U · P O · J

Volume 10 Spring 1997
Pages 30-39

Plain Radiographic Evaluation of the Pediatric Foot and Its Deformities

Mark A. Katz, M.D., Richard S. Davidson, M.D., Peter S. H. Chan, M.D., and R. J. Sullivan, M.D.Accurate diagnosis

Department of Orthopaedic Surgery, University of Pennsylvania, 8 Penn Tower, 34 and Civic Center Boulevard, Philadelphia, PA 19104.

Abstract: Accurate diagnosis and assessment of severity of pediatric foot deformities by physical examination can be challenging. Radiographs are a valuable adjunct for accurate diagnosis and effective treatment for many of these deformities. On the standing anteroposterior view useful measurements include the talocalcaneal and talus-first metatarsal angles; on the standing lateral view various measurements include the talocalcaneal, tibiocalcaneal, tibiotalar, talus-first metatarsal, and talohorizontal angles. Additionally, the talocalcaneal, tibiocalcaneal, and talus-first metatarsal angles in maximum dorsiflexion or plantar flexion illustrate dynamic characteristics of the pediatric foot. Standard radiographic techniques are necessary for accuracy and reproducibility of these angles. Thus, the importance of positioning the patient properly and focusing the x-ray beam on the area of interest is discussed. Radiographic evaluation of several pediatric foot deformities which include metatarsus adductus, skewfoot, clubfoot, vertical and oblique talus, and tarsal coalition is presented.

Introduction

Radiographs are a valuable adjunct for effective diagnosis and treatment of pediatric deformities of the foot. The value of radiographic evaluation had been limited by lack of comparative studies with normal infants and children. Although Barwell (1896) first described the use of radiographic evaluation of the clubfoot, Wisburn (1932) later quantified the abnormalities of the clubfoot by measuring the talocalcaneal angle. Those studies and other investigations focused on clubfeet and incidental evaluation of the contralateral normal foot. Accepted normal ranges of radiographic angle measurements were established, but they were based on small samples [17].

VanderWilde et al. [17] published normal values of various radiographic measurements of the pediatric foot. Radiographs of 74 normal infants and children, from six months to ten and one-half years of age, were reviewed. Their study demonstrated that normal ranges and mean values of radiographic measurements of the pediatric foot changed with age.

These data provide standards for evaluation and diagnosis of foot deformities in the pediatric population. It is important to understand that measurements varying more than ±2 SD do not necessarily imply a pathologic condition, future symptoms of degenerative disease, or a need for treatment.

Accuracy and reproducibility of each measured angle is dependent on positioning of the patient in the x-ray beam [5]. The x-ray beam must be focused on the area of interest to minimize distortion. The projected angle between two lines will be smallest and most accurate when the x-ray beam is perpendicular to the lines. As the x-ray beam moves away from the perpendicular, the projected angle becomes larger and less accurate. Additionally, the radiographic studies should be obtained during weight bearing or (in infants or patients unable to stand) simulated weight bearing to demonstrate the functional positions of the foot [16]. The bones of the foot and ankle move in a concerted fashion through the normal movements of the body, and radiographs provide static pictures of these bony relations. Although standing views are usually the most helpful, projections in other positions can add valuable information and documentation for particular deformities of the foot. For example, dorsiflexion lateral views can document hindfoot equinus.

The purpose of this review is to summarize the common radiographic lines and angles used for diagnostic evaluation of several foot deformities found in infants and children. Discussions are provided on comparing pediatric foot deformities with the normal foot, significant radiographic measurements of these deformities, obtaining dynamic views for specific deformities, and proper positioning of the patient and x-ray beam.

Normal Pediatric Foot

The skeletal components of the foot include the hindfoot, midfoot, and forefoot which are the talus and calcaneus; the navicular, cuboid, and cuneiforms; and the metatarsals and phalanges, respectively. At birth, only rounded ossific nuclei of some bones of the foot are visible radiographically. The calcaneus usually starts to ossify by week 23 of gestation; the talus often starts at approximately week 28. Substantial portions of both bones are usually ossified by the first month of infancy. The cuboid appears by six to seven months, whereas the navicular ranges from nine months to five years for ossification. The cuneiforms begin ossification between three months and two and one-half years of age with the lateral cuneiform appearing first. The metatarsals and phalanges are usually present at birth. On average, many of the ossification centers appear earlier in girls than in boys [11].

Numerous measurements can be made on routine radiographs (Figure 1).

