A Guide to Pediatric Foot Development and Shoe Selection

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Abstract: This article strives to educate the reader on the embryologic development of the child’s foot and also demonstrate the needs and effects that children’s shoe-gear has on the natural development of the foot and their progression to ambulation. Important aspects of normal foot development is compared and contrasted with congenital deformities along with a detailed discussion of weight-bearing milestones. The importance of proper and anatomically-friendly shoe design is emphasized as it relates to the above. A child’s shoe should not simply be a smaller version of an adult’s shoe. In summary, this article demonstrates the need for having a better understanding of shoe-gear science and gaining a greater appreciation for the interaction between the child's foot and shoe.

Keywords: Foot development; Shoe-gear; Footwear; Children; Shoes; Pediatrics; Biomechanics; Maturation

1. Introduction

Modern shoe trends are often influenced by aesthetics rather than concern for pedal health and development. Pediatric pedal development is influenced by congenital deformities as well as environmental factors. More emphasis should be placed on accurate shoe selection and fitting in pediatrics instead of style, as the pediatric foot structure has not completely ossified and is therefore more sensitive to external factors, such as ill-fitting shoes. The aim of this guide is to educate readers on the timeline of pedal development and the influence of internal and external factors on foot structures, as well as advise on proper pediatric shoe selection.

2. Embryologic Foot Development

Pediatric foot development begins during gestation. The key milestones for the growth and development of the fetal foot and lower extremity are measured in “intrauterine weeks”. Although there is normal variability from one individual to another, the embryologic period, extending from the third to the eighth week of gestation, is when many of the structural elements of the limbs are formed.

Beginning in the fourth intrauterine week, the limb bud develops. The limb bud is the precursor to all anatomic structures of the extremity including skin, muscle, nerves, arteries, veins, and bones. As the limb bud grows, the thigh, leg and foot can be clearly identified. By the fifth intrauterine week the foot plate can be seen extending from the lower limb bud [1]. This is the same time period when the hip, knee, and ankle joints begin to develop. By the sixth intrauterine week, the toes are becoming increasingly visible. Internally, the pedal bones and muscles are beginning to form. Skeletal formation of pedal bones continues into the seventh intrauterine week. At this time, the long bones of the leg are also beginning to develop. Nerves from the spinal cord extend out from their respective levels and grow into the limb bud, establishing the formation of the pedal nervous system.

At the eighth intrauterine week, the feet have rotated in such a way that the soles are touching in what is known as the “praying position”. The toes are each individually identified at this time. The muscle formation up to this point, allows for slow, generalized fetal movement, although any noticeable movement is usually not able to be detected by the mother until the twentieth intrauterine week.

As of the eighth intrauterine week, the pedal bones are made up mesenchymal stem cells and cartilage. Starting in the ninth intrauterine, the pedal bones begin the process of ossification or bone formation. Endochondral and intramembranous ossification are the specific types of ossification pedal bones undergo, in which cartilage and mesenchymal stem cells that make up the pedal bones at this time are gradually converted to bone. The first bones to ossify while in utero are the metatarsals. These are followed by the distal phalanx in the great toe at the eleventh week, the proximal phalanges of all toes and remaining distal phalanges in the twelfth week, and then the middle phalanges of all the toes from the seventeenth through twenty first intrauterine weeks [2].

The next bones to ossify are the hindfoot bones, first the calcaneus at fifth intrauterine month and then the talus at the sixth intrauterine month. The midfoot bones are the last to ossify, with the cuboid ossifying around birth and the remaining midfoot bones ossifying within the first few years of a child's life.

3. Congenital Foot Deformities

As the pedal bones ossify in utero, various foot deformities can be present at birth due to either positional or genetic factors. The incidence of congenital foot deformities is less than 5% [3]. Many of these deformities can be treated conservatively without requiring surgical correction.

Positional pedal deformities can be caused by restricted fetal movement or increase in fetal compression. Positional deformities are more common in term infants instead of preterm infants due to increased fetal size and decreased amniotic fluid in the third trimester. The position of the fetus in utero may also lead to positional pedal deformities, such as a fetus in the breech position. The most common positional deformity is metatarsus adductus or a C-shaped foot, which is seen in an estimated 3% of newborns. One of the most common characteristics seen with metatarsus adductus is an in-toe gait. Excellent outcome has been seen with nonsurgical treatment, which often includes no treatment for mild cases and serial manipulation and casting for moderate to severe cases [4]. Another positional deformity seen at birth is talipes calcaneovalgus, which is hyperdorsiflexion and abduction of the forefoot that allows the foot to rest on the anterior shin. This deformity also generally resolves without treatment or with casting required for more severe cases.

