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The diagnostic dilemma of congenital foot deformity in pediatrics: could adding ultrasound be problem solving?

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Abstract

Background: Foot deformity is one of the most common congenital musculoskeletal anomalies in the pediatric age group. Accurate diagnosis can be sometimes impossible to be established clinically. In the assessment of foot abnormalities, radiology plays a crucial role. Lack of ossification of the tarsal bones renders plain radiographs of the foot as of little diagnostic value in this age group. MRI apart from its cost requires anesthesia and sedation. In contrast, ultrasonography allows for the imaging of cartilaginous structures. As a result, newborn foot abnormalities can be thoroughly assessed. The whole anatomy of the foot is evaluated using several scanning views. Additional planes may be needed to show the pathologic features of a specific deformity. The purpose of this study was to demonstrate the additive value of ultrasound to plain radiographs in the assessment of foot deformities in the pediatric age group.

Results: This case–control study was performed on sixty children, 30 of which were patients admitted from the pediatric orthopedic clinic, presenting with foot deformity, after being examined clinically. Antero-posterior and lateral radiographs of foot, tibiocalcaneal, antero-posterior talocalcaneal, and lateral talocalcaneal angles were measured. Sonographic examination was done in different projections of both feet, while the patient is lying supine with dynamic sonography. The sonographic parameters measured were as follows: medial malleolar–navicular distance and medial soft tissue thickness on medial projection, calcaneocuboid distance on lateral projection, talonavicular relation on dorsal projection, and tibiocalcaneal distance on posterior projection. There was a statistically significant difference between patients and controls in the medial malleolar–navicular distance and medial soft tissue thickness measured on the medial view, the calcaneocuboid distance recorded on the lateral view, and the tibiocalcaneal distance measured on the posterior view.

Conclusions: Ultrasonography has a growing and useful role as a complementary imaging modality in the evaluation and follow-up of pediatric patients with foot deformity.

Keywords: Ultrasonography, Plain X-ray foot, Radiology, Foot deformities, Pediatrics

Background

The most frequent congenital musculoskeletal problem in children is foot deformity. Clinically, it is not always easy to provide an accurate diagnosis. In the examination of musculoskeletal disorders, radiologic imaging is crucial [1].

It is usually characterized by a complicated improper alignment of the foot, including soft and bony elements, with hindfoot equinus and varus deformity (talipes equinovarus), as well as cavus and adduction in the midfoot and forefoot [2].

Congenital talipes equinovarus, often known as congenital clubfoot, is one of the most frequent foot deformities. Typically, this abnormality is solitary, more common

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in boys, and it is bilateral in up to 50% of cases. It has several anatomic components including lateral talus rotation in the ankle joint, medial calcaneus rotation, talar and calcaneal equinus, medial navicular subluxation, medial cuboid subluxation, and various soft tissue contractures [3].

Until recently, radiography was the only imaging option for evaluating foot abnormalities. However, this imaging modality has several disadvantages, such as the inability to image tarsal bones, erroneous angular measurements on plain radiographic examinations, due to the delayed appearance and eccentric position of the ossification centers, and radiation exposure risks [4].

Recently, ultrasonography has emerged as a viable imaging tool for musculoskeletal diseases due to its dynamic capabilities and observation of cartilaginous structures and soft tissues. In addition, the radiation-free nature of this modality allows its repeated use for monitoring therapy response [4].

In this study, we aimed at demonstrating the additive diagnostic value of ultrasound to plain radiographs in the assessment of foot deformities in the pediatric age group.

Methods

Study population

This case–control analytical study included sixty children, thirty of which were patients recruited from the orthopedics outpatient clinic and thirty controls, over a period of 11 months. We included pediatric patients with congenital foot deformities, and their ages ranged from 7 days to 10 years. We excluded patients with previous surgical interventions or previously treated deformities. We also excluded patients with spinal deformities affecting the foot. Thirteen of the thirty patients were females and seventeen were males. Half of the cases had bilateral foot deformity. Thirty control children with the same demographic criteria as the patients, whose foot radiographs were obtained at our department for other conditions non-related to foot deformity, were examined for comparison. This study was approved from the institutional review board. Written consent was obtained from their legal guardians prior to any radiological examinations.