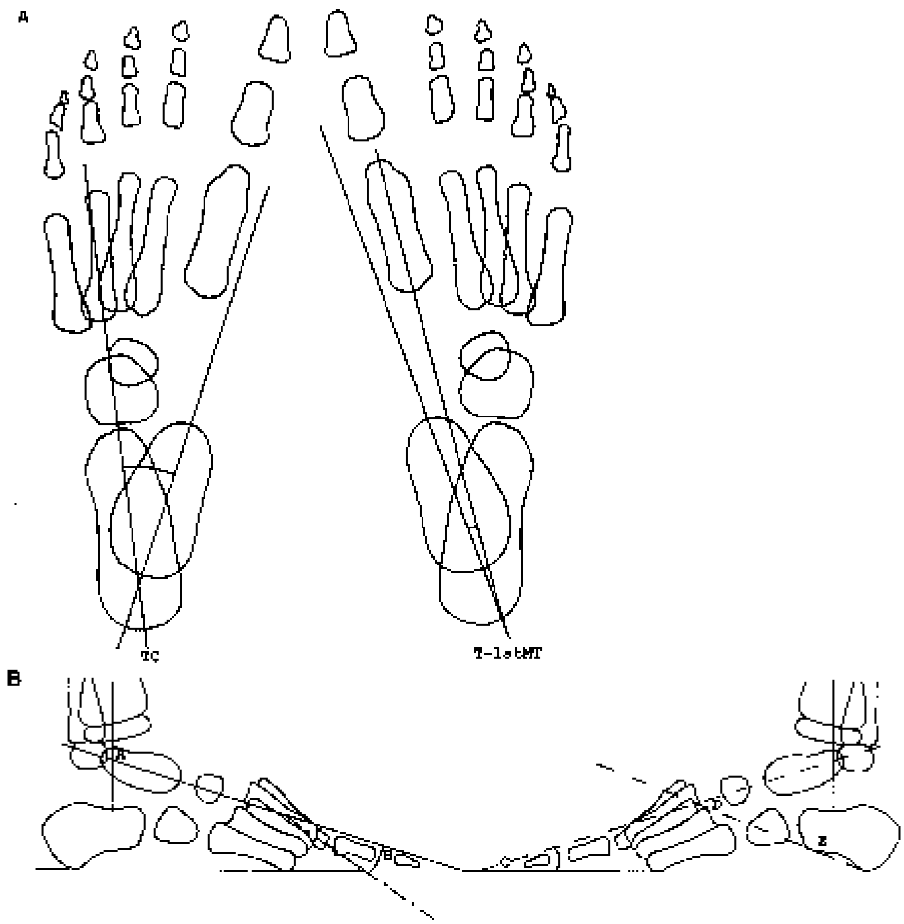

Fig. 1. Illustrations of usefully measured angles. **A:** AP views demonstrating TC = talocalcaneal and T-1stMT = talo-first metatarsal angles. **B:** Lateral views demonstrating A = tibiotalar; B = talo-first metatarsal; C = talohorizontal; D = talocalcaneal; and E = tibiocalcaneal angles.

On anteroposterior (AP) radiographs, useful measured angles include the talocalcaneal (Kite's) and talus-first metatarsal angles. Useful measurements on lateral radiographs are the talocalcaneal, tibiocalcaneal, tibiotalar, talus-first metatarsal (Meary's), and talohorizontal angles. Additionally, the talocalcaneal, tibiocalcaneal, and talus-first metatarsal angles can be assessed dynamically with the foot in maximum dorsiflexion or maximum plantar flexion [17]. Consistency in describing these measurements as well as the relationship of each bone is important. By convention, one should always describe the distal anatomy in reference to the proximal anatomy.

Standard radiographic techniques are important to obtain reproducible and accurate films for evaluation. Therefore, it is possible to recognize improperly obtained views which may not conform to standard techniques (Table 1) [14,16].

Table 1. Clues suggesting improper radiographic technique [14,16]
AP Views of the Foot

Anterior ends of talus and calcaneus at different levels If the heads of the talus and calcaneus are more than 2 to 3 mm apart longitudinally, the x-ray beam was not positioned 30 degrees from the vertical or the foot was improperly positioned in plantar flexion. As the x-ray beam is progressively angled, the calcaneus radiographically moves forward relative to the talus. Significant overlapping of the metatarsals Overlapping of these bones indicates inversion of the foot which falsely decreases the talocalcaneal angle. Clinical comparison is necessary to verify improper technique. Visualization of the tibial and fibular shafts Inadequate dorsiflexion of the foot or significant equinus preventing dorsiflexion is likely. A falsely decreased talocalcaneal angle is created with inadequate dorsiflexion. Clinical correlation is necessary.
Lateral Views of the Foot
Extreme posterior positioning of the fibula with respect to the tibia If the hindfoot is placed in external rotation, the talocalcaneal angle is falsely increased. This appearance may be secondary to improper positioning of the foot or improper positioning of the cassette with respect to significant medial deviation of the midfoot or forefoot. Stacking or loss of overlapping appearance of the metatarsals Inversion of the foot creates stacking of the metatarsals and a falsely decreases the talocalcaneal angle. The film must be compared to the clinical appearance of the foot. Lack of ankle dorsiflexion Inadequate dorsiflexion of the ankle may be secondary to improper positioning or an equinus deformity. Improper positioning causes a falsely decreased talocalcaneal angle. Clinical correlation is necessary.

Anteroposterior views of the foot

The anteroposterior talocalcaneal angle is formed by the intersection of the line drawn through the longitudinal axis of the talus and through the longitudinal axis of the calcaneus. An increased angle indicates valgus of the hindfoot whereas a decreased angle indicates varus of the hindfoot. The accepted normal range is 20°--40° although this range reflects children less than five years of age [14,16]. VanderWilde et al. [17] found values within ±2 SD equal to 10°--56° (25°--56° for ages five and less). An inverse relationship between the age and the angle are noted. Increasing age is correlated with a decreasing angle.

Alignment of the forefoot with respect to the hindfoot in the anteroposterior radiograph is depicted by the talus-first metatarsal angle. The normal range of the talus-first metatarsal angle is -10° (varus) to +30° (valgus) equalling ±2 SD [17].

Lateral views of the foot

The lateral talocalcaneal angle is defined by the intersection of a line through the longitudinal axis of the talus and a line along the plantar surface of the calcaneus. The accepted normal range is 35°--50° [5,16]. VanderWilde et al. [17] determined a range of 25°--55° with declining ranges with increasing age. In measurement of the hindfoot, the lateral talocalcaneal angle is decreased with varus or equinus deformities and is increased with valgus or calcaneus deformities. This angle demonstrates dynamic characteristics, increasing with dorsiflexion and decreasing with plantar flexion.

On the lateral standing radiograph, the tibiocalcaneal angle is the intersection between the anatomic axis of the tibia and plantar surface of the calcaneus. This angle characteristically increases with plantar flexion and decreases with dorsiflexion of the ankle. The reported ±2 SD at neutral is 55°--95°, and an age related decrease occurs [17].

Maximum-dorsiflexion talocalcaneal and tibiocalcaneal angles are useful in further evaluation of deformity, particularly in clubfeet. Increases in these angles occur with equinus or varus deformities. In the normal foot, VanderWilde et al. [17] observed a range of 25°--55° for the talocalcaneal angle in maximum dorsiflexion. The maximum-dorsiflexion tibiocalcaneal angle range is 25°--60° [16].

Ankle range of motion can be assessed radiographically with measurement of the tibiotalar angle in both dorsiflexion and plantar flexion. The angle is formed by the intersection of the longitudinal axes of the tibia and talus. In dorsiflexion, the normal range is 70°--100° whereas in plantar flexion the normal range is 120°--180° [16]. The true ankle range of motion is established by comparing these maximum flexion views. This measurement does not represent midfoot or forefoot motion. These articulations can be evaluated with the use of the talus-first metatarsal angle in maximum dorsiflexion.