Genetic pedal deformities include clubfoot, congenital vertical talus, and tarsal coalitions. Many of the deformities are not painful during infancy, but without treatment, the foot will remain deformed and present difficulties when the child begins to walk. Many of these deformities can be successfully treated without surgical correction. Proper treatment includes serial stretching, casting or bracing shortly after birth.

Clubfoot or talipes equinovarus is a multifactorial, polygenic inherited deformity in which a major causative gene has yet to be identified. Underlying factors relating to clubfoot deformities include chromosomal abnormalities, connective tissue, neurologic or muscular disorders, or intrauterine crowding or malposition. Clubfoot is characterized by inversion of a child's foot where the foot faces inward so severely that the bottom of the foot faces sideways. Up to 80% of clubfeet are diagnosed prenatally via ultrasound [5]. However, no prenatal preventions or treatments are available. Therefore, treatment is often initiated shortly after birth, with the most common treatment being Pontseti casting. Pontseti casting involves serial manipulation or reduction of the deformity with above the knee casting every five days [6]. Approximately five to six cast changes are required to correct the deformity. Bracing is essential following manipulation and casting until 3-4 years of age to prevent recurrence of the deformity as recurrence rate is only 6% with complaint families, but more than 80% when families are noncompliant with bracing [7].

Another genetic pedal deformity involving the hindfoot is congenital vertical talus. This deformity is characterized by a rocker bottom or significant flatfoot foot at birth. This is often associated with chromosomal abnormalities or neuromuscular disorders, such as spina bifida or neurofibromatosis [8]. This deformity can also be diagnosed in utero vis ultrasound. Similar treatment with serial manipulation and casting as to clubfoot can be successful if started early after birth. A more common genetic foot deformity of the hindfoot is a tarsal coalition. A coalition is the fusion between two bones where a joint is normally located, which impedes joint motion and displaces biomechanical loads abnormally throughout the rest of the foot [9]. Coalitions can occur between bones during the time of fetal ossification and therefore are present at birth. However, coalitions are not often symptomatic until the second decade of life when the foot structure has matured, growth plates are closing, and a child's foot is less flexible to adapt to the abnormal loading caused by the coalition. Tarsal coalitions are often characterized by rigid flatfeet and peroneal muscle spasms. Conservative treatments with orthotics and physical therapy often resolve many symptoms children have with tarsal coalitions. However, children with more severe symptoms unrelieved by conservative care may require surgical resection of the coalition or fusion of joints later in life.

Other genetic deformities are seen in the forefoot, which include syndactyly, polydactyly, macrodactyly, and brachymetatarsia. Syndactyly is the most common congenital deformity in the foot, in which there is an abnormal connection or "webbing" of toes [10]. There is simple syndactyly where only the soft tissues are fused or there is complex syndactyly where the underlying bones are also fused. Polydactyly is the presence of an extra toe. Macrodactyly is the presence of an enlarged toe. Brachymetatarsia is the presence of an abnormally shortened metatarsal due to premature closure of growth plates. This often presents with a short or floating toe that is associated with the short metatarsal. Surgical correction is not often required for these deformities as these are often asymptomatic or can be accommodated with shoe gear modifications or orthotics.

4. Childhood Normal Foot Development

For children without congenital foot deformities, their pedal development continues uninterrupted from the intrauterine state through birth. As noted above, a major development of pediatric feet is ossification, with only four bones in the midfoot remain unossified prior to birth. These bones ossify within the first three years of life, with the lateral cuneiform ossifying first followed by the medial then intermediate cuneiforms then lastly the navicular.

Prior to complete ossification or growth plate closure, the pedal bones undergo several changes. At birth, the calcaneus or heel is in a varus or inverted position, which decreased prior to complete ossification. There is also no arch present at birth and an arch is usually not first seen until around 2-2.5 years. Flat feet are frequent reasons for which parents seek medical attention [11]. However, children with flexible flat feet is not uncommon as the arch progressively develops throughout the first decade of life with mature arch position reached between 7-10 years of age. Following birth, a child's growth is primarily dependent on actively the dividing cartilage layer also known as the growth plate that is located between the shaft and epiphyses of bones. Cartilage cell division is regulated by hormones. As long as cartilage cell division exceeds the rate of growth from the shaft and epiphysis, growth will continue. At puberty, growth plate production slows, as osteoblast (bone forming cells) activity exceeds that of cartilage production. When the bony shaft and epiphysis meet, growth stops.

There is considerable variability in growth spurts between children. On average, girls' growth spurts generally occurs two years earlier than boys, with girls having majority of growth around 8-12 years and full growth plate closure by 16-18 years and boys with majority of growth 10-14 years and full growth plate closure by 18-20 years [12]. As for pedal growth, the foot grows in synchrony with the body, not the lower limb, with adult length first being achieved in the foot, then the long bones, and last stature. At 1-1.5 years of age, a child's foot is approximately half the adult dimension. Average increase in foot length per year is 0.9 cm from ages 5-12 in girls and 5-14 in boys. Mature foot length is often reached around the time of puberty with male feet being on average 2.2 cm longer than female feet.

