CHAPTER XI

RELATIVE TALOTIBIAL MOVEMENTS AND RELATIVE TARSAL MOVEMENTS

11.1 RELATIVE TALOTIBIAL MOVEMENTS

11.1.1 Directions and positions of talotibial axes, partial range

First, data relating to preparation nr. 1.

Figure 11-1a, the dorsoplantar projection. The bundle of axes is projected transversely over the corpus tali. In this projection, the axes are at such a wide angle to the X-axis, that it serves no purpose to refer to an anteromedial or anterolateral axial direction. The axes cross at a short distane, approximately over the centre of the corpus tali in the starting position.

Figure 11-1b, the frontal projection. Here, the steep position of axis nr 1 is noticeable; the other axes are projected transversely over the trochlea tali with slight angular deviation.

Figure 11-1c, the sagittal projection with the tibia and the talus in the starting and end positions. In this projection, we note the wide diversity of axial directions. Axes nrs 1, 4 and 5 have a direction from anteroinferior to posterosuperior, axes nrs 2, 3 and 6 have a direction from posteroinferior to anterosuperior. However, this diversity is an optical illusion, resulting from the fact that the axial directions and the 'viewing direction' in the sagittal projection virtually coincide. For the same reason, we see that the points of intersection of the axes with the XZ-plane in this sagittal projection are widely divergent, in contradistinction to the crossing at a short distance of the axes in the dorsoplantar projection.

Combination of the axial directions shows that the talus in relation to the tibia moves around axes that, with the exception of axis nr 1 are projected transversely over the trochlea tali; axis nr 1, on the other hand, is projected particularly steeply over the trochlea. In all phases, the range of movement will be maximal at the caput tali.

With the direction of rotation given and considering the axial direction for the first phase/axis nr 1, there is a combined adduction extension movement of the talus, while for the other phases there is an extension movement with a slight

Table 11-1. Deviation angles of talotibial axes (π TATI 10°) with summation, mean and range of deviation angles.

Specimen		R 1	R 2	R 3	R 4	R 5	R 6	R 7	L 8	L 9	L 10
	Phase										
π	1	268.7	260.3	293.9	268.8	244.9	272.9	250.3	93.2	128.8	93.2
π	2	89.2	89.2	103.4 (283.4)	92.5 (272.5)	92.0 (268.0)	94.8 (274.8)	82.9 (262.9)	100.0	115.8	-78.2 (-281.8)
π	3	87.9	92.2	93.6	93.9	108.4 (288.4)	93.7	6.2	92.1 (272.1)	115.7	-95.1 (264.9)
π	4	92.6	101.4	95.5	90.0	106.1	93.3	76.2	27.5	120.0	-161.2 (18.8)
π	5	99.5	159.9	99.2	81.1	98.7	96.0	75.9	6.4	8.2	-106.9 (73.1)
π	6	99.9 (279.9)	94.9	106.9	74.1	107.1				150.2 (330.2)	88.6 (271.4)
$\Sigma\ \pi$		469.1	537.6	498.6	431.6	512.3	377.8	241.2	226.9	509.9	-530.0
$\overline{\pi}$		93.8	107.5	99.7	86.3	102.5	94.5	60.3	56.7	102.0	-106.0
R π		12.0	70.7	13.3	19.8	16.4	2.7	76.7	94.5	142.0	83.0

Table 11-2. Inclination angles of talotibial axes (φ TATI 10°) with summation, mean and range of inclination angles.

Specimen		R 1	R 2	R 3	R 4	R 5	R 6	R 7	L 8	L 9	L 10
	Phase										
φ	1	35.2	47.8	86.5	73.7	76.1	76.2	82.2	68.6	74.3	34.5
φ	2	2.6	3.0	-35.8	- 3.3	-40.9	- 0.6	- 69.3	0.4	56.2	0.5
φ	3	7.6	4.0	10.6	12.5	- 16.7	17.6	83.2	- 6.2	49.6	4.5
φ	4	9.1	23.1	20.9	22.8	9.5	23.9	74.5	28.6	73.9	- 0.2
φ	5	5.8	57.7	24.0	17.3	10.2	22.5	80.8	33.3	80.4	- 25.4
φ	6	- 0.6	41.6	22.6	31.1	14.7				- 72.1	22.2
$\Sigma\ \varphi$		24.5	129.4	42.3	80.4	- 23.2	63.4	169.2	56.1	332.2	1.6
$\overline{\varphi}$		4.9	25.9	8.5	16.1	- 4.6	15.9	42.3	14.0	66.4	0.3
R φ		9.7	54.7	59.8	34.4	55.6	24.5	152.5	39.5	30.8	47.6

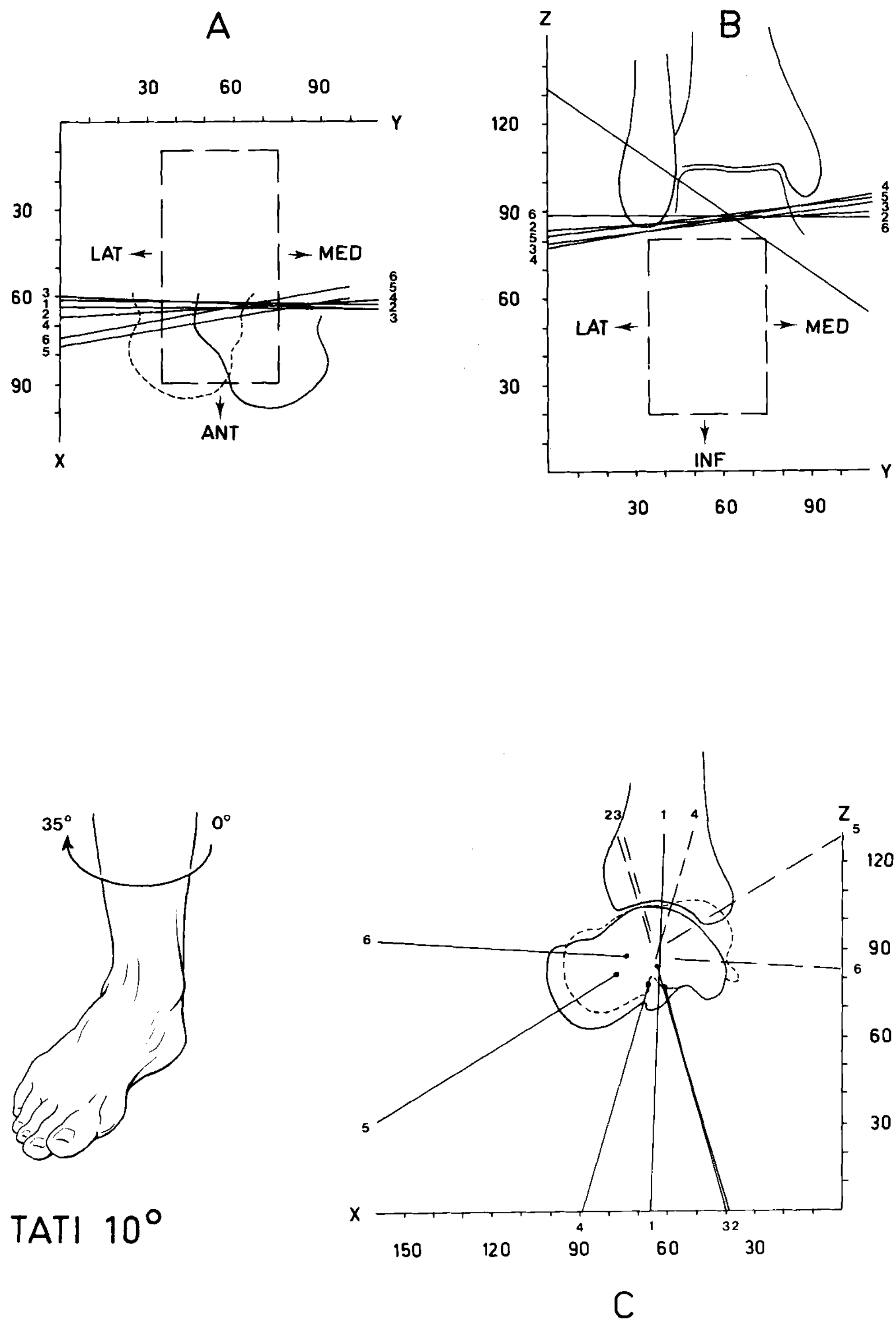


Figure 11-1. Projections of relative talotibial helical axes (TATI 10°) partial range.

abduction component. Besides, in phase 1, the talus lags behind the exorotating tibia; in other words, there is 'talar delay'.

1. The deviation angles, π TATI 10°, without phase 1 (see Table 11-1)
Among the 10 preparations there were some with axes running predominantly from anteromedial to posterolateral, the others running from anterolateral to posteromedial. Regardless of the sign, π for all phases ranged from 6.2° to 161.2°. The mean value of π for each of the preparations ranged from -102.0° to 107.5°. Accordingly, the TATI 10° axes in a dorsoplantar projection were always at a wide angle with the X-axis c.q. the longitudinal axis of the foot.
N.B.: Table 11-1 shows that three times noticeably low values of π were computed, viz. 6.2°, 6.4° and 8.2°, respectively, with computed rotations of 1.3°, 9.4° and 0.9°, respectively.
Two of these aberrant values of π can be attributed to inaccuracy resulting from a small rotation. In this connection it may be noted that considering the large number of small rotations for the relative talotibial movement (see Table 11-4), a far greater variation of π might be expected; clearly, the error due to inaccuracy is not too bad in practice!

However, in one phase in one preparation (nr 8 last phase) we did compute a large rotation (9.4°) with a small angle π (6.4°) and an angle φ of 33°. This indicates a strong inversion component combined with an adduction. This would mean that the values 'tilts' a little in the tibiofibular mortise; the foot, however, wants to 'turn'. Apparently, the talus is no longer able to follow tibial latero rotation, where as the tibia in this preparation is exorotated still further, resulting in a 'non-physiological' inversion tilt of the talus c.q. the foot. This 'abnormal' behaviour of the talus in this phase in this preparation was observed not only during the relative talotibial movement but also during the absolute talar movement, with abnormally small angles of deviation and inclination (32.8° and 24.9°, respectively) as well as during the relative talocalcaneal movement with an abnormally large deviation angle and an abnormally small inclination angle (78.7° and 13.3°, respectively) and further during the relative talonavicular movement with a 'normal' deviation angle and an abnormally small inclination angle (6.5° and 2.5°, respectively). The mechanism is consistent in this sense that whenever some 'abnormal' movement takes place in the chain, abnormal movements are registered for all movements in which the bone in question is involved.

2. The inclination angles, φ TATI 10°, without phase 1 (see Table 11-2)
There are preparations in which axes run from laterosuperior to medioinferior and others in which they run from lateroinferior to mediosuperior. In other words: angles open both in the lateral and in the medial direction. Regardless of the sign, the inclination angle ranged from 0.4° to 83°. The mean value of φ in the 10 preparations ranged from -6.4° to 66.4°. Interestingly, Table 11-2 shows that

Table 11-3. Angles between the successive axes γ TATI 10°.

Specimen	R	R	R	R	R	R	R	L	L	L
	1	2	3	4	5	6	7	8	9	10
Phase										
γ 2-3	5.1	3.2	47.3	15.9	29.9	18.3	23.2	11.0	6.6	17.4
γ 3-4	4.9	21.0	10.3	10.9	26.2	6.3	14.6	71.2	24.4	66.1
γ 4-5	7.6	53.9	4.6	170.0	11.3	2.8	6.3	18.6	21.5	121.8
γ 5-6	6.4	136.9	7.2	15.2	8.8				11.8	50.8
$\Sigma\gamma$	24.0	215.0	69.4	212.0	76.2	27.4	44.1	100.8	64.3	256.1

Table 11-4. Talotibial rotations (TATI α 10°) and translations (TATI t 10°), partial range.

Specimen		R	R	R	R	R	R	R	L	L	L	
		1	2	3	4	5	6	7	8	9	10	
	Phase											
t	1	0.1	0.1	0.0	0.0	0.3	0.1	0.1	0.0	0.0	0.0	TATI mm
α		2.9	4.1	6.6	4.3	7.0	4.8	3.7	3.2	3.2	3.1	TATI°
t	2	0.2	0.1	0.1	0.1	0.2	0.0	0.1	0.0	0.0	0.1	TATI mm
α		3.9	4.2	3.6	4.0	5.1	4.7	1.6	3.3	1.6	3.3	TATI°
t	3	0.2	0.1	0.1	0.0	0.0	0.0	0.1	0.2	0.0	0.2	TATI mm
α		3.6	3.1	5.8	4.4	5.0	7.6	1.3	3.6	0.8	2.1	TATI°
t	4	0.1	0.0	0.1	0.1	0.2	0.1	0.1	0.6	0.0	0.1	TATI mm
α		3.0	1.6	6.2	1.5	6.3	6.3	2.5	5.8	0.7	0.7	TATI°
t	5	0.0	0.1	0.1	0.1	0.1	0.0	0.2	0.1	0.0	0.0	TATI mm
α		2.1	0.6	4.0	1.5	6.3	3.0	3.4	9.4	0.9	0.6	TATI°
t	6	0.0	0.0	0.0	0.1	0.0				0.1	0.0	TATI mm
α		0.9	1.2	1.8	2.3	3.4				1.0	1.3	TATI°

there are two preparations (nrs 7 and 9) with high minimal as well as high maximal values of φ, in contradistinction to the other 8 preparations. For these 2, small rotations have been computed for all phases (see Table 11-4). Besides, they show a predominantly adduction component in *all* phases, unlike the predominantly extension component in the other 8 preparations.

Combination of the π and φ data gives axes with different directions for the 10 preparations. However, nearly all these axes in a dorsoplantar projection are projected transversely over the corpus tali.

The positions of the axes and the rotatory directions computed show that in most of the 47 phases, the movement was predominantly one of extension, combined with a small abduction component and, strictly speaking, a very small inversion component as well.
However, in two preparations (nrs 9 and 10) the movement computed for the last phase was a combination of flexion and adduction with a very small inversion component.

3. The deviation angle π and the inclination angle φ in the first phase TATI 10°
Since for this first phase the relative talotibial rotation was found to be large (see Chapter 11.1.2) and the values for π and φ were therefore reliable, and since there are striking differences with the other π and φ values, the data for this first phase are discussed separately. The π and φ values for the first phase are listed in Tables 11-1 and 11-2.
The deviation angle π, irrespective of the sign, ranged from 51.2° to 88.8°.
The inclination angle φ ranged from 34.5° to 86.5°, average value of φ for the first phase, 65.5°. In 8 of the 10 preparations (nrs 2, 3, 4, 5, 6, 7, 8 and 9), a very large inclination angle and a large deviation angle were computed for that first phase. Considering the direction of rotation, this indicates a large adduction component in that first phase. This first phase may be regarded as a phase of adjustment of the tibiotalar transmission mechanism at the start of the tibial rotation. In fact this confirms the 'talar delay'. Earlier, during the reproducibility analysis (see Chapter 8), we already observed a 'taking up the slack' in the first phase, followed by a more 'constrained mechanism' with high reproducibility during the subsequent phases. In the absolute tibial rotations, compared with the absolute talar rotations, we also observed this talar delay in the first phase (see Chapter 10.2.2). Comparing the inclination angles φ for the first and second phases, we observe in 8 of the 10 preparations (nrs 1, 2, 3, 4, 5, 6, 8 and 10) a pronounced decrease to far lower values in that second phase. In other words: precisely in that second phase there was a larger extension component of the talus relative to the tibia considered stationary. In 2 preparations (nrs 7 and 9) with very small rotations, this phenomenon was less pronounced.

4. The angles R π and R φ of the bundle width, the bundle angle. (Tables 11-1, 11-2)
R π ranged from 2.7° to 142.0°. R φ ranged from 9.7° to 152.5°.

5. The angles between the talotibial axes (γ)
These are listed in Table 11-3.
The angles between pairs of successive axes ranged from 2.8° to 170.0°. These successive angles were added up per preparation; these summation angles ranged from 24.0° to 256.1°.

6. Comparison with the literature
Most authors for the talocrural joint describe one rotation axis, running a more or less transverse course at the level of the borderline between the talar cylindre and the tibia.
Admittedly, Barnett and Napier (1952) and Hicks (1953) indicated two axes of motion; these, however, correspond to a transition from starting to end position. These axes are referred to in the discussion of the literature on the total range. De Vogel (1970) for the talocrural joint mentioned the possibility of an infinite number of axes: no single fixed axis could be indicated. In our experiment, only a small tract in the talocrural joint has been examined. On the basis of our observation, we computed an axis with a transverse direction for the talotibial movement, in agreement with the literature.

11.1.2 Rotations and translations along talotibial axes, partial range

1. The rotations, α TATI 10°, without phase 1 (Table 11-4)
The rotation α around the relative talotibial helical axis ranged from 0.7° to 9.4°. In most phases, small rotations were observed; in 37 of the 47 phases, a rotation amounting to less than 5° was seen.
Considering the fairly horizontal axes and the given direction of rotation, in 8 of the 10 preparations (nrs 1, 2, 3, 4, 5, 6, 8 and 10) extension of the talus relative to the tibia occurred. In 2 preparations (nrs 7 and 9), the rotations were noticeably small, which rendered the position of the axes c.q. the classification of the principal rotation component unreliable.
In a few preparations (nrs 9 and 10), conversely, a combination of flexion and adduction was found in the last phase.

The rotation α, TATI 10° in the first phase, ranged from 2.9° to 7.0°. In six preparations this 'first-phase' rotation was larger than that of the second phase, while in four preparations it was slightly smaller. Therefore, considering the very steep axial direction and the direction of the rotation, in this first phase there was a (large) adduction of the talus in relation to the tibia (see also Chapter 10.2.2 'talar delay').

2. The translations, t TATI 10°, without phase 1 (Table 11-4)
The translation t along the relative talotibial helical axis ranged from 0.0 mm to 0.2 mm. In most phases, very small translations were found; in 39 instances, the translation was 0.1 mm or less.
The direction of translation was fairly constant. In most phases, a transition of the talus along the helical axis in the medial direction was seen. Considering the required accuracy, only translations corresponding to a translation of 3° or more are relevant.
The relative talotibial translation in the first phase ranged from 0.0 mm to 0.1 mm, in 9 of the 10 preparations. In one preparation (nr. 5), the translation amounted to

0.3 mm. The direction of the translation in that first phase was away from the origin in all 10 preparations.

11.1.3 Directions and positions of talotibial axes, total range

Figure 11-2 shows the three projections of the single relative talotibial helical axis as computed for the total movement of preparation nr 1. Combination of the three projections reveals that in relation to the tibia, the talus appears to move around one single axis, at an approximately right angle to the longitudinal direction of the foot, passing through the corpus tali, with a direction from anterolaterosuperior to posteromedioinferior. This position of the axis corresponds to an extension movement of the talus in relation to the tibia.

1. The deviation angles, π TATI 30°/35° (Table 11-5)
Taking into account the left right difference, these angles ranged from -89.4° to 62.5°. The mean deviation angle was -55.2°. In two preparations (nrs 7 and 8), the deviation angles were particularly small, viz. 20.2° and 37.1°, respectively; in the other preparations, π: irrespective of the sign was 62.5° or larger.
N.B.: There was no similarity of direction in relation to the sagittal plane; three times, the direction was from anterolateral to posteromedial and 7 times, from anteromedial to posterolateral (cf. the diversity of directions for the partial range).
In case of a high value of π, as found for preparation nr 1, the sign is not very important since the projection of the axis in any case cuts straight across the longitudinal direction of the foot.

Table 11-5. Talotibial deviation angles (π TATI 30°/35°) and inclination angles (φ TATI 30°/35°) total range.