Clinical assessment was performed using the Pirani scoring system. This system consists of the mid foot contracture score (medial crease, curved lateral border, lateral head of talus) and the hindfoot contracture score (posterior crease, empty heel, and rigid equinus), and each component may score 0 (normal), 0.5 (partially abnormal), or 1 (severely abnormal).

Plain X-ray radiograph was performed in three views: antero-posterior, lateral, and oblique. The following angles were measured on the workstation:

- Tibiocalcaneal angle, which is defined as the angle formed by a line drawn down the shaft of the tibia and a line drawn across the long axis of the calcaneus.
- Talocalcaneal angle (in AP and lateral views), which is defined as the angle formed by two lines running down the talus and calcaneus axes.

The ultrasound examination was conducted using a Samsung Ultrasound Machine (HS60) with a linear transducer probe (5–13 MHz) in four views. The patients were fed before the examination, in order to keep them as calm and relaxed as possible. The acquired views were as follows:

- Medial coronal view, where the U/S probe was placed on the medial aspect of the foot in a slightly oblique position.
  - This is similar to the antero-posterior view of the plain X-ray of the foot.
  - This process assesses the talonavicular relationship and the alignment of the medial column of the foot.
  - Measuring medial malleolus–navicular distance in neutral, plantar flexion, and dorsiflexion positions.
  - It shows the talar outline.
  - It measures medial soft tissue thickness.
- Lateral coronal view, where the U/S probe was placed along the lateral aspect of the foot. It is used for measuring the calcaneocuboid distance and evaluating the alignment of the bones of the lateral aspect of the foot, namely the calcaneus, the cuboid, and the fifth metatarsal.
- Dorsal sagittal view, where the U/S probe was positioned on the medial aspect of the dorsum of the foot along the first ray. It is similar to the lateral view of the plain X-ray of the foot and can identify the changes in the talonavicular relation in plantar flexion and dorsiflexion.
- Posterior sagittal view, where the U/S probe was positioned along the posterior aspect of the foot and ankle with its long axis parallel to the Achilles tendon. It allows measuring the tibiocalcaneal distance in neutral, plantar flexion, and dorsiflexion.
- All examinations were performed by one investigator with five years of experience in pediatric musculoskeletal imaging, under observation of a senior ultrasound investigator. Interobserver agreement was 95%.

Statistical analysis

The statistical package for the social sciences version 26 was used to code and enter the data (IBM Corp., Armonk, NY, USA). For quantitative variables, the mean, standard deviation, minimum, and maximum were used, while for categorical variables, frequencies (number of cases) and relative frequencies (percentages) were used. The unpaired t test was used to compare the groups. Statistical significance was defined as a *P* value of less than 0.05.

Results

In our study, a total of 60 children were examined with consisting of 30 patients with foot deformities and 30 controls. Patients consisted of 13 girls and 17 boys, with a mean age of 7.81 ± 26.6 months with an age range between 7 days and 10 years, as shown in Table 1.

Half of the patients had bilateral deformity. The left foot was affected in 42.3% of cases (19 feet), and the right side was affected in 57.7% of cases (26 feet). Out of our cases, 63.3% of them were diagnosed with club foot deformity, 33.3% were diagnosed with vertical talus, and 3.3% were diagnosed with tarsal coalition in Table 1.

Furthermore, there was a statistically significant difference in the tibiocalcaneal, lateral talocalcaneal, and antero-posterior talocalcaneal angles calculated from plain radiographs between patients and controls (Table 2, Fig. 1). The tibiocalcaneal angle was more on the affected side in some cases, while the lateral and AP talocalcaneal angle was decreased in other cases.

Foot examination by ultrasonography (medial view) showed that the medial malleolar–navicular (MMN) distance was significantly reduced and the medial soft tissue thickness was increased in patients compared to the controls (Fig. 2).

Furthermore, the lateral view revealed that the C–C distance was significantly increased in patients compared to the controls (Fig. 3).

The tibiocalcaneal distance in the neutral position measured on the posterior sagittal view, as well as in the plantar flexion and dorsiflexion positions, was found to be decreased compared to the controls (Table 3, Fig. 4).

Discussion

Foot deformity in infants is the most common congenital anomaly of the musculoskeletal system. Multi-parametric assessment is mandatory for proper diagnosis and subsequently adequate therapeutic procedures. The assessment includes both clinical examination and imaging modalities [4].

