

Range of motion in the talo-navicular and the calcaneo-cuboid joints evaluated by ultrasound during clubfoot treatment with normal references up to the age of four years

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Abstract

Purpose Previous ultrasound studies of clubfeet have mainly focused on the first year of life. The purpose of this study was to improve the evaluation of the talo-navicular and calcaneo-cuboid joints by adding new variables, evaluating the repeatability of ultrasound measurements for normal feet and clubfeet and establishing values for normal feet up to four years of age.

Methods A control group of 105 children divided into ten age groups, and 71 clubfeet in 46 children were examined. Four new variables were introduced: medial malleolus–Talar head–Navicular distance, medial tangent of the talus to the medial border of the navicular distance, the angle between the longitudinal axis of the talus and a line from the centre of the talar head to the medial corner of the navicular, the angle between the lateral borders of the calcaneus and the cuboid. The mobility in the talo-navicular and the calcaneo-cuboid joints was assessed by comparing measurements with the foot in adduction and abduction.

Results The variables could be assessed with fair to very good intra- and inter-observer repeatability (intraclass correlation coefficient > 0.8 and ≥ 0.6 , respectively), with a few exceptions. There was less movement in talo-navicular and calcaneo-cuboid joints in clubfeet than in controls.

Conclusion Morphology of normal feet and clubfeet, as well as mobility in the talo-navicular and calcaneo-cuboid joints, can be assessed by ultrasound with a fair to very good reliability from birth to the age of four years.

Level of Evidence: III

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Keywords: clubfoot; ultrasound; Ponseti treatment; congenital deformities; range of movement; repeatability

Background

Clubfoot is one of the most common congenital deformities, affecting one to two per 1000 live births in Europe and North America and up to five to six out of 1000 in Polynesia. Since the Ponseti method has been introduced, this non-operative treatment has become the treatment of choice and the need for complementary surgery has decreased dramatically.¹ By the Ponseti method, the varus, adductus and cavus deformities are simultaneously corrected only by manipulation and serial casting. Only a few per cent need complementary surgery.

It is well known that proper correction of the displacement in the talo-navicular joint and maintenance of the corrected position is important in the treatment of clubfeet even if entirely normalized anatomy cannot be expected. At long-term follow-up radiographic abnormalities are seen also in feet with good function.¹⁻³

With conventional radiology it is only possible to visualize the ossified parts of the child's skeleton. Since MRI and high-resolution ultrasound have become available in the last few decades, it has been possible to provide images of the cartilaginous parts of the skeleton and the surrounding soft tissues. Ultrasound is a radiation-free, reliable imaging modality suitable for evaluation of congenital foot deformities.⁴⁻⁷ Ultrasound evaluation has been demonstrated to show better correlation to the severity grading of clubfeet than radiographic measurements.⁸

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Ultrasound protocols and normal values for the first year of life have been published.⁹ The treatment of clubfeet continues at least to the age of four years. To the best of our knowledge normal values have not been established for the ages between one and four years.

Purpose

The main purposes of this study are:

- to improve the evaluation of the anatomy and the mobility in the talo-navicular joint and in the calcaneo-cuboid joint in normal feet and clubfeet by adding new variables;
- to evaluate the intra- and inter-observer repeatability of these variables by measurements on frozen ultrasound scanings of normal feet and clubfeet from the neonatal period to the age of four years;
- to extend the inter- and intra-observer evaluation of earlier used variables from birth to the age of four years for normal feet and clubfeet. Earlier ultrasound studies have mainly focused on children up to the age of one year;
- to establish normal values for the whole age span from birth to the age of four years for the new and earlier used variables.

The secondary purpose of the study was to compare the results of measurements on clubfeet in this limited clubfoot cohort in various degrees of correction with those of the controls.

Materials

The control group, 105 healthy children (45 boys and 60 girls), were recruited from the local Child Care Centre, Billingsens Vårdcentral, Skövde, Sweden and the Maternity Department, Skaraborg Hospital, Skövde, Sweden. Ten age groups (newborn, three, six, 12, 18, 24, 30, 36, 42 and 48 months of age) with a minimum of ten children in each group were recruited. The patients in the clubfoot group were all recruited from the Department of Orthopaedics, Sahlgrenska University Hospital/Östra, Gothenburg, Sweden and included all children who were under treatment for idiopathic clubfoot in 2007 and who had not reached four years of age. The clubfoot cohort included 46 children (33 boys and 13 girls) with 71 clubfeet (25 bilateral and 21 unilateral). All the clubfeet were in different phases of Ponseti treatment. The same age groups as for the controls were used, but the number of patients in the groups varied. At age correlated statistical calculations the limit for the groups was set to ± 2.6 months (Tables 1 and 2).

Table 1. Number of feet included per age group

Age (mths)	0	3	6	12	18	24	30	36	42	48	Total
Controls	20	26	20	20	22	22	20	20	20	20	210
Clubfeet	0	2	12	3	8	8	12	5	6	13	69
Normal*	0	2	2	1	2	2	4	1	4	3	21

One nine-month-old child with bilateral clubfeet is not included in this table

* in unilateral cases

Table 2. Number of examinations measured

Measurement	1 (Interpreter A.J.)	2 (Interpreter A.J.)	3 (Interpreter Y.A.)
Controls	210	60	66
Clubfeet	71	36	71
Normal*	21	0	21

When the comparative statistical calculations were done the limit for the age groups was set to ± 2.6 months, hence one nine-month-old child with bilateral clubfeet and three children (six clubfeet) in the 48-month group who had passed the age limit $48 + 2.6$ months were excluded in the statistical tests, but in the intra- and inter-observer calculations they were included. See statistics and discussion.

* in unilateral cases

Method

The children were sitting on a parent's lap during the ultrasound examination. The child's foot was held by the orthopaedic surgeon (A.J.) in three different positions (neutral, maximal adduction and maximal abduction) during the medial and lateral coronal scanings (Figs 1a and 1b). During the dorsal sagittal scanning the foot was held in slight plantar flexion (Fig. 1c). For each position one to three frozen ultrasound images were saved and the images of best quality were analyzed.

The examinations were performed with a high-frequency linear transducer 8 to 15 and 5 to 17 (HD) MHz with an Acuson Sequoia (Acuson, Mountain View, California) ultrasound machine.

All images were stored in the same regional radiological archive and were measured using the picture archiving and communication system software (Centricity PACS, GE Healthcare Integrated IT Solutions, Barrington, Illinois and SECTRA PACS, Linköping Sweden).

The control group as well as the children with clubfeet were examined once by one of three experienced ultrasonography examiners: Stina-Britta Haux, Gudmundur Einarsson and Karin Steneryd.

