CURRENT LINES AND ANGLES USED IN PAEDIATRIC FOOT RADIOGRAPH: A SCOPING REVIEW OF LITERATURE

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ABSTRACT

Objective: **This article aimed to review the main currently described lines and angles and gather them in a single article and arrange them in a systematic way to facilitate the process of assessment of the pediatric foot for deformities.**

Methods: **The review was a scoping literature review. Electronic database websites such as PubMed, Europe PMC, Cochrane Library, and Google Scholar in addition to some books on anatomy and human movements biomechanics, diagnostic radiology, and orthopedics were searched for relevant articles for the topic of the present review. No statistical analysis was applied in this review.**

Results: **Data from thirty articles included in this review were arranged into different subheadings. In the anteroposterior view (AP), assessment of the hindfoot deviation was by the AP talo-calcaneal angle (Kite's angle); the forefoot and midfoot for abduction and adduction alignment was by the AP talo-first metatarsal angle, the talo-second metatarsal angle, the calcaneo-second metatarsal angle, the calcaneo-fifth metatarsal angle; the forefoot and midfoot rotation was by observing the normal proximal convergence of the metatarsal bones axes. In the lateral view, assessment of the hindfoot sagittal plane alignment was by the lateral tibio-calcaneal angle; hindfoot varus or valgus deviation by the lateral talo-calcaneal angle; talus bone alignment by talar declination angle and the tibio-talar angle; calcaneal bone alignment by the calcaneal inclination angle and the tibio-calcaneal angle, the midfoot and forefoot sagittal plane alignment for the plantar arch by the lateral talo-first metatarsal -Meary's- angle, the calcaneal inclination angle, and the lateral calcaneo-first metatarsal -Hibbs- angle; forefoot and midfoot rotational alignment by observing the overlap shadows of the metatarsals' shafts and drawing their axes.**

Conclusion: **Drawing certain lines and angles with a systematic approach to assess different regions of the foot in the radiographic films of children can facilitate the process of assessment of the foot (as a whole) for deformities.**

Keywords: Paediatric foot deformities, Radiography, Imaging, Lines, Angles

INTRODUCTION

Pediatric foot deformities are the deformities that could be found in the feet of newly born babies and children whether due to congenital or acquired causes. These deformities are diagnosed mainly clinically, but imaging studies are mainly used to assess association of bone deformities and may be required in certain conditions, either for confirmation of the clinical suspicion, measuring the degree of the malalignments (for grading and/or classification purposes), and/or follow-up of cases. Conventional radiography using plain X-ray is a useful imaging tool for the assessment of alignment for different regions of the foot. It is usually the first and the most common imaging study required. Additional imaging studies may be required but under the guidance of the plain X-ray film.[1,2] During the radiographic assessment of pediatric foot deformities, certain lines are drawn and certain angles are measured. Unfortunately, some articles and references describe the radiographic findings of pediatric foot deformities with general terms without using these specific lines and angles, others described them with less concern about their role in the diagnosis and definition of the deformity components, and others mention them in a scattered (non-systematic) manner.

This article aimed to review the main currently described lines and angles used in interpreting the plain radiographic film for assessment of pediatric foot deformities. The objective was to gather these lines and angles in a single article and arrange them in a systematic way to facilitate the process of assessment of the pediatric foot (as a whole) for deformities.

METHODS

Study design, protocol, and registration

The review was a scoping literature review done according to the Preferred Reporting Items for Systematic Reviews and Meta Analyses extension for Scoping Reviews (PRISMA ScR) checklist.[3,4] A review protocol was prepared before conducting the study and starting the search process. It was registered prospectively before starting data collection with the Open Science Framework on April 16, 2023 (https://osf.io/wn6hb/).

Information sources

Electronic database websites such as PubMed, Europe PMC, Cochrane Library, and Google Scholar were searched for relevant articles for the topic of the present review. The keywords and phrases used during the search process were selected according to the Medical Subject Headings (MeSH), and they were: pediatric foot deformities, pediatric foot imaging, and pediatric foot radiography.

In addition to the electronic database search, books were also involved in the search process. The searched books were on anatomy and biomechanics of human movements, diagnostic radiology, and orthopedics.

Eligibility criteria

Inclusion criteria were journal articles and book chapters discussing pediatric foot deformities (original or review articles). The search process was restricted to the articles published in the English language only. Exclusion criteria were grey literature, studies that discuss a specific subject other than imaging and radiography of children's feet.

Data collection and result synthesis

To understand how to assess the radiograph of a child's foot for alignment and how to draw lines and angles, it was vital to understand the basic sciences behind them. The data discussing the anatomy, biomechanics, and movements of different parts of the foot, pediatric foot development, normal clinical alignments of different foot regions, main radiological view in children, and main lines and angles drawn on the pediatric foot radiographic film to assess alignments were extracted and arranged into different subheadings. Assessment of risk of bias in the individual studies and across the studies was not applicable in this scoping review. No statistical analysis was applied in this review.