In the pediatric age group, the tarsal bones lack ossification, which limits the use of conventional radiographic techniques. US has emerged as a useful imaging modality

Table 1 Gender distribution of the patients, bilaterality, side, and diagnosis

	Count	%
Sex		
F	13	43.3%
M	17	56.7%
Bilaterality		
Bilateral	15	50.0%
Unilateral	15	50.0%
Side		
LT	19	42.3%
RT	26	57.7%
Diagnosis		
Club foot	19	63.3%
Tarsal coalition	1	3.3%
Vertical talus	10	33.3%

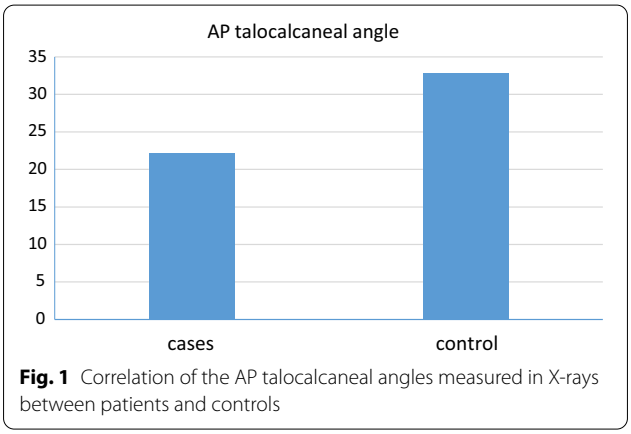

Fig. 1 Correlation of the AP talocalcaneal angles measured in X-rays between patients and controls

Table 2 Comparison of the radiographic parameters between cases and controls

X-ray	Cases				Control				*P* value
	Mean	SD	Minimum	Maximum	Mean	SD	Minimum	Maximum	
Tibiocalcaneal angle	101.30	12.05	72.50	130.00	80.57	6.55	70.00	90.00	< 0.001
Lat talocalcaneal angle	30.13	15.84	9.50	67.00	39.03	4.72	31.00	45.00	0.006
AP talocalcaneal angle	22.21	13.17	6.00	50.00	32.83	4.41	26.00	40.00	< 0.001

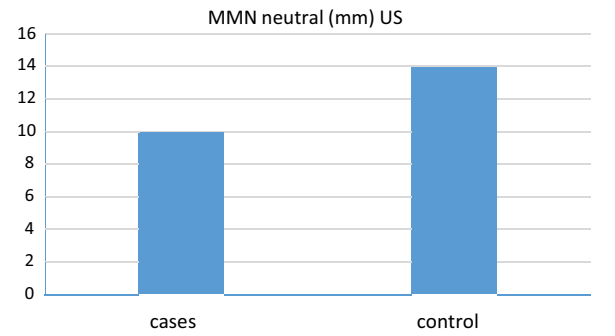

Fig. 2 Correlation of the medial malleolar–navicular distance (MMN) neutral measured by US between patients and controls

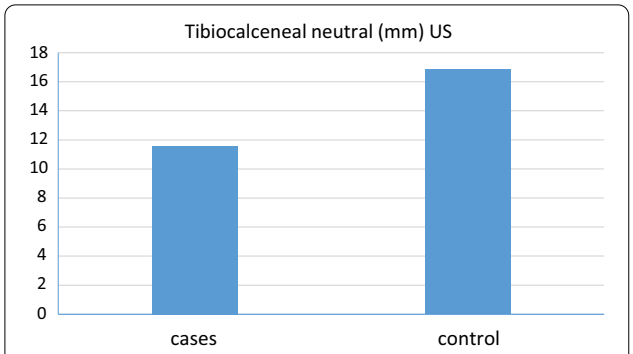

Fig. 4 Correlation of the tibiocalcaneal distance in the neutral position measured by US in patients and controls

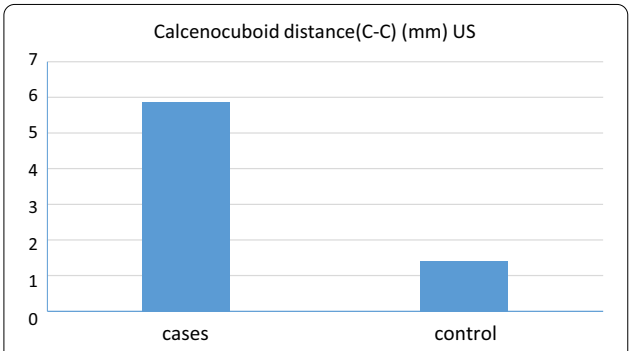

Fig. 3 Correlation of the calcaneocuboid distance (C–C) measured by US in patients and controls

for assessing foot deformities as it has the benefit of visualizing cartilaginous structures. Additionally, US can be repeated as much as we can in cases of correctable deformities, such as club foot, before and after cast application without radiation exposure. Also, US allows dynamic scanning of the foot in different planes [1].