Projections

The three standard projections of the midfoot evaluated and described in previous published papers were used⁹⁻¹¹ (Fig. 1). The examinations of the medial and lateral coronal projections were performed with the foot in neutral, adducted and abducted position. At least one image of each position was saved. If more than one image was available, the measurements were performed on the best quality image. The dorsal projection was performed only

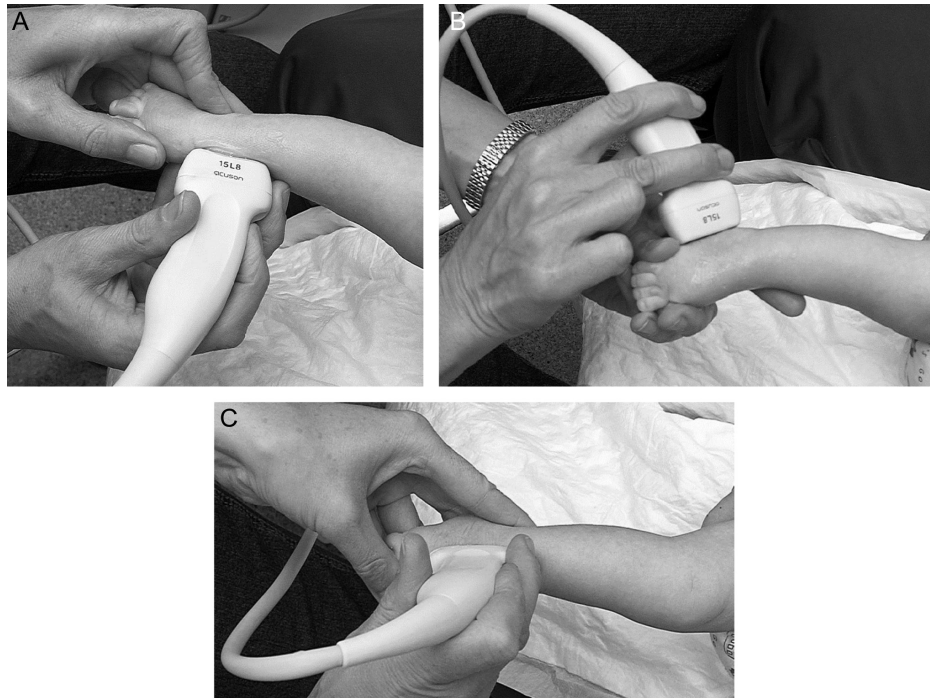


Fig. 1 Transducer position: (a) medial coronal projection; (b) lateral coronal projection; (c) dorsal sagittal projection.

with the foot in neutral ab- and adduction and slight plantar flexed position.

Repeatability of measurement on the ultrasound images

To evaluate the intra-observer repeatability of the measurements, 60 feet in 30 controls were chosen to represent different ages (three, six, 12 and 48 months) and 36 clubfeet (age six, 18, 24 and 48 months) were measured at two different times at more than one month's interval by one of the authors (A.J.).

The inter-observer repeatability of the measurements for the extended age span for the earlier used variables and the new variables were evaluated. This was done by measuring all variables independently by two of the authors (A.J. and Y.A.) on all 71 clubfeet (46 children) and 66 feet (33 children) of the controls chosen to represent different ages, three, six, 12 and 48 months.

Measurements at the medial coronal projection

The earlier established variables, validated for the first year of life, were used and the repeatability for these variables was extended to the age of four years:

1. Medial malleolus – navicular (MM – N) distance (Figs 2 and 3a).
2. Soft-tissue thickness (STT) (Fig. 2b).
3. Visual semi quantitative grading of the medial displacement of the navicular (normal, subluxated and luxated).⁹⁻¹¹

The foot skeleton and especially the deformities in clubfeet are complex 3D structures which cannot be fully described by the previously used variables. Therefore, new variables were added in order to improve the evaluation of the anatomy. The variables 4 to 6 described below were added in order to measure the medial dislocation of the navicular quantitatively.

4. Medial malleolus – Talar head – Navicular distance (MM – T – N): during the first phase of the treatment, when the navicular moves away from the medial malleolus the MM-N accurately measures the improvement (Figs 2 and 3a). But when the navicular turns around the talar head into abduction the MM-N does not measure the real distance which the navicular has moved. Therefore, an approximation was done by measuring the distance from the medial malleolus to the most medial part of the talar head and the distance from there to the navicular was added (MM – T – N) (Fig. 3b). This variable was used as a complement to the MM – N distance when the medial corner or the navicular was substantially lateral in relation to the medial side of the talus.
5. The perpendicular distance from the medial tangent of the talus to the medial border of the navicular (T-Tang – N) (Fig. 4).

This variable was added to improve the evaluation of the medial-lateral position of the navicular and the medial-lateral movement of the navicular in relation to the talar

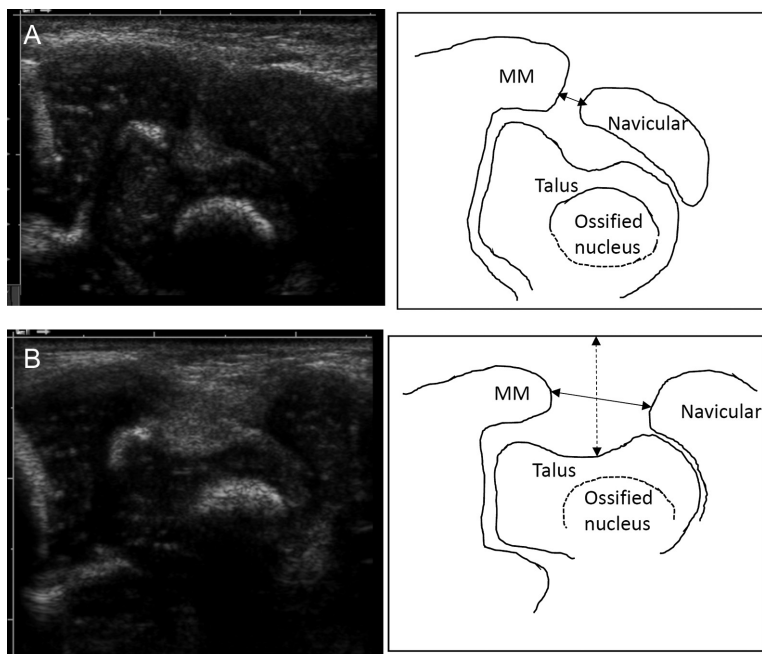


Fig. 2 The right foot in neutral position in a one-month-old girl with bilateral clubfeet after four weeks of serial castings (a). The same foot as in (a) in abducted position (Ponseti manipulation) (b) (unbroken double arrow, medial malleolus – navicular (MM – N) distance; dashed double arrow, soft-tissue thickness (STT)).

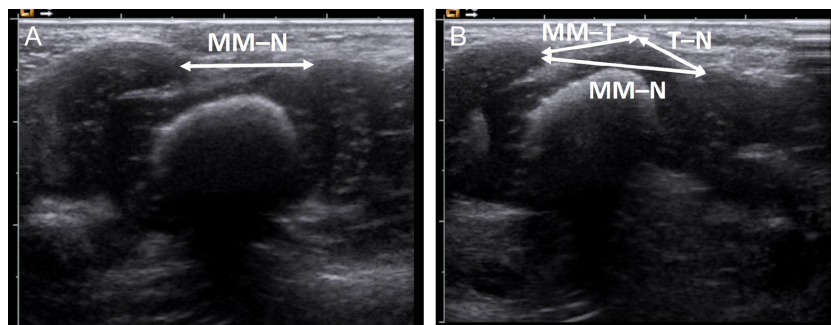


Fig. 3 Normal foot in a three-month-old girl: (a) in neutral position (MM – N, medial malleolus – navicular distance); (b) in abducted position (MM – T, medial malleolus – medial aspect of the talus distance; T – N, medial aspect of the talus – navicular distance). The sum of MM – T and T – N = MM – T – N.