RESULTS

From a total of 1571 articles identified from the electronic database searching with available books, only 30 articles were included in the qualitative synthesis of data for this review after excluding the duplicate records, those which don't meet the inclusion criteria, full-text did not access or having repeated information (Fig.1). They were 18 journal articles and 12 books (4

Table 1: Summary of current lines and angles used for assessment of the different region's alignment in pediatric foot radiographic film.

View	Region	Plane or axis	Purpose (alignment)	Measurement
AP*	Hindfoot	Coronal and longitudinal	Deviation and rotation	AP talo-calcaneal angle
	Midfoot and forefoot	Coronal	Adduction or abduction	1. Talo-first metatarsal angle 2. Talo-second metatarsal angle 3. Calcaneo-second metatarsal angle 4. Calcaneo-fifth metatarsal angle 5. Relation of the mid-talar axis to the base of the first metatarsal 6. Relation of the mid-calcaneal axis to the base of the fourth metatarsal bone
		Longitudinal	Rotation (supination or pronation)	Arrangement of the metatarsal bones and their axes
Lateral	Hindfoot	Sagittal	Dorsiflexion and planter flexion	Lateral tibio-calcaneal angle
			Talus alignment	1. Talar declination angle 2. Tibio-talar angle 3. Relation of mid-talar axis to cuboid bone
			Calcaneal alignment	1. Calcaneal inclination angle 2. Tibio-calcaneal angle 3. Relation of mid-calcaneal axis to cuboid bone
		Coronal	Deviation (varus or valgus) and rotational (internal or external)	Lateral talo-calcaneal angle
	Midfoot and forefoot	Sagittal	Arch of the foot	1. Lateral talo-first metatarsal (Meary's) angle 2. Calcaneal inclination angle (pitch) 3. Lateral calcaneo-first metatarsal (Hubb's) angle
		Longitudinal	Rotation (supination and pronation)	Arrangement of the metatarsal bones and their axes

**AP: Anteroposterior*

anatomy and biomechanics, 2 diagnostic radiology, and 6 orthopedics).

The extracted data were arranged into different subheadings. The subheadings included: background of the subject, foot regions, foot movements, clinical assessment of alignments, radiographic projections, and views, pre-request for performing the pediatric foot radiographs, ossification centers, radiographic assessment of alignments including main lines and angles, and finally opinions of different authors about the role of these lines and angles in the assessment of pediatric foot deformities.

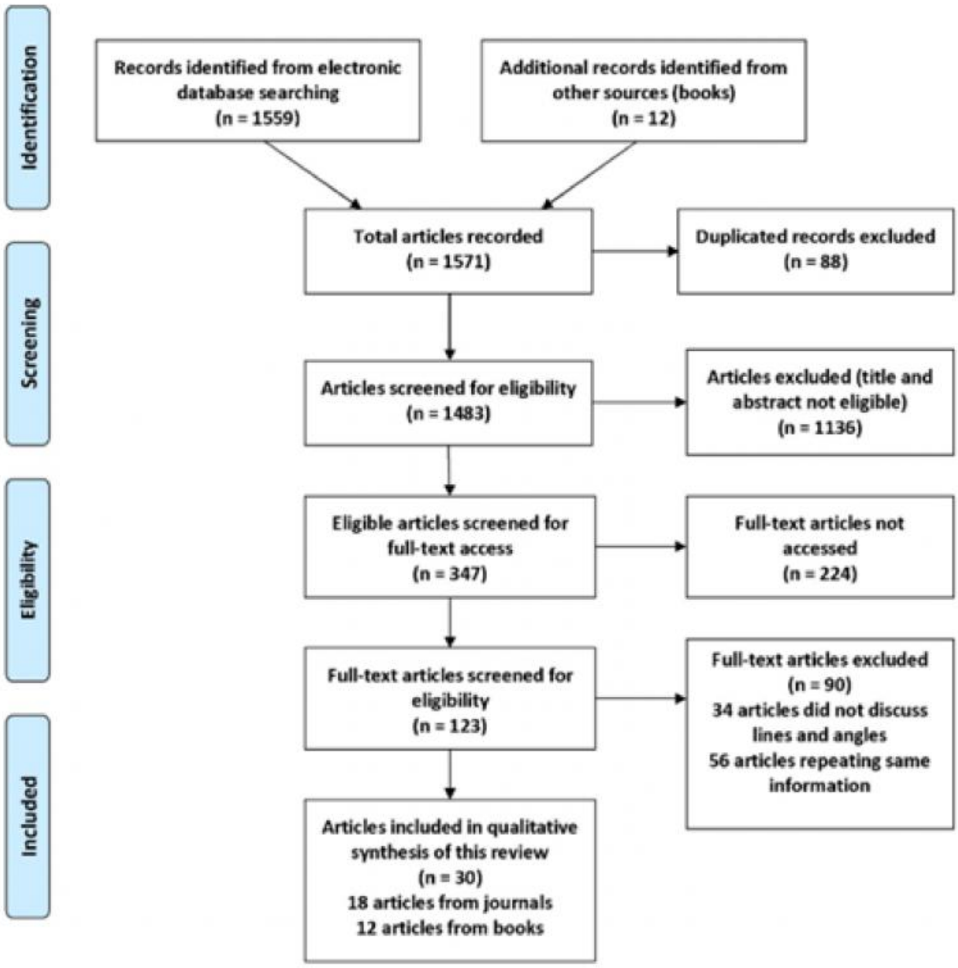

Figure 1: Flow chart for the articles identified in the search process and included in result synthesis