On the standing lateral roentgenogram, the talus-first metatarsal angle measures the alignment of the forefoot with respect to the hindfoot which is useful for interpretation of cavus and planus deformities. The intersection of the talar and the first metatarsal longitudinal axes creates this angle. The limits of normal are 0°--20° whereas the values are increasingly negative for cavus deformities (forefoot plantar flexion on the hindfoot) and increasingly positive for flat foot malformations (forefoot dorsiflexion on the hindfoot) [5,16].

VanderWilde et al. [17] first described measurement of the talohorizontal angle on the lateral standing radiograph. The angle is formed by the intersection of the lateral longitudinal axis of the talus and a line horizontal to the floor. A mean angle of approximately 35° is seen in infants to approximately 25° at nine years of age with a ±2 SD range of 15°--50° for all years studied [17]. This angle is helpful as an additional parameter for diagnosis of the vertical talus.

Metatarsus Adductus and Skewfoot

Metatarsus adductus and skewfoot are two different entities. With an incidence of approximately 1 in 1000 live births and about 50% bilaterality, metatarsus adductus is the most common congenital deformity referred to an orthopaedic surgeon; skewfoot is an infrequently seen foot deformity [4,10,16]. Both deformities are characterized by medial subluxation and supination of the forefoot at the tarsometatarsal joints creating lateral convexity of the foot. Midfoot findings differentiate metatarsus adductus from skewfoot. Skewfoot demonstrates lateral subluxation of the navicular on the head of the talus which renders the hindfoot in valgus. Differentiation of these entities is difficult in the infant foot. Identifying hindfoot valgus presents a challenge clinically in the chubby neonate, and limited pedal ossification centers make radiographic assessment difficult. Careful radiographic interpretation can prove useful for distinction of these two deformities.

Radiographic films are not usually needed for diagnosis of metatarsus adductus. However, roentgenograms are certainly indicated for difficult or severe cases in which a patient does not respond to serial casting or a definitive clinical diagnosis may not be possible. Because the deformity is forefoot varus with respect to the hindfoot, the x-ray beam must be focused on the midfoot with the foot gently held in position to correct the adduction and supination of the forefoot. Both the AP and lateral views are obtained in the weight-bearing position to determine if a fixed hindfoot deformity exists which can help distinguish metatarsus adductus from skewfoot.

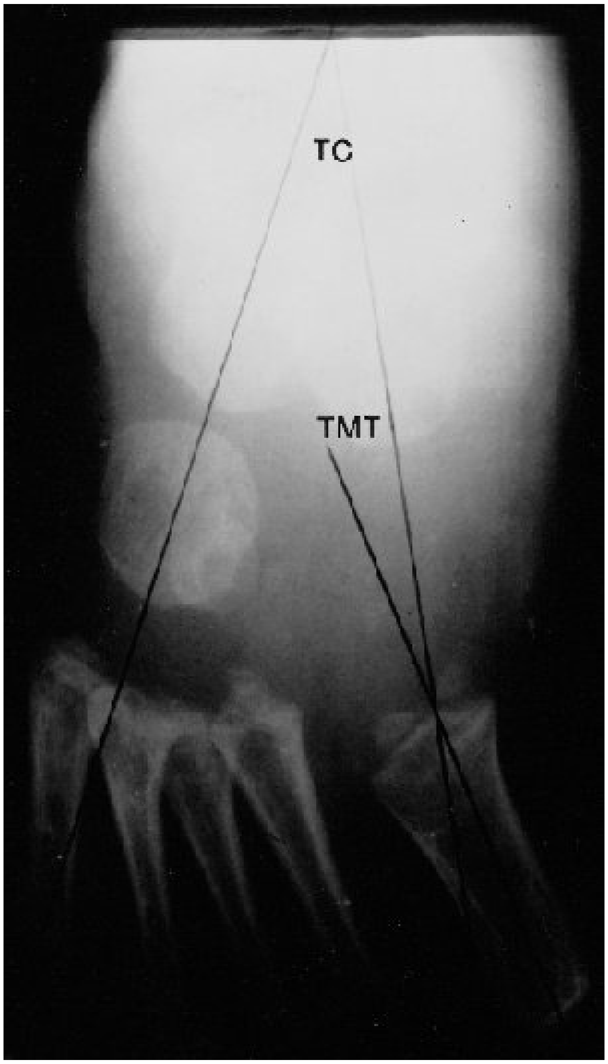

Fig. 2. Metatarsus Adductus: An AP radiograph demonstrates varus deformity of the forefoot relative to the hindfoot as represented by the negative value of the talo-first metatarsal angle. The talocalcaneal angle is normal.

The AP film demonstrates the severity of the forefoot varus by measurement of the talo-first metatarsal angle (Figure 2). This angle best depicts the deformity because the first metatarsal deviates greater than the lateral metatarsals. The AP along with the lateral view needs careful evaluation to assess the relationship of the hindfoot. The AP and lateral talocalcaneal angle is within normal limits (no varus or valgus) in metatarsus adductus. If this angle is decreased as in a hindfoot varus or equinus angulation, then a clubfoot deformity is suggested; an increased talocalcaneal angle on both the AP and lateral films is consistent with the hindfoot valgus deformity of skewfoot.

The skewfoot deformity depicts a serpentine shape of the foot. The forefoot is in rigid adduction, and the heel is in valgus. Medial deviation of the talus creates fullness on the medial aspect of the foot such that progression causes a concavity distally at the navicular position. This lateral subluxation of the navicular on the head of the talus is a radiographic cardinal sign of skewfoot. Unfortunately, documentation of lateral talonavicular subluxation is dependent on navicular ossification which is often delayed (Figure 3). Defining excessive hindfoot valgus is also difficult radiographically in an infant. Reproducible and accurate radiographs present a challenge for this age where measurement of the talocalcaneal angle can be inconsistent because of the relatively round and small appearance of the talus and calcaneus in early infancy [4,10].