Specimen	TATI π 30°/35°	TATI φ 30°/35°
1 R	- 89.4° (270.6°)	6.6°
2 R	- 91.8° (268.2°)	33.2°
3 R	- 85.6° (274.4°)	20.4°
4 R	- 72.3° (287.7°)	57.8°
5 R	- 82.8° (277.2°)	24.6°
6 R	- 88.2° (271.8°)	6.1°
7 R	20.2°	88.9°
8 L	37.1°	37.5°
9 L	- 62.5° (117.5°)	77.1°
10 L	87.7°	31.6°

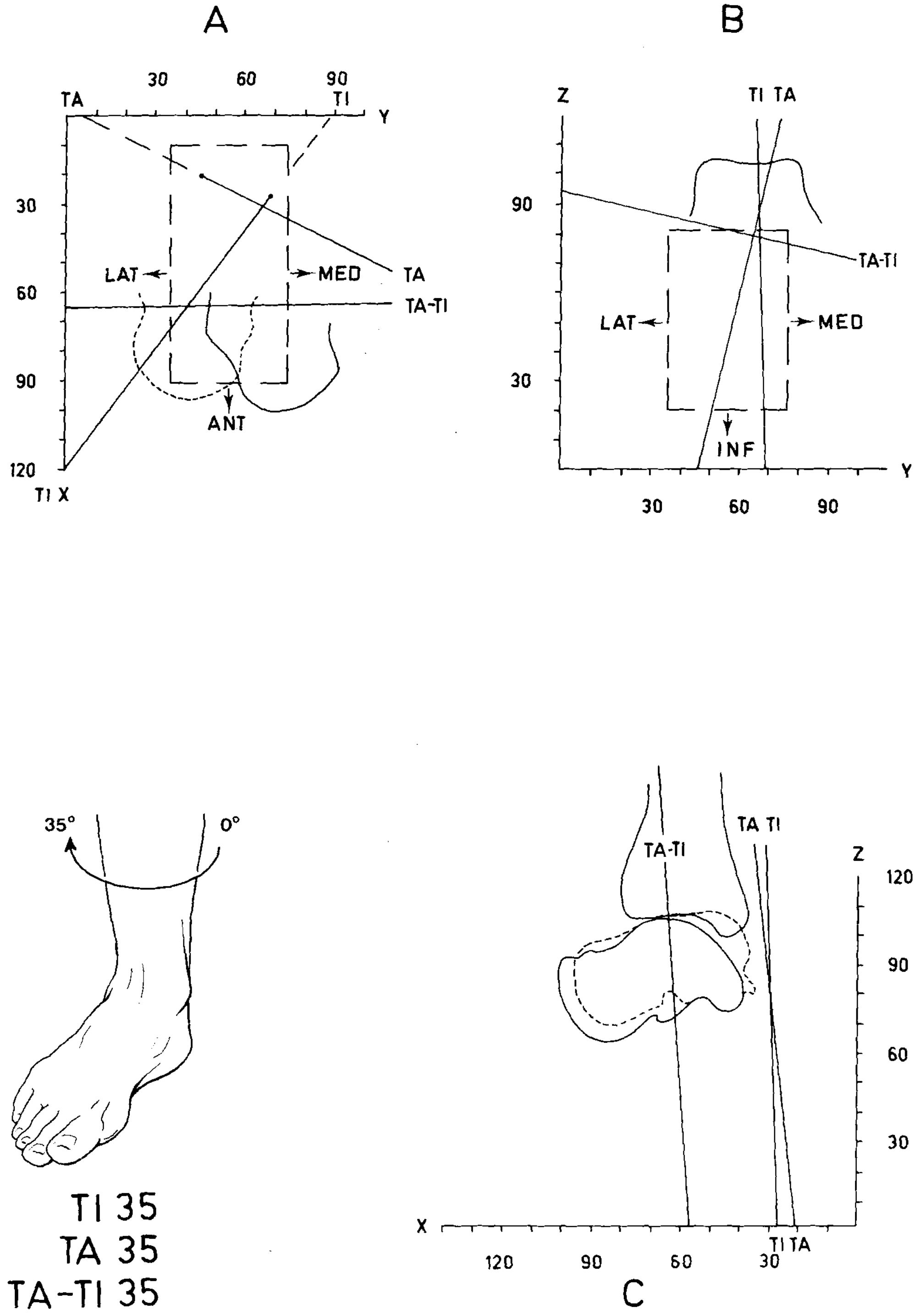


Figure 11-2. Projections of relative talotibial (TATI 30°/35°), absolute talar (TA 30°/35°) and absolute tibial (TI 30°/35°) helical axes, total range.

2. The inclination angles, φ TATI 30°/35° (Table 11-5)
Irrespective of the sign, these ranged from 6.1° to 88.9°. The mean value of φ here amounted to 38.4°.
N.B.: Similarity of direction in relation to the basal plane was not always observed here, either; twice there was an axis running from posterosuperior to antero-inferior and 8 times one running, conversely, from anterosuperior to postero-inferior.
An outstanding feature of these inclination angles was the high degree of interindividual variability.

3. Comparison with the literature
In our experiments we have described a part of the trajectory of the talotibial movement, for the transition from starting to end position. In the literature, the talotibial movement is described for transition from starting to end position of the talus in relation to the tibia. Where the movement in the talocrural joint is concerned, three groups of authors may be distinguished:

a. the group of authors who described the talotibial movement as a rotation round a single fixed axis which may or may not be associated with a translation along that one fixed axis (Von Lanz and Wachsmuth (1938, 1974), Fick (1904), Fischer (1906, 1907), Meyer (1856, 1886), Kapandji (1970), Elftman (1960), Elftman (1960), Inman (1977) and Caillet (1968)).
This single fixed axis a 'transverse' position in relation to the longitudinal axis of the foot. Inman (1977) described this position more accurately as an oblique transverse axis passing just as a 'connecting line' between the lower tips of the medial and lateral malleoli. Caillet (1968) describes this single axis as passing not through the medial malleolus but through a point approx 1 cm lower.

b. The group of authors who described the talotibial movement as a rotation round two axes, viz. one axis for the dorsoflexion and one axis for the plantar flexion movement. Barnett and Napier (1952) described for the transition from dorsoflexion to the neutral position a single axis medially higher than laterally and passing between the tips of the medial and lateral malleoli. For the movement from plantar flexion to the neutral position they described a second single axis: higher laterally, 2 cm below the tip of the medial malleolus.
Hicks (1953) described two similar axes, accurately indicated in three directions in his drawings.

c. The group of authors who described an (infinitely) large number of axes for the movements in the talocrural joint (De Vogel, 1970 and Van Langelaan, 1974). De Vogel asserted that in his view a motion axis could be determined for every position of the talocrural joint in relation to the talus and that these axes would not be identical for all positions.
In De Vogel's opinion, therefore, it is necessary to postulate a 'moving' axis describing a movement accounting for the anteroposterior movement of the tibia

in relation to the talus, the talotibial rotation and the talar tilt. However, he considered this 'far-fetched' and proposed ceasing all discussion of an axis of the talocrural joint.
In contradistinction to De Vogel, we ourselves use the concept of a 'moving' axis of rotation in the sense of a discrete or of an instantaneous helical axis. The fact remains clear that De Vogel in his experiments has clearly recognized the relative talotibial movements.

11.1.4 Rotations and translations along talotibial axes, total range

1. The rotations, α TATI 30°/35° (Table 11-6)
The rotations ranged from 3.4° to 14.1°, with an average of 8.5°. The direction of the rotation of the talus in relation to the assumedly stationary tibia are similar for all 10 preparations. Considering the position and direction of the axis, the computed direction of rotation gives us a combined extension-adduction movement. Mostly, the extension component is predominant; it was only in a few preparations that the adduction component predominated (e.g. preparation nr 7).

2. The translations, t TATI 30°/35° (Table 11-6)
The translations ranged from 0.0 mm to 0.7 mm, with an average of 0.2 mm. The directions of translation were dissimilar; in 2 preparations (nrs 1 and 10), the talus shifted slightly in the medial direction, while in the other 8 preparations it did so in the lateral direction.

3. Comparison with the literature
As mentioned in relation to the stepwise data, no comparable data are known.

Table 11-6. Talotibial rotations (α TATI 30°/35°) and translations (t TATI 30°/35°) total range.

Specimen	TATI α 30°/35°	TATI t 30°/35°
1 R	8.3°	0.3 mm to posteromedial
2 R	5.9°	0.2 mm to posterolateral
3 R	10.8°	0.1 mm to anterolateral
4 R	5.5°	0.0 mm
5 R	14.1°	0.1 mm to anterolateral
6 R	11.2°	0.2 mm to anterolateral
7 R	8.3°	0.2 mm to posterolateral
8 L	12.1°	0.7 mm to anterolateral
9 L	5.2°	0.1 mm to posterolateral
10 L	3.4°	0.1 mm to posteromedial

11.2.1 Directions and positions of talocalcaneal axes, partial range

We begin once more with a description on the basis of the drawings for preparation nr 1.
In the dorsoplantar projection (Figure 11-3a), the axes run from anteromedial to posterolateral. In this projection, the axes constitute a bundle divergent to posterolateral which, however, is at an acute angle to the X-axes.
In this projection, also, the bundle of axes covers the region of the tarsal sinus and canal. In the end position of the talus, the projection of the axes is entirely outside the talar head and neck, viz. medially to them.

Table 11-7. Coordinates tarsal sinus and tarsal canal (specimen 1).

	X	Y	Z
Tarsal sinus	70	60	60
	60	70	70
Tarsal canal	60	70	70
	50	75	80

In the frontal projection (Figure 11-3b), the direction of the axes is form mediosuperior to lateroinferior with, in addition, divergence in the lateroinferior direction.
In the sagittal projection (Figure 11-3c), the helical axes form a bundle with a position halfway between horizontal and vertical; the axes run from antero-superior to posteroinferior. The projection of the bundle of axes is found over the region of the tarsal sinus and canal. This area is localized within the coordinates of Table 11-7.

The combination of the three projections justifies the conclusion that the movement of the talus in relation to the calcaneus is around axes that form a bundle, which bundle makes an acute angle with the longitudinal direction of the foot and occupies a position halfway between horizontal and vertical in relation to the basal plane.
The axes pass through the tarsal canal and their direction is from anteromedio-superior to posterolateroinferior, which corresponds to a combined abduction-eversion movement with a little dorsoflexion, or an adductioninversion movement with a little plantar flexion. The wider the angle φ of the helical axis, the greater the ab- or adduction component, while a small angle φ corresponds to a greater eversion or inversion component.

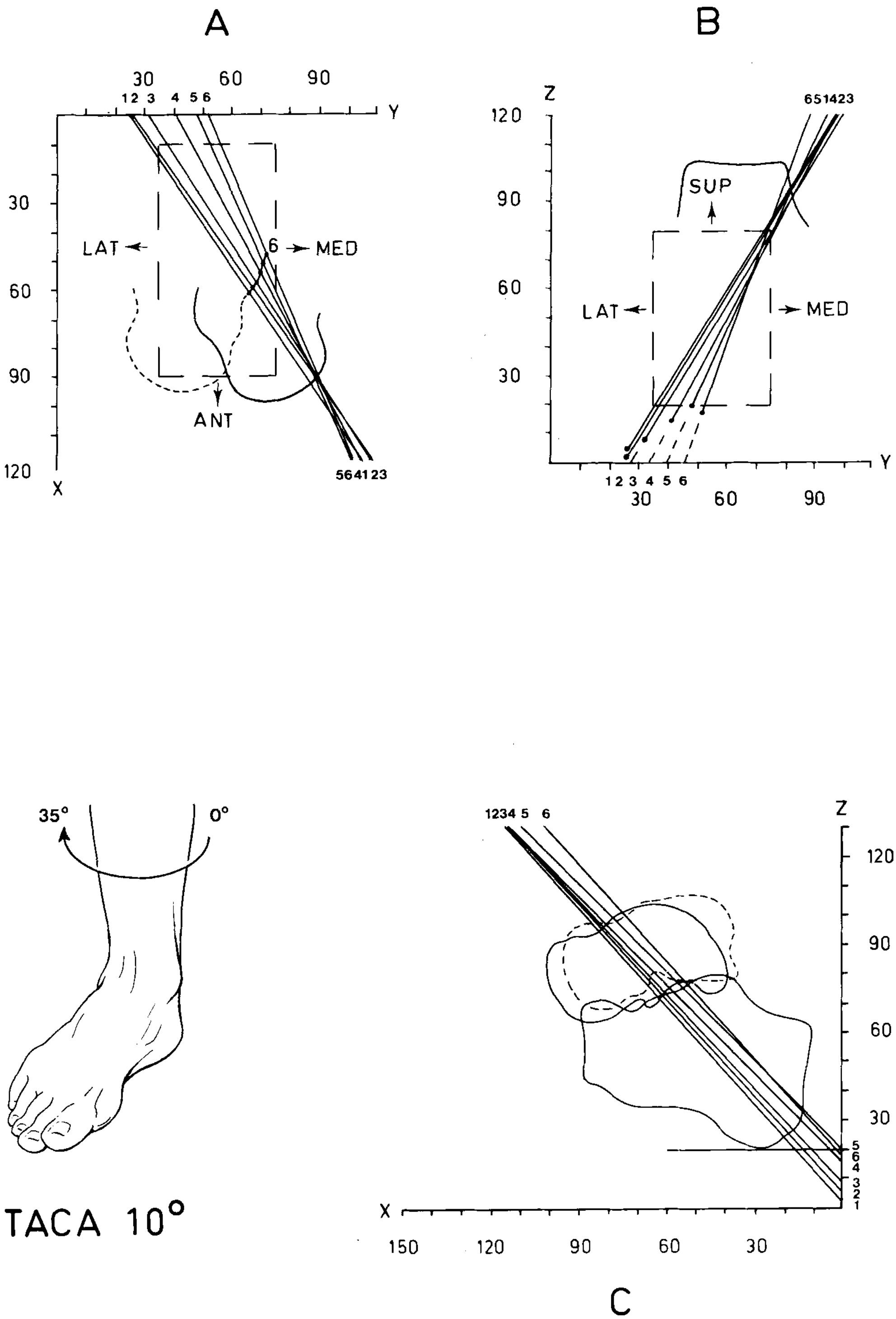


Figure 11-3. Projections of relative talocalcaneal helical axes. TACA 10°, partial range.

Table 11-8. Deviation angles of subtalar axes (π TACA 10°) with summation, mean and range of deviation angles.

Specimen	R 1	R 2	R 3	R 4	R 5	R 6	R 7	L 8	L 9	L 10
Phase										
π 1	33.8	33.1	345.5	20.9	20.4	17.8	28.6	342.8	344.8	328.5
π 2	34.3	33.1	16.1	24.5	29.5	29.8	24.9	-22.2	-18.1	-30.5
								(337.4)	(341.9)	(329.5)
π 3	32.2	33.2	28.1	24.9	32.3	35.6	20.7	-23.2	-13.1	-24.4
								(336.8)	(346.9)	(335.6)
π 4	27.6	32.8	31.2	22.2	33.9	33.9	17.5	-36.8	-3.3	-14.8
								(323.2)	(356.7)	(345.2)
π 5	24.1	32.2	30.8	13.6	32.3	29.8	25.1	78.7	2.6	-12.4
										(347.6)
π 6	22.2	21.4	28.5	1.5	30.3				4.8	-5.7
										(354.3)
$\Sigma\ \pi$	140.5	152.7	134.7	86.7	158.3	129.1	88.2	-3.5	-27.1	-87.8
$\overline{\pi}$	28.1	30.5	26.9	17.3	31.7	32.3	22.1	-0.9	-5.4	-17.6
R π	12.2	11.8	15.1	23.4	4.4	5.8	7.6	115.5	22.9	24.8

Table 11-9. Inclination angles of subtalar axes (φ TACA 10°) with summation, mean and range of inclination angles.

Specimen	R 1	R 2	R 3	R 4	R 5	R 6	R 7	L 8	L 9	L 10
Phase										
φ 1	42.9	38.6	57.9	43.3	30.7	56.8	44.7	40.9	51.4	40.9
φ 2	42.0	39.7	47.9	32.6	31.0	46.4	48.5	30.1	58.0	41.1
φ 3	41.9	39.1	39.0	26.8	29.6	37.5	52.4	27.1	62.4	43.7
φ 4	41.7	41.1	35.9	25.8	31.1	37.5	56.9	22.2	60.3	50.4
φ 5	42.1	48.0	38.1	35.5	28.3	43.7	59.1	13.3	53.3	56.8
φ 6	45.5	57.7	41.6	49.3	29.1				47.9	67.4
$\Sigma\ \varphi$	213.2	255.6	202.5	170.0	149.6	165.1	216.9	92.7	281.9	259.4
$\overline{\varphi}$	42.6	45.1	40.5	34.0	29.9	41.3	54.2	23.2	56.4	51.9
R φ	3.8	18.0	12.0	23.5	2.8	8.9	10.6	16.8	14.5	26.3

1. The deviation angles, π TACA 10°, without phase 1 in all 10 preparations (Table 11-8)
In nearly all phases, the axes ran from anteromedial to posterolateral. Taking into consideration the left-right difference, π for all phases ranged from -78.7° to 36.8°. It was only in one preparation (nr 8) that there was an extremely aberrant value of π (-78.7°) in the last phase. The mean value of π in the 10 preparations ranged from 0.9° to 32.3°. In other words, the TACA 10° axes in a dorsoplantar projection always made an acute angle with the X-axis c.q. the longitudinal axis of the foot.

2. The inclination angles, φ TACA 10°, without phase 1 in all 10 preparations (Table 11-9)
In all phases of all preparations, the directions of the helical axes were from anterosuperior to posteroinferior, making an angle open to anterior.
In nearly all phases, the magnitude of the inclination angle was between 25.8° and 67.4°. It was only in one preparation (nr 8) that the inclination angle was narrower in the last phase. No changes of quadrant were seen. The mean value of φ in the 10 preparations varied between 23.2° and 56.4°. In other words, the TACA 10° axes were always at a wide angle to the basal plane.
Combination of the π and φ values determined shows that all 10 preparations had a bundle of axes whose direction nearly always was from anteriomedio-superior to posterolateroinferior. The axes cross the region of the tarsal sinus and canal.

3. Changes of position of the axis of movement; changes of π and φ as a function of motion
Concerning the movement of the axis in relation to the coordinate axes we observed in 9 of the 10 preparations a decrease of π, i.e. a movement of the axis from an anteromedial position in an anterolateral direction. Preparation nr 8 was an exception, with a movement in the opposite direction.
In 8 of the 10 preparations we saw a gradual increase of the angle φ, preceded in some cases by an initial decrease; in other words, the axis turned to a steeper angle. In 2 preparations (nrs 8 and 9), there was a predominant decrease of the angle φ.

4. The angles R π and R φ of the bundle width, the bundle angle (Table 11-8, 11-9)
Provided the axis does not move backward and forward (which it clearly does not, see 3a), the difference between πmax and πmin constitutes a measure of the width or angle of the bundle. This bundle angle R π ranged from 4.4° to 24.8° for the 10 preparations.
In a similar way, a bundle angle R φ in relation to the basal plane was determined; this ranged from 2.8° to 26.3°.
Therefore, as Tables 11-8 and 11-9 show, there are preparations with small bundle angles for π as well as for φ (e.g. preparations nrs 5, 6 and 8). This does

Table 11-10. Angles between the successive axes γ TACA 10°.

Specimen	R 1	R 2	R 3	R 4	R 5	R 6	R 7	L 8	L 9	L 10
Phase										
γ 2-3	1.6	0.6	12.5	5.8	2.8	9.9	4.7	3.2	5.0	5.2
γ 3-4	3.4	2.1	3.9	2.7	2.1	1.3	4.9	13.2	5.1	9.4
γ 4-5	2.7	6.9	2.2	12.2	3.1	6.9	4.6	72.5	7.7	6.5
γ 5-6	4.7	11.7	3.9	16.4	2.1				5.6	11.0
$\Sigma\ \gamma$	12.4	21.3	22.5	39.1	10.1	18.1	14.2	88.9	23.4	32.1

not mean, however, that in these preparations the axis is virtually motionless, because there remains the possibility of translation! We shall return to this topic in paragraph 8.

5. The angles between the various talocalcaneal helical axes (γ)

These are listed in Table 11-10, in which phase 1-2 is omitted. The angles between pairs of successive axes then ranged from 0.6° to 72.5°. Just as the above-mentioned bundle angles, they give an idea of the movement of the axis. These successive angles were summated per preparation, and ranged from 10.1° to 88.9°. This high value of the last angle γ in preparation nr 8 may be due to an error in the determined position of axis nr 5, because for that phase an α of only 3.1° was calculated.

6. Comparison of relative talocalcaneal helical axes with absolute talar and absolute calcaneal helical axes

The values of φ for CA, TA and TACA have been compared; see Tables 10-10, 10-11 (Ta 10°), Tables 10-20, 10-21 (CA 10°), Tables 11-8, 11-9 (TACA 10°). There are clear interindividual differences: a comparable pattern for all 10 preparations could not be determined. On the other hand, there did appear to exist some similarity between the changes of angle φ for CA and TACA. Decreases and increases of φ for CA were found to be associated with decreases and increases, respectively, of angle φ for TACA.

7. Review of tarsal functional anatomical concepts in the literature

As a preliminary to the discussion of the position and direction of the helical axes in relation to the talocalcaneal joint and the ligaments in the tarsal sinus and canal, a short review should be presented of the literature on the functional anatomy of the tarsal sinus and canal.