This study was designed to compare the role of ultrasound and plain radiography in the evaluation of pediatric foot deformities and our findings reveal that both radiographic and sonographic parameters were significantly different between patients and controls.

In this study, thirty patients were recruited from the orthopedics outpatient clinic over a period of 11 months. The mean age of the enrolled patients was 7.81 ± 26.6 months with an age range between 7 days and 10 years. Thirteen of the thirty patients were females (56.7%), and seventeen were males (43.3%). Half of the patients were with bilateral deformity (50%). Twenty-six feet were right side (57.7%), and nineteen were left side (42.3%). Nineteen of the thirty patients diagnosed with club foot deformity (63.3%), and ten were diagnosed with vertical talus (33.3%) and only was diagnosed with tarsal coalition (3.3%).

Despite the fact that clubfoot is one of the most prevalent foot deformities, there is no commonly agreed approach for its conclusive assessment. The majority of clubfoot evaluations remain clinical; however, none of the recognized clinical classification systems have been completely satisfactory. As a result, there is a growing need for the development of an imaging tool that could

Table 3 Comparison of the sonographic parameters between cases and controls

US	Cases				Control				*P* value
	Mean	SD	Minimum	Maximum	Mean	SD	Minimum	Maximum	
MMN neutral (mm)	9.87	2.47	6.00	17.00	13.90	3.58	9.00	20.00	< 0.001
MMN planter flexion (mm)	12.73	3.77	4.00	22.00	15.57	3.20	11.00	21.00	0.003
MMN dorsiflexion (mm)	7.67	3.61	3.00	18.00	15.90	3.75	10.00	21.00	< 0.001
Medial soft tissue thickness (mm)	7.50	2.08	4.00	11.00	3.53	1.11	2.00	6.00	< 0.001
Calcaneocuboid distance (C–C) (mm)	5.87	1.66	3.00	9.00	1.40	1.13	0.00	3.00	< 0.001
Tibiocalcaneal neutral (mm)	11.57	4.45	5.00	21.00	16.83	3.18	12.00	22.00	< 0.001
Tibiocalcaneal planter flexion(mm)	9.60	3.75	4.00	20.00	14.00	3.04	10.00	19.00	< 0.001
Tibiocalcaneal dorsiflexion(mm)	13.23	4.69	6.00	22.00	18.57	2.60	14.00	22.00	< 0.001

Fig. 5 **a** A 2-month-old girl with right club foot. **b** Posterior sagittal view acquisition. **c** Medial coronal view acquisition. **d** Lateral coronal view acquisition. **e** Dorsal sagittal view acquisition

evaluate patients and monitor treating foot abnormalities in young infants.

Radiographic assessment

Radiographic views were easily obtained from all patients. However, in approximately one-third of patients, it was difficult to draw the long axis of talus and calcaneus due to small and round ossific nuclei. This difficulty has also been noted by Bhargava et al. [4] in their study. In contrast, Simons et al. [5] included only older patients with well-formed ossific centers, allowing adequate drawing of the talus and calcaneus axes. Simons et al. [5] had proposed the AP talocalcaneal angle and the lateral talocalcaneal angle as an indicator of varus and equinus, respectively.

