gross motor skills and gait pathologies.

Research into hypermobility and gait in children found greater passive knee range of motion, but less peak knee flexion during ambulation (9).

A large majority of adult orthopedic disabilities may have their origin in childhood malalignment, including:

- Shin splints
- Plantar fasciitis
- Tibialis posterior tendonitis
- Patello-femoral syndrome
- Lesser digital deformity
- Hallux abducto valgus
- Lower back pain
- Sciatica
- Metatarsal stress fracture

Clinical research also confirms that adults with low arches are more likely to develop retropatellar pain (4) and knee osteoarthritis (28).

Early Stance:

Upon initial contact, the calcaneus of a foot with an inadequate longitudinal arch everts with 32% more velocity than in the foot with an appropriate arch (55). This is problematic in that it subjects the restraining muscles and ligaments to greater strain. It may even be significant in that the angular velocity of subtalar joint pronation may be more damaging than the foot's total scope of pronation (32).

Consequential injuries & damage are not limited to the foot, and excessive subtalar pronation contributes to symptoms in the proximal kinetic chain. The tibialis posterior tendon is particularly prone to injury because of its long lever for controlling subtalar motion, and is therefore exposed to greater tensile strains than muscles working through shorter lever arms. This explains why clinically we so often see individuals with hypermobile flatfeet present with tibialis posterior changes and involvement. Research supports that excessive subtalar pronation causes medial tibial stress syndrome (32, 52).

In addition, Matheson et al (31) reported a clinically relevant relationship between excessive pronation and lower tibial stress fractures. They analyzed 320 athletes with positive stress fractures and assessed the results of conservative management. They found a significant age difference (femoral and tarsal stress fractures occurred in the oldest athletes; fibular and tibial stress fractures in the youngest). Varus alignment (as in pronation) was the most frequent malalignment. The use of bone scans for diagnosis indicated that stress fractures are much more common than previously realized.

Another study, by Barton et al, addressed the effect of pronation on knee motion and found that a low medial longitudinal arch predisposes the body to retropatellar pain. The studied individuals with patellofemoral pain syndrome had a more pronated foot posture (as per the foot posture index and longitudinal arch angle). The measurements relative to subtalar joint neutral (foot posture index, normalized navicular drop, and calcaneal angle) were also found to be related to patellofemoral pain syndrome (4).

Foot posture contributes to the development of lower limb musculoskeletal conditions as it alters the biomechanical alignment and dynamic function of the lower limb. A 2010 study by Levinger et al looked at the relationship between pronation and knee osteoarthritis. They compared foot posture in people with and without medial compartment knee osteoarthritis (OA) by using a range of clinical foot measures (Foot Posture Index, navicular drop and arch index). The OA group exhibited greater pronation as compared to the control group, with medium to large effect sizes (28).

Late Stance:

As stated, excessive pronation associated with a low longitudinal arch is problematic in that it overloads the medial foot and is associated with a more rapid rate of calcaneal eversion (55).

In addition, excessive pronation during late stance has a greater contribution to injury as it propels the head of the talus inferiorly & downward, thus forcefully separating the sustentaculum tali from the navicular acetabulum. This causes increased tensile strain on the plantar calcaneonavicular ligaments (especially the spring ligament) and the plantar fascia. Eventually, these important restraining tissues become deformed and ineffective.

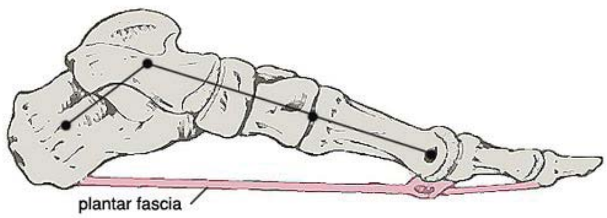
As can be seen in children with cerebral palsy who are able to ambulate, an overstretched spring ligament permits the talus to continue to migrate in a plantar direction, thus straining the plantar fascia. With progression of this situation, the increased tensile strain on the plantar fascia negatively affects the functioning of the windlass mechanism, and there is an ultimate collapse of the tarsal bones.

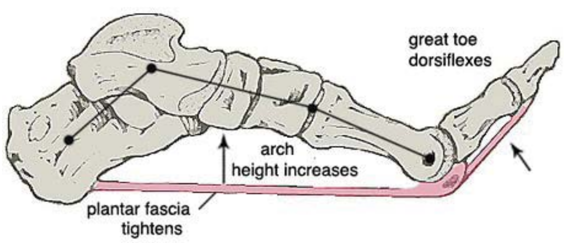
A "windlass" is the tightening of a rope or cable.

The anatomical windlass mechanism of the foot is a mechanical model that describes the manner which plantar fascia supports the foot during weight-bearing activities and provides information regarding the biomechanical stresses *placed on plantar fascia.*

At terminal stance, as the heel lifts, the MTP joints extend and the plantar fascia simulates a cable attached to both them and the calcaneus. Dorsiflexion during the following propulsive phase of gait shortens the distance between the calcaneus and metatarsals, and the medial longitudinal arch elevates. This plantar tissue shortening is the functioning principle of the windlass mechanism. This mechanism creates a dynamic stable arch and therefore a rigid lever for push off.

An inadequate windlass mechanism, as with hyperpronation for example, results in arch collapse at heel lift and poor stability for push off.