The tarsal sinus/canal may be described as a conical cavity between the talus

and the calcaneus with its maximal diameter laterally. In the medial direction this cavity narrows, but it slightly widens again at the medial end, behind the talar sustentaculum. The tarsal canal is some 10-15 mm high, 3-5 mm wide and 15-20 mm long. Various authors have given different descriptions of the contents of the tarsal sinus and canal.
Moreover, the various authors have attributed different functions to identical ligaments. Lapidus (1963), for instance, describes only one ligament, called the ligamentum talocalcaneale interosseum, which allegedly fills the entire tarsal sinus and canal to such an extent that the ligament would even be distinctly palpable just in front of the lateral malleolus! This ligament partitions the anterior and posterior articular cavities of the subtalar joint with fibres running in an oblique direction.
The plane of this ligament was said to make a right angle to the 'talocalcaneal rotation axis'. In Lapidus' conception, the major part of this ligament lies laterally to the rotation axis, so that "it is obvious that this ligament becomes tense on inversion and relaxes on eversion of the foot. Consequently: eversion (pronation or valgus) is the position of relaxation and therefore any lesion of the subtalar joint is associated with a protective spasm of the evertors".

Smith (1958) distinguished three major ligamentous structures in the tarsal sinus and canal, viz.: the ligamentum cervicale, the inferior extensor retinaculum and the tarsal canal ligament (c.q. the ligamentum talocalcaneale interosseum proper).
The ligamentum cervicale is situated in the anterior part of the tarsal sinus and is inserted on the floor of the tarsal sinus behind and medially to the insertion of the musculus extensor digitorum brevis. The talar insertion is situated latero-inferiorly on the collum tali. The direction of the fibres is from posterolatero-inferior to anteromediosuperior.
The retinaculum extensor inferius enters the tarsal sinus at the lateral side and within that sinus divides into three branches, the lateral, the intermedial and the medial branch. The intermedial branch descends to the calcaneus, the medial branch penetrates into the tarsal canal where it attaches itself to the sulcus calcanei, and the lateral branch turns into the deep fascia on the lateral side of the foot. The tarsal canal ligament c.q. ligamentum talocalcaneale interosseum is a broad ligament, extending from lateroinferior to posterosuperior, situated deep in the tarsal canal. There is a broad, linear insertion on the calcaneus; the insertion on the talus is localized on the medial part of the sulcus tali.

Smith, by trial and error determined 'the' subtalar rotation axis with the aid of a pin through the talus and calcaneus. At subsequent dissection the pin was found between the ligamentum cervicale and the tarsal canal ligament. From this, Smith concluded that the ligamentum cervicale is concerned with the limitation of inversion, whereas the function of the tarsal canal ligament is to assist in the limitation of eversion"; in other words, he considered the ligament's only function to be a limitation of movement. It is to be regretted that Smith made no study of the tension of the ligaments during in- and eversion. Kinematically, only ligaments that tense during movement can play a part in controlling movement; a simple relationship between ligaments and the position of a rotation axis, as postulated, among others, by Smith, is difficult to define.

Huson (1961) in his 'Een ontleedkundig-functioneel onderzoek van de voetwortel' (An anatomical-functional study of the tarsus) presents a detailed description of the ligamentous structures in the tarsal sinus and canal.
He, also, found a ligamentum cervicale, an inferior extensor retinaculum and a ligamentum talocalcaneale interosseum.
The fibres of the talocalcaneal interosseal ligament run in the longitudinal direction of the tarsal canal, i.e. from latero-anterior to medio-posterior.
On further examination, this ligament proved to consist of two bundles: a medial oblique bundle, almost a cylinder-shaped cord, running rather in an antero-posterior direction, with short fibres, and a more flattened lateral oblique bundle, a with relatively longer fibres running in a less markedly medial direction (see Figure 11-4). The insertion of the lateral oblique cord on the talus is situated close to the insertion of the medial oblique cord on the calcaneus. When the talocalcaneal movements were tested, it was found that the fibres of the ligamentum talocalcaneale interosseum remained tense throughout! It was further found that the ligamentous fibres that seal the posterior articular cavity at the front and delimit the anterior articular cavity at the back become gradually shorter in the medial direction. The movement of the talus in relation to the calcaneus which they permit should be maximal on the lateral and minimal on the medial side. In other words: they favour a swing of which the rotation centres should be situated medially in the narrowest part of the tarsal canal. This means that Huson regards the constantly taut oblique bundles of the ligamentum talocalcaneale interosseum as the bands that control the movement. In this respect he clearly disagrees with Lapidus and Smith.

Cahill (1965) also gave a detailed description of the ligaments in the tarsal sinus and canal. He, also, found a ligamentum cervicale, an inferior extensor retinaculum and a tarsal canal ligament. The lastmentioned structure, the actual ligamentum talocalcaneale interosseum, lies in the tarsal canal and is approximately 15 mm long, 5.6 mm wide and 1.6 mm thick. The fibres of this flat ligament run from anterolateral to posteromedial to the roof of the tarsal canal. Their direction is so oblique that the centre of the calcaneal insertion is situated laterally to the talar insertion.
Cahill did not describe any bundles within the ligamentum talocalcaneale interosseum in his Figure nr 8. However, this figure shows that two bundles are definitely present. (See Figure 11-5) Interestingly, it is only in Cahill's study that we find mention of an additional band, 'the oblique talocalcaneal band'. Allegedly, this is a separate group of fibres, to be distinguished from the pars intermedia of the inferior extensor retinaculum, with a joint calcaneal insertion that is subsequently inserted on the talus.

1. lig bifurcatum;
2. lig. cervicale;
3. retinaculum;
4. fibres partitioning off the posterior articular cavity at the front;
5. lateral oblique fibrous band of the lig. talocalcaneale interossei;
6. short vertical fibres behind the anterior articular cavity;
7. medial oblique fibrous band of the lig. talocalcaneale interossei.

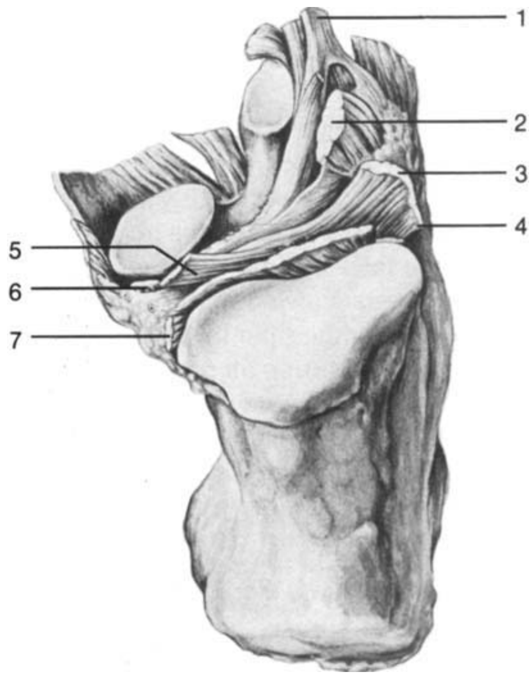


Figure 11-4. Right calcaneus with the insertions of the talocalcaneal ligaments according to Huson.

1. Medial root to talus;
2. Lig. of the tarsal canal;
3. Subtalar joint capsule;
4. Medial root to calcaneus;
5. Fibers from calcaneal attachment of intermediate root to talus;
6. Intermediate root.

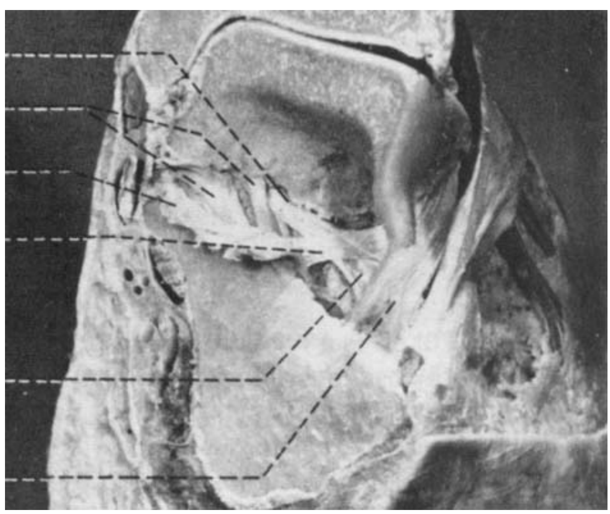


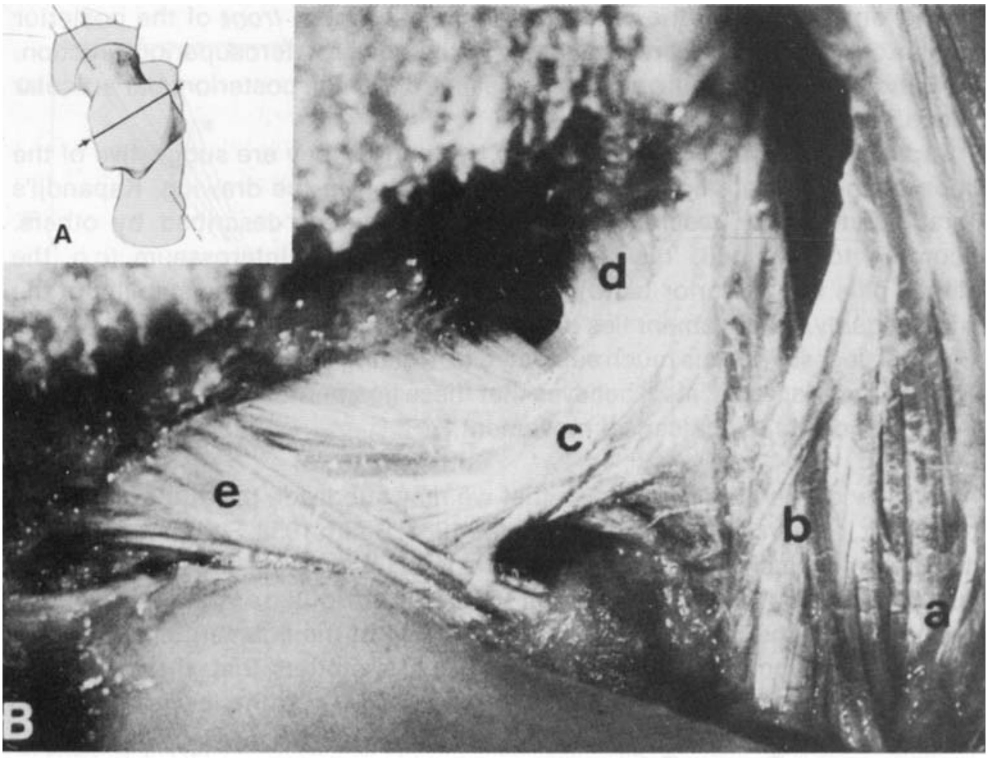
Figure 11-5. Posterolateral aspect of the right foot with ligaments in the tarsal sinus and canal according to Cahill.

(N.B.: This oblique talocalcaneal band described by Cahill is regarded by Schmidt as a variant of a part of the pars medialis of the inferior extensor retinaculum.)

Cahill described the connection of the inferior extensor retinaculum and the ligamentum talocalcanei interosseum. The pars medialis of the inferior extensor retinaculum fuses with the calcaneal insertion of the ligamentum talocalcaneale interosseum. Cahill's oblique talocalcaneal band and a part of the pars medialis join in the talar insertion of the ligamentum talocalcanei interosseum.
Function tests showed that the ligamentum cervicale and the interior extensor retinaculum limited the inversion. The ligamentum talocalcaneale interosseum remained 'taut during all phases of passive movements', no sign of loosening or tightening could be measured and it doesn't have any very obvious function in limiting either inversion or eversion". Cahill, also, suggested that "the talocalcaneal movements are centered around the tarsal canal ligament". This is in complete agreement with Huson's finding.

Schmidt (1978) just as Smith distinguished five distinctly delimited structures in the tarsal sinus and canal, viz.: the retinaculum mm. extensorum inferius, subdivided by direction of the fibres in a pars lateralis, a pars intermedia and a pars medialis; a ligamentum talocalcaneale obliquum (c.q. the ligamentum cervicale) and a ligamentum canalis tarsi. Schmidt in 78% of 40 preparations studied found a bifid talar insertion of the ligamentum canalis tarsi. He believed that the talocalcaneal movement axis was situated in the centre of the tarsal sinus, where the pars medialis and the ligamentum talocalcaneale obliquum cross (see Figures 11-6 and 11-7).
According to Schmidt, when the talus is moved passively in relation to the calcaneus, the supination is limited by the structures situated laterally to the rotation axis, i.e. the pars intermedia and the ligamentum talocalcaneale obliquum. He believed that pronation was limited by the structure situated medially to the rotation axis, viz. the ligamentum canalis tarsi.
In this respect, therefore, Schmidt disagrees with Smith about the function of the pars intermedia.
Schmidt does not offer any further data, either, on the tension during movement of the ligaments examined, nor does he describe in what way he determined the talocalcaneal rotation axis.

Kapandji (1970) gives a very sketchy description of the ligament of the subtalar joint. Kapandji describes a single ligament filling the entire tarsal sinus; in his opinion this is the ligamentum talocalcaneale interosseum. This ligament is said to consist of two separate fibrous bands, viz. the anterior band and the posterior band. The anterior band is inserted on the calcaneal sinus, just behind the anterior articular cavity. The fibres run obliquely in the anterolaterosuperior direction. This band is inserted on the talar sinus just behind the articular cartilage of the caput tali. The posterior band is situated farther back and is also



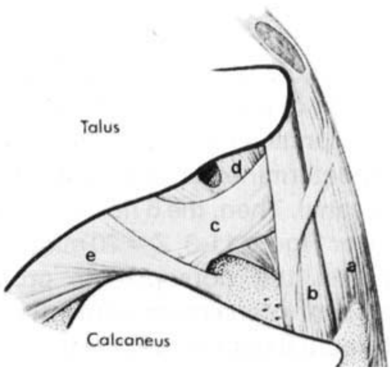


Figure 11-6 and Figure 11-7. Schmidt. Fibre system of the tarsal sinus and tarsal canal of a right foot preparated from the dorsal direction.
A. Direction of cutting (arrow) for opening of tarsal sinus and canal. Axis of the talo-calcaneal joint is shown as a dotted line.
B. Fibre bundles of the tarsal sinus and canal. a = retinaculum mm. extensorum inferius (pars lateralis); b = retinaculum mm. estensorum inferius (pars intermedialis); c = retinaculum mm. estensorum inferius (pars medialis); d = oblique talocalcaneal ligament (cervival ligament); e = ligament of canalis tarsi.

inserted on the floor of the calcaneal sinus, but just in *front* of the posterior articular cavity. The fibres run obliquely in the posterolaterosuperior direction. This band is inserted on the sinus tali, just in front of the posterior talar articular surface.
As Kapandji draws and describes these two bands, they are suggestive of the potion of the cruciate ligaments in the knee joint. In the drawing, Kapandji's lateral band greatly resembles the cervical ligament described by others. According to Kapandji, 'his' ligamentum talocalcanei interosseum (c.q. the anterior plus the posterior band) plays an essential part in the stability of the joint; allegedly, this ligament lies exactly in the continuation of the longitudinal axis of the leg, so that it is much subjected to 'twisting and stretching strain'. This suggests that Kapandji, also, believes that these ligamentous fibres play a part in the control of the talocalcaneal movement.

This review of the literature shows that we may subdivide the authors into two groups, viz. one group of authors (Lapidus 1963, Smith 1958, Schmidt 1978) who attribute an exclusively limiting role to the tarsal ligaments, and another group (Huson 1961, Cahill 1965 and Kapandji 1970) who attributed a limiting as well as a guiding role to the ligaments. This guiding role of the ligaments merits some further discussion. How valid is Huson's assumption that there exists a relationship between ligaments and positions of axes at the level of the short fibres?
In paragraph 8 below, we shall make a further investigation of the relationships between positions of axes and tarsal ligaments, by reconstructing the pathways of the points of intersection for all 10 preparations.

8. Movement of the axis in a path
As established earlier, the bundle of axes passes through the tarsal canal. In order to gain some impression of the positions of these helical axes in the tarsal canal, we have made a horizontal section at a level halfway the 'height' of the tarsal canal. This level was determined arbitrarily as the mean of the lowest and highest levels of the tarsal canal. Then, the 6 helical axes were made to intersect with this horizontal plane (for Figure 11-3, $Z = 70$ mm); this resulted in 6 points of intersection as indicated in the dorsoplantar projection (Figure 11-3a). Subsequently, these 6 points of intersection were interconnected; the result is a path that approximates the actual path of the points of intersection of the bundle of axes with the horizontal plane. These axes 'move' in the bundle along this path from anterolateral to posteromedial. Assuming that the bundles of the ligamentum talocalcanei interosseum remain taut, the axes in this projection during the first part of the subtalar movement prove to be situated in the region of the lateral (anterior) oblique bundle, whereas during the second part of the subtalar movement they should be situated, conversely, in the region of the medial (oblique) bundle. In the dorsoplantar projection we can also see that the direction of the bundle of axes makes either an approximately right angle or, in

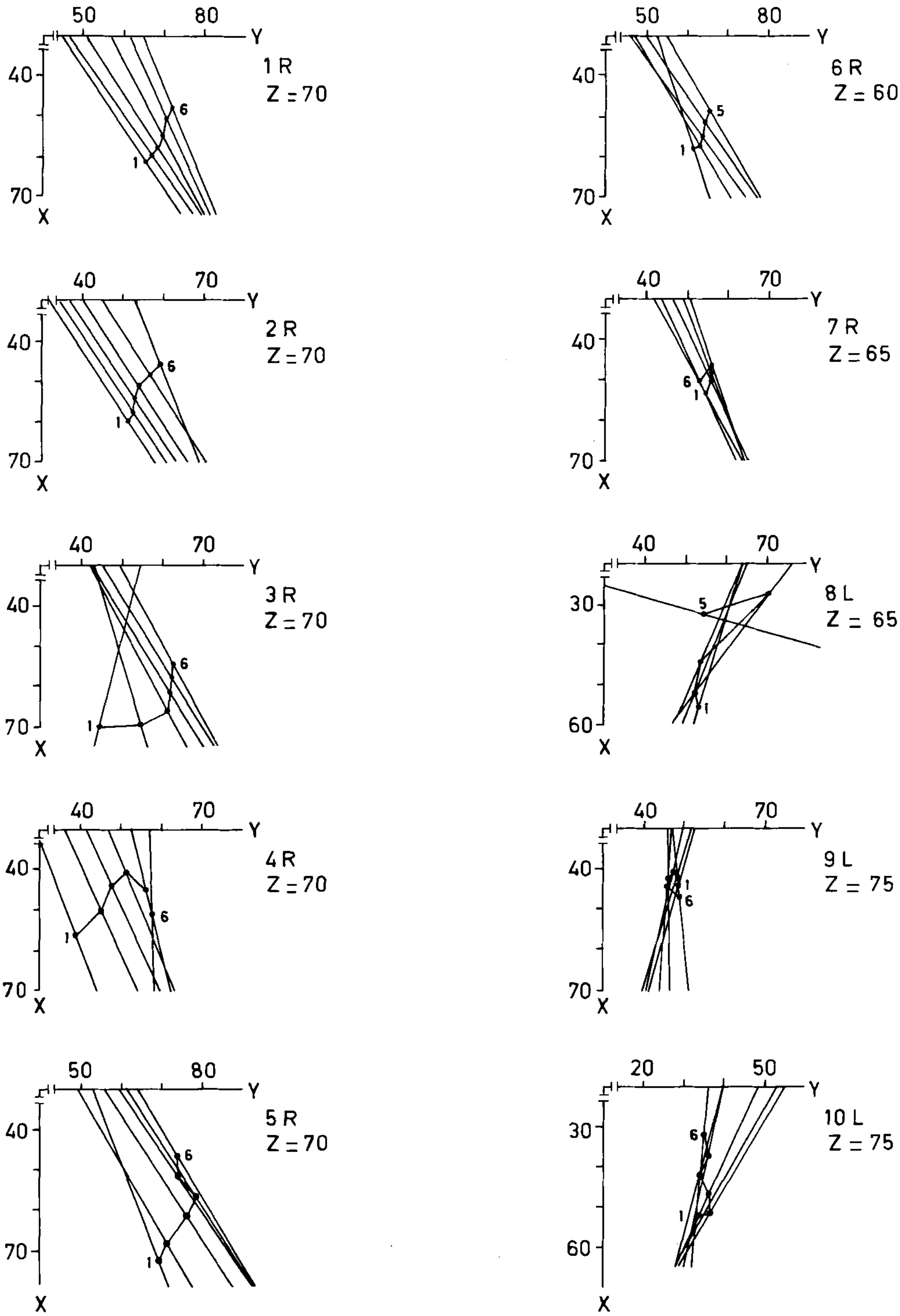


Figure 11-8. Points of intersection (axodepaths) TACA 10° for 10 specimen.

any case, a blunt angle with the ligamentum talocalcaneale interosseum. This holds true of the sagittal projection, as well, but in the frontal projection the direction of the bundle virtually parallels the direction of the fibres of the ligament.

These positions of the axes are in very good agreement with a minimal range of movement of the talus at the level of these ligaments with their short fibres.

