The Role of Ultrasound in Clubfoot Treatment

Correlation with the Pirani Score and Assessment of the Ponseti Method

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Abstract

Background To evaluate neonates and infants with clubfoot, clinical and imaging modalities are required. Conventional radiography is of limited value because the studied bones are not fully ossified.

Questions/purposes We attempted to (1) evaluate clinically and sonographically the reliability of the Ponseti method in correcting clubfeet; and (2) determine whether various ultrasound (US) variables correlated with each other and with the Pirani score before and after treatment. **Methods** We prospectively followed 17 infants (25 clubfeet) assessed using the Pirani score and US variables (medial malleolus navicular distance, navicular alignment in relation to the talar head, medial soft tissue thickness, talar length, and calcaneocuboid distance) and treated with the Ponseti method. The mean age of the patients at first casting was 30 days, and repeat assessment after treatment was performed at a mean age of 6.3 months. Patients were followed for a minimum of 0.75 months (mean, 14.1 months; range, 0.75–38 months).

Results The Ponseti method corrected all feet. We found three clinical/US correlations. Before treatment, we

observed a negative correlation between the clinical midfoot score and the sonographic medial malleolus navicular distance. After treatment we observed two negative correlations: one between the midfoot score and the sonographic talar length and the other between the hindfoot score and medial malleolus navicular distance. Four feet had recurrence of varus, two of which had an increased calcaneocuboid distance despite full restoration of navicular alignment in one foot.

Conclusions US can play a role in clubfoot assessment and may alert the surgeon to feet that may be prone to recurrence.

Level of Evidence Level II, prospective study. See Guidelines for Authors for a complete description of levels of evidence.

Introduction

Conventional radiography has been used for many years to assess clubfoot [30]. In the infant, its value is limited because major parts of the studied bones have not yet ossified [23]. Although the techniques are still evolving, US was used in many studies to assess clubfoot [3–6, 11, 13, 18, 20, 26, 27, 32, 34]. US allows observation of the cartilaginous components of the tarsal bones with relative ease and low cost. Despite the number of studies using this noninvasive modality, the techniques and measured variables are different from one study to another, and there is no standard way of performing the examination.

The Ponseti method of manipulation was first reported in 1963 [29]. Apparently it did not gain wide acceptability at the time, perhaps owing to the recurrence rate of 56% they reported, at an average followup of 2.5 years.

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research.

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Subsequently there was growing enthusiasm among the orthopaedic community to treat clubfeet surgically, perhaps thinking this could offer superior results. However, many complications were encountered with operative treatment such as forefoot adduction (range, 17%–81.1%), cavus (range, 5.9%–45.5%), overcorrection (range, 3.8%–22.2%), hindfoot equinus or varus (range, 7.2%–41.5%), and avascular necrosis of the talus (range, 3.2%–14.3%) [2, 25, 33]. Consequently, some centers around the world [1, 8, 12, 19, 21, 22] revived the Ponseti method with deformity correction being maintained short- and long-term. The importance of using postcasting abduction splints to maintain correction was stressed by Ponseti [28] and others [1, 8, 12, 19, 21, 22]. With this method, manipulation and casting can be completed within several months when patients present early, and the treatment is finished except for bracing. At this young age, reliable posttreatment radiographic evaluation is difficult and probably worthless although MRI or US can confirm clinical correction [9, 34]. However, imaging confirmation of restoration of normal talonavicular and calcaneocuboid relationships in clinically corrected feet has become increasingly important as spurious correction was reported with an incidence of 15.6% in one study [13, 20].