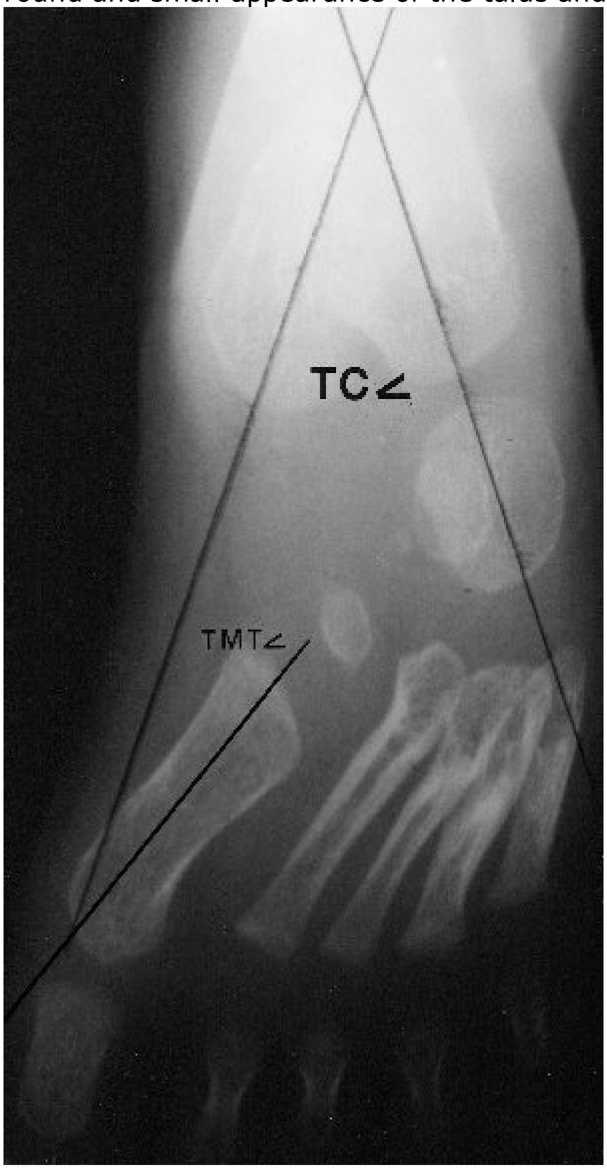

Fig. 3. Skewfoot: An AP radiograph reveals the significant varus deformity of the forefoot creating a negatively valued talo-first metatarsal angle. Delayed ossification of the navicular prevents radiographic documentation of the lateral talonavicular subluxation. The hindfoot valgus is portrayed by the increased talocalcaneal angle (the upper limits of normal as shown).

In the presence of a single deformity, the talo-first metatarsal angle better assesses the relationship between the forefoot and the hindfoot in both the sagittal and frontal planes. Skewfoot reveals two deformities in opposite directions between the talus and first metatarsal in both planes. Significant deformities may be present with tendency to cancel each other out with measurement of the talo-first metatarsal angle. Mosca [10] reports eight of ten patients with skewfoot had normal talo-first metatarsal measurements despite severe deformities.

Clubfoot

The clubfoot, congenital talipes equinovarus, is one of the most common congenital foot deformities with an incidence of about 1 in 1000 live births. Bilateral deformities present in approximately 50% of cases, and a male tendency has been observed. The etiology of clubfeet remains controversial, but is likely multifactorial [16].

Clinically, the clubfoot manifests hindfoot equinus and varus, forefoot adduction and supination, and variable rigidity. The talus and calcaneus are in equinus, and the navicular is subluxed medially on the talar head and abuts against the anterior medial malleolus. The anterior calcaneus pivots medially under the talus about an axis through the interosseous ligament such that the posterior aspect of the calcaneus is forced laterally. The calcaneus inverts under the talus creating a varus deformity. The cuboid subluxes medially in varying amounts on the calcaneus. Additionally, other possible findings include talar dome and talar head flattening [1,16].

Standardization of radiographic techniques helps eliminate inaccuracies. The x-ray beam on both the AP and lateral must be focused on the hindfoot, the area of interest. For the AP projection, the child is best placed in the sitting position with hips at 90° and the ankles dorsiflexed to neutral or not more than 15°. Ankle dorsiflexion causes the foot to move laterally and into dorsiflexion on the talus, and the anterior calcaneus moves laterally which increases the talocalcaneal angle. The medial deviation of the forefoot must be gently manipulated and held or taped in the position of maximal correction. The x-ray beam is directed toward the head of the talus at 30° to the vertical [14,16].

For the lateral view, the child straddles a cassette which is placed vertically in a holder or slotted board. The medial border of the hindfoot, not the forefoot, is positioned parallel to the edge of the cassette. Placing the typically "bean shaped" clubfoot parallel to the cassette edge creates hindfoot external rotation with respect to the x-ray beam falsely increasing the talocalcaneal angle. The talus becomes distorted and the fibula appears posterior to the tibia [14--16]. The x-ray tube is directed 90° to the cassette or perpendicular to the hindfoot. For maximal dorsiflexion in the lateral position, the tibia is then flexed forward maximally at the ankle without lifting the heel off the table. An accurate talocalcaneal angle is better portrayed to eliminate a falsely small value [14,16].

Multiple angular measurements are utilized in the radiographic evaluation of clubfeet. Useful angles are the talocalcaneal and talo-first metatarsal angles on the AP projection and the talocalcaneal and maximum-dorsiflexion talocalcaneal angles on the lateral view. The talocalcaneal angles are decreased, and the talo-first metatarsal angle demonstrates increased varus (Figure 4).