All preparations have bundles with the same main direction and also, similar (comparable) paths of points of intersection. It is only in the first and last phases that there are differences.

Figure 11-8 represents the dorsoplantar projections of the bundles of axes with their paths of points of intersection at the level of the tarsal sinus and canal for all 10 preparations. For all 10 preparations, similar directions of the bundles of axes were found, while the direction of the path of the points of intersection was also always from anterolateral to posteromedial.

11.2.2 Rotations and translations along talocalcaneal axes, partial range

1. The rotations, α TACA 10° (Table 11-11)

If we discount phase 1, the value of α in 8 preparations was higher in phase 3 than in phase 2; in 2 preparations (nrs 2 and 7), this was not the case. The rotation ranged from 15.8° to 3.1°. The direction of the rotation, considering the directions of the axes in all phases corresponded to a combined abduction-eversion movement.

Table 11-11. Subtalar rotations (TACA α 10°) and translations (TACA t 10°), partial range.

Specimen		R	R	R	R	R	R	R	L	L	L	
		1	2	3	4	5	6	7	8	9	10	
	Phase											
t	1	0.1	-0.3	0.0	0.0	0.0	0.0	-0.5	-0.1	-0.3	-0.5	TACA mm
α		5.3	8.4	1.5	2.8	2.6	3.5	5.2	3.2	4.9	5.5	TACA°
t	2	0.1	-0.5	0.0	-0.3	-0.1	-0.1	-0.6	-0.3	-0.3	-0.8	TACA mm
α		9.0	12.0	5.9	9.7	5.7	8.9	7.7	8.2	5.9	7.6	TACA°
t	3	-0.1	-0.9	-0.4	-1.2	-0.3	-0.6	-0.5	-0.9	-0.2	-0.9	TACA mm
α		9.3	10.9	12.2	15.8	7.2	13.1	7.2	12.0	5.9	7.6	TACA°
t	4	-0.4	-0.9	-0.9	-1.3	-0.6	-1.0	-0.3	-1.7	-0.2	-0.7	TACA mm
α		9.4	8.8	14.2	13.1	11.6	13.2	5.4	7.8	5.2	6.6	TACA°
t	5	-0.7	-0.6	-0.8	-0.5	-1.4	-0.8	-0.4	-2.1	-0.3	-0.4	TACA mm
α		9.5	6.4	11.1	7.6	15.8	9.8	4.3	3.1	4.2	5.8	TACA°
t	6	-0.6	-0.3	-0.6	0.0	-1.4				-0.4	0.1	TACA mm
α		7.7	5.0	7.8	4.7	12.9				4.0	4.2	TACA°

2. The translations, t TACA 10° (Table 11-11)
Discounting phase 1, the translation t in 8 preparations increased gradually to a maximum, followed in some cases by a decrease. In 2 preparations (nrs 7 and 9) the situation was different. The translation ranged from a minimum of 0 mm to a maximum of 2.1 mm. The direction of the translation in nearly all phases indicated that the talus moved in the posterolateral direction, i.e. towards the origin. Exceptions to this rule were seen twice: once in the starting phase of preparation nr 1 and once in the end phase of preparation nr 10.

3. Comparison of the literature
Comparison of our findings with data from the literature is difficult because none of the investigators has measured the entire subtalar rotation in steps or phases. Most of them only compared the end position with the starting position. Definitions of end and starting positions were not always identical, either.

Certain authors have studied the subtalar movement in phases during walking, which means that they measured only a small part of the total range of movement (Mann and Inman (1964), Wright et al (1964), Close et al (1967), Morris (1977) and Sethi (1977)).

Manter (1941) carried out a study in cadaver preparations. Although he did mention that every 10° talar rotation was associated with a translation of 1.5 mm, his data fail to show that he has measured these translations, also, in phases. Manter probably determined the total range of subtalar motion and subsequently computed the translation in millimetres per 10° rotation.
As mentioned before, Manter regarded the subtalar movement as a purely helical movement; accordingly, he concludes that there exists a regular pattern of subtalar rotation with corresponding subtalar translation.
Our own findings, on the other hand, show that there is no question of a 'regular combination of rotation with corresponding translation'. On the contrary, there exist different combinations of rotation and translation for the various phases of the movement, and a large rotation is certainly not always associated with a large translation!
Wright e.o. (1964) described 'the action of the subtalar and ankle joint complex during the stance-phase of walking'. The table below lists the values of the subtalar supination which they measured during exorotation of the tibia which from the neutral position amounts to approx 12° and takes place between 10% and 50% of the walking cycle (Table 11-12).
Even so, it remains doubtful whether it was indeed the rotation around the talocalcaneal axis that was measured! These authors studied inversion movements of the test shoe in relation to the leg; the test shoe reflects a sort of mean of all movements of bones.
This experiment did not include measurement of the translations, if any, between the talus and calcaneus. Interestingly, the 4° subtalar rotation without corresponding tibial rotation occurred just before the end of the stance phase.

Table 11-12. Subtalar supination according to Wright and co-authors.

Walking cycle	Subtalar supination	Tibial rotation
10% - 20%	2°	6°
20% - 30%	2°	6°
30% - 40%	0°	0°
40% - 50%	4°	0°
10% - 50%	8°	12°

The findings described above, and particularly the successive tibial exorotations of 6° that were accompanied by a decrease of the subtalar rotation, are clearly different from our own findings. We ourselves, namely, have observed an increase of the subtalar rotation with progressive tibial laterorotation.
The differences have to be explained by the fact that the authors could not accurately and selectively measure the movements between the talus and the calcaneus, but only the tilt movement between the test shoe and the leg.
Mann and Inman (1964) plotted the subtalar rotation against the electromyographically determined activity of the intrinsic muscles of the foot. However, the magnitudes of the subtalar rotations indicated in the graph have probably been borrowed from Wright et al. and not determined by direct measurement. Mann and Inman concluded that the supination in the subtalar joint starts at 40° of the walking cycle in normal feat and at 10° in pedes pronati; however, they fail to make clear their precise meaning. The graphic representation of their findings is not always in accordance with what is stated in the text.

Close, e.o. (1967) have made highly specific measurements of the movements of the calcaneus in relation to the talus during the walking cycle, and particularly during the stance phase. They computed the angle between two marking pins, one calcaneal and one talar, which were inplanted transcutaneously into a test subject. These authors obtained highly divergent values for the subtalar rotation when they repeated their experiments in the same test subject. In this connnection they remark: "the subject demonstrated no tendency to duplicate individual curves".
Also, the subtalar rotation showed a high degree of individual variability. For instance, for three test subjects they record 3-4°, 5-6° and 16°, respectively, of subtalar rotation for the entire stance phase. A comparison with the subtalar rotations and phases, as made in our study, is not possible. The causes of the deviating findings obtained by Close et al. may lie, among other things, in their method of study (see Chapter 2, literature). These authors supply no data on subtalar translations, if any.

Inman (1976) made an accurate study of a large series of skeletal preparations, although admittedly in the classical manner. In his test set-up (see Chapter 2, literature), the transition from 'full supination to full pronation' was examined step by step by rotating the calcaneus 10° at a time around the empirically determined subtalar rotation axis; a stylus passed over the inclining posterior talocalcaneal articular surface to measure the transaxial translation. Thus, Inman measured along a circular path over the posterior articular surface of the calcaneus the inclinations of this path. In 58% of the 102 specimens examined, he found an absolute linear foreward displacement of the talus, in 20% he observed a backward linear displacement and in another 20% what he called "complex movements and/or no translation".

The lack of constancy of the results obtained by Inman does not surprise us. His test set-up, namely, in fact measures one component of the fairly variable curvature profile of the articular surface, while in addition it is not at all certain that the stylus also passes over that part of the articular surface that is also followed by the talar articular surface; in other words: whether the stylus does indeed follow the path of the point of contact. Moreover, he found rather high values which in 75% of the experiments varied from 4 mm to 7 mm, whereas in our preparations these values varied from 1 mm to 2.7 mm.
The direction of these translations, unlike in Inman's findings was always the same, viz. dorsolateral.

11.2.3 Directions and positions of talocalcaneal axes, total range

The single, discrete relative talocalcaneal motion axis that was calculated for the transition from starting to the end position has a direction from anteromedio-superior to posterolateroinferior, passing through the neck of the talus and the tarsal canal and emerging from the posterior calcaneal process (see for the three projections Figure 11-13 a, b and c).

1. The deviation angles, π TACA 30°/35° (Table 11-13)
Taking into account the left right difference, this angle proves to vary from 7° (specimen nr 9) to 35.8° (specimen nr 8). The mean value in our series amounted to 22.2°. The directions in relation to the sagittal plane were similar for all ten specimens.

2. The inclination angles, φ TACA 30°/35° (Table 11-13)
This angle proves to vary from a minimum of 27° (specimen nr 8) to a maximum of 54.9° (specimen nr 9). The mean value in our series was 41.4°.

Summing up it may be stated that the single helical subtalar axis as calculated for the movement as a whole makes an acute angle with the longitudinal direction of the foot and has a mid-horizontal, mid-vertical direction in relation to the basal plane.

Table 11-13. Subtalar deviation angles (π TACA 30°/35°) and inclination angles (φ TACA 30°/35°) total range.

Specimen	TACA π 30°/35°	TACA φ 30°/35°
1 R	28.4°	42.8°
2 R	30.9°	42.6°
3 R	27.8°	40.7°
4 R	20.1°	32.3°
5 R	30.9°	30.5°
6 R	32.0°	42.5°
7 R	23.8°	51.7°
8 L	- 35.4° (324.6°)	27.5°
9 L	- 7.1° (352.9°)	54.9°
10 L	- 21.1° (338.9°)	49.2°

3. Comparison with the literature

In this instance there are better possibilities of comparing data in the literature with our results.

Numerous earlier authors have described a single subtalar axis, corresponding to the subtalar helical axis described by us for the transition from starting to end position.

In the literature, this axis has been described as an oblique axis, more or less slanting from anterosuperior through the talar head and the tarsal sinus, emerging inferoposteriorly at the back of the calcaneus. This description is to be found in the works of Meyer (1853, 1856, 1873 and 1886), Farabeuf (1889), Dönitz (1904), Fick (1904), Strasser (1917), Braus (1921), Manter (1941), Smith (1958), Lapidus (1963), McMaster (1976), Morris (1977) and Inman (1977).

Other authors, also, describe this slanting axis, but they do not call it the 'subtalar axis' but the axis of the 'articulatio talotarsalis' or of the 'talocalcaneonavicular joint'. These terms appear in works by Henke (1855), Von Lanz and Wachsmuth (1938), Shephard (1951), Hicks (1953) and Kapandji (1970).

Fick regarded this single subtalar axis as an approximation of the 'actual' subtalar rotation axes with variable position! (See also Chapter 2, literature.)

In Chapter 2 we presented a survey of the different methods of investigation applied by the various authors. It is interesting to note in this connection that in spite of the different methods used by the authors they always found an axis that approximates the one calculated accurately by us! Still, this is not really surprising. All the studies were concerned with a passive movement of the talus in relation to the calcaneus. Huson as early as 1961 pointed out that when the talus is moved passively in relation to the calcaneus, the possibilities of talar movement are limited: the head of the talus can move in a lateroposterior direction, and the posterior part of the talus in a medioanterior direction (or vice

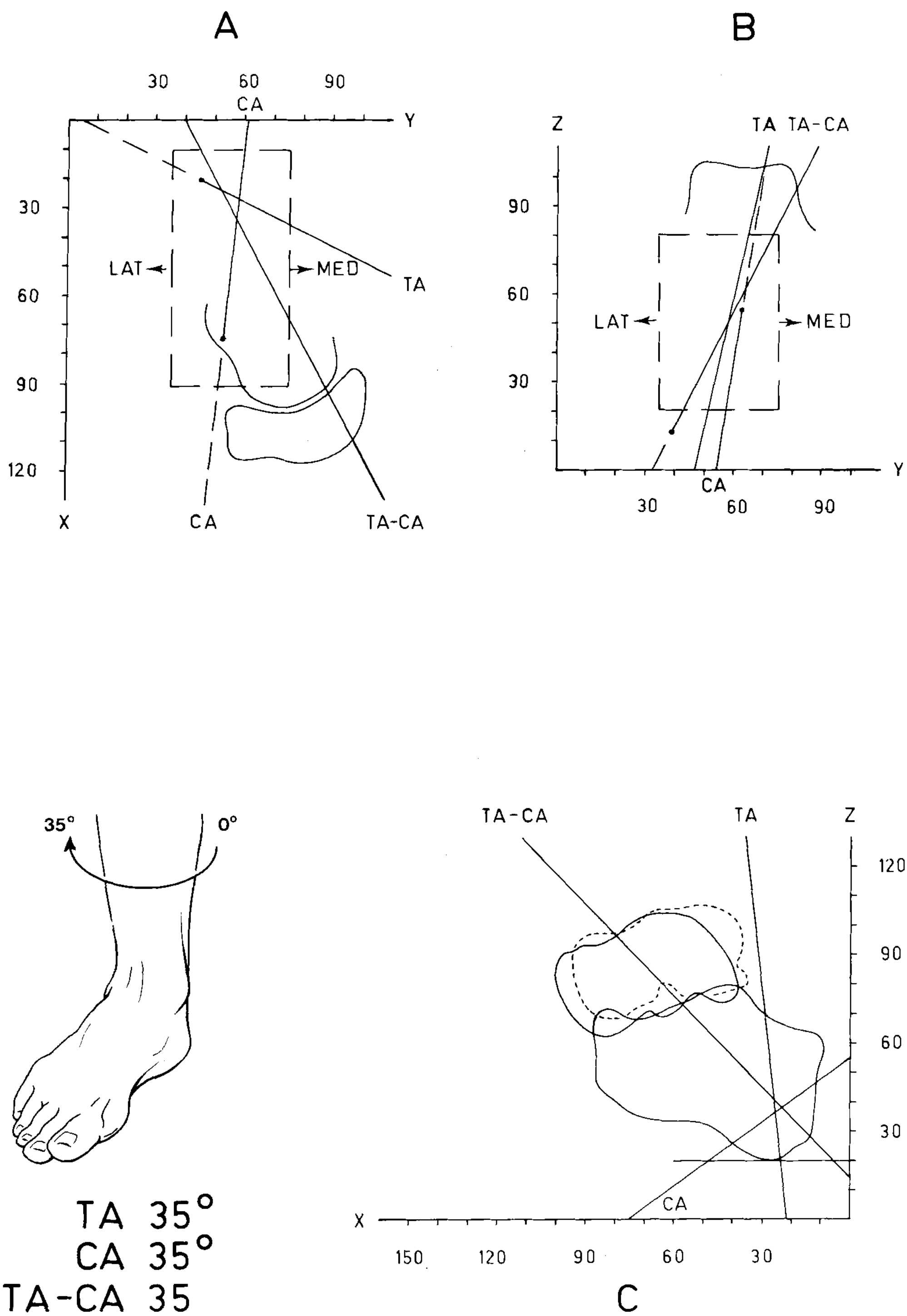


Figure 11-9. Projections of relative talocalcaneal, (TACA 30°/35°), absolute talar (TA 30°/35°) and absolute calcaneal (CA 30°/35°) helical axes, total range.

versa). It is always possible to find one area of the bones where motion is minimal, and it is through this area that the subtalar axis has to pass.
Still, in the directions and positions of the 'subtalar axis' as described by these authors, there are differences as well. Four causes of these differences can be listed:

a. the not very accurate, rather descriptive statement made by the various authors concerning the subtalar axis as found by them. Accurate comparison is possible only when quantitative data are given. Meyer and Fick indicate the angle of inclination only vaguely: "the subtalar axis" inclines with an angle of approx 40° with the horizontal.
It is only Manter (1941) and Isman (1968) quoted by Inman (1976) who state the position of 'their' respective subtalar axes in relation to the basal plane. Both Manter and Isman report an average inclination angle of 'the subtalar axis' of 42°; Manter's mean deviation angle was 16°, Isman's 23°. These mean values are of the same order of magnitude as our own mean inclination angle of 42° and mean deviation angle of 23°.

b. The individual variability
Most authors fail to mention the number of specimens examined. An impression of the variability in a series of 47 talocalcaneal specimens is only to be found in Inman's study (1976). The subtalar deviation angle in his series varied from 4° to 47°, the subtalar inclination angle varied from 20.5° to 68.5°.
Just as Manter and Inman, we have observed marked individual variability in the respective series. Table 11-14 lists the mean values and deviation for the angles of inclination and deviation of 'the' subtalar axis according to Manter, Inman and ourselves, and states the number of specimens examined as well.

Table 11-14. Comparison values of subtalar axis position according to Manter, Inman and our computed values.

	Average value	Maximal value	Minimal value	Total number of specimen
Manter 1942				
inclination	42°	47°	29°	16
deviation	16°	24°	8°	16
Inman 1968				
inclination	42°	68.5°	20.5°	47
deviation	23°	47°	4°	47
Van Langelaan 1976				
inclination	41.4°	54.9°	27.5°	10
deviation	22.2°	35.4°	7°	10

c. The relative inaccuracy of the methods of examination applied

Most authors make no statements regarding the accuracy of the determination. Hicks (1953) gives an indication of the accuracy of his determinations of the axis: the axis could occupy any position and have any direction within a cylinder with a diameter of 1 cm.

N.B.: As demonstrated in Chapter 11.2.1, it is certainly possible for several helical axes to be present in such a relatively large area!

d. The way in which the talus in the experimental set-up was moved in relation to the basal plane

Most authors report that the talus was moved passively in relation to the calcaneus in such a way that during the movement the maximally possible articular contact (congruence) was maintained. Inman (1977) even reports that if after determination of the subtalar rotation axis there still existed "separation of articular surfaces, the process of axis location is repeated"!

Inman, in our view here ignores the important finding by many authors (Weber, 1836; Henke, 1855; Henle, 1856; Meyer 1856; Virchow 1899; Fick, 1904, 1911; Dönitz, 1904; Braus, 1921; Farabeuf, 1889; Huson, 1961) that on the contrary, incongruence between the talar and calcaneal articular surfaces during the subtalar movement is unavoidable. It is noticeable in this respect that Inman reported that he, also, had found "at the extremes of motion, some incongruence".

In a comment on Huson's findings, Inman (1977) states that the "posterior articulation of the talocalcaneal joint is not a precisely lapped machine joint". Inman then adds that this incongruence is too slight to detract from the validity of his determinations!

11.2.4 Rotations and translations along talocalcaneal axes, total range

1. The rotations, α TACA 30°/35° (Table 11-15)

The rotations varied from 15.5° (specimen nr 8) to 30.0° (specimen nr 5). The mean value of α was 23.6°.

The direction of rotation of the talus in relation to the calcaneus considered immobile was clockwise (viewed in the anteroposterior direction) for the 7 right-foot specimens and counterclockwise for the 3 left-foot specimens. It follows from the position and the direction of the axis that the subtalar movement is a combined abduction-eversion movement.

2. The translations, t TACA 30°/35° (Table 11-15)

The translations varied from a minimum of 1 mm to a maximum of 2.6 mm. The mean subtalar translation in our series amounted to 1.7 mm. Clearly, these subtalar translations are very slight and can only be demonstrated with the aid of a highly accurate three-dimensional calculation method. It is therefore not

Table 11-15. Subtalar rotations (TACA α 30°/35°) and translations (t TACA 30°/35°) total range.

Specimen	TACA α 30°/35°	TACA t 30°/35°
1 R	27.2°	- 1.0 mm
2 R	28.1°	- 2.2 mm
3 R	27.6°	- 1.3 mm
4 R	27.4°	- 1.5 mm
5 R	30.0°	- 2.3 mm
6 R	26.2°	- 1.4 mm
7 R	16.6°	- 1.3 mm
8 L	15.8°	- 2.6 mm
9 L	16.9°	- 1.0 mm
10 L	19.9°	- 2.0 mm

surprising that Hicks wrote: "a shift along the axes accompanying the rotation was not observed and if present could not have exceeded 2-3 mm"!
The direction of translation is negative; the talus shifts along the subtalar helical axis in the posterolateroinferior direction.

3. Below, a comparison of our data with those from the literature
As already mentioned, only a few authors have measured the rotations in phases, and those only for a limited part of the total range of movements we have studied. On the other hand, a large number of authors have calculated the subtalar rotation for the transition from the starting to the end situation. A review of the different techniques used by the various authors has been presented in Chapter 2, literature. Several authors have described the 'total motion', i.e. the rotations for the supinatory and pronatory movements have been added together. According to these authors, the subtalar rotations in the pronatory as well as in the supinatory sense take place around the same subtalar or talotarsal rotation axis (A.O.O.S., 1965; Beetham et al. 1965; Kapandji, 1970; Von Lanz and Wachsmuth, 1972; McMaster, 1976).