To quantify objectively the severity of clubfoot deformity before and after treatment, several clinical scoring systems have been used [7, 10, 14, 31], two of which combine clinical assessment with radiographic evaluation [7, 10]. The one system that has been used before, during, and after treatment on a wider scale than others is the Pirani score [12, 13, 15, 19, 21]. In addition to serving as a guide to treatment, this score has the advantage of being quick, reliable, and easy to memorize [15]. The validity of this clinical score could be reinforced if supplemented by sonographic assessment, before and after treatment, to confirm return of normal anatomic relationships between the different bones. In one study [5], numerous US variables were examined in clubfoot: the medial malleolus navicular distance; medial and sagittal displacement of the navicular in relation to the talar head; range of mobility of the talonavicular joint; thickness of the medial soft tissues; medial deviation of the talar neck; calcaneocuboid relationship; and length of the talus. Aurell et al. recommended use of US as a guide during nonoperative treatment and for preoperative planning; however, they did not correlate US with clinical variables [5].

Our purposes therefore were to (1) evaluate clinically and sonographically the reliability of the Ponseti method in correcting clubfeet; (2) determine whether a correlation exists between the different US variables; and (3) determine whether a correlation exists between these variables and the Pirani score before and after treatment.

Patients and Methods

Between January 2006 and November 2007, we prospectively followed 29 consecutive infants with 43 clubfeet. All were treated using the Ponseti technique by one surgeon (KLE), who performed all manipulations. The parents of 23 infants (33 feet) agreed to clinical and sonographic assessment of their babies' feet. The clinical or US data were incomplete in five patients (six feet), and one patient (two feet) died as a result of an unknown cause before completing the posttreatment assessment. Complete clinical and US records before and after treatment therefore were available for 17 infants (25 clubfeet). All patients had idiopathic clubfoot except for one patient with myelomeningocele, who had bilateral affection. This patient's response to manipulation and duration of casting was similar to those of the patients with idiopathic clubfeet, and therefore his data were included in our study. There were 12 male and five female infants (eight bilateral, nine unilateral), with ages ranging from 2 to 90 days with a mean of 30 ± 28 days at the time of application of the first cast. Sixteen patients (23 feet) were treated for the first time at our center and only one patient (two feet) was treated by strapping elsewhere for 1 month before presenting to us at the age of 2 months. Ethical committee approval was obtained for this study.

Using the six signs of the Pirani scoring system [31], the orthopaedic surgeon (KLE) graded the feet before the start of treatment, the mid- and hindfoot scores being considered separately, the former designated as MS and the latter as HS, with each score ranging from zero to three. Curvature of the lateral border of the foot, depth of the medial crease, and uncovering of the talar head laterally are the three signs related to the midfoot deformity, whereas those related to the hindfoot deformity are emptiness of the heel, depth of the posterior crease of the ankle, and rigidity of the equinus. The principle of the method of scoring is that each of the six signs score from 0 to 1, in which 0 = no abnormality, 0.5 = moderate abnormality, and 1 = severe abnormality.

Twenty-two feet in 15 infants were studied sonographically before the start of treatment. In the remaining three feet (two infants), US was performed between 9 and 12 days after the start of treatment and after removal of the first cast when only the cavus component of the deformity had been corrected. Collectively, the US examination was performed at a mean age of 27 ± 28 days (range, 1–88 days).

One radiologist (HTK) experienced in musculoskeletal US performed the scans with a Philips Envisor US machine (Philips Medical Systems, Bothell, WA) using a 6- to 10-MHz linear transducer (11 feet) and a Siemens Acuson X300 US machine (Siemens Medical Solutions, Mountain View, CA) using a 6- to 11-MHz linear transducer (the remainder of the studied feet). Both feet were examined, even in patients with unilateral clubfoot, for the sole purpose of

improving the sonographic technique. The infant was placed on the parent's lap without sedation although we ensured the infant was quiet while the examiner held the clubfoot in a maximally corrected position with one hand and the US probe by the other hand, occasionally with an assistant stabilizing the leg. Generally, the nonossified cartilage gave a poor echo (black), whereas the ossification center of a bone showed a bright (white) echogenic focus within a cartilage matrix. Each foot was examined through three standard scanning projections (medial, lateral, and dorsal), as described by Aurell et al. [5, 6].