5. Weight Bearing Milestones in Child Development

During the early months of a child's life is when much of the strength and coordination required for walking develops. Within the first 6 months of life, a child is developing gross motor skills, such as pushing up, rolling, and sitting with support, that will help the child develop strength and coordination to eventually be able to begin walking. Important milestones include pushing up at 2-3 months, sitting with support by 4 months, and rolling (front to back or back to front) at 4-6 months. Then during 6 through 10 months of life, children are often beginning self-locomotion, which can start with classic crawling, scooting, crab crawling with one knee bent and other extended, commando crawl, or backward crawl. However, some children may skip the crawling milestone and go straight to pulling themselves up, cruising, or walking. Typically however, many children do not gain the strength to bounce up and down with assistance until 6 months or pull themselves up until 9 months [13, 14]. Therefore first steps are normally not seen until approximately 9-12 months of age.

The 12-month mark is often when children have not only developed the strength and coordination, but also the confidence to begin walking by themselves. This is often initiated with cruising, where the child will walk with assistance by utilizing furniture for support. By 14-17 months, children are often able to walk fairly well without assistance and as the child approaches two years of age, their gait begins to appear more natural as they become more comfortable with self-ambulation. There are several devices on the market, such as various baby walkers that appear as though they would help a child through these developmental milestones more quickly. However, devices are largely discouraged because they may prevent proper development of the child's upper leg muscles. The above described milestones occur in a specific order to allow children to gain strength, coordination, and confidence with minimal reliance on assistive devices.

6. Benefits of Weight Bearing in Child Development

There are several developmental benefits that come with weight bearing and ambulation as a child. Children's bodies learn proper joint alignment to allow for natural locomotion [15]. Weight bearing also helps children learn to balance and maintain that balance over a period of time. Children also learn mental and physical awareness, which includes development of proprioception or spatial relations. Overall, weight bearing and ambulation allow children to learn independence.

7. Anatomy of a Child's Shoe

Shoes are made of up six different parts that include the toe box, the vamp, the sole, the heel, the last, and the counter. The toe box is the tip of the shoe that provides space for the toes. The shape of the toe box often determines how much space there is to accommodate a child's toes. Various shapes include rounded, pointed, or squared. The vamp is the upper middle part of the shoe where the laces are commonly placed. For younger children, velcro is often utilized in this area to allow for children to easily secure their shoes without requiring the dexterity needed to tie laces. The sole includes the insole and outsole. The insole is the inside of the shoe. The outsole contacts the ground. The softer the sole, the greater the shoe's ability to absorb shock. The heel is the bottom part of the rear of the shoe, which can provide elevation if necessary. The last is the part of the shoe that curves in slightly near the arch to conform to the average foot shape. This shape often helps children tell the left from the right shoe. The counter is the material around the heel of the shoe to help stiffen and provide extra support and control, which is sometimes required for children with abnormal foot structures.

8. Shoe Selection

As discussed in the above section, shoes are made up of multiple different parts that can vary from shoe to shoe. For most children early on in development, shoes are not required for normal foot development. Barefoot walking during the earliest stages of ambulation allow for the foot to continue to develop unhindered by shoes as well as for the child to develop the sensory stimulation that otherwise may not be apparent in shoes. Therefore, in the earliest stages of walking shoe wearing should be minimized. Shoes truly only provide one function during the early stages of walking, which is protection. As a child ages and explores new territories, shoes can protect against new environments. Softer soled shoes may be ideal for allowing the tactility and motion of the foot, while still providing protection.

When deciding between various shoe models, one aspect to consider is the material makeup of the shoe, as different materials can have advantages depending on the child and terrain. Shoes made with certain materials like leather, canvas, or mesh, allow for “breathability”, while other materials such as rubber, may allow for the shoe to be more waterproof. Shoes worn more often should allow for adequate air flow to prevent sweat accumulation. The insole of the shoe should be made of an absorbent material to also assist with accumulation of moisture in the shoe. When analyzing the outsole of a shoe, a flat rubber outsole is recommended as this makes ambulation easier for the child and helps to prevent slipping.

In terms of wearing shoes to provide biomechanical control of the foot, there is no need for any built-in arch support as most children’s feet do not develop a significant arch until 6-8 years of age. If a child appears to have flatfeet or excessive pronation, a stiffer heel counter is recommended as this can help control the position of the foot and ankle. However, any further inserts, high top counters, or braces are often not needed early in childhood unless prescribed by a medical professional.

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