Most authors describe the subtalar rotation in one direction. Table 11-16 shows that the value of the subtalar rotation varies greatly, from 5° to 65°. The degree of individual variability as reported by the several authors also differs greatly, and this applies in particular to Inman (1976) who reports a variability from 10° to 65°. We have asked ourselves whether a relationship may exist between the examination techniques applied and the magnitudes of the subtalar rotation reported by the authors.
We can subdivide the authors by their methods of examination into three groups:

a. the group of authors who consider the passive movement of the calcaneus in relation to a more or less fixed talus in the free-hanging foot (A.O.O.S., 1965). The very slight subtalar rotation (5°) in this group deserves attention;

b. the group of authors who regard the passive or active movement of the forefoot in the free hanging foot as a measure of the subtalar movement (Albert, 1882; Fick, 1904; Von Lanz and Wachsmuth, 1938, 1972; Niederecker, 1959; Beetham et al, 1965; Inman, 1976; McMaster, 1976 and Brantigan, 1977).
These authors determined the 'subtalar' rotations by means of perimetric, goniometric or roentgen-planigraphic measuring methods. In reality, what they measured were no subtalar rotations but sums of talocalcaneal and cuboidcalcaneal rotations, and probably also motions in the Lisfranc joint.
In this group, there are widely divergent values to be found;

c. the group of authors who regard the passive movements of the talus in relation to the calcaneus; which might or might not be fixed, in a more or less 'loaded situation' (Manter, 1941; Hicks, 1953; Van Langelaan, 1974; Inman, 1976 and Ambagtsheer, 1978). These authors mostly determined the subtalar rotations by skiagraphic, or as in our study, by roentgenphotogrammetric methods.

In the sciagraphic experiments, it was usual, in order to describe a relative talocalcaneal (subtalar) rotation to state the rotation of the talus in relation to a firmly fixed calcaneus of a foot-lower leg preparation (Manter 1961 and Inman 1976). If in the skiagraphic experiments the calcaneus of a specimen is permitted some degree of freedom of motion, e.g. only tilting (cf. Ambagtsheer 1978), or if it is not fixed externally at all (Hicks 1953), it is difficult to indicate a subtalar rotation. The rotations of talus and calcaneus, namely, always take place simultaneously round different talar and calcaneal rotation axes. Furthermore, skiagrams just show projections, and for this reason cannot be compared satisfactorily either.

Ambagtsheer has nevertheless desired to indicate a relative calcaneotalar rotation for his dorsoplantar skiagrams (axial view). He described a relative calcaneotalar endorotation of 17° during tibial laterorotation, which he found by deducting the calcaneal abduction movement from the talar abduction movement.
In a few skiagraphic studies, reference is made to a 'subtalar movement' meaning the movement of the calcaneus in relation to the talus (taken to be stationary) (Kapandji 1970). For the transition from maximal eversion to inversion, Kapandji found a calcaneal, i.e. relative calcaneotalar rotation of 20°. Actually, this only holds true of the frontal skiagram!

From Hicks' (1953) experiments it is not quite clear how the 'tarsal movements' in the specimen were carried out. Hicks may have measured directly on his accessory axis!
Hicks states that "movements were always brought about by the natural means". From his descriptions of the experimental set-up, it appears that the calcaneus of the specimen in any case was not fixed externally. Still, the talocalcaneal navicular rotation of 24° reported by Hicks (minimum 21°, maximum 27°), is of the same order of magnitude as the subtalar rotation calculated by us.

As known, in our experimental set-up, it was not necessary to fix the calcaneus as a 'stationary element': the relative talocalcaneal movements were calculated at a later stage from the computed three-dimensional talar and calcaneal movements in relation to the reference system in the cage.
The above will have made clear that the way in which the experiment is carried out influences the subtalar rotation to be found. Taking into account our own findings and those in the literature, we believe that passive tilting of the calcaneus (as described by the A.O.O.S.) does not allow accurate determination of subtalar rotation. The high individual variability reported in particular by Inman is in agreement with our findings.
As a conclusion, it is therefore not correct to speak of 'the' subtalar rotation of 'the' foot.

Table 11-16. Subtalar rotations according to various authors.

"Subtalar" rotations		Degrees
Fick (Albert)	1911	20° min. 45° max.
Manter	1941	10° min. 15° max.
Hicks	1953	24°
Wright-Desai-Henderson	1964	6° during stance-phase
A.O.O.S.	1965	10° (5° inversion, 5° eversion)
Beetham-Polley-Slocum-Weaver	1965	50° (30° inversion, 20° eversion)
Close-Inman-Poor-Todd	1967	9.9° min. 28.0° max.
Kapandji	1970	20°
Lanz-Wachsmuth	1972	60° (30° inversion, 30° eversion)
Ambagtsheer	1974	45°
Inman	1976	10° min. 65° max.
McMaster	1976	30° (25° inversion, 5° eversion)
Brantigan-Pedegana-Lippert	1977	38° (SD. 5°)

11.3 RELATIVE CUBOIDCALCANEAL MOVEMENTS

11.3.1 Directions and positions of cuboidcalcaneal axes, partial range

The relative 'cuboidcalcaneal helical axes' describe the movements of the cuboid in relation to the calcaneus presumed stationary.
To begin with, the results for preparation nr 1.
Figure 11-10a represents the dorsoplantar projection and shows that the helical axes to a greater or lesser extent lie in the longitudinal direction of the foot. In the

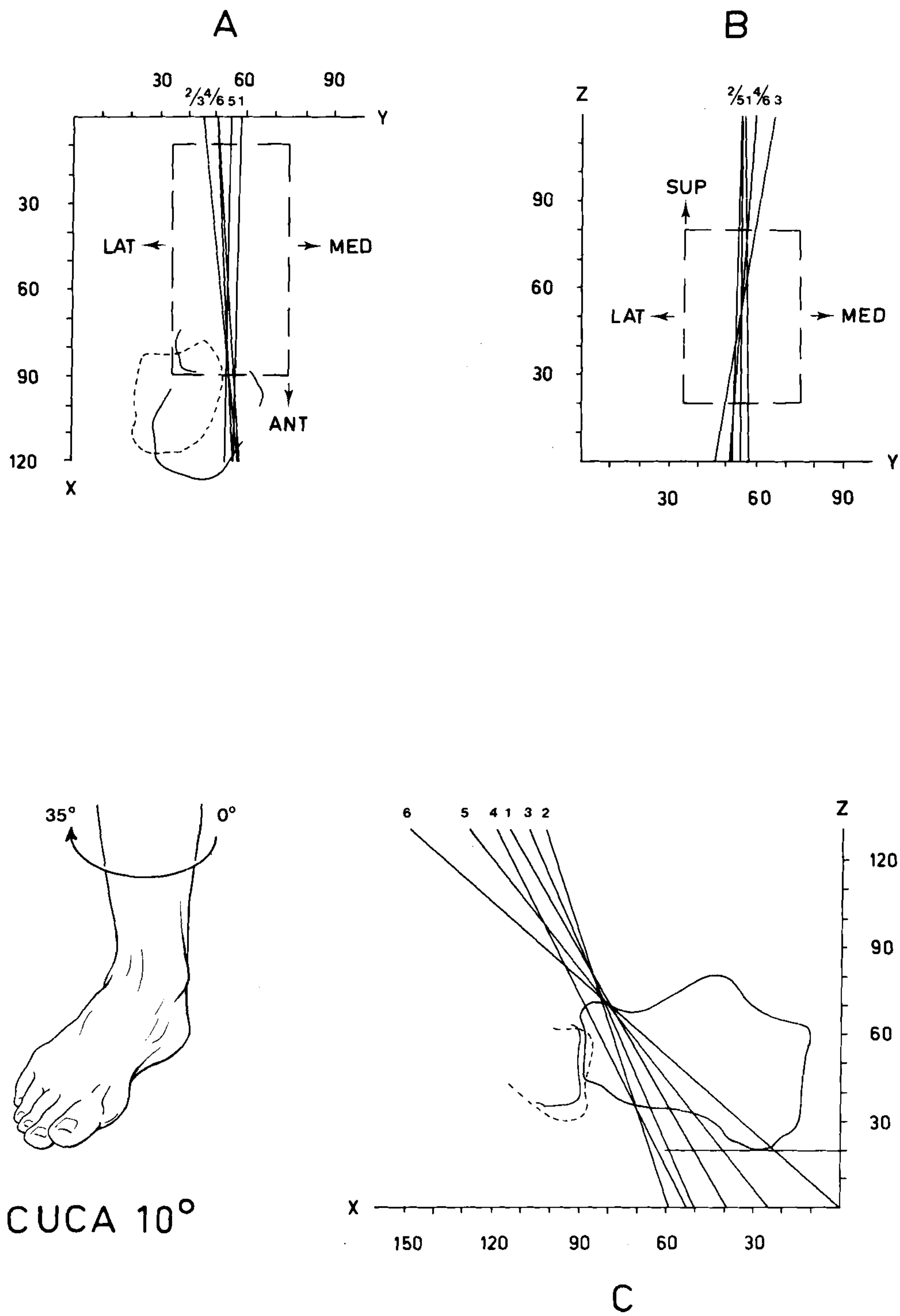


Figure 11-10. Projections of relative cuboidcalcaneal helical axes (CUCA 10°), partial range.

frontal projection, see Figure 11-10b, a narrow bundle is seen, running from superior to inferior.
Figure 11-10c shows a sagittal projection in which it is noticeable that on the whole the axes of this bundle are much closer to the vertical than is generally stated in the literature (see also Chapter 11.3.3). The axes proceed from anterosuperior to posteroinferior.

From the combination of these three projections it appears that the axes pass through the anteromedial and superior parts of the cuboidcalcaneal articular surfaces, with their points of intersection at short distances from each other. In this specimen, the axes constitute a small fan within a sagittal slice of the foot. From the stated direction of rotation (see below, Chapter 11.3.2) we may conclude that the relative cuboidcalcaneal movement has a distinct adduction as well as a distinct inversion component.

1. Deviation angles, π CUCA 10° (Table 11-17)
In 7 preparations (nrs 1, 2, 3, 4, 5, 6 and 9), the axes nearly always run from anteromedial to posterolateral (this is not the case in only 5 of the 34 cases). In 3 specimens (nrs 7, 8 and 10), this axial direction is predominantly from anterolateral to posteromedial (this is not the case in 2 of the 13 phases).
In most phases, the deviation angle varied between 0° and 30°. In only 5 instances did this angle exceed 30° (this was the case in specimen nr 2, phases 3 and 4; specimen nr 3, phases 2 and 3; specimen nr 5, phase 2).
We find that it is only in 2 specimens (nrs 1 and 10) that the axes spread inside a 'sagittal slice'; in the other 8, there are varying movements which also have varying directions. The mean value of the deviation angle π varied from -19.9° to 33.6°. Accordingly, in most phases, the relative cuboidcalcaneal axis makes a small or larger acute angle with the 'longitudinal axis' of the foot.
No recurrent pattern of changes of π could be observed.

2. The inclination angles, φ CUCA 10° (Table 11-18)
In all preparations the axes in all phases make a distally open angle with the basal plane; in other words, they run from anterosuperior to posteroinferior. In all phases in all preparations this angle had a value between 35° and 87°. The mean value of the inclination angle, $\overline{\varphi}$, varied from 43.2° to 72.1°. Accordingly, the relative cuboidcalcaneal axes always make a wide angle with the basal plane.

3. Changes of position of the axis of motion, the changes of π and φ as a function of motion
Where the changes of φ are concerned, there does not exist one single pattern. The table shows that in 5 preparations (nrs 1, 2, 3, 5 and 7) the cuboidcalcaneal axis moves to a position closer to the horizontal, in some cases after an initial increase of φ. In the other 5 specimens (nrs 4, 6, 8, 9 and 10), the axis moves closer to the vertical, sometimes descending again before the last phase. For

Table 11-17. Deviation angles of cuboidcalcaneal axes (π CUCA 10°) with summation, mean and range of deviation angles.

Specimen	R 1	R 2	R 3	R 4	R 5	R 6	R 7	L 8	L 9	L 10
Phase										
1	358.8	230.0	38.5	13.3	78.8	359.1	329.6	8.1	2.7	5.5
2	5.3	5.0	64.7	10.9	37.4	5.0	-28.7 (331.3)	14.0	2.9	5.6
3	5.4	70.6	62.3	-8.4 (351.6)	24.0	-8.0 (352.0)	-21.2 (338.8)	28.5	-4.8 (355.2)	5.6
4	2.7	49.5	13.2	-10.1 (349.9)	24.5	-11.2 (348.8)	-8.9 (351.1)	26.2	-20.0 (340.0)	4.6
5	-0.5 (359.5)	22.0	13.8	7.9	13.1	9.6	7.2 (352.8)	11.0	-27.3 (332.7)	0.3
6	4.7	14.5	13.8	12.1	6.8				-21.8 (338.2)	-2.3 (357.7)
$\Sigma \pi$	18.1	161.6	167.8	12.4	105.8	-4.6	-51.6	79.7	-71.0	16.1
$\overline{\pi}$	3.6	32.3	33.6	2.5	21.2	-1.2	-12.9	19.9	-14.2	3.2
R π	5.9	65.6	51.5	22.2	30.6	20.8	35.9	17.5	30.2	7.9

Table 11-18. Inclination angles of cuboidcalcaneal axes (φ CUCA 10°) with summation, mean and range of inclination angles.

Specimen	R 1	R 2	R 3	R 4	R 5	R 6	R 7	L 8	L 9	L 10
Phase										
φ 1	63.1	70.3	59.3	35.3	72.2	28.3	45.7	40.4	36.0	43.9
φ 2	71.3	87.0	62.9	33.0	62.9	38.0	56.2	55.8	39.6	48.4
φ 3	66.2	81.7	75.1	34.2	49.3	43.4	63.1	57.4	48.1	53.4
φ 4	59.8	79.5	67.5	50.7	43.8	49.1	54.3	47.2	52.7	56.6
φ 5	51.7	65.1	47.3	52.1	52.9	61.9	45.1	47.8	51.2	57.1
φ 6	41.3	47.2	38.2	45.8	36.1				47.0	57.0
$\Sigma \varphi$	290.3	360.5	290.8	215.8	245.0	192.4	218.7	208.2	238.6	272.5
$\overline{\varphi}$	58.1	72.1	58.2	43.2	49.0	48.1	54.7	52.1	47.7	54.5
R φ	30.0	39.8	36.9	19.1	26.8	23.9	18.0	8.6	13.1	8.7

preparations nrs 1, 2, 3, 5 and 7, the values for φ found during the first few phases were high, following which these 'fell' to between 36° and 47°; for specimens nrs 4, 6, 8, 9 and 10, on the other hand, the values were low during the first few phases and then increased. Taking the 10 preparations together, we may state that if at the start of the movement there is a relatively horizontal or a relatively vertical cuboidcalcaneal helical axis, φ subsequently will always reach a value between 36° and 62°.

In addition we have studied the relationship 'relative cuboidcalcaneal helical axes to absolute cuboid and absolute calcaneal helical axes'. It is interesting to note that in 9 of the 10 preparations the value of CUCA φ in nearly all phases exceeds that of CA φ; the converse applies only in specimen nr 9. There were only 4 exceptions: specimen nr 2, phase 6; specimen nr 3, phase 6 and specimen nr 10, phases 5 and 6.
In all 10 preparations the values of CU φ were low to very low, and constantly below those of CA φ and CUCA φ. The combined changes of φ CUCA, φ CU and φ CA follow no recognizable pattern. The relative cuboidcalcaneal axes are fairly steep; accordingly, the relative cuboidcalcaneal movement includes a considerable adduction component. The absolute cuboid axes, on the other hand, are in a practically horizontal position; therefore there will be hardly any abduction component in the absolute cuboid motion.

4. The angles R π and R φ of the bundle width, the bundle angle (Table 11-17, 11-18)
The bundle angle of the cuboidcalcaneal helical axis in the deviation direction, determined from differences between maxima and minima, ranged from 5.9° to 65.6° (R π). In 8 of the 10 preparations (nrs 2, 3, 4, 5, 6, 7, 8 and 9), a bundle width of the cuboidcalcaneal helical axes exceeding 10° was found; in 2 of the 10 preparations (nrs 1 and 10) it was narrower.
The bundle width of the cuboidcalcaneal helical axis in the inclination direction ranged from 8.7° to 39.8°.
In 8 of the 10 preparations (nrs 1, 2, 3, 4, 5, 6, 7 and 9) the bundle angle of R φ exceeded 10°; in 2 of the 10 preparations (nrs 8 and 10) it was narrower.
All in all, therefore, there was one specimen (nr 10) with a small 'swing' in both the deviation and the inclination direction. The changes of position of the axis, with movement in a path, will be discussed in the paragraph below.

5. The angles between successieve cuboidcalcaneal helical axes (γ)
These angles γ are listed in Table 11-19. The angle γ between two successive axes ranged from 1.4° to 20.0°. These successive angles were added up per specimen, and the totals ranged from 12.1° to 58.4°.

Before continuing our description of the position of the axes in relation to the calcaneocuboid joint, we present a brief review of the curvatures of the articular

Table 11-19. Angles between the successive axes γ CUCA 10°.

Specimen	R 1	R 2	R 3	R 4	R 5	R 6	R 7	L 8	L 9	L 10
Phase										
γ 2-3	5.2	7.5	12.3	16.1	15.5	11.2	7.9	8.1	10.1	5.0
γ 3-4	6.5	4.1	17.0	16.6	5.5	6.1	10.8	10.3	10.7	3.3
γ 4-5	8.3	16.2	20.0	11.2	11.8	17.3	9.4	10.3	4.7	2.4
γ 5-6	11.0	18.4	9.1	6.9	17.4				5.5	1.4
$\Sigma\gamma$	31.0	46.2	58.4	40.8	50.2	34.6	28.1	28.7	31.0	12.1

surfaces of the calcaneocuboid joint and of the insertions of the ligaments (from Huson and Bojsen Møller).
The calcaneocuboid joint resembles a saddle joint with its typical curvatures, almost at right angles to each other. In the vertical direction the curvature is concave on the calcaneal, and convex on the cuboid side; in the horizontal direction it is convex on the calcaneal and concave on the cuboid side.
The calcaneal articular surface occupies an oblique position in relation to the calcaneal 'longitudinal direction' and runs from laterodistal to medioproximal. See also the reconstruction of the calcaneal surface according to Huson (1961), Figure 11-11. The congruence of the calcaneus and the cuboid is optimal in one position, the starting position. All changes of position lead to more incongruence.

The following ligaments are discussed:

- The calcaneocuboid slip of the bifurcate ligament

It has its insertion close to the calcaneal edge of the articular surface and is attached to the cuboid at some distance from the joint. This ligament according to Huson occupies a central position in relation to the motion axes and therefore supposedly has a short lever arm. Allegedly, this ligament is tightened only during maximal plantar flexion of the cuboid and exerts only a braking function.

- The long plantar ligament

Its insertion is precisely the opposite as that of 1, viz. it arises at a distinct difference from the joint and inserts close to the cuboid articular surface. This ligament is believed to remain tight throughout the movement. The ligament has a typical oblique insertion in relation to the 'longitudinal direction' of the calcaneus; toward medial, the fibres insert more and more closely to the articular surface. A distinction is made between the long plantar ligament, situated in a more superficial (plantar) and more lateral position, a layer of long fibres running from the calcaneus to the cuboid, and the short plantar ligament, or ligamentum calcaneocuboideum plantare, with deep short oblique fibres. The oblique insertion of the long and the short plantar ligaments fits a rotation component in the cuboidcalcaneal movement. There occurs a more or less imposed plantar flexion-rotation movement of the cuboid in relation to the calcaneus, in which the short fibres of the short plantar ligament and the calcaneocuboid slip of the bifurcate ligament, as it were, 'centre' the movement.

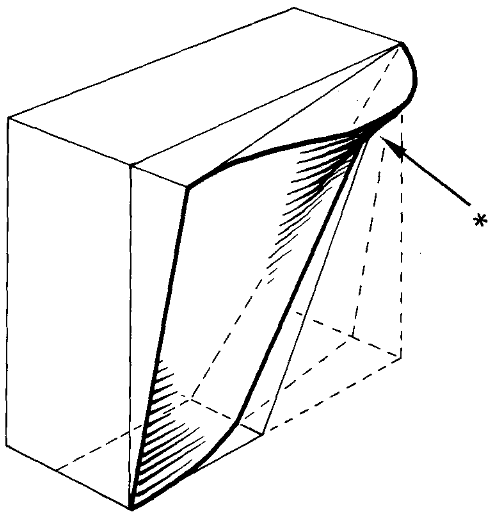


Figure 11-11. Reconstruction of the calcaneal surface of the calcaneocuboidal joint according to Huson. Neck shaped area of the anterior calcaneal proces indicated by arrow.