The medial projection on the US simulates an AP radiograph of the ankle. The talonavicular (TN) articulation was assessed by placing the transducer on the medial side of the foot in a slightly oblique or vertical direction (ie, almost in line with the tibia to match the degree of equinus in patients with severe deformities). The medial and lateral malleoli and the navicular form the landmarks of this

projection, as in a normal foot. The medial malleolus navicular distance (MMN), which is the shortest distance between the medial malleolus and the medial proximal part of the navicular, was measured in millimeters using a cursor on the US monitor. It represents the maximally abducted position and indicates the severity of the deformity in the TN complex. Medial displacement of the navicular in relation to the head of the talus or medial navicular alignment (NAL m) was scored subjectively according to four grades in which 0 = no displacement, 1 = less than 50% medial navicular displacement, 2 = greater than 50% displacement, and 3 = complete navicular subluxation. This scheme is a modification of that described by Aurell et al. [5], who considered our Grades 2 and 3 as one grade. The medial soft tissue thickness (MSTT) was measured in millimeters. It represents the perpendicular distance from the skin surface to the medial border of the cartilaginous talus at the level of the talar ossification center (Fig. 1).

Fig. 1A–B (A) A pretreatment line drawing and (B) the corresponding medial projection of the right foot of a 25-day-old neonate show Grade III medial displacement of the navicular over the talar head (ie, complete subluxation), an MMN distance (yellow line) of 3.1 mm, and a 12.8-mm MSTT (blue line). The red line delineates the cartilaginous border of the different bones. MM = medial malleolus; LM = lateral malleolus; TA = talus; OC = ossification center; and N = navicular.

A

B

In the lateral projection, assessment of the calcaneocuboid articulation was performed by placing the transducer along the lateral border of the foot and parallel to its plantar aspect. The calcaneocuboid alignment was assessed by drawing a tangent along the lateral border of the calcaneus. The perpendicular distance from the tangent to the midpoint of the lateral cartilage border of the cuboid was measured in millimeters and termed the calcaneocuboid distance (CC) (Fig. 2).

The dorsal projection was obtained by placing the transducer on the dorsal aspect of the foot. In clubfeet, the transducer was placed more laterally than on a normal foot to follow the main direction of the talus. The position of the navicular in relation to the talar head in the sagittal plane was estimated visually as aligned, dorsally, or plantarly displaced. This was graded as a percentage of plantar displacement (NAL p) as in NAL m (vide supra). In no

case was there dorsal displacement of the navicular, and the length of the talus (TL) was measured in millimeters (Fig. 3).

Each projection was screened twice, and the clearer of the two images was used to measure each variable. All these measurements were made on the sonography monitor using the appropriate software with a reliability of 0.1 mm [3].

One orthopaedic surgeon (KLE) scored the feet clinically and one radiologist (HTK) made all sonographic measurements. Both were blinded to one another's assessment.

The treatment regimen followed the Ponseti principles [29]. The need for additional casting or Achilles tenotomy was dependent on clinical judgment with each cast change. Plaster casts were changed every 7 to 10 days. Tenotomy was performed when the MS was less than one and the

Fig. 2A–B (A) A pretreatment line drawing and (B) the corresponding lateral projection of the same patient as in Figure 1 show medial displacement of the cuboid of 2.1 mm relative to the calcaneus. The red line delineates the cartilaginous border of the different bones. The yellow line represents the tangent along the lateral border of the calcaneus, whereas the blue line represents the measured CC distance. CAL = calcaneus; OC = ossification center; CU = cuboid.

Fig. 3A–B (A) A pretreatment line drawing and (B) the corresponding dorsal projection of the same patient as in Figures 1 and 2 show a normally aligned navicular relative to the talus with no plantar displacement. The red line delineates the cartilaginous border of the different bones, and the yellow line represents a 13.8-mm talar length. TA = talus; OC = ossification center; N = navicular.