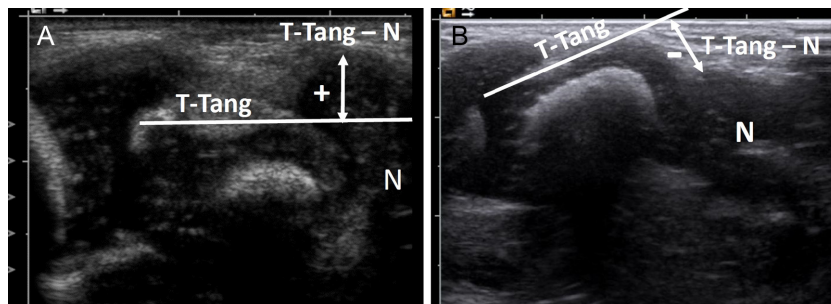


Fig. 4 Clubfoot during early treatment, the medial border of the navicular is medial to the tangent (a) and normal foot in abduction, the medial border of the navicular is lateral to the tangent (b). (T – Tang – N, the perpendicular distance from the medial tangent of the talus to the medial border of the navicular). When the medial border of the navicular is medial to the tangent (a) the values are positive (+) and when it is lateral to the tangent (b) the values are negative (-) (N, navicular bone).

head when the foot is adducted and abducted. The values were defined as positive (+) when the medial border of the navicular was medial to the talar tangent and negative (-) when it was lateral to the tangent.

6. The angle between the longitudinal axis of the talus and a line drawn from the medial corner of the navicular to the centre of the talar head (T – N angle) (Fig. 5). It reflects the medial-proximal dislocation of the navicular in clubfeet and the relationship between the navicular and the spherical head of the talus.
7. The range of movement (ROM) in the talo-navicular joint in the coronal plane was defined as the difference between T – N angle in maximally adducted and maximally abducted position of the foot (Figs 5b and 5c).
8. The length of the talus was measured in both neutral,

adducted and abducted positions in order to evaluate which position is most suitable for measurements of this variable and to compare with the earlier used measurements on the dorsal projection.

Measurement at the lateral coronal projection

1. The earlier used and validated variable C – C distance (the perpendicular distance from the lateral tangent of the calcaneus to the middle of the lateral border of the cuboid) was measured⁹⁻¹¹ (Fig. 6a). The values were defined as positive (+) when the lateral border of the cuboid was medial to the lateral tangent of the calcaneus and negative (-) if the lateral border of the cuboid was lateral to the calcaneal tangent (as the T –

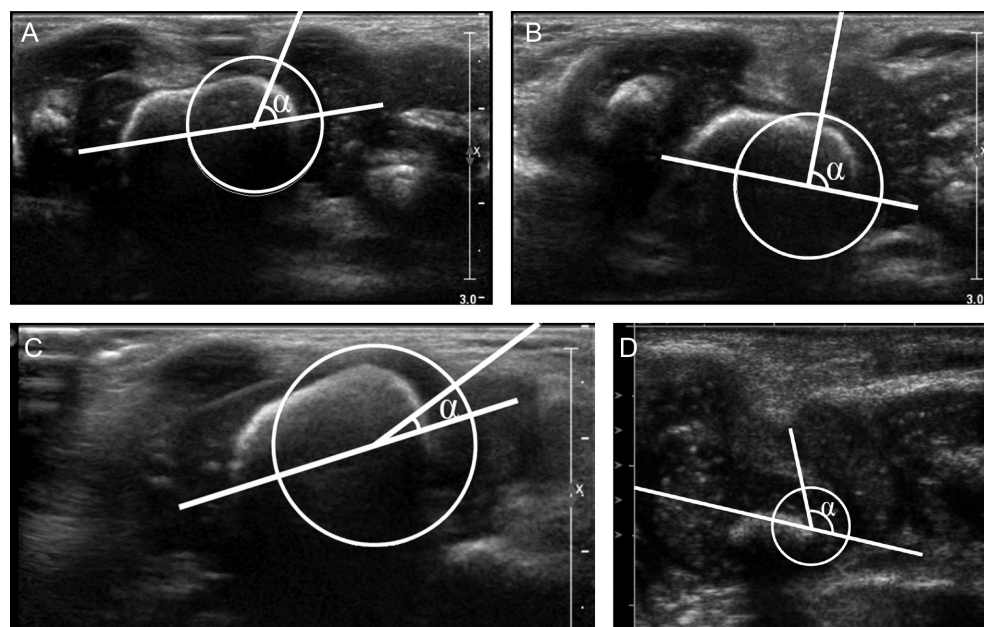


Fig. 5 Normal foot in a one-year-old boy in neutral position (a) (T – N angle (α), the angle between the longitudinal axis of talus and a line from the centre of the talar head to the medial border of the navicular bone). The same foot as in (a) in adducted position (b). The same foot as in (a and b) in abducted position (c). T – N angle (α) in an untreated clubfoot in a five-day-old girl (d).

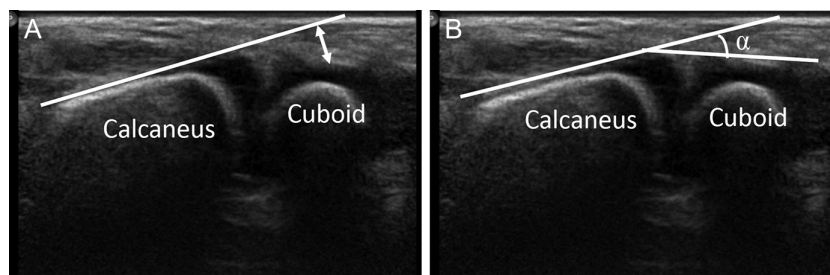


Fig. 6 Lateral coronal projection of a normal foot in neutral position in an 11-month-old girl: (a) calcaneo-cuboid (C – C) distance (double arrow) The values were defined as positive (+) when the lateral border of the cuboid was medial to the lateral tangent of the calcaneus and negative (-) if the lateral border of the cuboid was lateral to the tangent of calcaneus; (b) C – C angle (α). The values were defined as positive (+) when the angle was medially open and negative (-) when the angle was laterally open.

- Tang – N on the medial side).
- The angle between the tangents of the lateral borders of the calcaneus and the cuboid (C – C angle) was measured (Fig. 6b). The values were defined as positive (+) when the angle was medially open and negative (-) when the angle was laterally open.
 - The ROM in the calcaneo-cuboid joint was defined as the difference between C – C angle with the foot in ad- and abducted position, when the angle in abducted position is negative the result is the sum of the angles (- - = +).
 - The alignment in the calcaneo-cuboid joint was evaluated. If the lateral surfaces of the calcaneus and cuboid were not at the same level at the calcaneo-cuboid joint, it was classified as a lateral step (Fig. 7).