6. The position of the axes in relation to the calcanealcuboid joint

Returning to Figure 11-10, in the sagittal projection, we indeed to some extent observe a concentration of projections of helical axes in the region of the anterior calcaneal process. This is the area where the dorsal slip of the bifurcate ligament and the shortest fibres of the long plantar ligament (deep layer) and the short plantar ligament insert. This area may also be found in the frontal and dorsoplantar projections. Here, also, we shall attempt more precisely to determine the position of the axode bundle in this region with the aid of an intersection plane.

The relationship of the axode to the calcaneocuboid articular surface. In order to gain an impression of the relationship of the cuboid calcaneal 10° axode and the calcaneal surface of the calcaneocuboid joint, we determined the line of intersection of the axode with several frontal surfaces lying one after the other through the anterior portion of the calcaneus. The distances between these frontal surfaces amounted to 1 mm.

The plane chosen for study was the frontal plane in which the Y and Z coordinates of the intersection points approached one another as closely as possible, in other words, where the concentration of axes seemed to be maximal. This procedure has been used for all 10 specimens. Table 11-20 lists the X, Y and Z coordinates of the points of intersection of each of the 10 axodes with the frontal plane. Figure 11-12 shows the 10 areas in the various frontal projections.

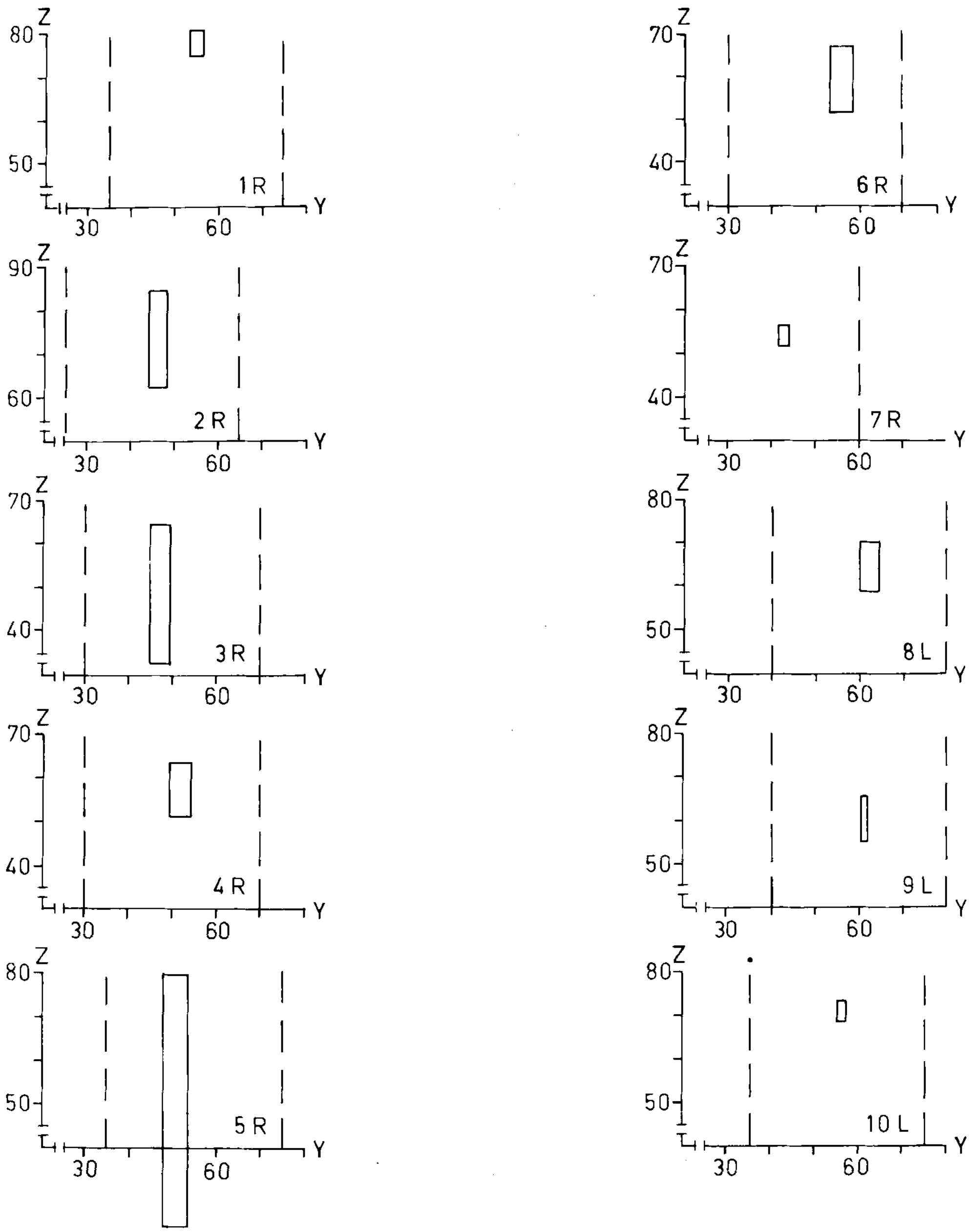


Figure 11-12. Areas of intersection helical axes CUCA 10° with vertical plane.

Table 11-20. Centres of intersection helical axes CUCA 10° with vertical plane and differences between max. and min. of coordinates.

	Phase	X	Y	Z		Phase	X	Y	Z
	2	86	53.96	79.61		2	75	53.18	52.27
	3	86	53.72	81.06		3	75	58.42	58.78
1 R	4	86	54.20	81.34	6 R	4	75	56.00	62.64
	5	86	53.95	77.31		5	75	54.53	67.20
	6	86	56.38	75.44					
	min/max diff.		3.11	5.89		min/max diff.		5.24	14.93

	Phase	X	Y	Z		Phase	X	Y	Z
	2	90	44.96	72.70		2	78	43.96	51.98
	3	90	48.04	78.96		3	78	41.81	53.87
2 R	4	90	48.53	84.73	7 R	4	78	42.62	57.05
	5	90	44.95	69.11		5	78	43.68	53.38
	6	90	44.75	62.22					
	min/max diff.		3.78	22.51		min/max diff.		2.15	5.07

	Phase	X	Y	Z		Phase	X	Y	Z
	2	80	45.01	32.81		2	89	60.12	61.01
	3	80	49.39	58.11		3	89	63.03	59.54
3 R	4	80	45.31	64.43	8 L	4	89	62.64	64.22
	5	80	46.57	58.28		5	89	64.67	70.29
	6	80	48.53	58.28					
	min/max diff.		3.52	31.62		min/max diff.		4.55	9.28

	Phase	X	Y	Z		Phase	X	Y	Z
	2	84	54.23	51.59		2	80	60.81	64.55
	3	84	53.53	55.75		3	80	61.87	65.92
4 R	4	84	49.37	60.77	9 L	4	80	61.57	65.11
	5	84	49.86	61.79		5	80	61.45	59.80
	6	84	50.27	63.51		6	80	61.99	55.50
	min/max diff.		4.86	11.92		min/max diff.		1.18	10.42

	Phase	X	Y	Z		Phase	X	Y	Z
	2	82	48.26	22.04		2	80	55.87	72.24
	3	82	53.79	48.10		3	80	56.80	72.70
5 R	4	82	53.58	59.86	10 L	4	80	57.32	73.41
	5	82	52.16	79.74		5	80	56.30	72.02
	6	82	52.62	72.84		6	80	55.68	68.36
	min/max diff.		5.53	57.75		min/max diff.		1.64	5.05

As the tables and the figure show, the points of intersection in all 10 specimens always occupied a narrow horizontal strip; the differences between the X and Y coordinates of the successive points of intersection are very small for all preparations. The Z coordinates, on the other hand, did show clear differences. A shift of the points of intersection in the Z direction should not be interpreted as an increase or decrease of φ, because the axes may undergo an additional anterior or posterior translation (Figure 11-13).

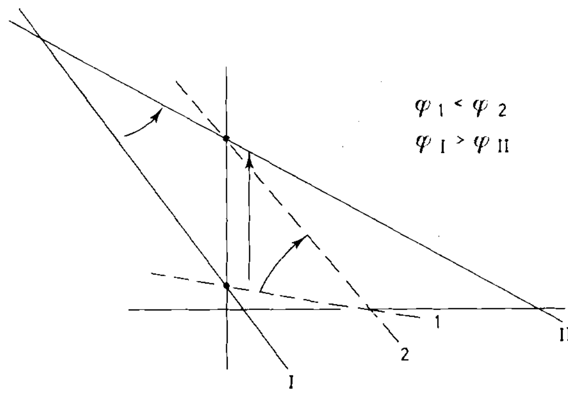


Figure 11-13. Points of intersection with frontal plane with a moving axis.

As known, the calcaneus has an oblique calcaneocuboid articular surface, see also Figure 11-11, the reconstructed calcaneocuboid articular surface according to Huson, with its typical neck-shaped area. Examination of a number of isolated calcanei showed that the oblique articular surface makes an angle of approx 30° with the Y axis. We find that the frontal planes with the highest concentrations of axes are all to be found approx 5 to 10 mm behind the most prominent point of the anterior process, and accordingly lie in the neck-shaped area.

Accordingly, there exists a plane in which the points of intersection behave fairly homogeneously and remain within a narrow area, in spite of the sometimes considerable variation of Z (see also Figure 11-12). For the 10 preparations, the Z coordinate difference ranges from 5.05 mm to 57.75 mm. The mean Z coordinate difference was 23.55 mm.

In 9 of the 10 preparations, the path of the points of intersection first showed a movement in a positive Z direction, which might or might not be followed by a movement in the negative Z direction. In one specimen (nr 8), the path first moves slightly in the negative Z direction, following which it once more moves in the positive Z direction. The difference between the bundle widths is clearly visible, as for instance in specimen nr 9 with a narrow bundle and specimen nr 5 with a wider bundle. This difference cannot be attributed simply to higher accuracy due to a greater rotation α, because the rotations α CUCA in specimen nr 9 are considerably smaller than the rotations in specimen nr 5. This, therefore, is an example of interindividual variability.

11.3.2 Rotations and translations along cuboidcalcaneal axes, partial range

1. The rotations, α CUCA 10° without phase 1 (Table 11-20a) varied from a minimum of 3.1° to a maximum of 8.2°.
In the first 5 specimens there was a gradual increase of the rotation sometimes followed by a decrease in the last phase. In the second group of 5 specimens, the 'course' was more mountain-shaped. In 9 of the 10 specimens we saw lower values of α in the first than in the second phase; in one specimen (nr 1) this was not the case, but the difference amounted to only 0.3°. In the specimens with higher values for α (nrs 2, 4 and 10) we find high as well as low values for γ. There is, therefore, nó reason to compare CUCA to a hinge and to regard a high γ as an inaccuracy. A hinge, namely, would have a very low γ.

The directions of rotation: in the 7 right-foot preparations the direction of the rotation was to the left (viewed in the a-p direction), while in the 3 left-foot preparations it was to the right. Considering the position of the relative cuboidcalcaneal axes, halfway between horizontal and vertical, and their sagittal direction, the movement of the cuboid in relation to the calcaneus during the standard motion was one of combined inversion and adduction. In case of a wide deviation angle, some plantar flexion occurs as well.

Table 11-20a. Cuboidcalcaneal rotations (CUCA α 10°) and translations (CUCA t 10°), partial range.

Specimen		R	R	R	R	R	R	R	L	L	L	
		1	2	3	4	5	6	7	8	9	10	
	Phase											
t	1	-0.1	-0.1	-0.3	-0.5	-0.3	-0.1	-0.4	-0.8	-0.7	-0.7	CUCA mm
α		3.4	2.4	1.6	3.6	1.6	2.6	2.5	4.2	4.5	7.1	CUCA°
t	2	0.1	0.1	-0.7	-0.5	-0.3	-0.3	-0.7	-0.8	-0.7	-1.0	CUCA mm
α		3.1	4.0	3.8	6.0	3.4	5.1	3.8	5.0	5.1	7.4	CUCA°
t	3	-0.1	0.3	-0.5	-1.2	-0.2	-1.1	-0.6	-0.9	-0.5	-1.0	CUCA mm
α		3.4	6.0	4.4	6.8	5.1	6.3	3.8	5.3	4.9	7.6	CUCA°
t	4	-0.4	0.3	-0.3	-1.8	-0.1	-1.4	-0.5	-1.1	-0.2	-1.0	CUCA mm
α		4.2	7.4	4.7	7.8	5.9	5.8	3.2	5.2	5.1	7.5	CUCA°
t	5	-0.8	-0.2	-0.4	-1.3	-0.6	-0.8	-0.3	-0.6	-0.1	-0.9	CUCA mm
α		4.9	7.9	6.0	8.2	4.6	4.7	2.6	3.7	4.7	7.2	CUCA°
t	6	-0.9	-0.9	-0.7	-0.9	-0.9				-0.1	-0.8	CUCA mm
α		5.1	7.5	7.3	5.5	5.6				3.6	7.1	CUCA°

2. The translations, t CUCA 10° without phase 1 (Table 11-20a)
The translation t along the cuboidcalcaneal helical axis ranged from a minimum of 0.1 mm to a maximum of 1.8 mm. Variation of the mean without phase 1 : 0.3 mm to 1.8 mm.
Since the direction of the axis in all specimens was from posteroinferior to anterosuperior, the cuboid in case of negative translation in relation to the calcaneus moves from anterior to posterior. In the mediolateral X-rays, the cuboid in the maximally supinated position is projected lower than the calcaneus. Because the translations are so small, they will never lead to a clearly visible plantar shift in the X-ray. Therefore, this shift of its projection results from the tilting of the cuboid.

3. Literature
We have not found any data in the literature with which our results could be checked.

11.3.3 Directions and positions of cuboidcalcaneal axes, total range

Figures 11-14a, b and c show the three projections of the relative cuboidcalcaneal helical axis during maximal tibial laterorotation for preparation nr 1 (CUCA 35°).
As appears from the combination of these 3 projections, the cuboid has rotated in relation to the calcaneus round an axis that runs approximately in the longitudinal direction of the foot, but at a relatively steep angle with the basal plane, halfway between horizontal and vertical, direction anteromediosuperior to posterolateroinferior. The position and direction of the axis indicate an important total adduction component in the relative cuboidcalcaneal motion, in addition to the inversion component.

1. The deviation angles, π CUCA 30°/35° (Table 11-21)
Taking into account the left-right difference, this angle ranges from -15.5° (specimen nr 8) to 19.9° (specimen nr 7). The mean value was 2.7°. (mean value irrespective to the sign: 10.3°)
The direction in relation to the longitudinal axis of the foot was nót constant: 6 times from anteromedial to posterolateral and 4 times, from anterolateral to posteromedial. We have seen these differences in the direction in relation to the longitudinal axis of the foot before, among the partial range data for the same specimens.

2. The inclination angles, φ CUCA 30°/35° (Table 11-21)
This angle proves to range from a minimum of 43.3° (specimen nr 4) to a maximum of 72° (specimen nr 2). The mean value was 51.9°. The axes, therefore, indeed always stood at a fairly steep angle.
The direction was the same for all 10 preparations, from anterosuperior to posteroinferior.

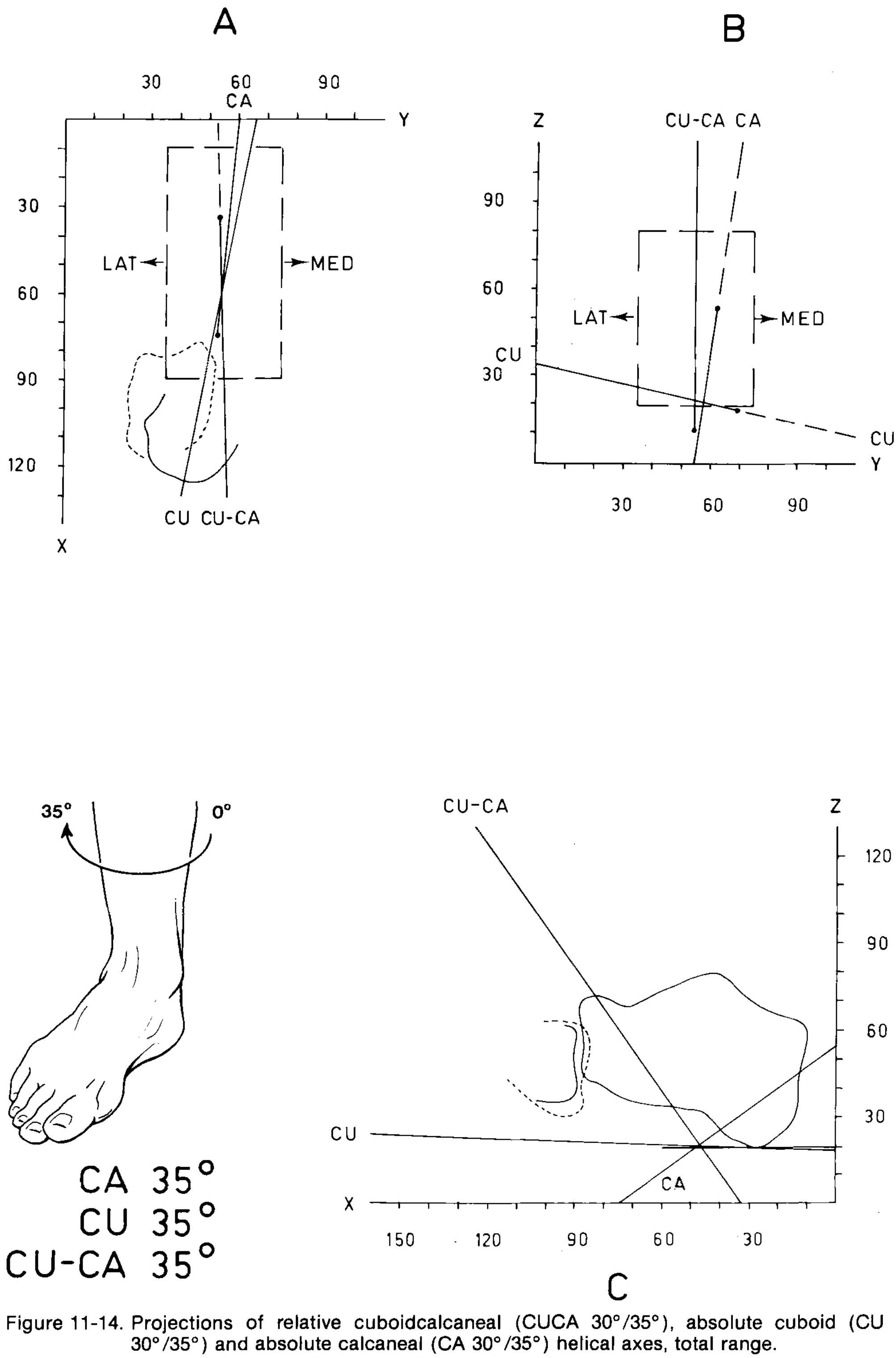


Figure 11-14. Projections of relative cuboidcalcaneal (CUCA 30°/35°), absolute cuboid (CU 30°/35°) and absolute calcaneal (CA 30°/35°) helical axes, total range.

Table 11-21. Cuboidcalcaneal deviation angles (π CUCA 30°/35°) and inclination angles (φ CUCA 30°/35°) total range.

Specimen	CUCA π 30°/35°	CUCA φ 30°/35°
1 R	+ 1.8°	54.7°
2 R	+ 12.0°	72.0°
3 R	+ 19.9°	54.8°
4 R	+ 3.8°	43.4°
5 R	+ 17.6°	47.4°
6 R	- 0.8° (359.2°)	47.1°
7 R	- 19.3° (340.7°)	53.0°
8 L	+ 15.5°	49.8°
9 L	- 9.9° (350.1°)	45.0°
10 L	+ 2.1°	52.2°

3. Since most authors have not described successive axes for the tarsal joint, but had to be content with one discrete axis for the total range of movements, of which at best they indicated the direction quantitatively as well, we shall compare our findings for the total range in somewhat greater detail with the literature data available.