HS was greater than one [19]. Eleven patients (16 feet) required a tenotomy (64%) when the patients were at a mean age of 3.7 ± 2.3 months. The procedure was performed with the patient under general anesthesia within the first 3 months of life in six patients (eight feet); at the age of 3 to 6 months in three patients (five feet); and thereafter in the remaining two patients (three feet). The mean number of casts for the tenotomy and no tenotomy groups was four, including the tenotomy cast. If the patient did not require a tenotomy, the last cast was kept for 3 weeks, whereas those who had a tenotomy wore a cast postoperatively for 6 weeks. Thereafter, Denis Browne frames were used with plastic AFOs attached at 70° external rotation on the affected side and 45° on the normal side [22, 24]. The frame was worn for 23 hours per day for the first 3 months and thereafter only at night.

Patients were examined clinically every 3 months and parents were instructed to use the splint for at least 3 years.

Posttreatment Pirani scores were recorded at each visit and US scans were performed at a mean age of 6.3 ± 4.3 months. The patients were followed for a minimum of 0.75 months (mean, 14 months; range, 0.75 to 38 months) after removal of the last cast at a time when the patients' mean age was 18.6 ± 9.4 months. The final followup was only clinical, the aim of which was to detect early recurrences.

There was a wide variation in age of the patients at the time of the first casting (range, 2–90 days). Owing to the possibility that the feet might be more difficult to correct in older patients, we arbitrarily divided the 25 feet into two groups by age of the patients: Group 1 comprised 13 infants (18 feet), whose age at first casting was younger than 1 month (mean, 14 days) and Group 2 with four infants (seven feet) with an age older than 1 month (mean, 70 days; range, 60 to 90 days). The pretreatment means of all clinical and US measurements were similar, except for

the MS, which was larger ($t = 2.812$, $p = 0.01$) in Group 1 than in Group 2, reflecting more severe adduction deformity in the younger age group. We also divided patients into three classes according to their age at the second US (mean, 6.3 ± 4.3 months). The ages for patients in these classes were 0 to 3 months, > 3 to 6 months, and > 6 months. This wide variation in age had no effect on all the posttreatment variables using ANOVA.

To determine the reliability of the Ponseti method in correcting clubfeet, we determined differences between pretreatment and posttreatment mean values of US variables and the Pirani score using paired t-test. Bivariate correlations between different US variables, and between these and the Pirani score, before and after treatment were tested using Pearson's correlation coefficient. SPSS Version 11.5 for Windows XP (SPSS Inc, Chicago, IL) was used for statistical analysis.

Results

The Ponseti method corrected all clubfeet. After treatment, we observed the following: (1) a decrease in mean MS and HS; (2) an increase in mean MMN distance (Fig. 4) and talar length (Fig. 5); and (3) reduction of mean medial navicular subluxation (NAL m) (Fig. 4). The mean displacement of the CC joint also improved but to a lesser extent (Fig. 6; Table 1). When the tenotomy and no tenotomy groups were compared, there was no difference between the means of all clinical and sonographic variables.

Before treatment, we observed a negative correlation between the MMN distance and the (1) MSTT; (2) CC distance; (3) NAL m; and (4) MS (Table 2). Conversely, the MMN distance correlated positively with the talar length, and the degree of medial displacement of the

Fig. 4A–B (A) A posttreatment line drawing and (B) the corresponding medial projection of the same patient as in Figures 1 through 3, obtained when the patient was 18 months old show an almost normally aligned navicular relative to the talar head, a MMN distance (yellow line) of 15.4 mm, and a 12-mm MSTT (blue line). The red line delineates the cartilaginous border of the different bones. MM = medial malleolus; LM = lateral malleolus; TA = talus; N = navicular.

A

B

Fig. 5A–B (A) A posttreatment line drawing and (B) the corresponding dorsal projection of the same patient as in Figures 1 through 4 show a normally aligned navicular relative to the talus with no plantar displacement. TA = talus; N = navicular. The red line delineates the cartilaginous border of the different bones. The yellow line represents a talar length of 22.2 mm.

talonavicular joint (NAL m) correlated with displacement of the CC joint. Similarly, the latter two variables correlated with the MSTT, and the MS correlated with the HS. A positive correlation also existed between the MS (but not the HS) and the number of casts needed to correct the deformity, including the tenotomy cast.