Measurement at the dorsal sagittal projection

- The length of the talus was measured (Fig. 8).
- The position of the navicular was evaluated as normal, dorsally or plantarly displaced in relation to the head of the talus.

Clinical variables

Foot length, passive plantar flexion and dorsiflexion in the ankle joint, varus, valgus and adductus deformities were registered.

Statistical analysis

The Mann-Witney U Test was used for the statistical calculations. The diagrams and calculations were done using IBM SPSS Statistics 22 (IBM Corp., Armonk, New York). Intra-class correlation coefficient (ICC) was used for the calculation of intra-observer and inter-observer reliability. In the comparative statistical analyses stratified by age, the limit was set to ± 2.6 months, therefore one nine-month-old child (two clubfeet) and three children (six clubfeet) who had passed the age of $48 + 2.6$ months were excluded.

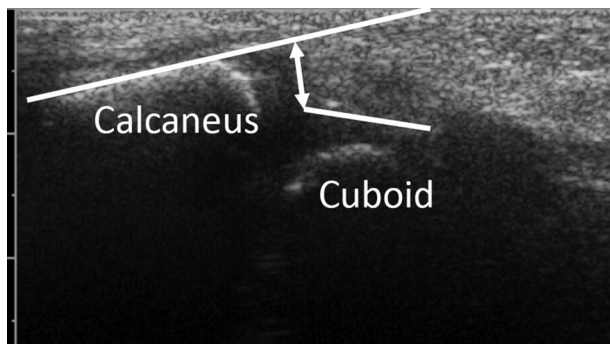


Fig. 7 Lateral coronal projection of a clubfoot in a three-month-old girl. The cuboid is medially positioned related to the calcaneus, resulting in a lateral step (double-ended arrow).

Results

Repeatability

The intra-observer agreement was calculated for totally 20 variables in the controls and 18 variables in the clubfeet, including measurements in different foot positions. In the controls MM – T – N was applicable in a few feet in neutral position and in clubfeet it was applicable only in abducted position in four of the feet measured twice. Because of image limitation on the dorsal projection the length of the talus could be measured only in five clubfeet. Therefore, ICC was not calculated for these variables.

The intra-observer agreement measured by ICC was > 0.8 for all calculated variables except for T – N angle in neutral position (0.75) and T – N angle in adducted position (0.71) in the control group and T – N angle in adducted position (0.58) and C – C distance in neutral position (0.75) in clubfeet. Details with 95% confidence intervals are presented in Table 3.

The inter-observer agreement was calculated for 20 variables in the controls and 19 variables in the clubfeet, including measurements in different foot positions. In the clubfeet the MM – T – N in neutral position was applicable in five feet, and because of image limitation the length of the talus could be measured only in eight, therefore ICC was not calculated for these two variables.

The inter-observer agreement was ≥ 0.6 ICC for all variables except C – C distance in abduction (0.58) in the control group, T – N angle adducted (0.59), C – C angle neutral (0.59) and C – C angle adducted (0.45) in the clubfoot group (Table 3).

In the intra- and inter-observer assessment the Kappa coefficient for lateral step and visual assessment of the navicular position were not calculated because of too few observations in one of the outcome categories.

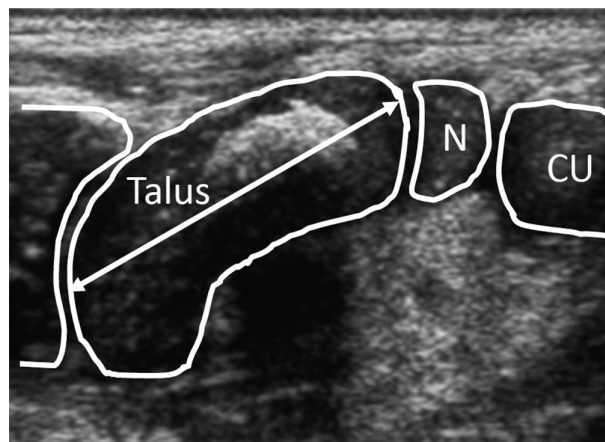


Fig. 8 Dorsal sagittal projection (N, navicular bone; CU, cuboid bone; double-ended arrow, length of the talus).

Table 3. Intra- and inter-observer reliability measured by intraclass correlation coefficient (ICC)

ProjectionVariable	Position of foot	n	Intra-observer						Inter-observer					
			Controls			Clubfeet			Controls			Clubfeet		
			ICC	95% CI	n	ICC	95% CI	n	ICC	95% CI	n	ICC	95% CI	
Medial STT	Neutral	57	0.95	0.92 to 0.97	34	0.82	0.68 to 0.91	64	0.85	0.77 to 0.91	65	0.96	0.94 to 0.98	
Medial MMN	Neutral	57	0.98	0.97 to 0.99	35	0.96	0.92 to 0.98	64	0.97	0.95 to 0.98	66	0.94	0.91 to 0.96	
Medial MMN	Adducted	54	0.97	0.95 to 0.98	29	0.96	0.91 to 0.98	51	0.88	0.79 to 0.93	61	0.87	0.80 to 0.92	
Medial MMN	Abducted	53	0.99	0.98 to 1.00	35	0.99	0.98 to 0.99	57	0.98	0.97 to 0.99	64	0.95	0.92 to 0.97	
Medial MM – T – N	Abducted	47	0.97	0.95 to 0.99	4	≠		55	0.95	0.92 to 0.97	17	0.85	0.63 to 0.94	
Medial T – Tang – N	Neutral	57	0.92	0.87 to 0.96	33	0.95	0.91 to 0.98	64	0.71	0.56 to 0.81	69	0.88	0.81 to 0.92	
Medial T – Tang – N	Adducted	55	0.95	0.91 to 0.97	29	0.88	0.76 to 0.94	58	0.68	0.51 to 0.79	64	0.67	0.51 to 0.79	
Medial T – Tang – N	Abducted	52	0.87	0.79 to 0.92	35	0.94	0.89 to 0.97	59	0.75	0.62 to 0.84	67	0.94	0.91 to 0.96	
Medial T – N angle	Neutral	55	0.75	0.61 to 0.85	31	0.91	0.83 to 0.96	64	0.86	0.77 to 0.91	69	0.84	0.76 to 0.90	
Medial T – N angle	Adducted	47	0.71	0.54 to 0.83	22	0.58	0.22 to 0.80	50	0.75	0.60 to 0.85	62	0.59	0.40 to 0.73	
Medial T – N angle	Abducted	51	0.86	0.77 to 0.92	34	0.93	0.87 to 0.96	58	0.79	0.66 to 0.87	66	0.90	0.84 to 0.94	
Medial Talar length	Neutral	39	0.99	0.98 to 1.00	17	0.99	0.98 to 1.00	45	0.97	0.95 to 0.98	35	0.87	0.77 to 0.93	
Medial Talar length	Abducted	29	0.99	0.98 to 1.00	11	0.99	0.97 to 1.00	37	0.99	0.98 to 0.99	25	0.76	0.53 to 0.89	
Dorsal Talar length	Neutral	32	0.99	0.98 to 0.99	5	≠		33	0.85	0.72 to 0.93	8	≠		
Lateral C – C dist.	Neutral	55	0.89	0.83 to 0.94	34	0.75	0.56 to 0.87	64	0.86	0.78 to 0.91	64	0.76	0.63 to 0.85	
Lateral C – C dist.	Adducted	48	0.92	0.86 to 0.95	28	0.88	0.77 to 0.94	56	0.90	0.84 to 0.94	56	0.73	0.58 to 0.83	
Lateral C – C dist.	Abducted	52	0.89	0.82 to 0.94	30	0.89	0.77 to 0.94	62	0.58	0.39 to 0.73	55	0.87	0.79 to 0.92	
Lateral C – C angle	Neutral	55	0.94	0.90 to 0.96	32	0.93	0.86 to 0.96	64	0.69	0.53 to 0.80	63	0.59	0.40 to 0.73	
Lateral C – C angle	Adducted	49	0.88	0.80 to 0.93	28	0.93	0.85 to 0.97	57	0.80	0.68 to 0.88	55	0.45	0.22 to 0.64	
Lateral C – C angle	Abducted	52	0.94	0.90 to 0.96	26	0.85	0.70 to 0.93	61	0.60	0.42 to 0.74	55	0.70	0.53 to 0.81	