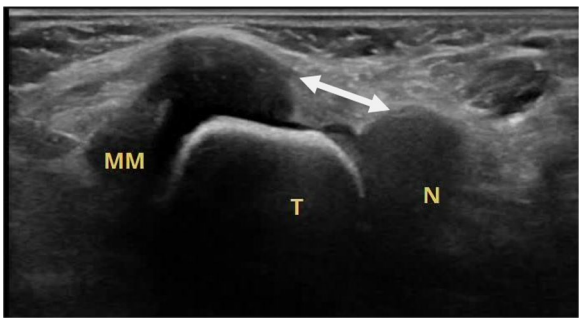

Fig. 6 Ultrasound scan dorsal sagittal view of the left foot for a 12-day-male newborn, presenting with club foot, which shows a decreased MMN distance in the neutral position

In our study, the AP talocalcaneal angle was significantly decreased in patients (22.21 ± 13.17 degrees) compared to the controls (32.83 ± 4.4 degrees) (*P* value < 0.0001). Also, the degree of angle reduction was proportionate to the degree of varus deformity. Our findings were consistent with the results of the study conducted by Simons et al. [5] who found a significant difference between cases and controls like our study. This goes also in line with Ippolito et al. [6] who found that the degree of angle correction can be used in the follow-up of the conservative treatment in patients with a club foot. In contrast, Bhargava et al. [4] reported that the AP T-C angle was the least informative and did not vary significantly between patients and controls.

The lateral talocalcaneal angle was significantly decreased in our cases (30.13 ± 15.84 degrees) compared to the controls (39.03 ± 4.72 degrees) (*P* value < 0.006). Bhargava et al. [4] reported similar values for these angles with *P* value: 0.003.

Furthermore, the tibiocalcaneal angle was significantly increased in patients compared to the controls (*P* value < 0.0001), with a mean value of 101.30 ± 12.05 degrees and 80.5 ± 6.5 degrees in patients and controls, respectively, which was in accordance to the results of the study conducted by Goyal et al. [7].

Sonographic assessment (as in Fig. 5)

A variety of sonographic images were used in our study. As a result, all aspects of the foot, including the medial,

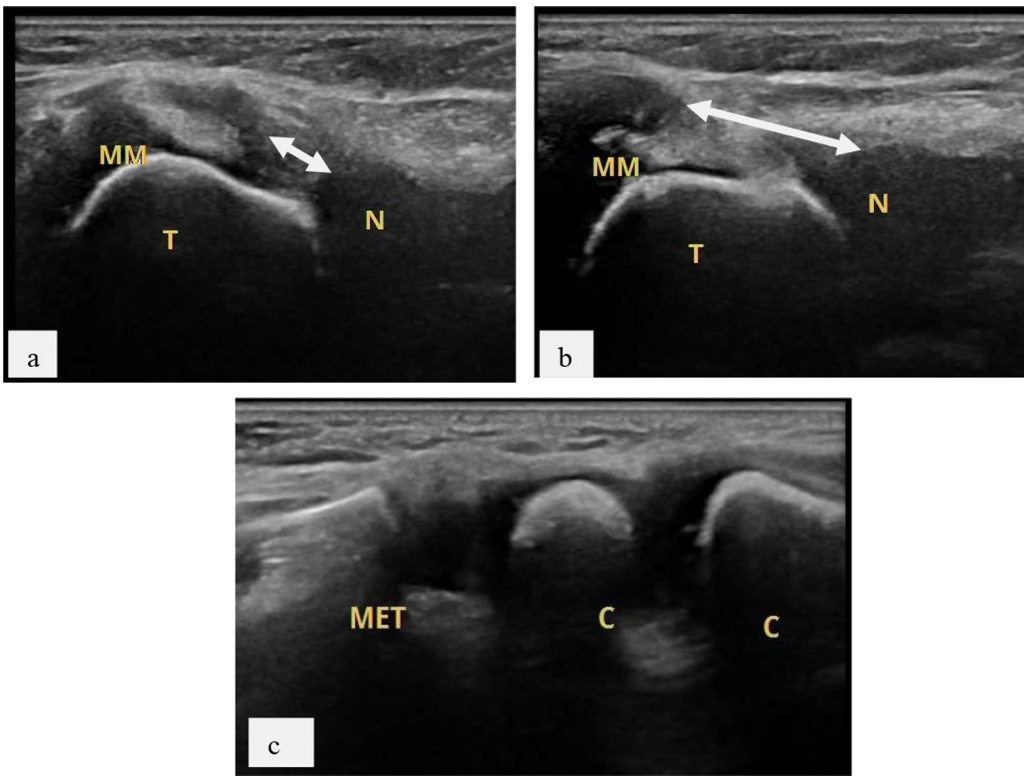

Fig. 7 Ultrasound scan dorsal sagittal view of left foot of another 12-day-male baby, presenting with club foot, showing **a** decreased MMN distance in dorsiflexion than neutral position. **b** Increased MMN distance in planter flexion. **c** Lateral coronal view of left foot showing angulation of the lateral column. (Met = Metatarsal bone, C = cuboid, C = calcaneus, respectively)