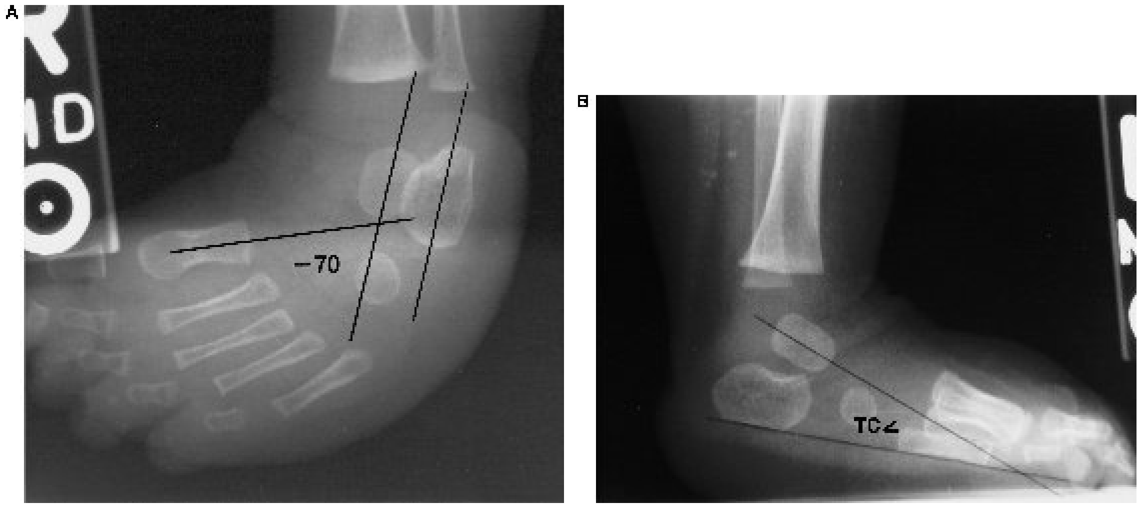

Fig. 4. Clubfoot: **A:** On the AP radiograph, the "parallelism" of the talus and calcaneus and negatively valued talus-first metatarsal angle demonstrate the varus deformities of both the hindfoot and forefoot, respectively. **B:** The lateral view reveals the decreased talocalcaneal angle characteristic of the hindfoot equinovarus deformity. Moderate stacking of the metatarsals depicts the forefoot supination.

Simons' review [14] provides suggestions for more accurate measurements of these angles in the infant's foot. On the AP, carefully tracing the outline of both the talus and calcaneus is often helpful. Because the talus is narrower anteriorly, a set of points can be placed anteriorly on the medial and lateral borders of the talus, and then a second set of points is placed similarly posteriorly. Two points placed midway between the anterior and posterior sets of points bisect the talus and create the longitudinal axis of the talus. The longitudinal calcaneal axis is achieved by drawing a parallel line to the lateral border of the calcaneus. On the lateral view, the long axis of the talus is obtained in the same manner as the AP. The calcaneal line is described as the plantar surface of the calcaneus; however, the inferior border may appear irregular in the first three to six weeks of life. Thus, the axis may be obtained by the midline method described for the talus.

Congenital Vertical Talus and Oblique Talus

Congenital vertical talus or rocker-bottom foot is an uncommon rigid foot deformity which represents the most severe malformation on the spectrum of congenital flatfoot. Congenital vertical talus, as well as oblique talus, is associated with several neuromuscular disorders which include arthrogryposis, neurofibromatosis, cerebral palsy, poliomyelitis, and spinal muscular atrophy. Neural tube defects, genetic disorders or inheritance, and malformation syndromes have also been associated with this pediatric deformity. However, isolated congenital vertical talus has been observed [2,6,13].

Differentiation of vertical talus from the other flatfoot deformities such as oblique talus and tarsal coalition is of importance because the prognosis and treatments are significantly different. Congenital vertical talus is characterized by the vertical placement of the talus and rigid talonavicular dislocation. In oblique talus deformities, the talonavicular joint maintains its articulation and is dorsally subluxated in dorsiflexion or standing. The talonavicular joint in an oblique talus foot is reducible with plantar flexion of the forefoot.

Clinically, the congenital vertical talus foot has a distinct plantar surface convexity, a rocker-bottom deformity. The head of the talus is prominent on the medial and plantar aspect of the foot. The hindfoot is fixed in equinovalgus with a tight tendo-Achilles, and the forefoot is rigidly abducted and dorsiflexed at the midtarsal joints. The contracted soft tissues resist manipulation; the navicular remains dislocated dorsally on the talus with forefoot plantar flexion.

At birth the midfoot is not yet ossified, and radiographs offer limited information. However, the radiographic findings in congenital vertical talus are characteristic even in the newborn. The vertical talus lies parallel to the anatomic axis of the tibia, and the calcaneus is in equinus angulation. The forefoot is dorsiflexed and translated laterally. Several measured angles provide objective evaluation which include the talocalcaneal on both the AP and lateral views, tibiotalar, tibiocalcaneal, talo-first metatarsal, and talohorizontal angles.

Radiographic projections for vertical talus are captured while weight bearing and include an AP, lateral, and maximally plantar flexed and dorsiflexed views (Figure 5).