Measurements may be missing because the variable is not applicable on all feet, the child did not cooperate to get a complete investigation or the image quality was insufficient.

n, number of valid measurements of the variable; CI, confidence interval; STT, soft-tissue thickness; MM – N, medial malleolus – navicular distance; MM – T – N, medial malleolus – talar head – navicular distance; T – Tang – N, distance from the medial tangent of the talus to the medial corner of the navicular bone; T – N angle, talo – navicular angle; C – C dist., calcaneo-cuboid distance; C – C angle, calcaneo-cuboid angle; ≠, not calculated because of insufficient observations

Normal values

The results of the measurements on the controls are presented in Tables 4 and 5.

Medial projection: STT

The medial STTs were statistically significantly ($p < 0.05$) thicker in the clubfeet than in the controls in all age groups.

Medial projection: MM – N distance

The mean MM – N-distance tended to be or was significantly shorter in clubfeet than in normal feet both in neutral, adducted and abducted position in all age groups, except in adducted position in the three months age group.

Medial projection: medial displacement of the navicular (visual semi quantitative grading)

In the clubfoot cohort the navicular was assessed as luxated in one, subluxated in eight and normal in 61 feet (data missing for one). In the control group all were assessed as normal.

Medial projection: MM – T – N distance

The MM – T – N distance was measured when the medial corner of the navicular was lateral to the medial side of

the talus. The mean value for the difference between MM – T – N, if applicable, and MM – N was calculated for the control and clubfoot groups without stratifying by age. In neutral position the MM – T – N was longer (mean 2.62% (0 to 7.91)) than the MM – N distance in 70/210 feet in the controls, and in 5/71 clubfeet it was longer (mean 3.07% (0.45 to 8.76)). The difference tended to be largest during the first year of life.

In abducted position the MM – T – N distance was longer than the MM – N distance in 164/210 feet in the control group (mean 3.87% (0 to 11.33)). In 15/71 clubfeet MM – T – N was longer than MM – N (mean 2.78% (0 to 7.74)).

Medial projection: T – Tang – N distance

The T – Tang – N distance tended to be longer in clubfeet than in controls in adducted position except in the 48 months group. In neutral position the difference was statistically significant in all age groups except in the three, 36 and 48 months groups. In abducted position the T – Tang – N distance was statistically significantly longer ($p < 0.05$ or < 0.01) in the clubfeet than in the controls in all age groups, i.e. the navicular was more medially positioned in relation to talus in the clubfeet. In the control group only 4/198 feet had positive values in abducted position, i.e. the medial border of the navicular was lateral to the talar tangent in all but four: in the clubfoot

Table 4. Measurements controls (normal values)

Age group (mths)	STT neutral, mm (n)	MM - N adducted, mm (n)	MM - N neutral, mm (n)	MM - N abducted, mm (n)	MM - T - N adducted, mm (n)	T - Tang - N adducted, mm (n)	T - Tang - N neutral, mm (n)	T - Tang - N abducted, mm (n)	T - N angle adducted (n)
0	5.0 SD 0.9 (20)	6.6 SD 2.0 (20)	10.3 SD 1.6 (20)	12.4 SD 1.2 (19)	12.7 SD 1.4 (19)	3.2 SD 0.9 (20)	-0.4 SD 1.3 (20)	-2.8 SD 1.0 (19)	77.3° SD 8.5° (20)
3	6.2 SD 1.2 (25)	7.4 SD 2.0 (23)	12.2 SD 1.5 (24)	14.2 SD 1.3 (22)	14.9 SD 1.4 (21)	3.9 SD 0.8 (23)	-0.6 SD 1.5 (24)	-3.1 SD 1.2 (23)	80.6° SD 7.1° (23)
6	6.8 SD 1.1 (20)	9.2 SD 1.9 (18)	14.0 SD 1.6 (20)	16.4 SD 1.0 (18)	17.0 SD 1.2 (18)	4.5 SD 0.9 (19)	-0.9 SD 2.0 (20)	-3.7 SD 1.2 (17)	85.8° SD 10.5° (18)
12	7.6 SD 1.0 (19)	11.1 SD 2.6 (16)	16.3 SD 1.8 (19)	17.6 SD 1.7 (19)	18.4 SD 1.8 (19)	4.9 SD 1.4 (17)	-0.2 SD 2.4 (19)	-3.5 SD 1.0 (20)	80.0° SD 11.7° (10)
18	8.4 SD 1.1 (22)	12.8 SD 2.5 (20)	17.4 SD 3.0 (22)	20.0 SD 3.2 (20)	20.6 SD 3.1 (20)	5.5 SD 1.1 (19)	0.8 SD 1.9 (22)	-3.0 SD 1.3 (21)	90.2° SD 10.7° (16)
24	8.2 SD 1.3 (22)	13.1 SD 2.8 (21)	18.0 SD 2.1 (22)	21.1 SD 2.6 (21)	21.9 SD 3.1 (20)	5.8 SD 1.6 (22)	1.2 SD 2.2 (22)	-2.7 SD 2.3 (22)	88.4° SD 10.8° (17)
30	7.5 SD 1.0 (20)	14.9 SD 2.1 (18)	19.9 SD 1.9 (20)	22.5 SD 1.9 (19)	23.0 SD 2.1 (19)	6.1 SD 1.1 (19)	0.5 SD 2.6 (20)	-2.8 SD 1.4 (20)	88.0° SD 8.4° (17)
36	8.6 SD 1.4 (19)	15.7 SD 2.3 (18)	20.6 SD 2.6 (20)	24.1 SD 2.3 (18)	24.8 SD 2.6 (18)	6.9 SD 1.4 (18)	1.1 SD 2.1 (20)	-3.4 SD 1.5 (19)	86.6° SD 7.8° (18)
42	8.1 SD 1.3 (19)	17.5 SD 2.5 (18)	23.1 SD 2.3 (19)	25.2 SD 1.5 (19)	25.9 SD 1.7 (19)	7.1 SD 1.7 (19)	1.0 SD 2.5 (19)	-3.2 SD 1.1 (19)	83.0° SD 9.6° (19)
48	8.6 SD 1.3 (19)	16.0 SD 2.8 (20)	23.4 SD 2.3 (19)	26.3 SD 2.1 (18)	26.8 SD 1.9 (18)	7.0 SD 1.9 (20)	1.5 SD 2.8 (19)	-2.5 SD 1.9 (18)	90.9° SD 10.2° (18)