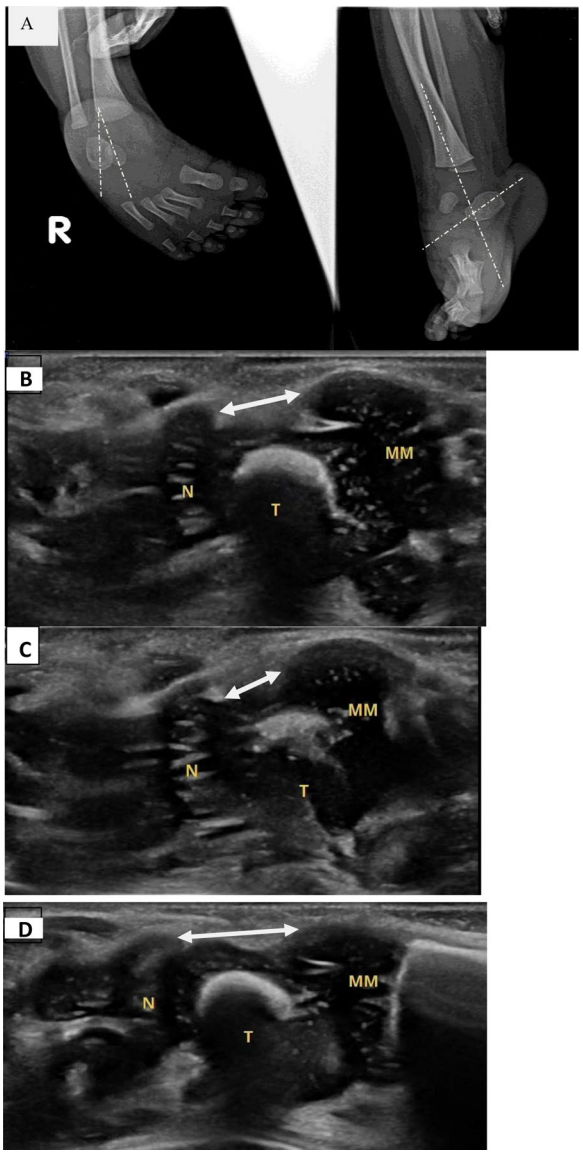

Fig. 8 **A** Plain X-ray foot for a 19-day-old male baby, diagnosed as right club foot, showing increased tibiocalcaneal angle measuring 100 degrees (in the lateral view, image to the right) and decreased talocalcaneal angle measuring 8.5 degrees (in the AP view, image to the left). **B–D** Ultrasound examination of the same patient showing: **B** MMN distance (the distance between the medial malleolus and the navicular) in neutral position (less than normal value). **C** MMN distance in dorsiflexion position (less than neural). **D** MMN in planter flexion (more than neutral)

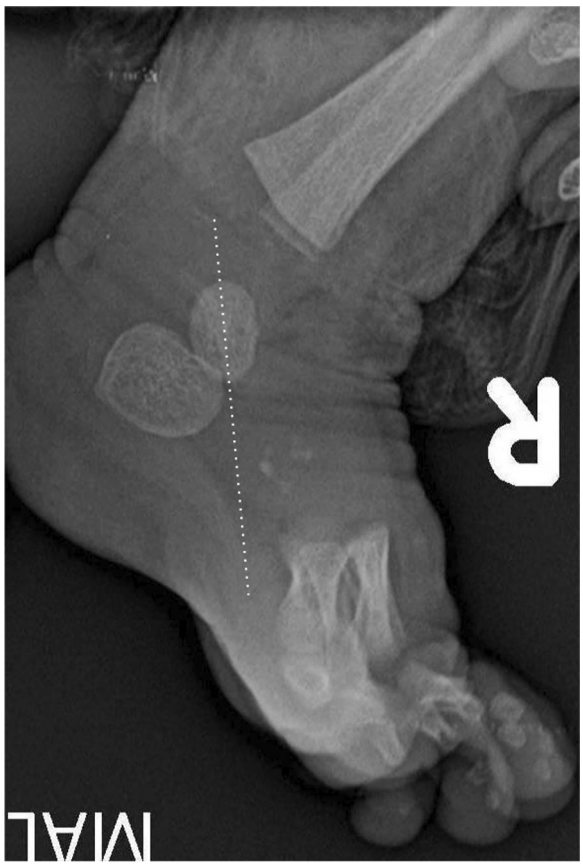

Fig. 9 Plain X-ray lateral view of 23-day-old male baby showing vertically oriented talus bone

lateral, dorsal, and posterior, were assessed. A dynamic examination of talonavicular movement was performed in addition to static views.