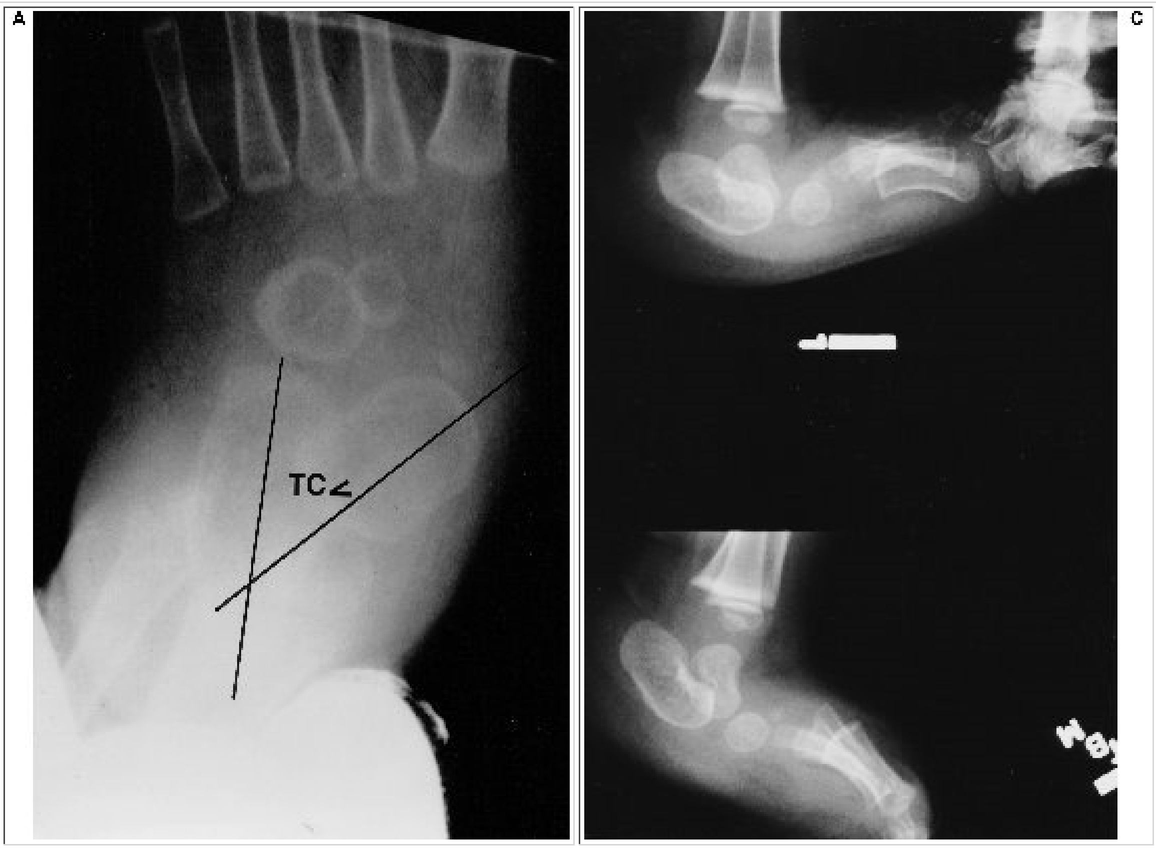

Fig. 5. Congenital Vertical Talus: **A:** An AP radiograph demonstrates an increased talocalcaneal angle due to the equinovalgus angulation of the os calcis. **B:** The lateral view depicts the significant hindfoot equinus and vertical position of the talus. Thus, the talohorizontal and tibiotalar angles approach 90° and 180°, respectively. **C:** The maximum-dorsiflexion view reveals the rigidly fixed hindfoot equinus. The maximum-plantar flexion view confirms the irreducibility of the midfoot on the hindfoot in vertical talus.

The x-ray beam is focused on the midfoot, the location of the primary pathoanatomy in vertical or oblique talus. The talocalcaneal angle on the AP view is abnormally increased secondary to the equinovalgus angulation of the calcaneus. On the lateral projection, the hindfoot abnormality is characterized by an increase in the talocalcaneal angle and by an increase in the tibiocalcaneal angle. The maximum-dorsiflexion view depicts an inability to dorsiflex the os calcis as a result of the rigidly fixed hindfoot equinus. The relationship of the forefoot to the hindfoot demonstrates an increasingly abnormal positive value of the talus-first metatarsal angle. Because the talus is positioned vertically, the talohorizontal and tibiotalar angles approach 90° and 180°, respectively. To make a definitive diagnosis of congenital vertical talus, the maximum-plantar flexion view confirms irreducibility of the talonavicular joint. When the foot is maintained in extreme plantar flexion, the navicular remains dislocated dorsally on the talar neck which correlates with a persistently positive increase in the talo-first metatarsal angle [2]. A reducible talonavicular joint is observed in oblique talus (Figure 6).

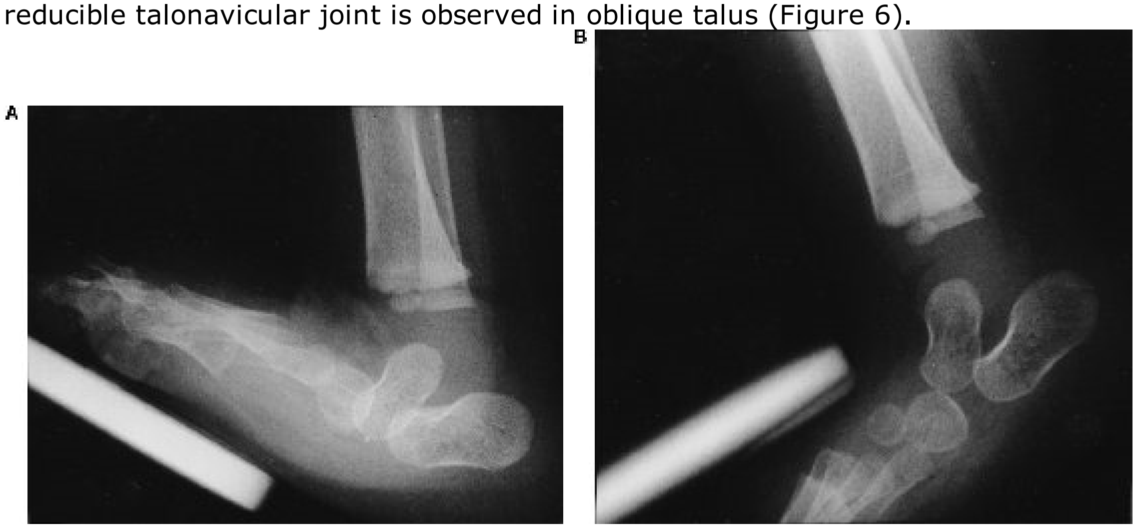

Fig. 6. Oblique talus: Comparison of the maximum-dorsiflexion and plantar flexion views demonstrate the reduction of the midfoot on the hindfoot in plantar flexion which establishes the diagnosis of oblique talus.

Hamanishi (1984) [6] published a new measurement system based on review of 69 cases of congenital vertical talus. Hamanishi introduced the measurements of the talar axis-first metatarsal base angle (TAMBA) and calcaneal axis-first metatarsal base angle (CAMBA). These angles delineate the obliquity of the talus and calcaneus and characterize the talonavicular joint. Transition from flexible oblique talus to rigid congenital vertical talus may be identifiable on the basis of these measured angles. Hamanishi believes identification of borderline cases of vertical talus can be treated conservatively rather than by surgical reduction.