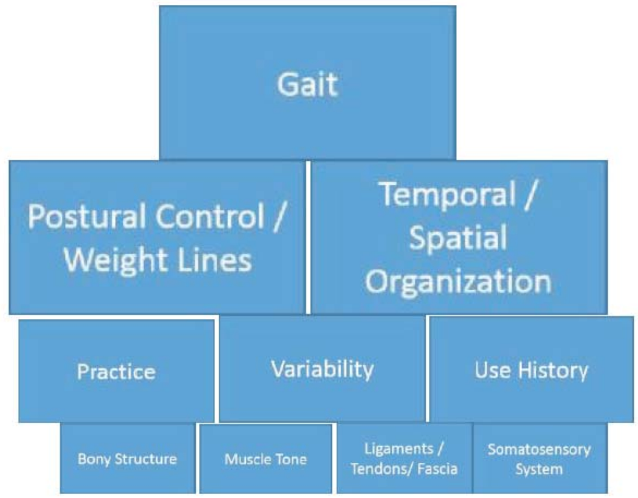




TREATING PEDIATRIC FLEXIBLE FLATFOOT

The literature supports addressing pediatric flexible flatfoot when it is painful (15, 20). However, as we've discussed above, there are also many convincing rationales to intervene with non-painful cases of pediatric flatfoot.

The components of gait development can be visualized as building blocks in a pyramid (48).



By utilizing a proactive approach to intervention at the pyramid's base the stability of the entire pyramid is increased: the function of the muscles of the foot, ankle and leg are improved in integrity, strength and timing.

Gait & Balance Assessment

Abnormal gait and/or poor balance are two of the primary reasons for referral to a pediatric physical therapist. To complete a thorough assessment, the clinician must both know what is normal and recognize variations; objective testing therefore, is an important component. Pediatric gait and balance assessments include:

Pediatric Balance Scale (PBS)

Clinical Applications: This test provides clinicians with a balance test similar to the Berg Balance Scale but organized and designed to assess a child's developing balance skills. This could be a helpful tool to assess balance in children with motor impairments (1).

Strengths: Provides clinicians with a standardized protocol for testing balance more appropriate for a child's developing balance skills; inexpensive; requires no additional equipment

Weaknesses: Test does not assess locomotive balance; test does not assess overhead reaching

Administration: This is a 14 item test. Verbal instructions for each item are given. The child may receive one practice trial per item. If the child is unable to understand the directions, a second trial may be given. Verbal and visual instructions are given to clarify.

Scoring: Each item is scored 0-4

Type of information resulting from testing: Balance score out of 56 with average scores for specific age groups.

Environment for testing: Anywhere in the clinic or school

Equipment and materials needed: Adjustable height bench, chair with back support and arm rest, stopwatch or watch with a second hand, masking tape, – 1 inch wide, a step stool 6 inches in height, chalkboard eraser, ruler or yardstick, a small level.

Reliability:

1. Typically developing 5-7 y/o test-retest: 0.850
2. Motor impairment 5-15 y/o interrater: 0.997; test-retest: 0.998
3. Cerebral palsy 6-13 y/o intrarater: 0.978-0.988; interrater: 0.905; test-retest: 0.958

Evidence of Reliability:

1. Test-retest reliability: high [ICC (3,1) = 0.998]
2. Interrater reliability: high [ICC (3,1) = 0.997]

Evidence of Validity:

One study found good criterion-related concurrent and predictive validity with children with cerebral palsy. The authors state that PBS has the capability to predict motor function and Activities of Daily Living (ADLs) at follow up.

Pediatric Reach Test:

Clinical Applications: Incorporation of a sitting component enables use with more diverse groups of children with cerebral palsy, including those who are unable to stand independently.

Strengths: Tests aspects of balance and postural control in a standing position.

Weaknesses: Requires participants to be able to stand barefoot in a static position for at least two minutes before testing

Administration: This is a 2 item test. Verbal instructions for each item are given. The child may receive one practice trial per item. If the child is unable to understand the directions, a second trial may be given. Verbal and visual instructions are given to clarify.

Scoring: Measures the distance (using a yardstick at the level of the acromion) that an individual is able to reach forward from a starting standing position with a fixed base of support without loss of balance.

Type of information resulting from testing: If orthoses and gait aides are used when administering the test, it reflects functional aspects of balance in a more typical context than standing barefoot without aides.

Environment for testing: Anywhere in the clinic or school

Equipment and materials needed: Paper taped to the floor with child's foot tracings & yard stick.

Reliability: Interrater: 0.93; intrarater: 0.88

Observational Gait Scale

Clinical Applications: Visual assessment of gait remains a standard part of orthopedic assessment.

Strengths: Measures the amount of change in an individual's gait pattern over time

Weaknesses: Variable interrater agreement.

Administration: Video recording of child walking

Scoring: Scale of 8 sections to score both the L and R LE out of a possible 22 each.

Type of information resulting from testing: Gait evaluation when 3-Dimensional Gait Analysis (3-DGA) is not possible.

Environment for testing: Anywhere in the clinic or school

Equipment and materials needed: Video recording device.

Reliability: Interrater: 0.58 to 0.52; intrarater: 0.56 to 0.72

The Influence of Footwear on Gait, Postural Control, & Proprioception

We've already discussed shoes in the context of the foot's development. The influence of footwear should also be considered when assessing children's gait and determining interventions – especially the implications for postural control and proprioception.