Regarding the medial view, the MMN distance was significantly shorter compared to the controls (*P* value < 0.001) in both neutral and dorsiflexion positions, as shown in Figs. 6, 7 and 8. The mean value for MMN in the neutral position was 9.8 ± 2.7 mm and 13.9 ± 3.5 mm in our cases and controls, respectively. The MMN distance is clinically relevant as an indicator of talonavicular malalignment, which is one of the most significant components of clubfoot. In our study, the lower the MMN distance, the greater the soft tissue thickness (*P* value < 0.001) with a concurrent increase in deformity grade. This finding is consistent with the studies conducted by Bhargava et al. [4], Shiels et al. [8], and Johansson et al. [9, 10], who reported that the MMN distance was 5.3 ± 2.8 mm in patients and 11.9 ± 2.6 mm in the controls. In contrast, our finding is inconsistent with the results published by Aurell et al. [11], who reported the MMN distance to be twice as much in patients compared to controls (mean value of 11.6 ± 2 mm in patients and 4.8 ± 1.2 mm in controls).

On the lateral view, the C–C distance was 5.87 ± 1.66 mm in patients and1.40 ± 1.1 mm in the controls, showing that this distance was significantly longer in patients (*P* value < 0.001) (Fig. 7). This finding is of great importance because it is difficult to detect this distance through clinical examinations and plain X-rays

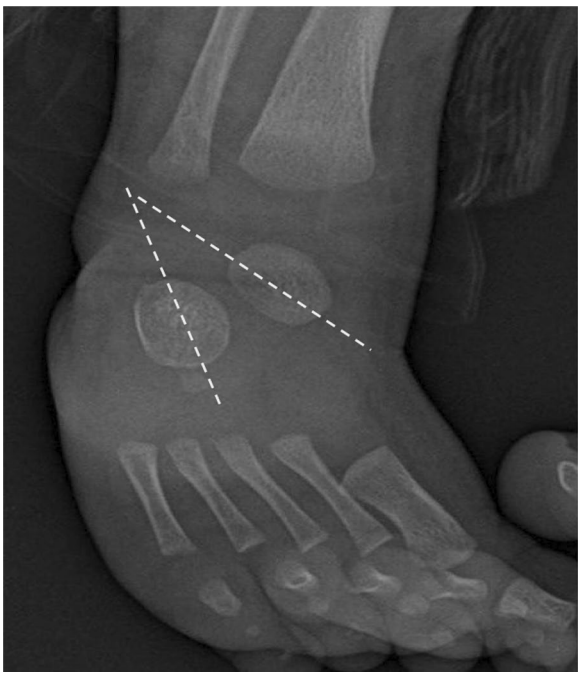

Fig. 10 Plain X-ray AP view of the of the left foot for a 23-day-old male baby, presenting with vertical talus, showing increased talocalcaneal angle

due to its latent ossification. Consequently, sonographic assessment can be significantly helpful in detecting the medial deviation of cuboid in early cases. However, it should be noted that our values are different from the ones reported by Bhargava et al. [4] and Aurell et al. [11], who reported mean C–C distances of 3.4 ± 2.0 mm and 2.5 ± 1.3 mm in patients, respectively, and 0.8 ± 1 mm and 1.0 ± 1.1 mm in the controls.

The posterior sagittal view was useful in evaluating the tibiocalcaneal relationship. The tibiocalcaneal distance (tcal distance) was a direct indicator of equinus. In our study, the tcal distance was reduced significantly in patients, especially in patients with increased severity of equinus deformity (P value < 0.001). More specifically, our findings revealed a mean tcal distance of 11.5 mm in neutral and 13.23 mm in maximum dorsiflexion in patients and 16.83 mm and 18.57 mm, respectively, in the controls. These results are close to the values found by Gigante et al. [12] with a mean tcal distance of 9 mm in neutral and 10.5 mm in maximum dorsiflexion in patients, and 10 mm and 20 mm, respectively, in the controls. These values were also reported by Chawla et al. [13], who found a tibiocalcaneal distance of 11.25 mm in their study group.