Measurements related to age and position of the foot, mean and SD

n, number of images with good enough quality to permit adequate measurement of the specific variable; MM - N, medial malleolus - navicular distance; MM - T - N, medial malleolus - talar head - navicular distance; T - Tang - N, distance from the medial tangent of the talus to the medial corner of the navicular bone; T - N, talo-navicular

Table 5. Measurements controls (normal values)

Age group (mths)	T - N angle neutral (n)	T - N angle adducted (n)	Talar length dorsal mm (n)	C - C distance adducted, mm (n)	C - C distance neutral, mm (n)	C - C distance abducted, mm (n)	C - C angle adducted (n)	C - C angle neutral (n)	C - C angle abducted (n)
0	39.7° SD 12.3° (20)	18.7° SD 8.1° (19)	19.0 SD 1.8 (18)	2.2 SD 1.1 (17)	1.2 SD 1.1 (20)	-0.6 SD 0.9 (18)	15.3° SD 10.1° (17)	7.0° SD 11.3° (20)	-8.7° SD 11.1° (18)
3	41.6° SD 13.4° (24)	19.4° SD 8.0° (23)	21.4 SD 1.5 (10)	2.3 SD 1.4 (24)	1.2 SD 1.2 (25)	-0.2 SD 0.9 (22)	13.3° SD 11.6° (24)	4.5° SD 9.3° (25)	-5.0° SD 11.7° (22)
6	40.6° SD 12.8° (20)	18.4° SD 10.9° (16)	21.4 SD 1.9 (10)	3.0 SD 1.2 (20)	1.6 SD 1.0 (20)	0.3 SD 0.8 (20)	16.6° SD 11.2° (20)	7.0° SD 9.7° (20)	-1.5° SD 9.6° (20)
12	44.1° SD 11.4° (19)	22.6° SD 6.7° (19)	26.6 SD 2.6 (15)	3.9 SD 1.9 (19)	2.0 SD 1.4 (20)	-0.5 SD 1.4 (20)	19.1° SD 9.4° (19)	10.2° SD 8.0° (20)	-4.3° SD 9.0° (19)
18	49.2° SD 9.4° (21)	26.7° SD 8.2° (21)	29.0 SD 1.5 (16)	3.5 SD 1.3 (17)	2.1 SD 1.6 (21)	0.2 SD 1.7 (18)	14.7° SD 6.2° (17)	11.1° SD 6.2° (21)	2.4° SD 8.1° (18)
24	52.6° SD 10.8° (22)	29.1° SD 11.7° (22)	30.0 SD 2.4 (11)	3.4 SD 2.2 (18)	2.1 SD 1.3 (21)	0.1 SD 1.3 (18)	14.3° SD 8.5° (17)	8.8° SD 7.8° (21)	-1.0° SD 10.5° (17)
30	46.7° SD 13.9° (20)	30.1° SD 8.5° (20)	30.5 SD 1.6 (8)	5.1 SD 2.4 (19)	3.1 SD 1.8 (20)	1.4 SD 1.6 (19)	10.2° SD 7.2° (19)	10.2° SD 8.5° (20)	3.6° SD 8.6° (19)
36	53.8° SD 11.7° (20)	28.7° SD 8.4° (18)	34.1 SD 1.9 (10)	6.0 SD 2.1 (15)	3.6 SD 1.9 (19)	1.8 SD 2.8 (17)	20.4° SD 6.9° (15)	13.4° SD 6.8° (19)	9.1° SD 9.7° (17)
42	50.2° SD 12.3° (19)	28.6° SD 7.5° (19)	36.2 SD 4.1 (3)	3.1 SD 1.7 (17)	3.3 SD 1.9 (16)	0.4 SD 2.5 (20)	14.1° SD 8.4° (17)	10.3° SD 7.2° (16)	4.3° SD 7.8° (20)
48	51.0° SD 12.7° (19)	31.3° SD 8.8° (18)	35.6 SD 2.9 (9)	4.4 SD 3.3 (15)	3.0 SD 1.6 (19)	1.2 SD 1.7 (18)	16.0° SD 9.9° (15)	11.9° SD 6.1° (19)	3.3° SD 9.2° (18)

Measurements related to age and position of the foot, mean and SD

n, number of images with good enough quality to permit adequate measurement of the specific variable; T - N, talo-navicular; C - C, calcaneo-cuboid

group only 22/70 (31%) had negative values (one missing value). It means that in the clubfeet the navicular did not move as far laterally as in the controls when the foot was abducted. The difference between adducted and abducted position (mobility) tended to be or was significantly smaller in clubfeet compared with normal feet in all age groups.

Medial projection: T – N angle

In adducted position the T – N angle tended to be larger in clubfeet than in the controls, except in the three and 18 months groups, and it was statistically significant in some age groups. In neutral position the T – N angle was statistically significantly larger in the clubfeet than in the controls, except in the three and 36 months groups. In abducted position it was statistically significantly larger in all age groups except the 36 months group, but there was the same tendency in this group.

Medial projection: ROM in the talo-navicular joint

For the whole control cohort, the mean value for the difference between T – N angle in ad- and abducted position of the foot (ROM) was 59.2° (SD 11.8°). In the clubfoot cohort it was 41.1° (SD 19.7°). Thus the mean ROM in the talo-navicular joint was 18.1° less in the clubfoot cohort compared with the controls.

Medial projection: association between the semi-quantitative assessment of navicular position and the quantitative variables (MM – N, T-Tang – N distance and T – N angle)

In eight of the clubfeet the navicular was assessed as subluxated. In these feet the mean MM – N was 8.1 mm while in the clubfeet assessed as not displaced it was 14.4 mm ($p < 0.01$), the mean T – Tang – N were 6.32 mm and 2.82 mm respectively ($p < 0.01$) and the mean T – N angles were 85.2° and 65.8° respectively ($p < 0.01$).

Only one out of the eight clubfeet with navicular subluxation had clinical adductus and data was missing for three. We could not show any association between clinically remaining adductus and subluxation of the navicular.