At the 2009 annual meeting of the American Academy of Orthopaedic Surgeons in Switzerland, it was reported that (based on the foot measurements of nearly 250 boys and girls from age five to age ten and their indoor and outdoor footwear) 53% of children had outdoor shoes that were too small, and 13% percent were wearing outdoor shoes that were too large. A similar pattern was seen with children's indoor shoes, where 61% were wearing indoor shoes that were too small, and 10% were wearing indoor shoes that were too large (17). Another study found that 89% of children examined wore indoor footwear that was of insufficient length ("insufficient length" in the study was defined as footwear that is not at least 10 mm/1⁄2 inches longer than the foot of the child wearing the shoes), and 69% of children wore outdoor shoes that were of insufficient length (26).

A systematic review conducted in 2011 included eleven studies that investigated the effects of children's footwear. Children wearing shoes were found to walk faster by taking longer steps with greater ankle and knee motion and increased tibialis anterior activity. Shoes were also found to reduce foot motion and increase the support phases of the gait cycle (53).

Children who go barefoot have a lower incidence of pes planus and deformity, and display greater foot flexibility when compared to children who wear shoes (49).

All of this information contributes to the knowledge that many adult foot issues begin in childhood.

Implications for Footwear

In general, infant feet should be bare and able to move without restriction. This promotes strength gains and contributes to correct skeletal development.

Prior to upright mobility, the feet do not need to be covered except for warmth or hygiene purposes. It is best to cover them with fairly loose booties, as tight footwear can impede growth and development.

During the initial weeks of independent gait, the arches of the foot begin to develop and the muscles gain strength as they grow in both length and width.

In the initial stages of gait, children will grip the floor with their toes. By way of this muscle action, they increase strength in the intrinsic muscles of the foot, which contributes to appropriate arch development.

At this time, shoes are unnecessary when indoors. In fact, barefoot (or socks only) facilitates ideal growth and development of strength and muscle tone. In addition, barefoot also supports development of the "grasping" action of the toes. Outside or on rough surfaces, the feet should be protected by lightweight, flexible footwear.

When a child is able to walk independently with good stability they are ready to wear shoes. Shoes should be re-assessed every three months during the first months of independent gait, as the foot undergoes rapid growth at this time.

Recommendations for Shoes

The shoe is constructed of four parts: the upper, the insole, the outer sole, and the heel.

1. The upper should be made of leather, canvas, or mesh. Children's feet perspire a lot, so the upper should be a breathable material.
2. The insole should be made of absorbent material. There is no need for a "special arch support."
3. The outer sole provides traction, cushioning, and flexibility to the shoe. Flat outer soles are preferable.
4. The heel is unnecessary for toddlers. For older children, the heel should not be higher than one inch as this can cause the foot to slide forward, creating pressure on the forefoot.

For young children, shoes should provide some degree of rear foot cushioning and stability, and forefoot flexibility. Children's shoes should have a flexible toe box and a firm heel counter. They should permit foot mobility that equals barefoot activity: when developing stability of gait, children repeat toe flexion, thus increasing strength in the intrinsic musculature.

Pre-Walking Shoes: Babies and crawlers do not need shoes. They need booties or pre-walking shoes that do not restrict movement or create pressure. The shoe should be flexible (rather than providing rigid "support") and shaped like the child's foot. The function of a shoe at this age is warmth and protection.

Toddler Shoes: Choose a lightweight shoe, as children at this age tend to use a lot of energy walking. A leather or canvas tie shoe is more secure, will stay on the foot, and will have a better fit. Toddlers should be barefoot in a protected environment such as indoors.

School-Age Children's Shoes: Style and shoe fit is important for school-age children. Their main function is shock absorption and protection. At this age, they can choose from a variety of options including athletic shoes, sandals, hiking shoes, etc. It is very important to wear the right shoes for the right activity to prevent injury. Look for reasonably priced, flexible, well-ventilated shoes that allow plenty of room for growth.

The American Academy of Pediatrics (AAP) recommends the following when considering shoes for children:

- Shoes should be lightweight and flexible to support natural foot movement with a stable base of support.
- Shoes should be made of leather or mesh to allow the feet to breathe comfortably.
- Shoes should have rubber soles for traction to prevent slipping or sliding.
- Stiff and compressive footwear may cause deformity, weakness, and loss of mobility.
- Base shoe selection for children on the contours of a bare foot.
- Shoes should have good shock absorption with durable soles as children participate in more high impact activities.

Intervention

Orthoses

Physical therapist Nancy Hylton describes orthoses as "primarily a specialized therapy tool that allows more rapid acquisition of postural control and function in individuals with various disturbances of posture and movement." She suggests that they should be used only in conjunction with an active postural control and balance oriented therapy program (22).

A minimum controlled dynamic foot orthosis (DFO) is a general term that describes a thinly layered shoe insert. This is a device that is placed in the shoes of children with motor delays to improve their balance and motor capacities. A DFO can be used as a therapy device that allows a child with motor developmental delays to quickly (i.e., within days) improve his or her postural control and balance. DFOs contain one layer of foam and a thin layer of polyethylene plastic. They are designed to give mild mechanical support and proprioceptive feedback to children with subtle neurological anomalies (23, 30). Therefore, the approach of therapy is often required to address balance, postural control, muscle tone, and antigravity stability and mobility.

The primary goal of orthoses is to reduce hyperpronation while simultaneously providing optimum subtalar movement. Following is a checklist of ideal characteristics of appropriate orthoses:

- *Dynamic stability of movement into the age-appropriate parameters of pronation and supination.*
- *Correct calcaneal alignment.*
- *Optimal alignment during ossification.*
- *Facilitates variability of movement when indicated.*
- *Restricts excessive mobility when necessary.*
- *Proprioceptive contributions through contact and compression.*
- *Improve real time functional ability (as opposed to limit it).*
- *Allow, or facilitate, the 3rd rocker of gait and action of the windlass mechanism.*

Beginning in 1984, extrinsic biomechanical forefoot posting was added to orthoses to better address stability and tone. As a result, extreme deformities were able to be remediated or at least improved upon. Rearfoot varus posting is intrinsically managed, with the goal of providing optimum postural control, stability and proprioceptive feedback with the least rigidity and impairment of movement (22).