Contrary to the studies we included in this comparison, which focused solely on the club foot, our study had a wider scope as we included patients with tarsal coalition and vertical talus.

Ten of our cases were found to be vertical talus. Although plain radiographs (antero-posterior and lateral radiographs) suggested this diagnosis, this condition was confirmed by U/S.

Radiographs, as the ones shown in Figs. 9, 10, are useful to assess the talocalcaneal angle shown on the antero-posterior view of the foot, which was increased in all patients. The malalignment of the long axis of the talus and the first metatarsal leads to the assumption of navicular dislocation on the head of the talus.

Ultrasound has emerged as a useful diagnostic modality for cases of congenital vertical talus. In all our patients, we found dorsal dislocation of the navicular on the head of the talus, which does not decrease with plantar flexion as opposed to oblique talus (Fig. 11). Due to the fact that the navicular bones are not ossified, in mild cases, plain X-rays cannot confirm this condition, and thus, ultrasound is very useful in such cases. In contrast, severe cases are obvious to detect and confirm with different modalities.

Only one case with tarsal coalition was found in this study which showed a fibrous connection between the

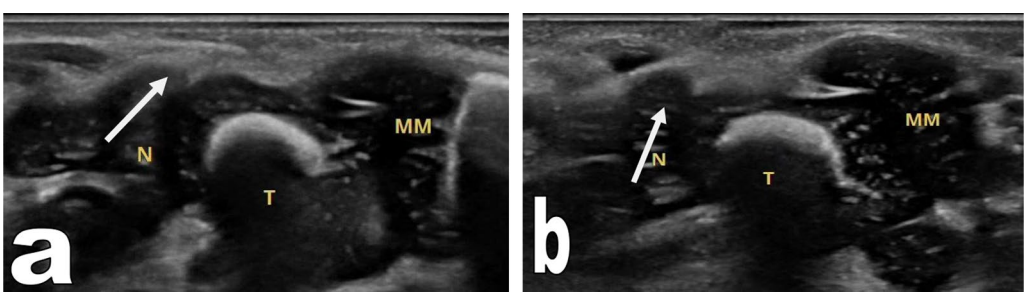

Fig. 11 Bilateral vertical talus in a 23-day-old boy. Dorsal sagittal view **a** in neutral position, a dorsal dislocation of the navicular on the head of the talus. **b** Irreducibility of the dorsal displacement of the navicular in maximal plantar flexion. (N = navicular bone, T = Talus bone, MM = Medial malleolus of tibia)

cuneiform bones that was not evident in plain X-rays, but was detected by ultrasound.

The main limitation of this study was that there were no reference values for the normal angles measured in different pediatric age groups. Also, we could not do follow-up for the patients, post-treatment, as we could not retain data or get back them for research purposes. Finally, in patients with rigid equinus, the dynamic examination was significantly painful, and thus, it was necessary to prolong the examination time in order to calm the patient down.

Conclusions

Sonography, as a non-ionizing imaging modality, has a significant potential for evaluating pediatric foot abnormalities. In cartilaginous areas that are not visible on X-rays, ultrasound is a superior technique. Individual component abnormalities can be predicted using a variety of sonographic views, and thus, it plays an important complementary role in the evaluation of pediatric foot deformities in conjunction with plain X-rays.

Abbreviations

AP: Antero-posterior; (C–C) distance: Calcaneocuboid distance; MMN: Medial malleolar–navicular distance; STT: Soft tissue thickness; T-C: Talocalcaneal; tcal: Tibiocalcaneal.

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We acknowledge all patients who were involved in the study.

Author contributions

SM and SF have designed this study together. AS and JW contributed to the data collection, and SM and JW contributed to data analysis. SF contributed to data processing. SM and SF shared together in writing the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

Data within the article or its supplementary materials are available upon reasonable request from the authors.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethical Research Committee of Faculty of Medicine Cairo University in Egypt. The ethics committee reference number is not available. A written consent was taken from the legal guardians of all patients accepting to participate in our research work.

Consent for publication

All patients included in this research gave written informed consent to publish the data contained within this study.

Competing interests

The authors declared that they have no conflicts of interest.

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