When all the posttreatment variables were considered (Table 3), the MMN distance continued to show a negative correlation with medial displacement of the navicular. Even after clinical correction of the adduction deformity ($MS_2 = 0$ in 24 feet), the positive correlation between the talonavicular (NAL m_2) and CC displacements remained. We observed two negative correlations not apparent before treatment: one between MS_2 and TL_2 ($r = -0.456$; $p = 0.022$) and the second between HS_2 and MMN_2 distance ($r = -0.461$; $p = 0.020$). Age at first cast

application correlated positively with HS_2 ($r = 0.737$; $p = 0.000$), with the age at tenotomy having no bearing on the final correction of the hindfoot ($r = 0.186$; $p = 0.374$). When the pretreatment and posttreatment variables were examined (Table 4), we observed a positive correlation between the initial MSTT and the final NAL m. There was also a positive correlation between the CC distance before and after treatment, but not at the TN joint (NAL m versus NAL m_2). The plantar displacement of navicular before treatment also correlated with its corresponding figure after treatment.

Discussion

In neonates and infants, US has been used by numerous authors to assess clubfoot [4, 5, 13, 20, 26, 32]. However,

Fig. 6A–B (A) A posttreatment line drawing and (B) the corresponding lateral projection of the same patient as in Figures 1 through 5 show that the cuboid is normally aligned with the calcaneus. CAL = calcaneus; CU = cuboid. The red line delineates the cartilaginous border of the different bones. The yellow line represents the tangent along the lateral border of the calcaneus, whereas the blue line represents a CC distance of 0.3 mm.

A

B

there has been no consistency in the measured variables. Hamel and Becker [20] and Suda et al. [32] used angles, the validity of which was disputed by Aurell et al. [6] who [3–5] used distances, which we utilized in this study. Although Desai et al. [13] used a combination of an angle and a distance (vide infra). The advantage of using US is that it provides a convenient and relatively inexpensive imaging modality to supplement clinical scores and confirm return of normal TN and CC relationships [5]. The purposes of our study were to (1) evaluate clinically and sonographically the reliability of the Ponseti method in correcting clubfeet; and (2) determine whether a correlation exists between the different US variables; and (3) between these variables and the Pirani score before and after treatment.

The readers should be aware of several limitations of our study. First, we had a small number of patients. However we found some correlations with this small group. Second,

we were unable to assess the equinus deformity sonographically with the planes used. The value of US would be enhanced with use of a posterior projection [18, 32] to predict the need and possibly the timing of tenotomy. Third, we did not assess interobserver variability as we had only one senior radiologist with sufficient experience in musculoskeletal US for the readings. In a study on repeatability of sonographic measurements by Aurell et al. [3], intraobserver and interobserver assessments were acceptable for NAL m (0.82 and 0.70 mean kappa value, respectively). The mean interobserver difference for MMN distance was 0.42 ± 3.0 mm, and for MSTT it was 0.35 ± 2.0 mm. The mean intraobserver differences for MMN distance were 0.17 ± 1.6 mm for Observer 1 and 0.0 ± 0.94 mm for Observer 2. The corresponding values for MSTT were 0.10 ± 1.0 mm and 0.23 ± 1.1 mm, respectively. From the clinical viewpoint, Flynn et al. reported a correlation coefficient of 0.90 for the original

10-sign classification of Pirani et al. [16]. Fourth, we included one patient with myelomeningocele. Gerlach et al. [17] compared the early results of the Ponseti method in patients with myelomeningocele with those of patients with idiopathic clubfoot and found no differences between the two groups regarding initial correction with a similar mean number of casts in both.