Rigidity in an orthosis, while limiting hyper-pronation and providing stability to the foot and ankle, focuses only on structure and neglects function. Rather, the goal of an orthotic should be for it to act as a gait training device. It should provide dynamic stability and alignment through the facilitation of improved proprioception and function. For example, orthoses that are designed to provide input to the musculotendinous junctions in the foot will relax or activate particular muscles, thus improving movement patterns. By enabling guided pronation and supination within suitable parameters, the correct orthosis allows appropriate motor learning through better muscle recruitment and timing.

There have been descriptive and observational reports (i.e., anecdotal) on the benefits (e.g., improved balance and motor skills) of DFOs in treating neurological and developmental disorders, but there is a limited body of science that addresses the effectiveness of DFOs.

C.G. Ross, in Arcadia, CA, looked at the effectiveness of a physical therapy intervention for children with hypotonia and flatfoot dysfunction. The purpose of the study was to determine the effectiveness of physical therapy using orthoses and an exercise program for children with hypotonia and flat feet. She utilized thirty-seven children, aged 18 months to 5 years. Three groups (consisting of control, orthotic, and orthotic-exercise), were studied. The orthotic-exercise group practiced bilateral heel raise exercises in addition to wearing the orthoses. The width of the medial longitudinal arch (MLA) was measured using an arch index. Other measured outcomes were gait velocity, step-length, single-limb support and cadence, and these were documented using the GAITRite. The GAITRite is a portable, electronic gait analysis walkway that measures the temporal (timing) and spatial (two dimension geometric position) parameters of gait via its pressure activated sensors. The outcomes were assessed four times in a six month period. Results of this study found significant differences pre/post testing (P 0.05) in the arch index for the orthotic group. Also, positive trends were observed for the orthotic-exercise group. Velocity, step-length, single-limb support, and cadence changes were also significant for the three groups over time. All three groups showed significant improvements in velocity, step-length, single-limb support, and cadence. However, the intervention groups demonstrated stronger improvements in arch development, velocity, single-limb support, and cadence. Therefore, the author concluded that interventions do benefit children with hypotonia and flat feet. These findings are clinically relevant in that they indicate that interventions of orthotic wear and exercise are appropriate choices for children with hypotonia and flatfoot dysfunction (40).

Pitetti and Wondra, in Wichita, KS, investigated the effect of a foot orthosis on children with delayed gross motor skills. They evaluated gross motor skill ability of 25 children using the Peabody Developmental Motor Scales Test-2 (PDMS-2): specifically, the PDMS-2 motor age-equivalent scores at four months (for 18 of the children) and at twelve months (for eight of the children). The children had an average age of four years and eighteen months, with diagnoses of Down syndrome, cerebral palsy, and developmental delay. The chosen orthosis was a Cascade DAFO Pattibob.

The Cascade Dynamic Ankle Foot Orthosis (DAFO) Pattibob is a prefabricated shoe insert that consists of a thin layer of plastic on the bottom of dense foam (aliplast-like material) contoured and shaped to fit the plantar surface of the foot. It is constructed of low density polyethylene (LDPE), with a flexible, semi-flexible arch, and a rigid heel. It also has an arch support, a metatarsal head depression, a heel cup, and toe rise for toes two through five. Comparisons were made between an evaluation without the orthoses and another after seven days of wearing the orthoses. Other evaluations were then repeated at two months and four months post-initial evaluation; and eight of the children were evaluated again at twelve months post-initial evaluation. Results of the evaluations found a significant increase in age-equivalent scores after seven days, with a mean improvement of 1.22 months. Further, average gains from initial age-equivalent scores (without the orthoses) of 4.5, 4.0 months and 4.7 2.9 months were seen at two and four months, respectively. For the eight children who were evaluated at twelve months, progress from initial age-equivalent scores was 8.0, 2.6 months. While the limitations of this study are a small number of participants, no controls, and different diagnoses, it does suggest measurable improvements in gross motor skills for children with gross motor delays who wear orthotics similar to the Pattibob. The clinical relevance of this study is that shoe inserts do improve the gross motor skills of children with gross motor delays (56).

The results of a 2004study by K. Martin et al demonstrated the benefits of supramalleolar orthoses for postural stability, both immediately and after seven weeks of use (30).

However, the quality and appropriateness of the orthotic device is paramount. One particular study demonstrated how immobilization caused an extreme and rapid decrease in muscle mass (29).

Splinting

Per Cary Croner (2013), Debbie Strobach, MA, PT, a pediatric physical therapist and splinting specialist at Mercy Children's Hospital in St. Louis, MO reports that she "…splints children with ankle foot orthoses (AFOs) before they leave our neonatal intensive care unit (10)." According to Strobach, prematurity prior to 30 weeks has a greater risk of hypotonia and muscle imbalance. Therefore, this population presents with significant ankle and hindfoot eversion, which correlates with poor performance of related musculature. For example, "…the fibularis becomes more powerful than the anterior and posterior tibialis, stretching the medial structures of the foot and putting children at risk for pronation when they're getting ready to stand." Conversely, with the facilitation of improved alignment, tendons and ligaments are better able to support the ankle and foot. Therefore, the associated musculature also functions better.