Background

Pediatric foot deformities may have a malalignment in one (simple) or more than one (complex) region or plane of the foot.[5,6] Some deformities may have frank malalignment but other may be subtle.[7] Therefore, it is important to assess the whole foot, region by region, and plane by plane in a systematic one for possible malalignments. This systematic assessment will help in the orientation of all the components of the deformity (malalignments), ensure a proper diagnosis, and of course a better plan for treatment.

Imaging investigations are helpful during the assessment process of the alignment of different regions of the foot. Although magnetic resonance imaging provides excellent anatomical details of the cartilaginous bones in the pediatric foot, its performance in children younger than seven years usually requires sedation with continuous monitoring of the child, an expert radiologist specialized in pediatric disorders, in addition to the cost.[2] Imaging by conventional radiography is practically performed easier for this age group with lesser cost, but its application is limited by the incomplete ossification of all foot bones. Its value for assessment of the alignment for different foot regions improved by drawing certain lines through the centers of the available ossified bones. These lines and some angular measurements can provide valuable information about the normal versus pathologic alignment of the different foot regions. Before describing the lines and angles used for assessment of pediatric foot deformity, it is vital to be oriented about some basic issues of the foot like anatomical regions of the foot, normal possible movements, normal clinical alignments of different foot regions, main radiographic views and projections used, and pre-requests to perform the radiographs for the foot of children. Then the details of the lines and angles will be described in case of normal and abnormal alignments.

Foot regions

The foot can be divided into three regions: hindfoot for the posterior region of the foot containing talus and calcaneus, forefoot for the metatarsals and phalanges, and midfoot for the in-between region which contains cuboid, navicular, and the three cuneiform bones.[1,5,6]

Movements

The ankle allows movement in the sagittal plane around a transverse axis in the form of plantar and dorsal flexion.[5,8,9] In the hindfoot, the possible movement occurs at the subtalar joint in the form of adduction and abduction of the heel. However, this gliding movement of the calcaneum under the talus is usually accompanied by some rotation. In the case of adduction, some internal rotation also occurs because the adducted calcaneum uplifts the anterior talus. Vice versa, when the calcaneal bone is abducted, it rotated away from the talus and later loses some of its head support.[1,10]

The movements between the joints of the midfoot and forefoot (intertarsal, tarso-metatarsal, and inter-metatarsals) are limited due to their bony contour and tight ligaments. Their movements usually occur simultaneously.[8,9,11] Therefore, they will be described together in this review.

Adduction and abduction of the forefoot toward or away from the body midline around a vertical axis occur mainly at the tarso-metatarsal articulations and slightly in the inter-tarsal joints.[5,11] However, adduction and abduction of the whole foot toward and away from the body midline are produced by rotation of the entire leg below the knee.[12]

Pronation and supination are limited in the foot and occur at the intertarsal, intermetatarsal, and tarso-metatarsal joints by rotating the forefoot around an anteroposterior axis running through the second metatarsal bone resulting in turning the plantar surface of the foot medially (supination) or laterally (pronation).[5,13] Because of the arrangement of the foot joints, neither adduction and abduction nor supination and pronation can occur as pure movements.[12]

Inversion and eversion are terms used to describe composite movements of the foot that cause turning the whole foot inward and outward, respectively. The combination of hindfoot varus deviation with midfoot and forefoot supination and adduction together results in inversion, while eversion includes hindfoot valgus with midfoot and forefoot pronation and abduction.[6,8,12] In some literature, the terms inversion and eversion are used (simply and non-anatomically based) instate of supination and pronation respectively.[14]

Clinical assessment of alignments

Before assessment of a foot radiographic film for alignment, it is essential to be familiar with the normal clinical alignment of different foot regions in a normal foot. Although, foot regions are anatomically and functionally related together, for the assessment of alignment purpose, it is better if they have been evaluated separately with a systematic approach (which is the objective of this article), starting proximally and advancing distally (author's opinion). This policy will be applied throughout all sections of this review. So, the assessment process is better to be started by finding the relationship between the leg with hindfoot, then the hindfoot with the midfoot and the forefoot.[1] The ankle and toes alignment will not be included in this review.