Lateral projection: C – C distance

In the adducted position there was no obvious difference between clubfeet and controls.

In the controls the C – C distance in neutral position increased with increasing age. In the clubfeet the C – C distance tended to be longer than in the controls in the younger children up to the age of two years and was significant at six months (more adducted).

In the abducted position the C – C distance in the control group increased with age up to the age of three years. In the clubfeet it tended to be longer than in the

controls in all age groups and the difference was statistically significant only in the age groups six, 18, 24 and 30 months.

Lateral projection: C – C angle

In adducted position the mean values for the control group varied between 13.3° to 20.4° from birth to four years of age. In the clubfeet the angle tended to be larger in the younger children and from the age of 18 months it tended to be smaller than in the controls.

In neutral position the C – C angle in the clubfeet tended to decrease over time and from the age of 18 months it tended to be smaller than in the controls (gradually less adducted).

In the abducted position the values were negative in newborn controls (mean -8.7°) and increased with age and were positive after the age of two years (positive values mean that the lateral tangent of the cuboid deviates medially in relation to the tangent of calcaneus and negative values means that the cuboid tangent deviates laterally related to the calcaneal tangent). In the clubfeet the trend was the opposite. The values tended to be larger than in the controls in the younger children and smaller than in the controls after the age of two years.

Lateral projection: ROM in the calcaneo-cuboid joint

The difference between C – C angle in ad- and abducted position (ROM) for the whole control cohort was mean 17.0° (SD 11.7°). For the whole clubfoot cohort, the mean value was 8.5° (SD 9.0°). The ROM tended to be less in the clubfeet i.e. the clubfeet are stiffer.

Dorsal projection

In the controls one navicular was plantarly positioned in relation to the talar head (value missing for one) and all the others were normal. In seven of the clubfeet the navicular was plantarly positioned, in three it was dorsally positioned, normally positioned in 57 and values were missing in four because of missing images or images of low quality.

Length of the talus

The length of the talus was measured on the dorsal projection and on the medial projection to evaluate if it matters on which projection the measurements are performed. The measurements tended to be shorter on the medial projection than on the dorsal projection, but the differences were small. The mean difference was in neutral position -1.8% (SD 7.9%), in adducted position -4.4% (SD 7.6%) and in abducted position -2.6% (SD 6.6%). The talar length tended to be shorter in the clubfeet than in the controls in all age groups.

Clinical measurements

In the 17 unilateral cases where the foot length measured by a ruler was available, the clubfoot was shorter, mean 0.59 cm (0 to 1.5), than the contralateral normal foot.

Eight out of the 71 clubfeet had remaining clinical adductus deformity.

Association between clinical and ultrasound evaluation

The eight clubfeet with remaining adductus showed significant differences compared with the clubfeet without adductus deformity in the following four parameters:

1. the MM – N distance was shorter in neutral ($p < 0.05$), adducted ($p < 0.05$) and abducted ($p < 0.01$) position;
2. the T – Tang – N distance in abducted position was longer ($p < 0.05$);
3. the T – N angle in neutral and abducted position was greater ($p < 0.05$);
4. the C – C angle in adducted position was greater ($p < 0.05$).

The T – Tang – N distance tended to be longer in neutral position and shorter in adducted position. The T – N angle in adducted position and C – C angle in neutral and abducted position tended to be greater.

Discussion

Ultrasound has several advantages compared with MRI for clubfoot imaging in children. There is no need for sedation of the child; the foot can be manipulated obtaining dynamic images; it is easily available and the cost is reasonable. However, to become a useful and reliable instrument in clubfoot imaging evaluation, normal values and repeatability assessment have to be established during the whole treatment period up to the age of four years. In previous studies the position of the navicular has been subjectively assessed as no displacement, $< 50\%$ and $\geq 50\%$ dislocated. In order to improve the assessment of navicular position the quantitative variables T – Tang –

N distance and T – N angle were introduced. The T – N angle was also used to assess the movement in the talo-navicular joint.

Circumstances during the examination

It is very important to have a relaxed child, otherwise images of good quality in maximal abduction and adduction cannot be obtained (Fig. 9).

Limitations of the study

As this is a cross-section methodological study we chose to include all the patients with clubfoot who were under treatment when the study started. Thus no untreated newborns were included in the clubfoot group. Some variables are, however, presented for children from birth up to the age of one year in earlier published studies.^{9,10}

In some age groups there were too few clubfeet to permit cross-sectional statistical calculations, and the feet were in various stages of correction.

In the clubfeet cohort chosen for the second measurement for intra-observer agreement, the MM – T – N distance was applicable only in four feet. The length of the talus in dorsal projection could be measured only in five feet because of image limitation. Therefore the ICC was not calculated for these two variables.

Repeatability

The evaluation of the majority of the variables could be done with fair to very good intra- and inter-observer repeatability, except for intra-observer T – N angle adducted in clubfeet, inter-observer C – C distance abducted in controls and T – N angle adducted and C – C angle in neutral and adducted clubfeet (Table 3). Measuring the T – N angle it is sometimes difficult to define the boundary between the navicular cartilage and the insertion of the posterior tibial tendon, especially in adduction when the soft tissues are folding. The C – C distance and C – C angle are usually small and therefore the influence of the measurement error is proportionally great. This is probably the reason why these variables had low values for ICC.

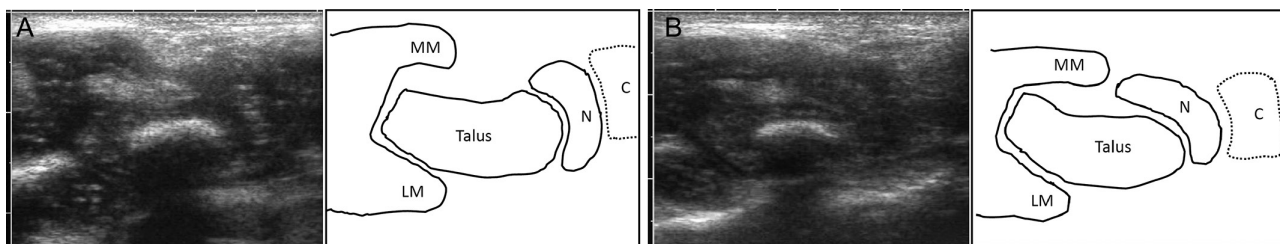


Fig. 9 Clubfoot in an 18-day-old boy after two plasters, during Ponseti manoeuvre: (a) relaxed; (b) the baby is crying. Notice how the posterior tibial muscle is activated dislocating the navicular medially while the forefoot is still passively held in abducted position (MM, medial malleolus; LM, lateral malleolus; N, navicular; C, cuneiform bones).

Medial projection

The medial displacement of the navicular has earlier been scored subjectively on a three-grade score expressed by Aurell et al⁹ as: 1) no displacement, 2) < 50% of the navicular displaced medially, 3) ≥50% displacement or complete subluxation. Bhargava et al⁸ graded the percentage uncovering of the talar head as: 1) no displacement, 2) > 50% coverage of talar head by navicular, 3) < 50% coverage of talar head by navicular. In this study the quantitative variables MM – T – N, T – Tang – N distance and T – N angle were introduced.