Hamanishi [6] stated that the usual angles used for objective evaluation of vertical talus are ineffective in determining the anatomical relationship between the talus and navicular. The talar-first metatarsal angle describes the relationship theoretically, but it is susceptible to inaccuracies during filming of the foot. TAMBA and CAMBA are both established by a line extending perpendicularly from a point originating on the base of the first metatarsal bone which is the midpoint of the ossified metaphysis. The first metatarsal is identified on the lateral view by location of the widest and most distal metatarsal bone. The talar and calcaneal axes pass through the midpoints of the anterior curvatures of their respective ossified heads; the posterior points of the axes in older feet pass through the posterior third of the trochlea tali and the superior end of the calcaneal apophysis, respectively. Intersection of the talar axis with the line originating from the first metatarsal base creates the TAMBA, and the calcaneal axis intersection corresponds with formation of the CAMBA. These angles can also be measured in maximum plantar flexion which differentiates congenital vertical talus and oblique talus most clearly. TAMBA of about 60° and CAMBA of about 20° represents the transition from oblique talus to congenital vertical talus [6].

Tarsal Coalition

Tarsal coalition or rigid flatfoot is a congenital fibrous, cartilaginous, or osseous union between two or more tarsal bones as a result of failure of segmentation. Although the overall incidence for the general population is uncertain, the best estimate is likely an incidence of less than 1%. Most studies reveal a male preponderance of about 60%--80%. An incidence of bilateral occurrence has been reported as more than 50%. The calcaneonavicular and talocalcaneal forms of coalition are most common. Numerous other coalitions have been documented, but are extremely rare [3,9,12].

Coalitions are primarily fibrous or cartilaginous during the early years of growth. Ossification occurs in late childhood or adolescence. Some subtalar joint motion can persist during the nonossified stage, but as ossification proceeds joint motion becomes rigid and painful. Coalitions ossify at different times with the talonavicular coalition ossifying between ages three and five years, the calcaneonavicular between ages eight and twelve years, and the talocalcaneal between ages 12 and 16 years [3,12].

The most common coalition occurs between the talus and calcaneus involving the middle facet. Harris [7] described different types of talocalcaneal middle facet coalitions which are complete, incomplete, and rudimentary forms. The complete form is characterized by a continuous osseous bridge joining the talus and calcaneus. The incomplete type involves bony projections from the medial talus and sustentaculum tali separated by a fibrous or cartilaginous plate which may continue to complete ossification or may persist into adulthood. Two rudimentary types exist in which a bony projection extends from either the medial talus or sustentaculum tali.

Clinically, as the tarsal coalitions ossify, subtalar motion is often restricted in talonavicular and calcaneonavicular types and is usually absent in talocalcaneal coalitions. When subtalar motion is limited, the calcaneus is forced into rigid valgus which ranges from slight tilt without appreciable loss of the longitudinal arch to severe valgus deformity with complete loss of the longitudinal arch. In contrast, the flexible flatfoot has similar variations of hindfoot valgus and loss of the longitudinal arch upon weight bearing, but the normal anatomy reconstitutes with cessation of weight bearing. The heel converts to varus, and the longitudinal arch is reestablished upon toe standing or with Jack's toe raising test (dorsiflexion of the great toe).

Radiographic evaluation of the rigid flatfoot deformity should begin with weight bearing AP, lateral, and internal oblique views of the foot. Hindfoot valgus angulation and loss of the longitudinal arch demonstrate an increased talocalcaneal angle on both the standing AP and lateral views and an increasingly positive value of the talus-first metatarsal angle on the standing lateral view. Differentiation from the flexible flatfoot includes a maximum-plantar flexed lateral view which demonstrates flexibility as well as return to normal alignment.

Tarsal coalitions are easily overlooked because of bone overlap as well as the presence of incomplete ossification of a coalition. Diagnoses of calcaneonavicular, talonavicular, and calcaneocuboid coalitions are usually obtained on plain radiographs, but talocalcaneal coalitions are often difficult to detect. This challenge reflects the inherent obscurity created by overlapping bony shadows of the obliquely oriented middle and posterior facets of the subtalar joint. For example, if the hindfoot is rotated with respect to the x-ray beam (i.e., loss of a perpendicular relationship), the middle facet becomes superimposed on the calcaneal mass incorrectly suggesting the presence of a talocalcaneal coalition. This artifact results from overlap of the anterior edge of the lateral talar process and the posterior border of the sustentaculum tali [9].

Fig. 7. Tarsal coalition: **A:** The 45° internal oblique view may prove useful for diagnosis of calcaneonavicular coalitions as shown (arrow). **B:** The lateral view may demonstrate the "anteater nose sign" typically characteristic of calcaneonavicular coalitions (arrow). Note the tubular elongation of the anterior aspect of the calcaneus towards the mid-navicular region.

Fig. 8. Tarsal coalition: The Harris view may prove useful for the diagnosis of talocalcaneal coalitions involving the middle or posterior facet. As shown, this view demonstrates involvement of the middle facet as depicted by obliteration of this joint space (arrow). The posterior facet joint space is well visualized without any signs of involvement.

Calcaneonavicular defects are best revealed on the 45° oblique view (Figure 7) [3,9,12]. The joint space between the calcaneus and navicular is obliterated in complete ossification of the coalition. Non-osseous bridging is depicted as an elongation of either the calcaneus or navicular. Incomplete ossification can also demonstrate hypoplasia of the talar head and flattening of the navicular toward the calcaneus. However, critical assessment is necessary since overlapping structures can mimic coalition on the oblique view. The lateral view may render the "anteater nose sign" characteristic of the calcaneonavicular bridge (Figure 7) [9,12]. The anterior superior aspect of the calcaneus develops a tubular elongation directed towards the mid-navicular region.