Strobach reports that children who were not proactively splinted in the NICU often have a contracted fibularis. The graduates of Mercy Children's Hospital that have worn splints are followed as outpatients with a splint wear schedule of three hours on and off. She states that, with proactive intervention such as this, the need for future bracing is much less.

She reiterates that the quality and appropriateness of the orthotic device is crucial, and recommends "…splints that don't inhibit the muscles so you can strengthen them and align the foot correctly throughout the day, for good muscle balance."

Therapeutic Taping

Kinesiology taping is a therapeutic tool used with increasing frequency within musculoskeletal rehabilitation (36). It is used to treat a variety of orthopedic, neuromuscular, neurological and medical conditions. Tape provides proprioceptive feedback to achieve and maintain preferred body alignment (5). It is a complementary treatment and is designed to facilitate the body's natural healing process while allowing support and stability to muscles and joints without restricting the body's range of motion. Kinesiology tape should be used in combination with other interventions (45). The tape has a texture and elasticity very close to living human tissue, as it provides immediate sensorimotor feedback regarding functional abilities (57). For example, Simsek et al found that kinesiology taping had positive effect on sitting posture for children with cerebral palsy (46).

The two types of application that are most appropriate for the pediatric foot are functional correction and ligament/tendon correction.

Functional correction provides sensory stimulation that assists or limits a motion. Tension created on the tape during active movement provides proprioception to the mechanoreceptors. By acting as a pre-load during end of motion positions, the mechanoreceptors interpret the stimulus of the tape as normal joint position. During joint extension, the increased tension of the tape is interpreted by the mechanoreceptors as joint end range of motion (since skin tension would normally occur in this joint position). The result is assisted joint flexion and muscular contraction, as the joint repositions in order to normalize the (perceived) skin tension (25).

Ligament/tendon correction creates increased stimulation over the area of a ligament or tendon. This, again, results in increased stimulation to the mechanoreceptors. This stimulus is interpreted by the brain as normal tissue tension, and when applied from proximal muscle attachment to distal, the tension of the tape limits the allowable movement of the ligament (25).

Camerota et al quantified the changes in walking biomechanics, as induced by neuromuscular taping, in a patient with Ehlers–Danlos syndrome (hypermobility type). Application sites were low back, spine and bilateral knees. Results demonstrated improvements in cadence and velocity, a reduction in knee flexion at initial contact, and an improvement in ankle position at initial contact and during swing phase. Improvements were also shown in ankle moment and power. It was concluded that neuromuscular taping is a viable intervention for improving gait performance in hypermobility (8).

A 2012 study showed that the tactile stimulation provided by kinesiology tape promotes muscular strengthening. The mechanism of action was suggested to be that stimulation of skin activated afferent nerve activity (24).

Per Wondra and Pitetti (2005), Thedon et al investigated the ability to maintain a quiet standing postural performance via the compensation of ankle muscle fatigue by stimulating skin with kinesiology tape: "Subjects were tested with the eyes closed in four conditions of quiet stance: with or without skin stimulation and before and after a fatigue protocol. The skin was stimulated with a piece of medical adhesive tape on the Achilles' tendon. The fatigue protocol consisted of multiple sets of ankle plantar flexion of both legs on a stool. Without fatigue, we did not observe a significant effect of the tape. With fatigue, subjects decreased their postural performance significantly, but this effect was cancelled out when a piece of tape was glued on the Achilles' tendon." They determined that the beneficial effect of the tape was to provide muscular sensory input via cutaneous information, resulting in improved postural control (56).

Konishi showed how prolonged vibration stimulation could lead to muscle weakness attributable to attenuation of afferent feedback. This weakness is neurophysiologically similar to that seen in study participants. Therefore, increased input to gamma motor neurons could reverse this weakness, and sensory input to these neurons from the skin could indirectly increase afferent feedback. His study examined the effect of such tactile stimulation by the use kinesiology tape. The eccentric maximal voluntary contractions of study participants were measured their under two conditions: with and without tape. Mean percentage changes between pre- and post-vibration stimulation were compared between the two conditions. The results showed that maximal voluntary contraction, and average electromyography, was significantly in the group with tape as that compared to those without tape. These results indicate that tactile stimulation, in the form of kinesiology tape, inhibits the decline of both strength and electromyography. Therefore, decreased alpha motor neuron activity could be improved by such tactile stimulation (27).

Yasukawa et al. found an immediate, statistically significant ($F(1, 14) = 18.9$; $p < .02$) effect of kinesiology tape when applied on children in an acute rehabilitation setting. Results of this study suggest that kinesiology tape may be associated with improvement in control and function, and that the use of kinesiology tape as an adjunct to other interventions may assist with goal-focused therapy (57).

Specific case studies report the following:

1. A 5 year old boy, diagnosed with multiple joint hypermobility, had kinesiology tape applied to facilitate quadricep activity & prevent hyperextension of the knee. The child did not rest once during training (with repeated trials). However, when not taped, he required at least ten rest periods during the same training activity (36).
2. A girl of two years of age, with multi-joint hypermobility, frequently complained of fatigue, often refused to walk, and always refused to ascend stairs. Prior to kinesiology taping, she climbed stairs twice (up and down) with right foot leading, then refused to walk more. This was reported by her mother as typical behavior. When kinesiology tape was applied to facilitate quadricep activity & prevent hyperextension of the knees, she climbed the stairs ten times, reciprocally, and did not stop until she was persuaded to do so (36).
3. A girl of seventeen years of age, who was awaiting surgery to address a stiff and painful foot, received kinesiology taping for muscle facilitation, and a corrective technique to provide support to the foot. She reported immediate pain relief (36).