In the hindfoot, three planes of alignment can be noticed: The first one is in the sagittal plane, where it assumes relatively a perpendicular position to the leg. When the posterior part of the hindfoot becomes in a higher posture with the downward pointing of its anterior end, the deformity is called the equinus. In some literature, the term equinus may be used to refer to the persistent plantar flexion of the entire foot (in which case the calcaneal bone itself may not be in the equinus position).[1] However, the description of the whole foot by a single term may be misleading and may not help in the specification of the treatment process for each part of the foot. Therefore, it is better to avoid this curriculum and it is better to preserve each term for a specific region of the foot. In reverse to the equinus, the calcaneus deformity indicates a lower attitude of the hindfoot with an elevation of its anterior end more than usual. The second alignment of the hindfoot is in the coronal plane, where it may become in the valgus or varus position (due to abduction and adduction movements of the subtalar joint). Normally the hindfoot is in slight (5-10 degrees) valgus position.[6] The third alignment is the forward orientation of the hindfoot. The talus is pointing forward and because it has no muscle attachments, it is helpful to assume its position exactly where it should be and all the other bones have repositioned themselves with respect to the talus.[10] If this idea becomes accepted, then the calcaneal bone (under it) will have an external rotation alignment. However, practically this rotation occurs in combination with adduction and abduction of the calcaneal bone under the talus resulting in varus and valgus deviation of the hindfoot.[1]

In the midfoot and forefoot regions, also three planes of alignment can be noticed: The first one is the alignment of the forefoot and midfoot with the hindfoot in the coronal plane. Deviation of the forefoot and midfoot toward or away from the midline of the body are considered adduction or abduction deformity, respectively.[5] The second alignment is in the sagittal plane. The midfoot and forefoot both make an arch with the hindfoot called the plantar arch which is located mainly medially and therefore called the medial longitudinal arch (the lateral longitudinal arch is much less pronounced and less significant than the medial one).[11] When the depth of the plantar arch increases (elevation of the medial longitudinal arch), the deformity is called cavus. In reverse, planus deformity indicates a decrease in the plantar arch depth (dropping of the arch).[1] The third alignment is the rotation of the forefoot and midfoot around an axis running through the second metatarsal bone resulting in pronation and supination of the foot. Normally, there is slight supination when the foot is in a weight-bearing or simulated plantigrade position.[11]

Main radiographic views and projections

The basic radiographic examination in evaluating any foot deformity consists of weight-bearing anteroposterior (dorsoplantar) and lateral views. Other oblique views may be required for certain cases of trauma, tarsal coalition, or surgical follow-up. The 45° axially angulated Harris-Beath projection of the heel (Harris's view of the calcaneum) may be required to evaluate the subtalar joint.[1,2,6]

Weight-bearing views provide the most reliable information about alignment and are required when evaluating children with deformities.[6,15] They can be obtained with the child standing and the legs perpendicular to the film plane. Non-weight-bearing views are inadequate for the assessment of foot deformities because the bones will not be in their functional states and even may 'hide' the true components of deformities.[6,15] A simulated weight-bearing technique can be used to obtain a proper view in infants or non-ambulatory patients. This technique uses a solid plastic or wooden board to apply plantar pressure to maintain the foot in forced dorsiflexion to allow the correct position of the foot.[1,2,6]

In a certain situation with a suspected diagnosis, certain modifications may be required when taking the radiograph to exclude a differential diagnosis. For example, to differentiate congenital vertical talus from a severe form of pes planus, forced plantar flexion may be required when taking the lateral view.[16] In talipes equinovarus deformity, the dorsoplantar film is taken with the foot 30 degrees plantarflexed or the tube likewise angled 30 degrees perpendicular to facilitate the drawing of the mid-talar and mid-calcaneal lines.[6,15] While the lateral view may be taken with forced dorsiflexion.[15]

Pre-requests for performing the pediatric foot radiographs

Because children are usually less cooperative and their feet are smaller than adults, special care is needed when performing the radiographs.[2] They need to be comfortable and calm with a minimum level of anxiety. Positioning devices are required to perform weight-bearing or simulated weight-bearing films. Knowledge about the anatomy, ossification centers, important lines, and angles used for assessment of the alignment of different foot regions, as well as the main disorders of the growing foot are important when interpreting the findings in the radiographic film of pediatric age group.[2]

Ossification centers

Drawing the lines and angles on the pediatric foot radiographic film requires the presence of the bones' ossification centers. At birth, in a full-term baby, the calcaneum, talus, cuboid, and all the metatarsal and phalangeal diaphyses had primary ossification centers.[6,7] They can be seen clearly in the foot radiographic film. In other words, all the bones in the foot are ossified (have a primary ossification center) except the navicular and the three cuneiforms. By the end of the fifth year of life, all the other bones will have ossification centers.

Figure 2: Anteroposterior talo-calcaneal angle.

Radiographic assessment of alignments

For accurate assessment of pediatric foot alignment by the radiographic films, there should be at least two orthogonal views (AP and lateral) performed during weight bearing (or simulated weight bearing). Drawing the required lines and angles for alignment assessment in the correct place and correct direction is as important as understanding the normal alignment.

