MRI study of talonavicular alignment in club foot

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We studied in vivo the talonavicular alignment of club foot in infants using MRI. We examined 26 patients (36 feet) with congenital club foot. The mean age at examination was 9.0 months (4 to 12). All analyses used MRI of the earliest cartilaginous development of the tarsal bones in the transverse plane, rather than the ossific nucleus. The difference in the mean talar neck angle ($44.0 \pm 8.1^\circ$) in club foot was statistically significant ($p < 0.001$) when compared with that of the normal foot ($30.8 \pm 5.5^\circ$). The difference between the mean angles in the group treated by operation ($47.9 \pm 6.7^\circ$) and those treated conservatively ($40.1 \pm 7.5^\circ$) was also statistically significant. The anatomical relationship between the head of the talus and the navicular was divided into two patterns, based on the position of the mid-point of the navicular related to the long axis of the head. In the operative group, 18 feet were classified as having a medial shift of the navicular and none had a lateral shift. In the conservative group, 12 showed a medial shift of the navicular and six a lateral shift. All nine unaffected normal feet in which satisfactory MRI measurements were made showed a lateral shift of the navicular.

Club feet had a larger talar neck angle and a more medially deviated navicular when compared with normal feet. This was more marked in the surgical group than in the conservative group.

J Bone Joint Surg [Br] 2001;83-B:726-30.

Received 20 January 2000; Accepted after revision 26 July 2000

There have been a number of studies of the pathological anatomy of club foot in fetal and neonatal specimens.¹⁻³ Of the abnormalities described, only an equinus deformity could be recognised and evaluated by plain radiography. It has been very difficult to analyse the other elements of the deformity radiologically because of the largely cartilaginous nature of the tarsal bones in the infant. Preoperative and intraoperative assessment of talonavicular malalignment, considered one of the most serious deformities requiring correction at operation, has also been difficult. Some authors have tried to demonstrate this by arthrography^{3,4} or by plain radiography,⁵ but these methods are still not entirely satisfactory. Recently, MRI studies have been reported which attempt to clarify the pathological abnormalities of club foot, but they do not mention the actual malalignment of the talonavicular joint.⁶⁻⁸

Our aim was to analyse the talonavicular joint in club foot using MRI and to clarify the relationship between the head of the talus and the navicular, according to the severity of the club foot.

Patients and Methods

We examined 26 patients (36 feet) with congenital club foot using MRI. Details of the 21 boys and five girls are shown in Table I. In 11 involvement was bilateral and in 15 unilateral. The left foot of one bilateral case was excluded because the MR scan was unsatisfactory. The mean age at examination was 9.0 months (4 to 12). All patients were initially treated by corrective casts for three or four months. The indications for surgery were based mainly on clinical grounds and, to some extent, on plain radiography after serial casting. A total of 13 patients (16 feet) required complete subtalar release (CSR) operations and the remaining 20 (20 feet) were treated conservatively by a variety of orthoses or corrective shoes. Two patients had conservative treatment on one side and surgery on the other. Two families (two feet) refused operation despite severe deformity. In the surgically treated feet, MRI was undertaken preoperatively at a mean age of 9.3 months (6 to 12).

Chloral hydrate was used for sedation and the feet were maintained in the position of maximal correction with a special board made from stylofoam. We used a 0.5 T MRI scanner (Resona; Yokogawa Medical Systems, Japan) with

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0301-620X/01/510936 \$2.00

Table I. Details of the 26 patients with club foot

Case	Age (mth)	Gender	Side	Measurements on MRI			Category	Treatment
				Cartilaginous-TNA (degrees)	Navicular shift	Ossific-TNA (degrees)		
1	8	M	R	24	Lateral	30	IIB	Conservative
			L	35	Medial	45	IIA	Conservative
2	11	M	R	28	Medial	37	IIA	Conservative
3	8	F	L	58	Medial	60	IA	CSR
4	13	M	L	52	Medial	56	IA	CSR
5	9	M	R	50	Medial	60	IA	Conservative*
			L	50	Medial	53	IA	Conservative
6	5	M	L	48	Lateral	48	IB	Conservative
7	4	M	R	48	Medial	70	IA	Conservative
			L	44	Lateral	52	IB	Conservative
8	12	M	R	47	Medial	62	IA	CSR
			L	56	Medial	61	IA	CSR
9	12	M	L	53	Medial	60	IA	Conservative*
10	7	F	R	42	Medial		IA	Conservative
			L	46	Medial	57	IA	Conservative
11	12	M	R	38	Lateral	42	IB	Conservative
12	12	M	L	47	Medial	47	IA	CSR
13	10	M	R	36	Medial	46	IA	CSR
14	6	M	R	45	Medial	53	IA	CSR
15	7	M	L	48	Medial	48	IA	CSR
16	6	M	R	38	Medial	45	IA	CSR
17	8	M	R	46	Lateral	52	IB	Conservative
			L	45	Medial	55	IA	CSR
18	12	F	R	33	Medial	44	IIA	Conservative
19	9	M	R	34	Medial	52	IIA	Conservative
20	7	M	R	52	Medial	65	IA	CSR
			L	61	Medial	73	IA	CSR
21	12	M	R	35	Medial	50	IIA	Conservative
			L	50	Medial	65	IA	Conservative
22	11	M	R	46	Medial	52	IA	CSR
			L	44	Medial	55	IA	CSR
23	7	F	R	38	Medial	52	IA	Conservative
			L	40	Medial	52	IA	CSR
24	12	M	L	44	Medial	60	IA	CSR
25	4	M	R	40	Lateral	47	IB	Conservative
26	10	F	R	42	Medial	42	IA	Conservative