In summary, kinesiology tape is a valid, complementary tool in addressing the alignment and function of the pediatric foot. Be it to reduce fatigue, improve alignment, provide proprioceptive feedback, or facilitate cumulative strengthening, the ultimate result is improved function.

CONCLUSION

As we've discussed, a common assumption is that inappropriate foot development and/or abnormal childhood gait, is of no concern. Such a generalized conclusion is formed on the basis of incomplete information.

This course has addressed ideal development, therefore providing a reference for when it is abnormal, and its significance for function, both current and future. Human skeletal alignment consists of isolated components that are compressed in a state of continuous tension, and operate within a system. This compressive state reduces damage that would otherwise occur in the presence of tensile stress generated by external loading. With correct alignment of the arches of the foot, the foot is loaded with the greatest weight through the hindfoot. This provides stability for upright mobility.

This course has also emphasized the value of deliberate intervention for pediatric gait, and proposed potential consequences of future affects on balance, postural control, strength and the musculoskeletal system. Developmentally, a child undergoes many anatomical and functional changes. This is greatest during the first three years of life – and therefore proactive intervention, when indicated, is paramount to optimize future outcomes.

REFERENCES

1. Adolph, K. E. & Robinson, S. R. (in press). The road to walking: What learning to walk tells us about development. In P. Zelazo (Ed.) Oxford handbook of developmental psychology. NY: Oxford University Press.

2. Aharonson Z et al. Normal foot--ground pressure pattern in children. Clin Orthop Relat Res. 1980 Jul-Aug;(150):220-3.

3. Assaiante C et al. Development of postural adjustment during gait initiation: Kinematic & EMG Analysis. J Mot Beahav 2000. Sep;32(3):211-26.

4. Barton CJ, Bonanno D, Levinger P, Menz HB. Foot and ankle characteristics in patellofemoral pain syndrome: a case control study. J Orthop Sports Phys Ther 2010;40(5):286-296.

5. Basett KT, Lingman SA, Ellis RF (2010) The use and treatment efficacy of kinaesthetic taping for musculoskeltetal condition: a systematic review. NZ J Phys Ther 38: 56-62.

6. Bly, Lois. Motor Skills Acquisition in the First Year: An illustrated guide to normal development. Academic Press. Feb 20, 1998.

7. Bordelon R. Hypermobile flatfoot in children. Comprehension, evaluation and treatment. Clin Orthop Relat Res 1983;181:7-14.

8. Camerota F et al. The effects of neuromuscular taping on gait walking strategy in a patient with joint hypermobility syndrome/Ehlers–Danlos syndrome hypermobility type. Ther Adv Musculoskel Dis. 2015, Vol. 7(1) 3–10.

9. Cary Croner. Orthotic Solutions for Children with Hypotonia. Lower Extremity Review (2013).

10. Cary Croner. The Cornerstone of Intervention. Lower Extremity Review (2013).

11. Cavanagh PR, Rodgers MM & Liboshi A. Pressure Distribution under Symptom-Free Feet during Barefoot Standing. American Orthopaedic Foot and Ankle Society, 1987.

12. Coplan JA. Rotational motion of the knee: a comparison of normal and pronating subjects. J Orthop Sports Phys Ther 1989;10(9):366-369.

13. Cuisiner R et al. Reweighting of sensory inputs to control quiet standing in children from 7-11 & in adults. PLoS ONE 6(5):e19697.

14. Cusick B. Developmental Orthopedics, Part IIIb: Frontal-Plane Developmental Changes in the Torso & Hips. NDTA Network. 2007, Vol 14(4).

15. Evans A. The flat-footed child—To treat or not to treat, what is the clinician to do? J Am Podiatr Med Assoc 2008;98(5):383-393.

16. Evans, Angela (2010). Paediatrics. The Pocket Podiatry Guide. Churchill Livingstone Elsevier.

17. Espinosa, Norman MD (University of Zurich), presentation to American Academy of Orthopedic Surgeons Annual Meeting. March 2009.

18. Gould N, Moreland M, Alvarez R, et al. Development of the child's arch. Foot Ankle 1989;9(5):241-245.

19. Hallemans A, De Clerq D, et al. Changes in foot function parameters during the first 5 months after the onset of independent walking: A longitudinal follow up study. Gait & Posture 23 (2006) 142-148.

20. Harris EJ et al. Diagnosis and Treatment of Pediatric Flat Foot. J of Foot & Ankle Surg. 2004 (43):341-373.

21. Harris RI, Beath T. Army foot survey. Ottawa: National Research Council of Canada; 1947. pp. 1–268.

22. Hylton N. Postural and Functional Impact of Dynamic AFOs and FOs in a Pediatric Population. JPO 1989; Vol 2, Num 1.

23. Hylton NM. Dynamic Orthotic Concepts: Background and Experiences. Dortmund, Germany: Verlag Orthopaedic-Technik, 2000.

24. J Sci Med Sport. 2013 Jan;16(1):45-8. 2012 Jun 6.Tactile stimulation with kinesiology tape alleviates muscle weakness attributable to attenuation of Ia afferents.

25. Kase K, Martin P & Yasukawa A. Kinesio Taping in Pediatrics: Fundamentals & Whole Body Taping. Orthopedic Physical Therapy & Rehabilitation Products 2006.