Antero-posterior (dorsoplantar) view

In the anteroposterior (AP, dorsoplantar) view, it is possible to assess both rotation and deviation of the hindfoot as well as the rotation and coronal plane alignment (abduction and adduction) of the midfoot and forefoot.

The AP talo-calcaneal angle (Kite's angle) is drawn to assess the hindfoot alignment for both rotation and deviation.[15] This angle is drawn between the mid-talar line and the mid-calcaneal line (Fig. 2). The first line is considered the longitudinal axis of the talus and is drawn through the center of the bone parallel to its medial cortical surface. The second line is considered the longitudinal axis of the calcaneum and is drawn through the center of the bone parallel to its lateral cortical surface.[6] This angle measures mainly the calcaneal bone rotation under the talus. The calcaneal rotation is compared with the axis of the talus since the latter is considered to be stable because it has no muscle attachments and no movements apart from dorsal and plantar flexion.[6,10] However, this rotation is usually accompanied by valgus and varus deviation of the calcaneum in the coronal plane. Therefore, different literature considered that this talo-calcaneal angle does measure the varus and valgus deviation of the calcaneum.[7,17] The normal range of this angle is diminished with age, being more in newborns (35-55 degrees) and less in late childhood.[6,18] On average it is between 20-40 degrees.[15] So, an angle measuring less than 20 degrees indicates an internally rotated (turned) with a varus deviation of the calcaneum resulting in the hindfoot varus deformity as in talipes equinovarus deformity. Vice versa, an angle measuring more than 40 degrees indicates an external rotation with a valgus deviation of the calcaneum (hindfoot valgus deformity) as in flatfoot.[2,19]

Assessment of the forefoot and midfoot in the coronal plane for abduction and adduction alignment is done by six methods (Fig. 3): First by drawing of AP talo-first metatarsal angle between the mid-talar line and the longitudinal axis of the first metatarsal shaft (Fig. 3a). This measurement is simple because the two bones are ossified and visible radiographically at birth. Normally this angle diminished with age being more in newborns and less in late childhood.[6,18] On average it measures 5-15 degrees in the valgus direction.[16,17] Angles measuring less than 5 degrees indicate forefoot

Figure 3: Assessment of forefoot and midfoot in the coronal plane: (a) anteroposterior talo-first metatarsal angle, (b) talo-second metatarsal angle, (c) calcaneo-second metatarsal angle, (d) calcaneo-fifth metatarsal angle.

adduction. Second by drawing the talo-second metatarsal angle between the mid-talar line and the longitudinal axis of the second metatarsal bone (Fig. 3b). It provides a more consistent measurement of the foot alignment in the coronal plane. The average normal measure is about 3 ±7 degrees in the valgus direction. So, according to this measure, the normal forefoot is about three degrees of abduction).[20] Third by drawing the calcaneo-second metatarsal angle between the mid-calcaneal axis and longitudinal axis of the second metatarsal bone (Fig. 3c). The average is about 10 degrees. An increase in this angle generally indicates a metatarsus adductus deformity. It is more closely linked to the metatarsals than is the talus, and most cases show little motion between the bones at these joints. However, this angle had low intra- and interobserver reliability in the assessment of the forefoot alignment in the coronal plane.[21] Fourth by drawing the calcaneo-fifth metatarsal angle which is drawn between the mid-calcaneal line and the longitudinal axis of the fifth metatarsal bone (Fig. 3d). The range of this angle remains stable without significant change with aging (-8 to +15, average 3 degrees in valgus direction).[6,18] Fifth by observing the mid-talar and mid-calcaneal lines (as mentioned previously). The mid-talar line normally passes through or is slightly medial to the base of the first metatarsal, and the mid-calcaneal line normally intersects the base of the fourth metatarsal (Fig. 1).[6] The relation of these two lines to their corresponding metatarsal shafts is of no significance because the latter has a wider flexible range of motion and their alignment may alter if the patient was not cooperative during imaging.[1,6] When the mid-talar line passes far away medial to the base of the first metatarsal bone, the forefoot is in abduction posture and vice versa. The sixth method is by finding the relation of the navicular bone (if ossified) to the talus bone. Normally, the navicular bone should be positioned directly opposite the talus. Unfortunately, the navicular bone is the last bone to be ossified in the foot; therefore, this sign has less value in early childhood.[5,6]

Assessment of the forefoot and midfoot rotation by drawing the longitudinal axes of the metatarsal bones. Normally a slight proximal convergence of these axes can be noticed from the slight overlap of the bases of these bones because the foot assumes some supination during weight bearing (Fig. 4).[11] Too many or fewer convergences of these lines are abnormal and may indicate supination or pronation respectively.[6]

Lateral view

In the lateral view, the hindfoot is assessed for alignment in the sagittal plane and for any deviation, along with the assessment of the talus and calcaneal bones alignment separately. Midfoot and forefoot alignment in the sagittal plane (arch of the foot) and their rotation are also possible in this view.

Figure 4: Anteroposterior metatarsal axes proximal convergence.