* parents rejected operations

a surface coil. The talonavicular alignment was analysed on the transverse plane of the T1-weighted image, which was derived from a section along the long axis of the talus on the transient sagittal image. The latter was made in relation to the long axis of the tibia.

The talar neck angle (TNA) was measured by drawing lines through the long axis of the talar head and body. The long axis of the head was drawn as a line connecting two bisected points of the width of the neck and the best-fit arc of the cartilaginous anlage of the head (Fig. 1). The long axis of the ossific nucleus of the talus was also used for measuring a second TNA angle. The former was named the cartilaginous TNA and the latter the ossific TNA. Identification of the longitudinal axis of the body of the talus was

sometimes difficult on the MR scans, but it virtually coincided with a line perpendicular to the transmalleolar line through the centre of the medial and lateral malleoli in all the images which showed the axis of the body clearly. We therefore considered a line perpendicular to the transmalleolar line as the axis of the talar body. Measurements were made on two superimposed images at both levels.

The anatomical relationship between the head of the talus and the navicular was divided into two patterns, based on the position of the mid-point of the navicular in relation to the long axis of the talar head. The mid-point of the navicular was defined as the mid-point of both the width and thickness of the navicular. We defined two patterns. Medial shift of the navicular was the position at which the

Fig. 1

Diagram showing the long axis of the talar head drawn as a line connecting two bisected points of the width of the talar neck and the best-fit arc of the cartilaginous anlage of the talar head (right foot).

point was shifted medially to the long axis of the talar head. Lateral shift of the navicular was where it was just on the long axis or shifted laterally. Two staff surgeons and one resident measured the angles separately to minimise inter-observer error. If the difference between the measured angles was more than 5° and if classifications of the talonavicular relationship were not the same, the results were excluded from the study. The mean of the angles measured by all three observers was used as an actual value if the difference was within 5° between observers.

The unaffected feet in the 15 unilateral cases were also examined. Nine of these feet which had clear MR scans were used as a control group.

Results

Talar neck angle (TNA). The mean cartilaginous TNA for the 36 club feet was $44.0 \pm 8.1^\circ$ (24 to 61). This was statistically significant ($p < 0.001$), compared with the mean in nine normal feet of $30.8 \pm 5.5^\circ$ (26 to 37) using Student's *t*-test. The difference between the mean angle of $47.9 \pm 6.7^\circ$ (36 to 61) for the 18 in the operative group, which included two feet in patients whose parents refused operation, and that of $40.1 \pm 7.5^\circ$ (24 to 50) for the 18 in the conservative group was also statistically significant ($p < 0.005$). The mean ossific TNA was $52.8 \pm 9.0^\circ$ (30 to 73) in 35 club feet and $45.0 \pm 5.5^\circ$ (34 to 52) in eight normal feet. The ossific TNAs for both club feet and normal feet were larger, than the cartilaginous TNAs for the same feet. This difference was statistically significant ($p < 0.001$).

Talonavicular alignment. The position of the navicular in relation to the long axis of the talar head was divided into

two groups based on a critical cartilaginous TNA of 35° (Fig. 2). Howard and Benson⁹ showed the same talar neck angle in a fetal specimen of a normal foot. One group had a TNA of more than 35° , and the other an angle of 35° or less. The talonavicular alignment could then be subdivided into four categories by combining the navicular position with the cartilaginous TNA ($>35^\circ$ or $\leq 35^\circ$). Patients with a TNA of $>35^\circ$ and a medial shift of the navicular were put in category IA, and those with a lateral shift of the navicular, IB. Patients with a TNA of $\leq 35^\circ$ were categorised as IIA or IIB according to the position of the navicular (Fig. 3). The categories for patients with club feet were as follows: IA, 25 feet; IB, five feet; IIA, five feet; and IIB, one foot. All the normal control feet were categorised as IIB. All 18 feet in the operative group were classified as IA. In the conservative group seven were categorised as IA, five as IB, five as IIA, and one as IIB.

Discussion

Medial displacement of the navicular and medial and plantar deviation of the neck of the talus have been reported in fetal studies of club foot as talonavicular malalignment.¹⁻³

In the past, some authors have tried to assess this abnormality using plain radiography⁵ or arthrography.^{3,4} This has proved difficult because of the lack of ossification in the tarsal bones. Recent MRI studies have clarified the pathological abnormalities of club foot to some extent.⁶⁻⁸ Downey et al⁶ described MR images in patients with congenital talipes equinovarus aged from 4 to 15 months. They also measured abnormalities of the calcaneum and talus in the transverse plane and noted the navicular to be medially

Fig. 2

Comparison of the cartilaginous (C) TNA between the club foot and the normal foot (bars represent standard deviations).