26. Klein C et al. Increased Hallux Angle in Children and its association with insufficient length of footwear: A Community Based Cross-Sectional Study, BMC Musculoskeletal Disorders, 10:159, Dec 2009.

27. Konishi Y. Tactile stimulation with kinesiology tape alleviates muscle weakness attributable to attenuation of Ia afferents.J Sci Med Sport. 2013 Jan;16(1):45-8.

28. Levinger P, Menz HB, Fotoohabadi MR, et al. Foot posture in people with medial compartment knee osteoarthritis. J Foot Ankle Res 2010;3:29.

29. Looper J. Effect of treadmill training and supramalleolar orthosis use on motor skill development in infants with Down syndrome. Phys Ther. 2010 Mar;90(3):382-90.

30. Martin K. Dev Med Child Neurol. 2004 Jun;46(6):406-11. Effects of supramalleolar orthoses on postural stability in children with Down syndrome.

31. Matheson GO, Clement DB, McKenzie DC, et al. Stress fractures in athletes. A study of 320 cases. Am J Sports Med 1987;15(1):46-58.

32. Messier SP, Pittala KA. Etiologic factors associated with selected running injuries. Med Sci Sports Exerc 1988;20(5):501-505.

33. Michaud, TC. Human Locomotion: The Conservative Management of Gait-Related Disorders. www.HumanLocomotion.org

34. Michaud Thomas C. Development of the arch: Functional implications. LER: July 2012.

35. Nigg BM, Cole GK, Nachbauer W. Effects of arch height of the foot on angular motion of the lower extremities in running. J Biomech 1993;26(8):909-916.

36. Öhman AM. Kinesiology Taping: A Therapeutic Tool in the Paediatric Population? J Nov Physiother 2013, 3:5.

37. Poduval M & Gest TR. Skeletal System Anatomy in Children and Toddlers. Jul 28, 2015.

38. Rao UB, Joseph B. The influence of footwear on the prevalence of flat foot. A survey of 2300 children. J Bone Joint Surg Br 1992;74(4):525-527.

39. Robbins SE, Hanna AM. Running-related injury prevention through barefoot adaptations. Med Sci Sports Exerc 1987;19(2):148-156.

40. Ross, C G et al. The Effectiveness of a Physical Therapy Intervention for Children with Hypotonia and Flatfoot. Pediatric Physical Therapy:Spring 2005 (Vol 17, 1) pp 81-82, 2005.

41. Ruff, Christopher; Holt, Brigitte; Trinkaus, Erik (April 2006). “Who’s afraid of the big bad Wolff?: “Wolff’s law” and bone functional adaptation”. American Journal of Physical Anthropology. 129 (4): 484–498. doi:10.1002/ajpa.20371. Retrieved 2 March 2015.

42. Saladin, Kenneth (2012). Anatomy and Physiology: The Unity of Form and Function. New York: McGraw-Hill. p. 217. ISBN 978-0-07-337825-1.

43. Samson W et al. Biomechanical maturation of joint dynamics during early childhood: Updated conclusions. J of Bio. June 17, 2013.

44. Schumway-Cook A, & Woollacott H. Motor Control: Theory and Practical Applications. Baltimore, Maryland: Lippincott Williams & Wilkins; 2001:25.

45. Short-Term Effects of Cervical Kinesio Taping on Pain and Cervical Range of Motion in Patients With Acute Whiplash Injury. Journal of Orthopaedic and Sports Physical Therapy · February 2009.

46. Simsek TT et al. The effects of Kinesiotaping on sitting posture, functional independence and gross motor function in children with cerebral palsy. Disability and Rehabilitation, 2011; 33(21–22): 2058–2063

47. Sisson GA Jr, Weck M, Prihoda W, Vankoski S, Kelp-Lenane C, Moore C, Weyers A. The effect on gait of an anterior placement of the whole body center of mass. Gait & Posture 1994. 2(1): 56.

48. Smith, M. The Development of Gait: Back To The Basics. SureStep.

49. Stable L. “Shoes”, Practice of pediatric orthopedics, P. 47. 2006.

50. Valmassey RL (1996) Biomechanical evaluation of the child, 243-277. In Clinical Biomechanics of the Lower Extremities, 243-277. St. Louis, MO: Mosby. (RCS formula on p.248.); and Valmassy RL. (1984) Biomechanical evaluation of the child. Symposium on Podopediatrics - Clin Podiatr 1: 563-579.

51. Viel S et al. Adolesence: a transient period of proprioceptive neglect in sensory integration of postural control. Motor Control. 2009 Jan;12(1):25-42.

52. Vtasalo JT, Kvist M. Some biomechanical aspects of the foot and ankle in athletes with and without shin splints. Am J Sports Med 1983;11(3):125-130.

53. Wegener C et al. Effect of Children’s Shoes on Gait: A Systematic Review & Meta Analysis. J of Foot & Ankle Research. (1):3. 2011.

54. Williams DS, McClay IS. Measurements used to characterize the foot and the medial longitudinal arch: reliability and validity. Phys Ther 2000;80(9):864-871.

55. Williams DS, McClay IS, Hamill J, Buchanan TS. Lower extremity kinematic and kinetic differences in runners with high and low arches. J Appl Biomech 2001;17(2):153-163.

56. Wondra VC & Pitetti KH. The Effect of a Dynamic Foot Orthosis on Children with Delayed Gross Motor Locomotion Skills: A Four and Twelve Month Follow Up (platform and poster presentations for the 2005 combined sections meeting) Wichita, KS.