Assessment of the hindfoot in the sagittal plane for the dorsiflexion and plantar flexion alignment. This is done by drawing the lateral tibio-calcaneal angle. This angle is drawn between the longitudinal axis of the distal tibial shaft and the calcaneal inclination axis (a line drawn between the most inferior portion of the calcaneal tuberosity and the most distal inferior point of the calcaneal bone at the calcaneocuboid joint) (Fig. 5a). Normally it is less than 80 (range 60-77) degrees because the anterior calcaneum is in slight dorsiflexion with respect to the tibia.[1,6] When it becomes more than 80 degrees, the calcaneal bone is pointing downward, the hindfoot assumes equinus posture. In reverse, the calcaneus deformity is considered when the calcaneal bone becomes elevated more than usual and the angle becomes less than 60°.[6] This angle can be measured in another way by comparing the calcaneal inclination axes with the perpendicular line of the tibial longitudinal axis (Fig. 5b). In this situation, the normal range will be 10-30 degrees.[16]

Assessment of the talus bone alignment. This is done by three methods: first by measuring the degree of plantar flexion of the talus (talar declination angle). This is done by drawing an angle between the longitudinal axis of the talus and the horizontal baseline of the foot (plane of support, a line between the most inferior point of calcaneum and the most inferior point

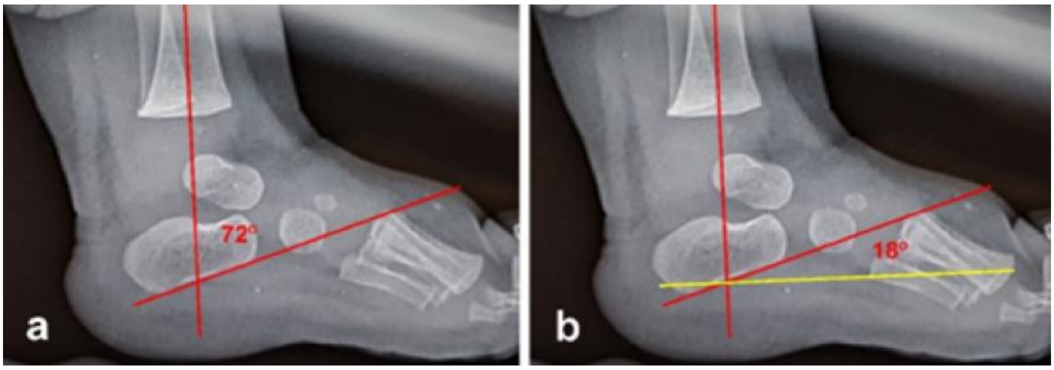

Figure 5: Lateral tibio-calcaneal angle: (a) calcaneal inclination axis with the tibial longitudinal axis, (b) calcaneal inclination axis with the perpendicular line of the tibial longitudinal axis

of the fifth metatarsal head) (fig. 6a).[22] This angle diminishes with age from an average of 34 degrees in newborns to an average of 25 degrees in late childhood because the talus becomes less vertical with growth and when weight bearing starts.[6,7,18] Second by drawing the tibio-talar angle which is drawn between the tibial longitudinal axis and the mid-talar axis (Fig. 6b). This angle diminishes with aging from newborn (average 115 degrees) to late childhood (average 108 degrees) because the talus becomes less vertical with weight bearing. The normal range is 100-120 degrees.[6,18] An angle of more than 120 degrees may suggest vertical talus abnormality. Third by observing the long axis of the talus which normally cuts the lower half of the cuboid (Fig. 6).[7]

arch. It increases (more than 30 degrees) in the calcaneus type of pes cavus deformity and decreased (less than 10 degrees) in pes planus (flatfoot) deformity.[6,15,24] Second by measuring the tibio-calcaneal angle (as mentioned previously) (Fig. 5). Third by observing the long axis of the calcaneum (mid-calcaneal line) which normally passes through the upper half of the cuboid (Fig. 7b).[7]

Assessment of the hindfoot for deviation (varus or valgus) and rotational (internal or external) alignment. This is done in two ways: First by drawing the lateral talo-calcaneal angle. The first line is drawn through the mid-longitudinal axis of the talus (parallel to its superior and inferior margins) and the second one is

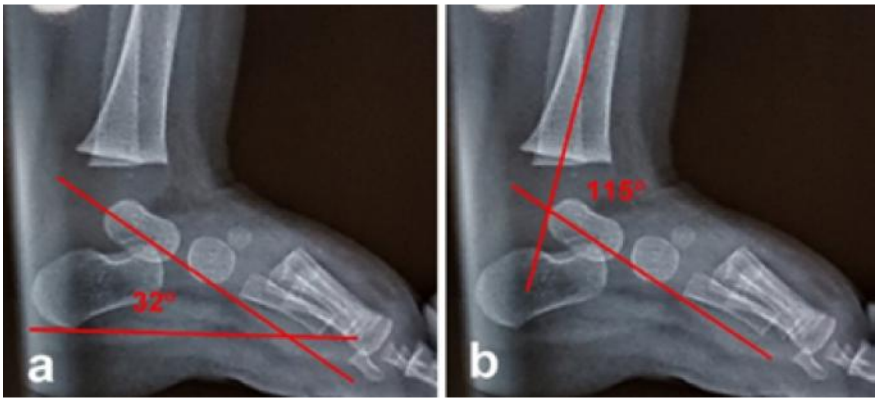

Figure 6: Assessment of talus bone alignment: (a) talar declination angle, (b) lateral tibio-talar angle.