Fig. 3

Diagram showing four patterns of talonavicular alignment according to the combination of the cartilaginous TNA and the navicular position corresponding to the long axis of the head of the talus in the right foot. A superimposed shadow shows a transmaleolar section in which a line perpendicular to the transmaleolar line was considered as the talar body axis. IA, a medial shift of the navicular with a TNA $>35^\circ$; IB, a lateral shift of the navicular with a TNA $>35^\circ$; IIA, a medial shift of the navicular with a cartilaginous TNA $\leq 35^\circ$; and IIB, a lateral shift of the navicular with a cartilaginous TNA $\leq 35^\circ$ (N, navicular; T, talus; LM, lateral malleolus; MM, medial malleolus).

Fig. 4

Case 22. MRI of the left side in an 11-month-old boy with bilateral club feet. This was classified as a medial shift of the navicular, with a cartilaginous TNA of 44° (the ossific TNA, 55°). A white line depicts the superimposed transmaleolar line.

Fig. 5

Case 24. MRI of the right normal foot of a 12-month-old boy. This was classified as a lateral shift of the navicular, with a cartilaginous TNA of 30° (the ossific TNA, 40°). A white line depicts the superimposed transmaleolar line.

dislocated in three of 13 abnormal feet. In our series, we visualised the entire anlagen of the navicular and talus, and were able to analyse the relationship between the navicular and neck of the talus.

The degree of medial deviation of the neck has usually been estimated by using the long axis of the ossified nucleus of the talus on a plain radiograph. Since the

cartilaginous TNA is smaller than the ossific TNA in infants, it does not delineate the pathological anatomy. Howard and Benson⁹ described, in fetal specimens, a discrepancy between the long axis of the neck of the cartilaginous anlage and of the ossific nucleus of the talus. Hubbard et al⁸ also showed, in their MRI study, that both axes differed in orientation in the normal hindfoot.

With the development of computer technology, attempts have been made to analyse the shape of the tarsal bones three-dimensionally.¹⁰⁻¹² In these studies, the long axis of the cartilaginous neck of the talus was drawn using a graphic workstation to avoid interobserver or intraobserver error. The line drawn by the computer measures the biomechanical long axis of the whole cartilaginous anlage of the talus, and not the anatomical long axis of the neck. We were able to measure the latter on the MR images by the method shown in Figure 1.

McKay¹³ described "the subtalar complex concept" since he had been unable to find any rotation of the talus in the ankle or an abnormal plane of movement of the talus relative to the bimalleolar plane of the talocrural articulation. In relation to their neonatal specimens Howard and Benson¹⁴ stated that "the talus lies in equinus and rotated medially such that its anterolateral border protrudes in front of the tibia at the ankle. This is not pathological, but a consequence of normal joint mechanics". Based on these observations we thought it reasonable to define the line perpendicular to the transmalleolar line as the long axis of the body of the talus. The transient sagittal plane along the long axis of the tibia allowed us to make proper transient sagittal images of any club foot which was not affected by torsion of the talus. The tarsal malalignment of all the club feet had been corrected to some extent by treatment in a cast. Plantar deviation of the talus in the sagittal plane in this study varied from 15° to 40°. There was no relationship between plantar deviation and the TNA. Some feet in the normal group also showed no difference in the TNA at two selected positions of the ankle of 10° and 40° of plantar flexion. As a result, we considered that torsional deformity within the range of ankle movement would not affect the TNA.

The severity of club foot can be assessed by the degree of talonavicular malalignment. All patients in the operative group had a cartilaginous TNA of more than 35° and a medial shift of the navicular (Fig. 4). The degree of both these deformities was variable in the conservative group. There were six feet with a lateral shift of the navicular and six with a cartilaginous TNA of 35° or less like the normal group (Fig. 5). The greater the severity of the club foot the greater was the medial shift of the navicular and the angulation of the neck of the talus. In mild or moderate club feet, there may be various combinations of talonavicular malalignment, e.g., a lateral shift of the navicular with an excessive angulation of the neck of the talus or a medial shift of the navicular with a normal neck. In these cases, we tried to clarify whether the whole of the deviated navicular was in contact with the articular cartilage of the head or not. This has been difficult to observe even during

operation. We failed to identify the exact location of the articular cartilage on MR images. There were five patients who had a lateral shift of the navicular with a TNA of >35° in the conservative group, but none in the operative group. This may reflect the effectiveness of the treatment by serial corrective casting which had caused movement of the medially-placed navicular laterally. Measurement of the cartilaginous TNA can be a useful indicator of the severity of club foot. If the angle is 35° or less we would be encouraged to treat the foot conservatively by casting. On the other hand, if the foot was in a IA category (>35° cartilaginous TNA, medial shift of the navicular) conservative treatment may be unsuccessful or lead to later deterioration.

We conclude that MRI can be helpful in visualising the anatomy of the deformity in club foot. It gave us useful information in the assessment of the severity of the deformity and the choice of treatment.

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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