Several authors have described different articular movement in Chopart's articulation. Not all of them have divided these movements in cuboidcalcaneal and talonavicular movements. There are authors who indicate óne axis for the 'articulatio Chopart' (Henke 1855 and Meyer 1856, 1886) in order to stress the functional linking between the tarsal bones. The authors also sometimes speak of 'Chopart's axis' (Meyer 1856, 1886 and Fick 1904) and then later mention that they mean the cuboidcalcaneal axis. Only few authors have supplied exact data concerning the position and direction of the motion axis of the cuboidcalcaneal joint. In Dönitz's thesis (1903, Figure 11-15) we find one axis for the cuboidcalcaneal joint which runs in the longitudinal direction of the foot, fairly

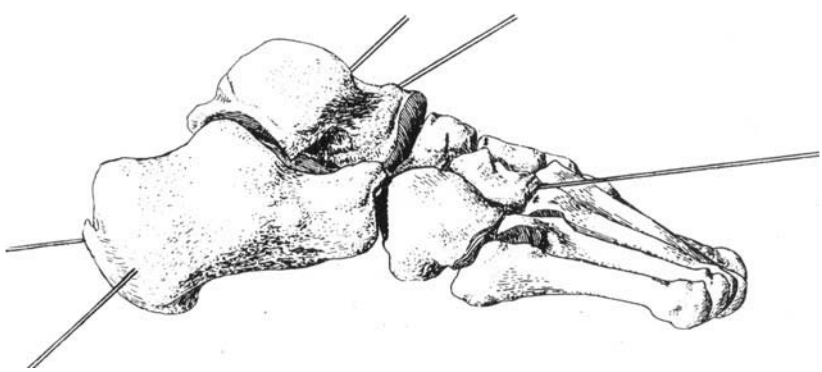


Figure 11-15. The three tarsal axes according to Dönitz with a steep talocalcaneal, a less steep talonavicular and a horizontal Chopart axis.

horizontally, with an inclination angle of approx 10°. This axial direction, therefore, resembles that of the absolute cuboid helical axis found by us! Fick (1909) describes a direction and position similar to Dönitz's. Both Dönitz and Fick only represent this axis in a sagittal view from the tarsus and they fail to state exact figures for the angles of inclination or deviation. However this may be, it is clear that the relative cuboidcalcaneal axis we have found has a far steeper direction.
Manter (1942), Figure 11-16 does present quantitative data. Manter describes two axes for the 'tarsal transversal joints', one of which, for the cuboidcalcaneal joint, he calls the 'first axis of the tarsal transversal joints', with an inclination angle of 15° and a deviation angle (medial slant) of 9°. In a dorsoplantar view, this axis passes centrally over the calcaneocuboid articular surface. In a sagittal view, this axis passes through the anterior calcaneal process, just above the proximal part of the cuboid. These last-mentioned two positions of Manter's cuboidcalcaneal axis are in good agreement with our findings.

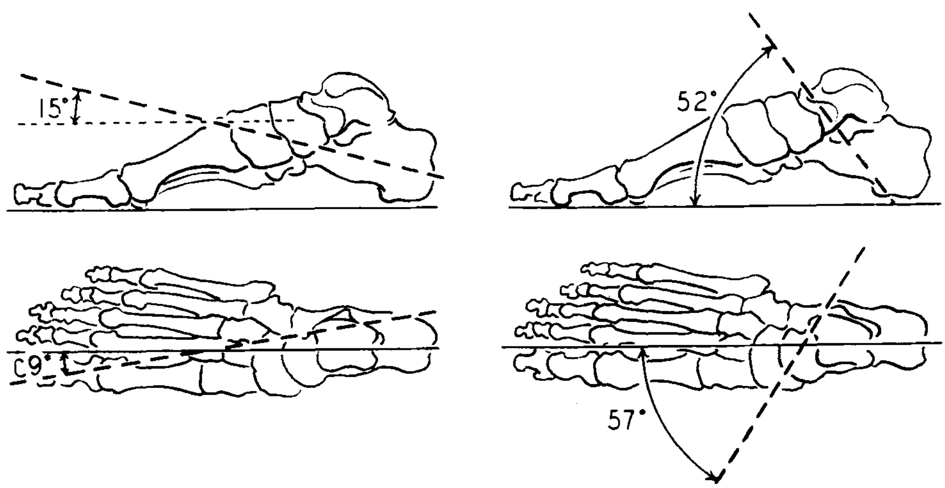


Figure 11-16. The two tarsal axes for the articulation of Chopart in a sagittal and dorsoplantar view according to Mantar.

The findings reported by Elftman (1960) for the movements in the cuboidcalcaneal joint, on the other hand, are far more difficult to compare with our data. He describes two cuboidcalcaneal axes, determined 'with they eye of the connoisseur'. These are the two axes of curvature of the more or less saddle-shaped joint. These axes cross at a small distance from one another. When 'both axes are used at once', there would occur a 'resultant movement involving an instantaneous axis passing through the perpendicular line connecting the two calcaneocuboid axes'. In humans, this point of intersection is supposed to lie just below the sustentaculum tali'.

These two cuboidcalcaneal axes are represented in Figures 11-17 and 11-19.

CC-1 is the axis of curvature for the convex calcaneal articular surface. The axis CC-2, the distal axis for the cuboidcalcaneal joint is inside the cuboid, at right angles to CC-1. In a frontal and approximately dorsoplantar view this shortest interconnecting distance between CC-1 and CC-2 is indicated by a dotted line. This line runs from posterolateral to anteromedial. In the frontal view, this line passes transversely over the proximal part of the calcaneal articular surface, from proximolateral to distomedial. This rotation axis, although described rather vaguely, is frequently referred to, even in recent literature (Morris, 1977, in which, however, only the illustrations are reproduced, without a clear explanation).

In a publication by Mann and Inman (1964), in which they refer to Elftman, the frontal view of Chopart's articulation is again reproduced (see Figure 11-18). Here, a line is shown, marked CC-1, whichs runs from laterosuperior to medio-inferior, transversely over the calcaneal articular surface and approximately bisecting it.

However, no line with this position and direction is to be found in Elftman's original publication! According to Mann and Inman, this line is the 'resultant axis of rotation' for the cuboidcalcaneal joint.

Comparing Elftman's data with those of Mann and Inman, we find that where the direction is concerned, Elftman's axis CC-2 and also Elftman's shortest distance between CC-1 and CC-2 very markedly resemble Mann and Inman's 'resultant axis' CC-1!

It also remains obscure why, where Mann and Inman refer to Elftman, they do borrow Elftman's nomenclature, CC-1, in a frontal view through the tarsus, but use CC-1 to indicate a 'resultant axis' that has never been indicated in this manner by Elftman himself!

Mann and Inman in their paper pay no further attention to the position and direction of 'their' resultant axis in the three projection directions; they restrict themselves to the frontal view.

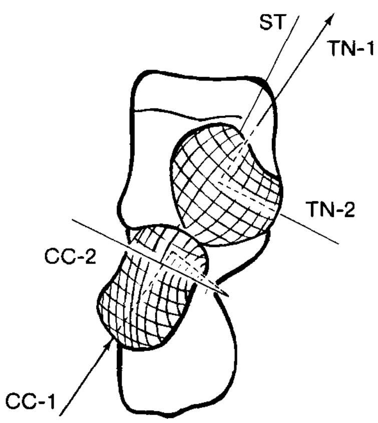


Figure 11-17.

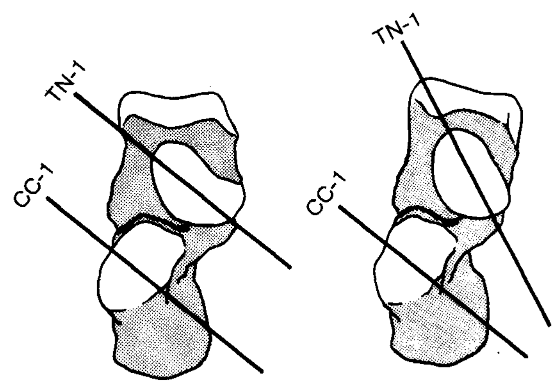


Figure 11-18.

Figure 11-17. Subtalar, talonavicular and calcaneocuboid axes according to Elftman, frontal view.
Figure 11-18. Talonavicular and calcaneocuboid axes according to Mann, Inman, frontal view.

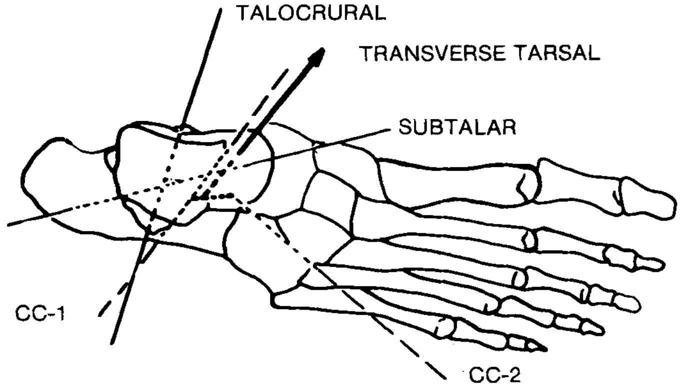
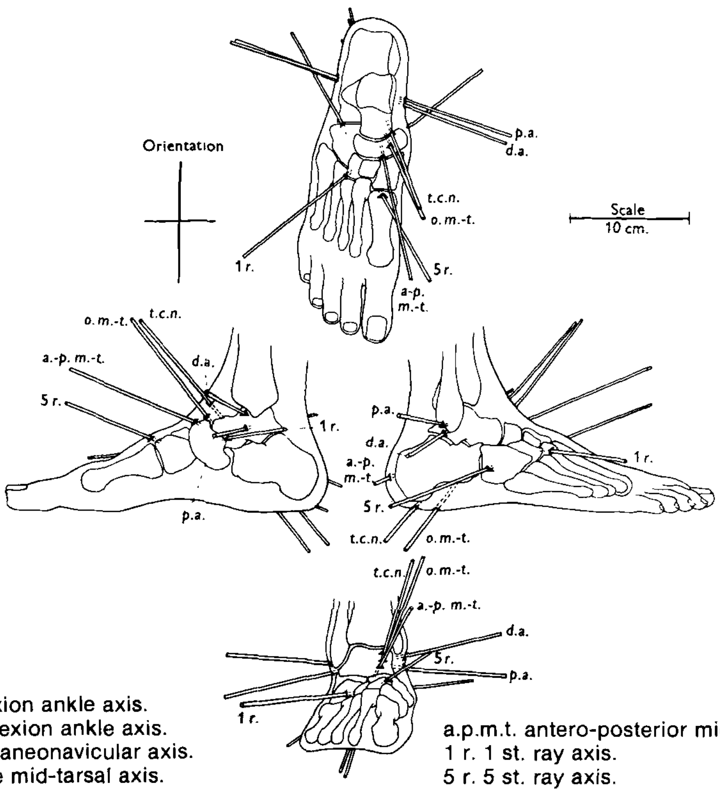


Figure 11-19. Talocrural, transverse tarsal and subtalar axes according to Elftman, dorsoplantar view.

In the recent paper by Morris (1977) we once more encounter Mann and Inman's presentation. No accurate position and direction of the cuboidcalcaneal axis are given. In our investigation we found a relative cuboidcalcaneal axis which in a frontal projection lies centrally over the calcaneus, precisely in the Z direction. This is due to its slight deviation from the X axis.
In our frontal projection, we admittedly also indicate a seemingly transverse axis, reminiscent of the CC-1 axis of Mann and Inman, but this is a projection of the absolute axis of the cuboid!

Hicks (1953), Figure 11-20, determined a large number of axes for various joints of the foot. No cuboidcalcaneal rotation axis as such is described. Hicks does mention, however, two axes for the combined transverse tarsal articulation (midtarsal joint), which 'can be used simultaneously'. Hicks describes one 'oblique midtarsal axis', running from anteroproximomedial to postero-distolateral, which enters the navicular bone on the dorsomedial side. As his second midtarsal axis, Hicks described an 'anteroposterior midtarsal axis', which also has a direction from anteromediosuperior to posterolateroinferior. This axis enters the navicular bone at a point approximately halfway its dorsal aspect.
In Hicks' drawings, the oblique axis is shown as steeper and more deviating than the anteroposterior axis. The angles, as they can be measured in his drawings, amounted to 52° for the inclination of the oblique axis and to 25° for the inclination of the anteroposterior axis. The deviations were 25° and 12°, respectively. In a frontal view, the oblique axis makes an angle of approx. 70° with the horizontal, and the anteroposterior axis an angle of approx 63° with the horizontal. When we compare the values measured in Hicks' drawings with the results of our 10 determinations of axes (mean inclination 51.9°; mean deviation 10.3°), we find that the steepness of our relative cuboidcalcaneal axis corresponds to that of Hicks' oblique axis (52°). Cf. inclination measured in the drawings of Van Langelaan and Manter (spec. 1 : 54° resp. 52°). The deviation of



d.a. dorsoflexion ankle axis.
p.a. plantar flexion ankle axis.
t.c.n. talocalcaneonavicular axis.
o.m.t. oblique mid-tarsal axis.
a.p.m.t. antero-posterior mid-tarsal axis.
1 r. 1 st. ray axis.
5 r. 5 st. ray axis.

Figure 11-20. The respective tarsal axes according to Hicks.

our relative cuboid calcaneal axis, on the other hand, corresponds better to that of Hicks' anteroposterior axis (12°). Cf. deviation measured in the drawings of Van Langelaan and Manter (spec. 1, 4°-12°).

In 1962, Feist and Mankin list a description of "the tarsus, basic relationships and motions in the adult and definition of optimal recumbent oblique projection". Although these authors have not carried out any functional anatomical studies of their own, the article gives us an impression of their vision on the tarsal movements, a vision based on studies by Lapidus (1955) and Elftman (1960). The eversion allegedly takes place predominantly in the cuboidcalcaneal and talonavicular joints. "Most of this motion takes place at the calcaneocuboid joint in a gliding rotatory manner. The calcaneocuboid joint permits mostly gliding and slight rotation. There is little motion at the calcaneocuboid joint during inversion since the calcaneus and cuboid move as a unit."
We most definitely do not agree with the above statements. On the contrary - we shall refute them!

These authors also fail to make clear, when they speak of 'little motion at the calcaneocuboid joint' whether they mean absolute or relative movement. Should Feist and Mankin mean the absolute movements, the implication is rotation of calcaneus and cuboid around 'their own' axes, which are not identical!

'As a unit' in our opinion should be interpreted in a functional sense as moving in a chain, and not in a morphological sense as moving as a block as implied by Feist and Mankin. In 8 of the 10 specimens, the π of the absolute calcaneal and absolute cuboid axes have similar directions (not in specimens nrs 2 and 7), while the φ has an opposite direction. The φ of absolute calcaneal is open posteriorly, while the φ of absolute cuboid on the contrary is open anteriorly. Moreover, the absolute calcaneal axis passes through the calcaneus, while the absolute cuboid axis lies just outside the cuboid.

The absolute calcaneal and absolute cuboid rotations, also, differ in this sense that the absolute calcaneal rotation is always slightly less than the absolute cuboid rotation, with mean values of 18.8° and 23.8°, respectively. Although the rotations of the two bones have directions in the sense of an inversion, it is precisely as the result of these different axial directions for calcaneus and cuboid that the movement of the cuboid is an almost 'pure' inversion while that of the calcaneus is a 'combined' inversion-abduction movement.

The directions of the translations of calcaneus and cuboid are also opposite: the calcaneus undergoes a slight anterior, the cuboid a slight posterior translation, with average of 0.7 mm and 1.1 mm, respectively.

If Feist and Mankin mean the relative movements, in our opinion there indeed occurs a combined rotation and translation in the calcaneocuboid joint.

In our series, there is an average of 15.8° cuboidcalcaneal rotation and an (average) translation of 1.8 mm. It is interesting in this connection that the relative cuboid calcaneal translation is the largest of all intertarsal translations. However, these authors' description of 'mostly gliding and slight rotation' is not clear.

11.3.4 Rotations and translations along cuboidcalcaneal axes, total range

1. The rotations, α CUCA 30°/35° (Table 11-22)

The rotations ranged from a minimum of 8.8° to a maximum of 25.3°. The mean value was 15.8°; range 16.5°.

The direction of the rotation of the cuboid in relation to the calcaneus presumed immobile was counter-clockwise (viewed in the a-p direction) for the 7 right-foot specimens and clockwise for the 3 left-foot specimens. This means, in consideration of the position and direction of the cuboidcalcaneal helical axis, that the movement involved was a combination of adduction and inversion.

2. The translations, t CUCA 30°/35° (Table 11-22)

The translations t varied from 0.6 mm to 3.4 mm.

Table 11-22. Cuboidcalcaneal rotations (α CUCA 30°/35°) and translations (t CUCA 30°/35°) total range.

Specimen	CUCA α 30°/35°	CUCA t 30°/35°
1 R	14.0°	- 1.4 mm
2 R	18.3°	- 0.6 mm
3 R	15.3°	- 1.4 mm
4 R	19.9°	- 3.4 mm
5 R	14.4°	- 1.1 mm
6 R	13.3°	- 2.1 mm
7 R	8.8°	- 1.4 mm
8 L	13.0°	- 2.4 mm
9 L	15.5°	- 1.2 mm
10 L	25.3°	- 3.0 mm

The mean translation was 1.8 mm, variation range 2.3 mm. The direction of the translation was negative for all specimens, i.e. the cuboid moved toward the origin; the cuboid translated in the posterior direction.

3. Comparing our own data with those in the literature, we find only few authors who describe the movements in the cuboidcalcaneal joint with numbers of degrees of rotation and/or numbers of milimeters of translation.
In the works of certain authors, Albert (1882), Strasser (1917), Braus (1921), Von Lanz and Wachsmuth (1938 and 1970) we find no 'separate' cuboidcalcaneal movement. These authors mention only the talotarsal rotation, with the talus rotating in relation to a rather rigid, subtalar footplate (calcaneus, cuboid and navicular) round one oblique axis. The only function of the cuboid then is to support the movements in the talonavicular joint. Henke (1835, 1857, 1863 and 1888) admittedly describes a movement of the cuboid in relation to the calcaneus during supination but according to him, this movement only increases the range of motion in the talonavicular joint after the 'extreme position' reached in the talocalcaneal joint. Henke does not describe the rotation in degrees or translation in millimeters, either.
Farabeuf (1889) also only describes a movement of the cuboid in relation to the calcaneus during supination, without further details. In more recent literature, Henke's views are reflected. For instance, Wells (1950) states: "the calcaneocuboid joint is non-axial and permits only a slight gliding movement. This would seem to be supplementary to the real motions of the talonavicular joint".
In the works of Meyer (1853, 1873 and 1886), Dönitz (1903), Fick (1904), Strasser (1917), Manter (1941) and Hicks (1953), we always find a rotation of the cuboid in relation to the calcaneus described as taking place around an axis lying more or less in the longitudinal direction of the foot, with a slight anterior inclination.

Manter (1941) stated that the motion of the cuboid in relation to the calcaneus "involves screwlike action rather than simple rotation".
The pitch angle for the cuboidcalcaneal joint (calcaneal surface) amounted to 10°. Cf. the subtalar (calcaneal) pitch of 12°. Allegedly, the movement of the cuboidcalcaneal joint might be compared to a screw with left-hand thread. According to Manter, in eversion of the right foot, a "counterclockwise rotation of the cuboid with a small advancement along the axis of the joint" is involved. Manter's observation that the eversion of the foot is linked to a pronatory deformation of the tarsus has been made concerning motions such as they occur in a foot hanging free.
In our experiments, during the standard movements, a pronation twist of the forefoot linked to a supinatory deformation of the tarsus is involved; here, we observed the 'counterclockwise rotation' of the cuboid (inversion), with this bone retracting toward the calcaneus (cf. left-threaded screw). A quantitative description of the relative cuboidcalcaneal rotation in degrees was given only by Fick and Hicks, viz. 20° and 8°, respectively.

11.4 RELATIVE NAVICULOCALCANEAL MOVEMENTS

11.4.1 Directions and positions of naviculocalcaneal axes, partial range

The relative navicularcalcaneal helical axes describe the movement of the navicular bone in relation to the calcaneus considered stationary.
First the findings obtained for specimen nr 1.
Figure 11-21a shows the dorsoplantar projection in which the helical axes run mostly in a direction from anteromedial to posterolateral. The bundle here is projected obliquely over the projections of the starting and end positions of the navicular bone: axis nr 1 approximately through the centre of the starting position and axis nr 6 approximately over the centre of the end position.
In the frontal projection (Figure 11-21b) the axes mostly run from mediosuperior to lateroinferior.
Figure 11-21c shows the sagittal projection in which the steepness of the projected axes is noticeable. The axes run from anterosuperior to postero-inferior. The first few axes are projected outside the projection of the navicular bone in the starting position.