Assessment of the calcaneal bone alignment. This is done also by three methods: First by measuring the calcaneal inclination angle (calcaneal pitch) which is calculated by a tangent line drawn along the inferior surface of the calcaneum (calcaneal inclination axis) and compared with the horizontal baseline of the foot (a line drawn from the most inferior point of calcaneal bone to the lowermost inferior point of the fifth metatarsal bone's head) (Fig. 7a).[22,23] Normally the formed angle measures 10-30 degrees. It shows the calcaneal bone posture, which is slightly dorsiflexed anteriorly, forming the posterior portion of the planar

along the lower border of the calcaneum (calcaneal inclination axis).[15,23] The latter is more easily and more accurately drawn than the mid-calcaneal line (Fig. 8). It is slightly steeper and accordingly, the measured angle will be slightly greater but without significant difference.[25] The angle gradually decreases with growth (from an average of 45 degrees in the newborn to an average of 33 degrees in late childhood) as the talus becomes less vertical.[6,16] The average range is between 20 to 50 degrees.[6,15,17] When the angle measures less than 20 degrees, it indicates a varus deviation of the hindfoot due to an abnormal relationship between the

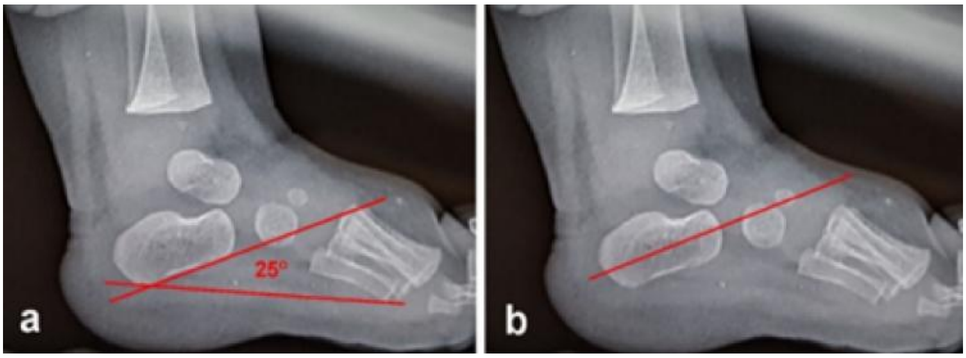

Figure 7: Assessment of calcaneal bone alignment: (a) calcaneal inclination angle, (b) mid-calcaneal axis passes through the upper half of the cuboid.

talus and the calcaneum. This can be noticed in talipes equinovarus (with diminished calcaneal inclination) and in the cavo-varus type of pes cavus deformity (with increased calcaneal inclination).[7,15] An increase in this angle indicates a valgus alignment of the hindfoot as in flatfoot, skewfoot, and congenital vertical talus.[2,6,7,17] Second by inspection of the subtalar joint on the standing lateral radiograph. Usually, there is some overlap (superimposition) of the talus and calcaneum in the joint in a normal foot.[7] When there is a varus tilt

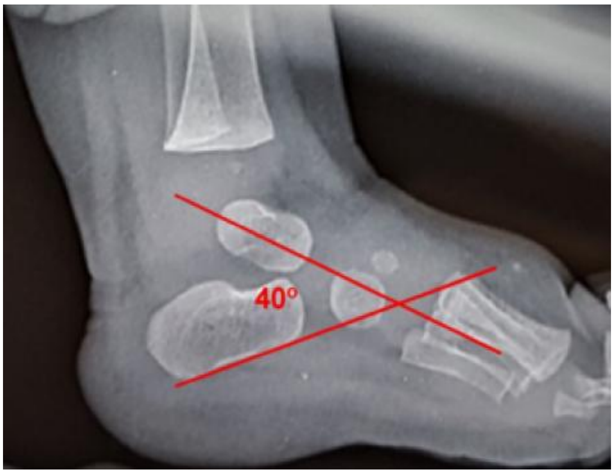

Figure 8: Lateral talo-calcaneal angle.

of the calcaneal bone, the subtalar joint is seen en face (no superimposition between both bones). This method is observational without using any line or angle and is not consistent.[7]