Although talocalcaneal coalitions are difficult to diagnose on plain radiographs, an alternative technique may prove helpful for evaluation. The Harris view [7], described first by Korvin (1934) is essentially an axial view of the hindfoot at approximately 45° (Figure 8). Coalitions at the middle or posterior facets can be identified. The patient is positioned standing on the cassette with the ankle dorsiflexed approximately 10° (heel maintained on the table), and the x-ray beam is directed through the subtalar joint at about 45° to the floor. This 45° angle is not an absolute value as adjustments for variations of the foot are usually necessary to acquire views of the posterior and middle facets. On the properly acquired axial view the facets will appear horizontal and parallel to each other. For improved accuracy, the angle of the posterior facet from the horizontal is measured on the lateral radiograph and the x-ray beam adjusted accordingly. However, the posterior facet and middle facets may not occupy the same planes, and serial axial views at different angles may be necessary to demonstrate both facets [8]. An oblique plane of the middle facet or hypertrophy of the sustentaculum tali are suggestive of fibrous or cartilaginous coalition, whereas obliteration of the middle facet is indicative of a completely ossified coalition. Because the Harris view is often difficult to assess, computerized tomography scanning has become the study of choice for diagnosis of talocalcaneal coalitions. Computerized tomography in the coronal plane is most informative, which allows early detection and accurate determination of the type, location, and size of the coalition. Magnetic resonance imaging is helpful for the immature foot as well as the nonosseous forms of coalition because visualization of cartilaginous and fibrous tissue is achieved [3,9,12].

Secondary signs on the lateral radiograph may also provide information most suggestive of talocalcaneal coalition. These signs include talar beaking, posterior facet narrowing, flattening of the lateral talar process, concavity of the inferior talar neck, and obliteration of the middle subtalar facet. The talar beaking occurs at the normal talar ridge and extends distally to the talonavicular joint as a result of anterior joint capsule traction by abnormal motion of the navicular. Recognition of these signs may demand the pursuit of further studies to determine a cause [3,9,12].

Conclusion

Radiographs are a critical tool in evaluation of pediatric foot abnormalities. The resulting angular measurements can define the boundaries of normal and assist in the diagnosis as well as quantify the degree of deformity. However, accurate and reproducible radiographic studies are essential for effective use of these lines and angles. Small flaws in radiographic techniques may significantly alter these measurements. Weight bearing films, positioning the patient properly with respect to the cassette, focusing the x-ray beam on the area of interest, and obtaining dynamic views for specific deformities are essential.

Radiographic evaluation of the pediatric foot differs from x-ray assessment of the adult foot. The pediatric foot provides less radiographic information because of variation in ossification of the pedal bones. Only rounded ossific nuclei of some bones are visible radiographically at birth. Additionally, normative radiographic values for adults are not necessarily applicable to the pediatric population. VanderWilde et al. [17] established a large spectrum of normal values for numerous measurements of the pediatric foot and demonstrated changes in values toward the adult norms with increasing age. Therefore, awareness of these characteristics are essential to allow careful application of the many measurements discussed to minimize inaccuracies and misdiagnoses.

Ultimately, diagnosis of congenital foot deformities is accomplished clinically. Radiographic studies are an effective adjunct used to exclude unexpected deformities or to document the evolution of deformities. Thus, clinical management should not be determined solely on these radiographic measurements. Values beyond normal ranges do not imply presence of a pathologic condition or a need for treatment.

References

1. Carroll, NC: Congenital Clubfoot: Pathoanatomy and Treatment. In: *Instructional Course Lectures, The American Academy of Orthopaedic Surgeons.* Vol. 36. St. Louis, MO, C.V. Mosby, pp. 117--121, 1987.

2. Drennan, JC: Congenital Vertical Talus. In: *The Child's Foot and Ankle.* New York, NY, Raven Press, pp. 155--168, 1992.
3. Drennan, JC: Tarsal Coalitions. In: *Instructional Course Lectures, The American Academy of Orthopaedic Surgeons.* Vol. 46. St. Louis, MO, C.V. Mosby, pp. 323--329, 1996.
4. Greene, WB: Metatarsus Adductus and Skewfoot. In: *Instructional Course Lectures, The American Academy of Orthopaedic Surgeons.* Vol. 43. St. Louis, MO, C.V. Mosby, pp. 161--178, 1994.
5. Hak DJ and Gautsch TL: A Review of Radiographic Lines and Angles Used in Orthopedics. *Am J Orthop* Aug:590--601, 1995.
6. Hamanishi C: Congenital Vertical Talus: Classification with 69 Cases and New Measurement System. *J Pediatr Orthop* 4:318--326, 1984.
7. Harris RI and Beath T: Etiology of Peroneal Spastic Flatfoot. *J Bone J Surg* 30-B:624--634, 1948.
8. Jayakumar S and Cowell HR: Rigid Flatfoot. *Clin Orthop* 122:77--84, 1977.
9. Kulik SA and Clanton TO: Tarsal Coalition. *Foot Ankle* 17:286--296, 1996.
10. Mosca VS: Flexible Flatfoot and Skewfoot. In: *Instructional Course Lectures, The American Academy of Orthopaedic Surgeons.* Vol. 46. St. Louis, MO, C.V. Mosby, pp. 347--354, 1996.
11. Oestreich AE: Radiology. In: Drennan JC (ed). *The Child's Foot and Ankle.* New York, NY, Raven Press, pp. 37--70, 1992.
12. Olney BW: Tarsal Coalition. In: Drennan JC (ed). *The Child's Foot and Ankle.* New York, NY, Raven Press, pp. 169--182, 1992.
13. Robbins H: Congenital Vertical Talus and Arthrogryposis. In: Jahss MH (ed). *Disorders of the Foot and Ankle, Medical and Surgical Management.* Vol. I, 2nd ed. Philadelphia, PA, W.B. Saunders Co., pp. 848--871, 1991.
14. Simons GW: A Standardized Method for the Radiographic Evaluation of Clubfeet. *Clin Orthop* 135:107--118, 1978.
15. Sullivan JA: The Child's Foot. In: Morrissy RT and Weinstein SL (eds). *Lovell and Winter's Pediatric Orthopaedics.* Philadelphia, PA, Lippincott-Raven Publishers, pp. 1077--1136, 1996.
16. Thompson GH and Simons GW III: Congenital Talipes Equinovarus (Clubfeet) and Metatarsus Adductus. In: Drennan JC (ed). *The Child's Foot and Ankle.* New York, NY, Raven Press, pp. 97--133, 1992.
17. VanderWilde R, Staheli LT, Chew DE, and Malagon V: Measurements on Radiographs of the Foot in Normal Infants and Children. *J Bone J Surg* 70-A:407--415, 1988.