57. Yasukawa A, Patel P, Sisung C (2006) Pilot study: investigating the effects of Kinesio Taping in an acute pediatric rehabilitation setting. Am J Occup Ther (2005) Vol 17, Num 1: 104-110.

The Pediatric Foot: Anatomical Development, Clinical Assessment, and Considerations for Intervention
(2 CE Hours)

1. **________, the process by which skeletal modeling occurs, specifies that a bone will adapt to the mechanical stress (load) under which it is placed.**
   a. Bly's Postural Influence
   b. Haversian Stressors
   c. Reduction with Age
   d. Wolff's Law

2. **Ossification of the bones in the feet, which takes place over many years, generally is complete by the age of ________.**
   a. 8-10
   b. 13-15
   c. 18-20
   d. 23-25

3. **At ________, there are proportionally large spaces between the tarsal bones, and so the infant's foot is susceptible to deformation. Therefore, the shoe style should have a protective toe and heel with a firm top cover and textured side patterns to aid in gripping the foot.**
   a. The crawling stage (3-6 months)
   b. The cruising stage (6-9 months)
   c. The onset of independent gait (9-18 months)
   d. The pre-school stage (2-4 years)

4. **A study conducted by Gould et al showed how arch height increases with age, and the authors concluded that the critical period for arch development is ________.**
   a. Before age 6
   b. Between ages 4-9
   c. By age 12
   d. Post-ossification

5. **In a study of 2,300 children in rural India, aged four to thirteen years, Rao and Joseph found that children who were raised barefoot ________.**
   a. All displayed low arches
   b. Consistently displayed low arches
   c. Demonstrated no significant arch development patterns
   d. Rarely displayed low arches

6. **Which of the following is NOT a characteristic of the early gait of new-walkers?**
   a. Frontal plane sway
   b. High guard posture for balance
   c. Shortened stride
   d. Transverse plane motion

7. **Pes planus does not often result from a genetic cause. It is more often due to other conditions, such as ________.**
   a. A long, flexible Achilles tendon
   b. An unstable first ray
   c. Overdeveloped musculature
   d. All of the above

8. **A study by Barton et al addressed the effect of pronation on knee motion, and found that a low medial longitudinal arch ________.**
   a. Has no relation to occurrences of patellofemoral pain syndrome
   b. Predisposes the body to retropatellar pain
   c. Reduces incidences of medial compartment knee osteoarthritis
   d. None of the above

9. **This balance assessment provides clinicians with a test that is organized and designed to assess a child's developing balance skills. It is inexpensive and demonstrates high reliability; however, it does not assess locomotive balance and overhead reaching. It is a 14 item test; each item is scored 0-4.**
   a. Berg Balance Scale
   b. Observational Gait Scale
   c. Pediatric Balance Scale
   d. Pediatric Reach Test

10. **This balance assessment tests aspects of balance and postural control in a standing position, and incorporates a sitting component for those who are unable to stand independently. It is a 2 item test.**
   a. Berg Balance Scale
   b. Observational Gait Scale
   c. Pediatric Balance Scale
   d. Pediatric Reach Test

11. **Which of the following is NOT a recommendation of the American Academy of Pediatrics (AAP) when considering shoes for children?**
    a. Base shoe selection for children on the contours of a bare foot
    b. Shoes should be lightweight and flexible to support natural foot movement with a stable base of support
    c. Shoes should be made of leather or mesh to allow the feet to breathe comfortably
    d. Shoes should have smooth soles to encourage toe-gripping

12. **C.G. Ross, in Arcadia, CA, looked at the effectiveness of a physical therapy intervention using orthoses and an exercise program for children with hypotonia and flat feet. She studied three groups: control, orthotic, and orthotic-exercise). Results included ________.**
    a. No improvements in velocity, step-length, single-limb support, and cadence for the control group
    b. No significant differences pre/post testing in the arch index for the orthotic group
    c. Stronger improvements in arch development, velocity, single-limb support, and cadence for the intervention groups
    d. All of the above

13. **Debbie Strobach, MA, PT, a pediatric physical therapist and splinting specialist at Mercy Children's Hospital in St. Louis, MO reports that she "...splints children with ankle foot orthoses (AFOs) before they leave our neonatal intensive care unit." In addition, she ________.**
    a. Recommends splints that inhibit the muscles, to eliminate the need for adjustment throughout the day
    b. Reports that children who were proactively splinted in the NICU always have a contracted fibularis
    c. States that, with proactive intervention such as this, the need for future bracing is much less
    d. All of the above

14. **The two types of therapeutic taping application that are most appropriate for the pediatric foot are functional correction and ligament/tendon correction. In functional correction, ________.**
    a. During joint extension, the increased tension of the tape is interpreted by the mechanoreceptors as joint end range of motion
    b. Tension created on the tape during rest periods eliminates proprioception to the mechanoreceptors
    c. The tape helps to reduce the sensory stimulation that assists or limits a motion
    d. All of the above

15. **Thedon et al investigated the ability to maintain a quiet standing postural performance via the compensation of ankle muscle fatigue by stimulating skin with kinesiology tape. Results included ________.**
    a. With fatigue, subjects decreased their postural performance significantly, but this effect was cancelled out when a piece of tape was glued on the Achilles' tendon
    b. With fatigue, subjects decreased their postural performance significantly when a piece of tape was glued on the Achilles' tendon
    c. Without fatigue, subjects decreased their postural performance significantly when a piece of tape was glued on the Achilles' tendon
    d. None of the above