Assessment of the midfoot and forefoot in the sagittal plane for the plantar arch alignment. The plantar arch is the result of slight dorsiflexion of the anterior end of the calcaneum and plantar flexion of the metatarsals.[6] The assessment of this arch is done by three methods: First by drawing the lateral talo-first metatarsal (Meary's) angle is drawn between the longitudinal axis of the talus (mid-talar line) and the shaft of the first metatarsal (Fig. 9a).[15] In the normal foot, these lines are parallel and the angle is straight.[7] An angle greater than 8 degrees convex upward indicates a high arch foot (pes cavus) deformity. An angle greater than 4 degrees convex downward indicates a dropped plantar arch and flatten arch foot (pes planus, flatfoot) deformity.[6,7,15] Second by measuring the calcaneal inclination angle (calcaneal pitch) (as mentioned previously) (Fig. 7a). Third by measuring the Hibbs angle which is drawn between the longitudinal axes of the calcaneus and the first metatarsal bone (Fig. 9b).[7] This angle should be greater than 150 degrees in a normal foot. When it becomes

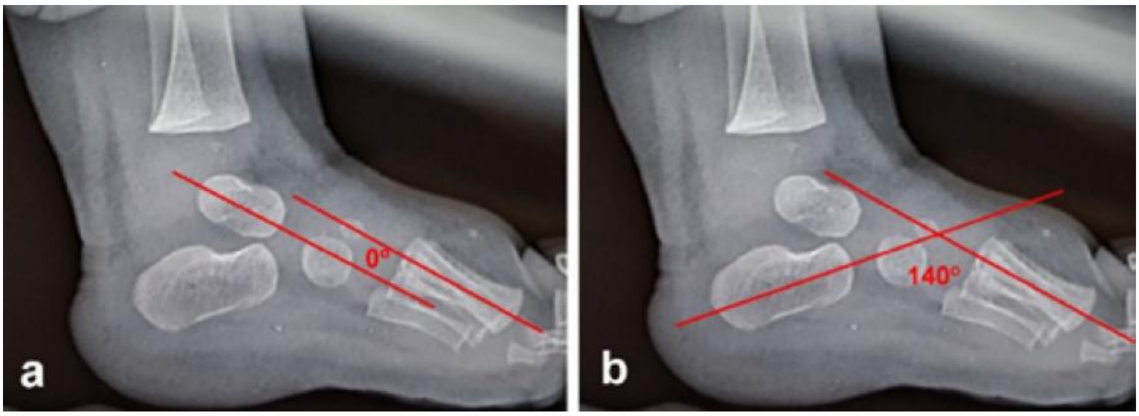

Figure 9: Assessment of the forefoot and midfoot in the sagittal plane for the plantar arch alignment: (a) lateral talo-first metatarsal (Meary's) angle, (b) calcaneo-first metatarsal (Hibbs).

less than this reference, it may suggest pes cavus deformity.[6,7]

Assessment of forefoot and midfoot for the rotational alignment. This is done by observing the overlap shadows of the metatarsals' shafts and drawing their axes. Normally there is an overlap of these bones on each other especially the central metatarsals, making it difficult to identify them separately other than the short first one and their axes converge distally (Fig. 10).[6] The ladder-like arrangement of these bones and their axes

Figure 10: Lateral metatarsal axes distal convergence

is considered an abnormal appearance and indicates rotation of the forefoot either into supination or pronation. When the forefoot has a supination posture, the first metatarsal shaft will be the highest and the fifth one will be the lowest. In reverse, when there is pronation, the first metatarsal becomes most plantar.[1,6]

DISCUSSION

The summary table of the results of this review can be used in the radiographic assessment of the alignment of different regions of the children's feet (Table 1). It makes the assessment process organized and systematic and can augment the clinical one.

There are more measurements available for assessment of the adult foot radiogram for deformities, but they are not applicable in the pediatric age group because the appearance of the ossification center of the small bone in children may make them not applicable, or the deformity does not occur in younger age.[18,22] Incomplete ossification of the bone combined with difficult positioning of the pediatric foot during radiography may limit the role of this diagnostic tool for the diagnosis of pediatric foot deformities. These limitations can be overcome by the proper drawing of certain lines and angles on the available ossification centers.

There is considerable variation between different authors about the value of these lines and angles in the assessment of alignment in the pediatric foot. Some of them questioned their value and found them less accurate due to the variation in their normal ranges between different references or when compared with the CT scan or MRI measures.[19,26] However, most authors agree that optimally exposed and well-positioned radiographs with well-drawn lines and angles can answer many questions. The quantified reproduction of their finding is essential for the diagnosis and evaluation of foot deformities and is reliable for surgical planning and postoperative follow-up.[26-31] The value increases when the static measures (lines and angles) are combined with dynamic ones, especially for the evaluation of flexible foot deformities.[32]

Limitations of the study

Assessment of risk of bias in the individual studies and across the studies was not applicable in this scoping review. No statistical analysis was applied in this review. This article discusses the basic principles of the current lines and angles with their normal values and ranges. The article didn't discuss the detail of the findings in each pediatric foot deformity. These details will be described in subsequen publications.

CONCLUSION

Drawing certain lines and angles with a systematic approach to assess different regions of the foot in the radiographic films of children can facilitate the process of assessment of the foot (as a whole) for deformities.

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