Table 1. Difference between sonographic and clinical means pretreatment and posttreatment

Variable	Mean	SD	t	p Value
MMN	4.1	3.1	−7.11	< 0.001
MMN ₂	11	4.3		
MSTT	11.2	3.5	1.52	0.142
MSTT ₂	10	2.3		
TL	16	2.9	−5.49	< 0.001
TL ₂	20	2.8		
CC	1.4	0.8	2.56	0.017
CC ₂	0.9	0.9		
NAL m	2.2	1.1	8.61	< 0.001
NAL m ₂	0.2	0.6		
NAL p	0.2	0.4	1.81	0.083
NAL p ₂	0	0.2		
MS	1.8	0.8	11.78	< 0.001
MS ₂	0	0.1		
HS	2	0.7	10.47	< 0.001
HS ₂	0.2	0.4		

MMN = medial malleolus navicular distance; MSTT = medial soft tissue thickness; TL = talar length; CC = calcaneocuboid distance; NAL = navicular alignment in relation to the talar head (m = medial/p = plantar); MS = midfoot score; HS = hindfoot score; all measurements for MMN, MSTT, TL, and C are in millimeters; NAL is a percentage of displacement; ₂ indicates posttreatment values.

Based on the pretreatment and posttreatment Pirani scores and sonographic measures, the Ponseti method reliably corrected all foot deformities initially. Desai et al. [13], using the Pirani score and the sonographic MMN distance and talocuneiform angle, reported improvement in sonographic values using the Ponseti method in 27 of 32 feet. However, in five feet (15.6%) that initially were rigid and severely deformed in infants older than 6 weeks, they reported spurious correction, ie, with a break at the

Table 3. Posttreatment correlations between sonographic and clinical data

Variable	MMN ₂		NAL m ₂		MS ₂	
	r	p	r	p	r	p
TL ₂	0.316	0.124	−0.212	0.308	−0.456	0.022
CC ₂	−0.360	0.077	0.54	0.005	−0.005	0.980
NAL m ₂	−0.568	0.003	–	–	−0.084	0.691
HS ₂	−0.461	0.02	0.250	0.229	−0.115	0.585

₂ indicates posttreatment values; MMN = medial malleolus navicular distance, NAL m = medial navicular alignment in relation to the talar head, TL = talar length, CC = calcaneocuboid distance, MS = midfoot score, and HS = hindfoot score; the rest of the correlations included in Table 2 were all insignificant and were omitted for simplicity.

Table 4. Correlation between sonographic variables pretreatment and posttreatment

Variable	MSTT		CC		NAL m		NAL p	
	r	p	r	p	r	p	r	p
CC ₂	0.279	0.178	0.427	0.033	0.217	0.298	0.107	0.61
NAL m ₂	0.47	0.018	0.337	0.099	0.199	0.341	−0.179	0.392
NAL p ₂	0.256	0.217	−0.078	0.709	0.164	0.434	0.468	0.018

₂ indicates posttreatment values; MSTT = medial soft tissue thickness; CC = calcaneocuboid distance; NAL = navicular alignment in relation to the talar head (m = medial/p = plantar).

Table 2. Pretreatment correlations between sonographic and clinical data

Variable	MMN		MSTT		NAL m		MS	
	r	p	r	p	r	p	r	p
MSTT	−0.596	0.002	–	–	**	**	**	**
TL	0.418	0.038	−0.332	0.105	−0.389	0.055	−0.038	0.875
CC	−0.501	0.011	0.455	0.022	0.605	0.001	0.129	0.537
NAL m	−0.856	< 0.001	0.69	< 0.001	–	–	**	**
MS	−0.467	0.018	0.142	0.498	0.165	0.431	–	–
HS	−0.359	0.078	0.354	0.083	0.267	0.197	0.708	< 0.001

MMN = medial malleolus navicular distance, MSTT = medial soft tissue thickness, NAL m = medial navicular alignment in relation to the talar head, TL = talar length, CC = calcaneocuboid distance, MS = midfoot score, and HS = hindfoot score; ** values previously mentioned in the table.