The measurements of all variables at the medial projection (STT, MM – N, MM – T – N, T – Tang – N distances and the T – N angle) showed fair to good reproducibility on normal feet as well as on clubfeet (Table 3).

Medial projection: MM – N distance

It is documented in other studies that the MM – N distance increases in clubfeet during the first two months of treatment when the deformities are corrected.¹² This study shows that the MM – N distance is shorter in relation to normal feet to the age of four years both in neutral, adducted and abducted position in clubfeet. This may partly be explained by differences in foot size. In the 21 unilateral cases the MM – N distance in neutral position was a mean 5.9 mm (SD 4 mm), 32.1% shorter in the clubfeet. In the 17 unilateral cases where foot length measured by a ruler was available the clubfeet were 0 cm to 1.5 cm, a mean 0.59 cm (SD 0.4 cm), 4% shorter. If the difference in size is proportional in the whole foot only a small part of the difference can be explained by the difference in foot size. However, Beck et al¹³ reported that in Ponseti treated unilateral clubfeet the percentage hypoplasia of the osteocartilaginous structures was greatest in the hindfoot compared with the contralateral unaffected foot on radiographs. At two years of age, the mean difference for the talus was 7.3% and for the first metatarsal it was 3.0%.¹³

Medial projection: MM – T – N distance

A curved line would be the most accurate way to measure MM – T – N distance. The MM – T – N distance will be a little shorter than the real distance but can serve as a good approximation. In abducted position this variable was applicable in 15/71 clubfeet and 164/205 controls. The percentage difference compared with the MM – N distance was small, a mean of 2.78% (0.00 to 7.74) in the clubfeet and 3.87% (0.00 to 11.33) in the controls and, therefore, this variable will have limited importance in clinical practice.

Medial projection: T – Tang – N distance

The variable T – Tang – N distance measures the displacement accurately if the medial displacement of the navicular is moderately displaced to subluxated, but when

the navicular turns around the head of the talus into total medial luxation this variable does not increase correspondingly because the maximal value is equal to the thickness of the navicular.

During the late stage of the clubfoot correction when the navicular is moving mainly laterally, this variable ought to be the most sensitive variable to evaluate changes, the progression/lack of progression of treatment or beginning of a recurrence. This variable can also be used to assess the medial alignment of the navicular.

Medial projection: T – N angle and ROM

The difference between T – N angle in adducted and abducted position gives a value of the ROM in the talo-navicular joint, which is an important issue in clubfeet. The ROM is less in the clubfeet than in the controls. Our results show that these new variables give a more detailed information of this correction process which can be helpful for the clubfoot treatment team.

The T – Tang – N distance and T – N angle variables revealed that in clubfeet the navicular is more medially positioned in relation to talus than in controls in neutral and abducted position of the foot up to the age of four years. The positive mean values for the T – Tang – N distance in the clubfeet indicate that in the majority (69%) of the clubfeet the navicular did not move laterally to the medial tangent of the talus in maximal abduction, while the navicular moved laterally to the tangent in all the controls. The decreased difference between the T – Tang – N distance in abducted and neutral position and the decreased difference between the MM – N and the T – Tang – N distance in adduction and abduction all reveal a decreased mobility in the talo-navicular joint in the clubfeet. This is in accordance with the clinical experience that clubfeet generally are less flexible than normal feet.¹⁴ The ligaments, muscles and tendons at the medial side of the foot and the posterior aspect of the ankle joint and distal lower leg are less elastic because of hypercollagenosis.^{1,15}

It has been documented in other radiological and ultrasound studies that the navicular often is more medially positioned in treated clubfeet compared with normal feet.¹⁶ It remains to investigate to what degree this is related to function.

Lateral projection: C – C distance

Validations for the first year of life have been published previously for this variable.^{9,10} The earlier established variables are usable with good repeatability during the whole treatment period until the age of four years.

Lateral projection: C – C angle

This variable has earlier been described in the literature (with slightly different measurement points than in this

study), but we have not found any intra- and inter-observer agreement studies.^{8,17}

Our study showed that in normal feet the C – C angle in neutral position increased slightly with age, which means that in relation to the lateral border of the calcaneus the contour of the cuboid became medially angulated. In clubfeet the tendency was inverse, i. e. the cuboid was more laterally angulated with increasing age.

It is logical that the angle is larger in clubfeet than in normal feet in the beginning of the treatment because adductus of the forefoot is part of the deformity. At the age of 18 months the values had normalized but after that the angle continued to decrease during the maintenance phase of treatment with foot abduction orthoses. A possible explanation could be that the outward rotation of the calcaneus under the talus is restricted and a compensatory lateral angulation of the cuboid occurs when the forefoot is abducted in the orthoses. Further examination with a longer probe permitting measurement of the angle between calcaneus and the fifth metatarsal would be of interest. The decreased difference between the values in abducted and adducted position for the C – C distance and the C – C angle indicates less flexibility in the clubfeet.

ROM

The considerable difference of the ROM in the talo-navicular and calcaneo-cuboid joints was expected because of the different functional anatomy of these joints but simultaneous interdependent movement is possible because the calcaneus rotates underneath the talus.

Dorsal projection: length of the talus

The values for the length of the talus were the highest when measured on the dorsal projection compared with the medial projections, even if the percentage differences were small. The reason for this is probably that the image planes on the medial projections did not always pass through the outermost posterior edge of the talus. Therefore, the dorsal projection is recommended for measurements of the talar length.

Further examination

It would be of interest to include the metatarsals to investigate if the difference in size of the bones is proportional in the whole foot.

Clinical relevance

Clubfoot is a complex 3D deformity. Length measurements are influenced by the size and age of the child, the size-difference between clubfeet and normal feet, severity of the deformity and the stage of the treatment. Therefore, decisions on altered treatment cannot be based on single

measurements, but the global assessment of dynamic ultrasound examination can be a valuable complement to the clinical evaluation and an aid in planning the continued treatment. In clinical practice the variables MM – N distance, T – Tang – N distance and T – N angle will be the most useful. There was an association between these variables and adductus deformity.

Conclusion

Morphology of normal feet and clubfeet, as well as mobility in the talo-navicular and calcaneo-cuboid joints, can be assessed by ultrasound with fair to very good reliability from birth to the age of four years. The ROM in talo-navicular and calcaneo-cuboid joints was less in clubfeet than in controls. Ultrasound can be a valuable complement to the clinical evaluation of the anatomy of the clubfeet, as it will show, what is sometimes difficult to feel at clinical examination.

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COMPLIANCE WITH ETHICAL STANDARDS

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OA LICENCE TEXT

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ETHICAL STATEMENT

Ethical approval: The study was conducted in accordance with the 1964 Declaration of Helsinki and its later amendments.

The study was approved by the regional ethical review board in Gothenburg, Sweden (ref. 031-06 and T397-07).

Informed consent: All caregivers of the children included in this study signed an informed consent.

ICMJE CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest. No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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