naviculocuneiform joint, where the medial cuneiform shifts lateral to the navicular leaving the latter subluxated medially over the talus [20]. In our study, there were four such feet (16%), two of which had a severe deformity (initial Pirani score of 5.5). Their age at second US ranged from 3.75 to 9.5 months, all had an MS_2 of zero, $NAL m_2$ was Grade 1 in two feet, and Grade 2 in the other two, three with a CC_2 of 1.3 mm and one of 3.8 mm. Furthermore, four feet (in four patients) had recurrence of the varus deformity (one of which had spurious correction) in patients with ages ranging from 19 to 33 months at final followup. Of these four feet, two had mild deformity and required no additional treatment. The other two feet, with clinically more obvious deformity in the older two patients, were treated by recasting supplemented by Achilles tenotomy in one. Using the Ponseti method, it appears that substantial correction occurred at the TN and CC joints (Table 1). However, the persistence of a positive correlation between the pretreatment and posttreatment CC distances (Table 4) may imply that displacement of the CC joint is a more sensitive US variable for assessment of the adduction deformity. This is probably the result of the fact that it is measured in millimeters rather than in percentage as the subjectively scored TN displacement. The contribution of the malaligned CC joint to undercorrection and subsequent recurrence was described previously [33]. Aurell et al., in a study assessing treatment [4], concluded the CC distance is of limited use because of its small range. We question this conclusion as we found two feet with recurrence (not yet treated) with a posttreatment CC distance of 3.5 and 3.8 mm in patients with ages of 3 and 4 months, respectively. Both showed an MS_2 of 0, one with a fully restored navicular alignment and the other with spurious correction and Grade 2 displacement. Both initially were treated a few days after birth, and at a followup age of 20.25 and 19 months, respectively, recurrence was obvious. This suggests that the $NAL m$ and the CC distance may be important in the posttreatment evaluation, when they could warn the surgeon which feet are prone to recurrence.

The negative correlation between MMN distance and each of the MSTT, CC distance, $NAL m$, and MS before treatment suggests an interplay between the US variables and between MMN distance and clinical MS. The negative correlation between MMN distance and $NAL m$ was reported by Aurell et al. [5] (Fig. 7). They also found navicular displacement over the talar head greater than 50% was associated with an MMN distance less than 5 mm. This also was true in our patients before and after treatment. Furthermore, we found an interaction between the CC (CC distance) and TN joints ($NAL m$), and their contribution in causing the adduction deformity was seen

Fig. 7A–B (A) Pretreatment and (B) posttreatment plots show the medial malleolus navicular distance against medial navicular alignment over the talar head.

as a positive correlation between both variables before and after treatment (Fig. 8).

Three previous studies assessed US measures and clinical classifications. Suda et al. [32] and Aurell et al. [4] used the Dimeglio classification, whereas Desai et al. [13] used the six-point Pirani score, with the latter two studies looking at posttreatment results. However, there was no consistency in the measured US variables and none of the authors found clinical/US correlations. In contrast, we found three significant negative correlations. Before

A

B

Fig. 8A–B (A) Pretreatment and (B) posttreatment plots show CC displacement against medial navicular alignment.

treatment, one was seen between the MS and MMN distance (Fig. 9). We believe this justifies use of the Pirani score in assessment of the initial severity of the deformity. After treatment, two additional negative correlations were found, one between MS₂ and TL₂ (Fig. 10), ie, the presence of a residual adduction deformity hinders growth of the talus. The second was between HS₂ and MMN₂ distance (Fig. 11), ie, a residual equinus deformity is likely to be associated with a smaller MMN₂ distance (a residual adduction deformity) than if the hindfoot had been fully corrected. This proved correct for the tenotomy and no

Fig. 9 A plot is shown of the pretreatment midfoot score against the corresponding medial malleolus navicular distance.

Fig. 10 A plot is shown of the posttreatment midfoot score against the corresponding talar length.

tenotomy groups (one-tailed test, $p = 0.026$ and 0.027 , respectively).

Finally, we believe US can play an important role in assessing neonates and infants with clubfoot before and after treatment. Additional studies are needed to confirm if residual posttreatment US abnormalities are associated with future recurrences.

Fig. 11 A plot is shown of the posttreatment hindfoot score against the corresponding medial malleolus navicular distance.

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