Combining the three projections we find that the navicular bone moves in relation to the calcaneus around helical axes that occupy a position halfway between the vertical and the horizontal, with a direction from anteromedio-superior to posterolateroinferior. The bundle of axes enters the calcaneus from anteromedial. Accordingly, the direction of this bundle resembles that of the

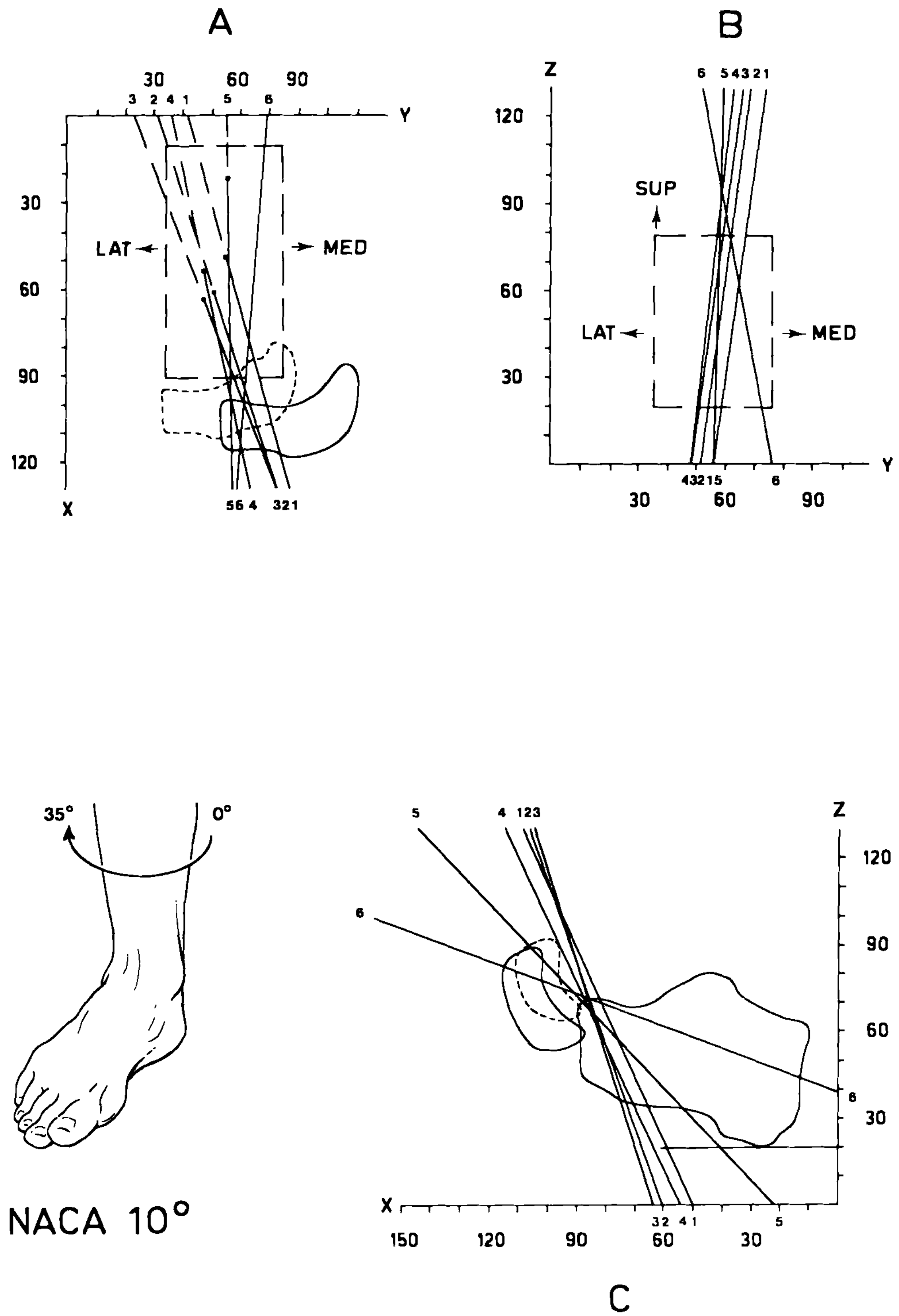


Figure 11-21. Projections of relative naviculocalcaneal helical axes, NACA 10°, partial range.

TACA bundle and even more, that of the CUCA bundle. The NACA bundle lies in a farther anterolateral position than the TACA bundle, see Figures 11-22a, b and c. The similarities of direction and position of the NACA and CUCA bundles can be observed in Figures 11-22d, e and f.
In view of the direction of rotation stated, see below Chapter 11.4.2, the relative naviculocalcaneal movement has an adduction as well as an inversion component.

The positions and directions of the relative naviculocalcaneal helical axes in the other specimen, 10° step size, without phase 1.

1. The deviation angles, π NACA 10°, without phase 1 (Table 11-23)
Interestingly, in the 6 right-foot specimens, the directions of the axes are predominantly from anteromedial to posterolateral, whereas in the 3 left foot specimens and one right-foot specimen (nr 7), this direction is from anterolateral to posteromedial. The deviation angle taking into account the left right difference, ranged from -21° tot 47.8°. The mean values ranged from -16.0° tot 22.6°. Accordingly, the axes always made a (very) acute angle with the X axis (or the longitudinal axis of the foot).
No typical pattern of the changes of π in the sense of movement of the axis toward or away from the sagittal plane could be observed.

2. The inclination angles, φ NACA 10°, without phase 1 (Table 11-23)
In all phases and in all specimens the axes had a direction from anterosuperior to posteroinferior, in other words, made an anteriorly open angle.
The inclination angle ranged from 10.6° to 73.9°. The mean value for the individual specimens ranged from 17.9° to 59.7°.
In specimen nr 9, fairly low values of φ were found; if this preparation is discounted, φ ranged from 32.5° to 59.7°.
We did observe a certain trend in the changes of position in relation to the basal plane: in all specimens, there was a distinct decrease of φ, sometimes preceded by an increase; in other words, the relative naviculocalcaneal axis turned to a more horizontal position. Combining the data for π and φ, we find that in 6 specimens the bundle contained axes with a direction from anteromediosuperior to posterolateroinferior, while in 4 specimens, conversely, the directions were from anterolaterosuperior to posteromedioinferior.

3. The angles R π and R φ of the bundle width, the bundle angle (Table 11-23, 11-24)
In 6 specimens (nrs 1, 2, 3, 4, 5 and 9), the bundle angle exceeded 10°. In 4 specimens (nrs 6, 7, 8 and 10) it was less than 10°. A distinct interindividual variability can be observed. The bundle angle for the deviation ranged from 3.0° to 45.5°. The bundle angle for the inclination ranged from 16.4° to 50.0°. No correlation could be established between the magnitudes of the bundle angles

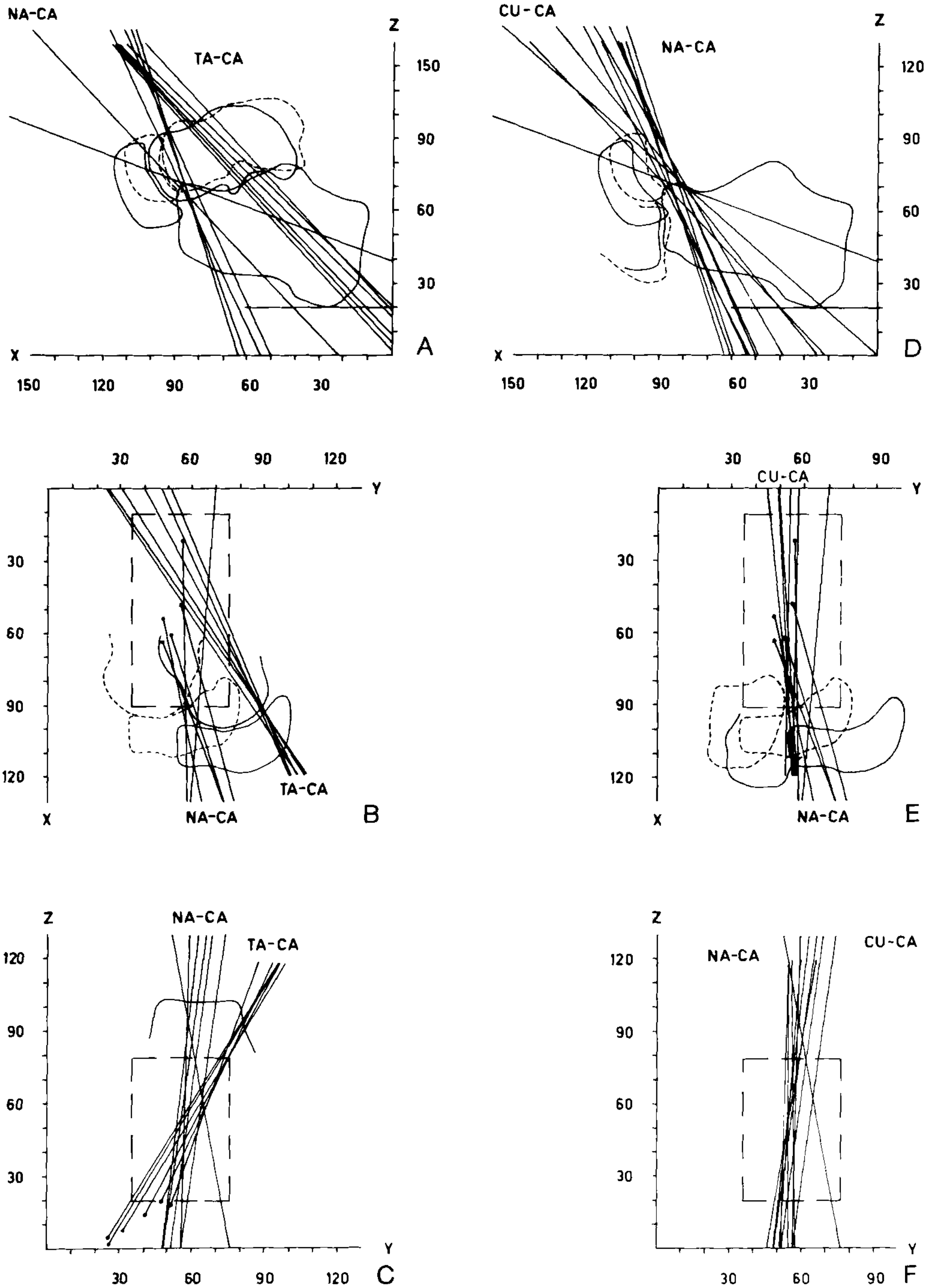


Figure 11-22. TACA 10° and NACA 10° helical axes; sagittal, dorsoplantar and frontal projections. NACA 10° and CUCA 10° helical axes; sagittal, dorsoplantar and frontal projections.

Table 11-23. Deviation angles of naviculocalcaneal axes (π NACA 10°) with summation, mean and range of deviation angles.

Specimen	R 1	R 2	R 3	R 4	R 5	R 6	R 7	L 8	L 9	L 10
Phase										
π 1	15.5	356.9	74.7	18.9	49.1	4.6	343.8	356.5	2.0	3.0
π 2	18.6	- 6.1 (353.9)	47.8	8.1	31.5	3.2	- 12.6 (347.4)	4.2	10.6	0.5
π 3	21.1	4.4	13.3	- 0.5 (359.5)	32.4	- 3.7 (356.3)	- 12.4 (347.6)	9.5	18.3	0.7
π 4	12.9	39.4	5.6	7.2	23.0	- 2.3 (357.7)	- 9.2 (350.7)	9.8	21.0	0.7
π 5	0.6	22.4	8.0	11.2	5.2	4.0	- 6.9 (353.1)	12.7	16.4	- 0.4 (359.6)
π 6	- 4.1 (355.9)	10.6	6.7	6.0	- 1.6 (358.4)				13.6	2.6
$\Sigma\,\pi$	50.1	70.7	81.4	32.0	90.5	1.2	- 41.1	36.2	79.9	4.1
$\overline{\pi}$	10.2	14.2	16.3	6.4	22.6	0.3	-10.3	9.1	16.0	0.8
R π	25.2	45.5	42.2	11.7	34.0	7.7	5.7	5.6	10.4	3.0

Table 11-24. Inclination angles of naviculocalcaneal axes (φ NACA 10°) with summation, mean and range of inclination angles.

Specimen	R 1	R 2	R 3	R 4	R 5	R 6	R 7	L 8	L 9	L 10
Phase										
φ 1	64.8	64.0	49.3	27.7	66.6	32.1	44.6	34.1	38.0	41.2
φ 2	69.4	61.2	47.6	30.1	49.8	35.0	53.4	40.8	27.0	46.0
φ 3	70.4	67.5	42.5	33.2	45.2	34.0	47.8	42.9	18.2	50.8
φ 4	64.2	73.9	45.3	44.6	41.9	35.8	26.7	34.7	17.1	51.2
φ 5	46.5	63.4	40.5	41.6	37.3	42.8	12.4	11.4	16.6	42.7
φ 6	20.4	32.3	25.1	23.6	28.6				10.6	25.6
$\Sigma\,\varphi$	270.9	298.3	201.0	173.1	202.8	147.6	140.3	129.8	89.5	216.3
$\overline{\varphi}$	54.2	59.7	40.2	34.6	40.6	36.9	35.1	32.5	17.9	43.3
R φ	50.0	41.6	22.5	21.0	21.2	18.0	41.0	31.5	16.4	25.2

for the deviation and the inclination! Interestingly, in specimens that showed a small bundle angle for the deviation, the values found for the bundle angle for φ were not so small.

4. The angles between the naviculocalcaneal axes (γ)
These are listed in Table 11-25.
The angles between pairs of successive axes ranged from 0.4° to 32.0°. These successive angles were added up per specimen; these summation angles ranged from 16.3° to 64.7°.

Table 11-25. Angles between the successive axes γ NACA 10°.

Specimen	R 1	R 2	R 3	R 4	R 5	R 6	R 7	L 8	L 9	L 10
Phase										
γ 2-3	1.3	7.7	24.6	8.0	4.6	5.7	5.5	4.5	11.3	4.8
γ 3-4	6.9	13.0	6.2	12.9	7.6	2.1	21.4	8.2	2.7	0.4
γ 4-5	19.0	12.0	5.1	4.2	14.4	8.5	14.5	23.4	4.4	8.6
γ 5-6	26.4	32.0	15.5	18.5	10.4				6.6	17.3
$\Sigma\ \gamma$	53.6	64.7	51.4	43.6	37.0	16.3	41.4	36.1	25.0	31.1

5. We shall concisely review the relationships between the calcaneus and the navicular bone, with the insertions of the ligaments (from Huson, Volkmann and Schmidt). In this connection see also Figure 11-23, which have been borrowed from Huson.
The navicular bone does not have an articular surface on its calcaneal side, although occasionally the two bones have a small area of contact. On the other hand, there exists an extensive network of ligaments between the navicular and the calcaneus, namely:

a. the calcaneonavicular slip of the bifurcate ligament, situated dorsally; a broad slip, with fibres running from lateroposterior to medioanterior, inserting laterally on the navicular. During supination, this ligament relaxes;

b. the plantar calcaneonavicular ligament (Pfannenband, springligament), a broad ligament, inserting on the anteromedial surface of the calcaneus with horizontal directions of the fibres, then converging in the medial direction, toward the medial navicular tubercle where the fibres run more vertically. The shortest fibres run in a lateral direction; there is some degree of torsion in the direction of the fibres. During supination, this ligament remains taut, partly due to the torsion of the fibres.

Huson (1961) has already described two bands between the calcaneus and the navicular bone which deserve separate consideration.
He distinguished:
a) a thick short fibrous band, with fibres implanted close to the articular surface of calcaneus and navicular, the fibres running in the direction of the lateral navicular tubercle;
b) a thick fibrous band with fibres that spring from the edge of the sustentaculum tali; it is situated medially of the calcaneocuboid articular surface and inserts below the lateral angle of the navicular bone, with fibres running from latero-proximal to mediodistal.

According to Huson (1961), these two short fibrous bands from the calcaneus to the navicular relax during supination, just as the calcaneonavicular slip of the bifurcate ligament. This would imply that *these* fibres should *not* be regarded as a ligemantous bundle of axes!

According to Huson, the calcaneonavicular (and also the talonavicular) bands impose a tilting movement on the navicular bone in which the centres of the motion should be situated in the area of the short and shortest calcaneonavicular ligaments; this is the neck-shaped region of the calcaneocuboid joint. The calcaneonavicular fibres lengthen in the medial direction and accordingly constitute the mirror image of the calcaneocuboid fibres.

Volkmann (1970, 1972 and 1973) has given a highly detailed description of the plantar calcaneonavicular ligament. In this ligament, Volkmann distinguishes two groups of fibres:
a) a plantar band with relatively short fibres (which according to Volkmann is the calcaneonavicular ligament proper) and
b) a medial band with longer fibres.
The latter band, situated medially and dorsally, Volkmann calls the 'ligamentum neglectum'. It is approx 15 mm wide and runs along the medially exposed surface of the talar head (without articulation) and inserts on the navicular bone. The direction of the fibres is diagonally at an angle of approx 45° with the horizontal and viewed dorsally, diagonally at an angle of approx 30° with the 'longitudinal axis of the foot', the fibres running from posteromedial to anterolateral. According to Volkmann this ligamentum neglectum resists the pronation of the heel and the adduction (endorotation) of the talus. Volkmann emphasizes that this ligament is not a supporting part of the socket for the talar head but has the function of resisting the medialward thrust of the talar head sliding over the superior aspect of the calcaneus.

6. The relationship of the naviculocalcaneal axode with the ligaments between the navicular bone and the calcaneus

Huson (1961) already presumed a position of the relative naviculocalcaneal axes in the neck-shaped region of the calcaneus. Just as in the preceding chapter we

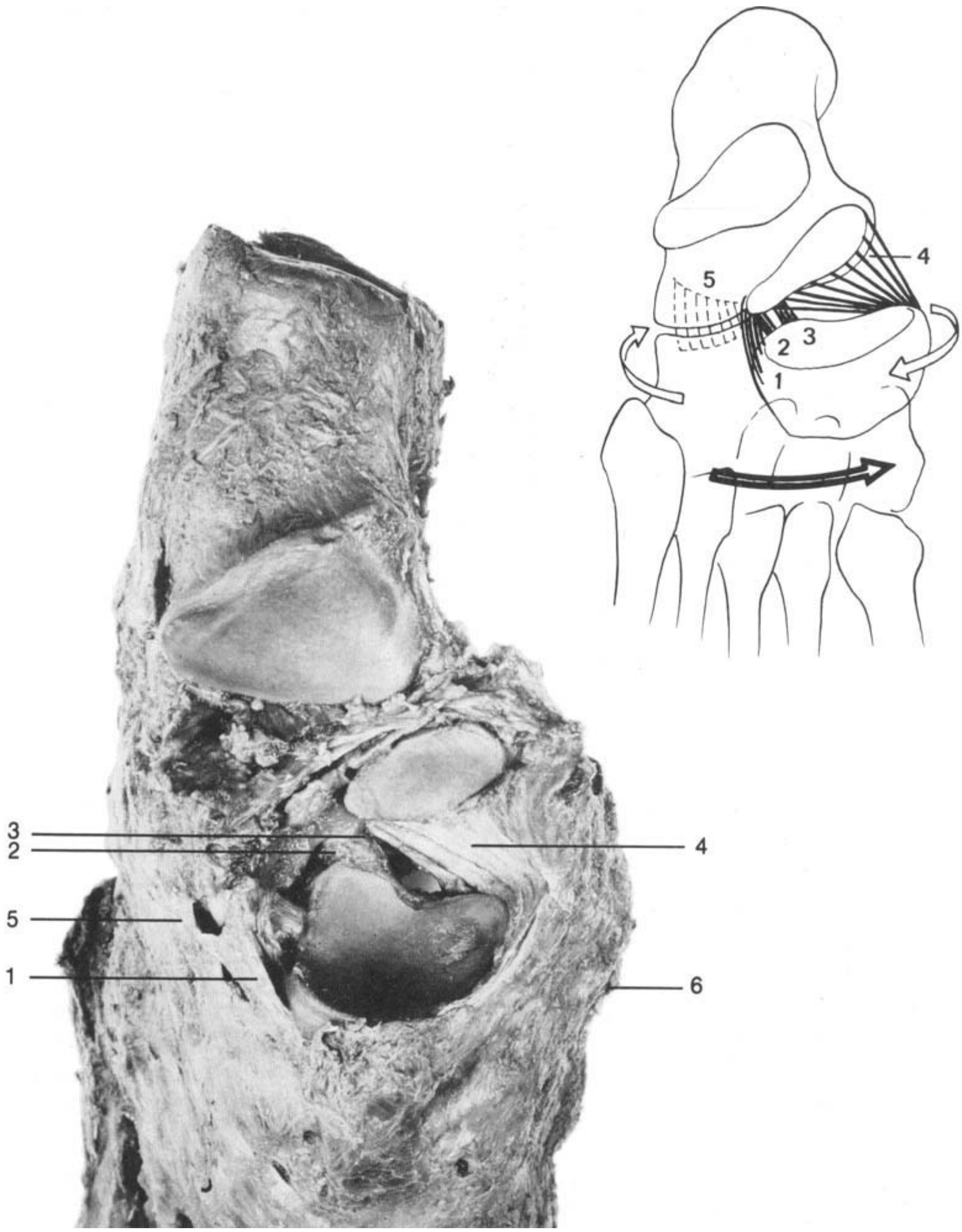


Figure 11-23. View from above right foot, with talus removed.

1. bifurcate ligament (calcaneonavicular ligament)
2. lateral band
3. medial band
4. plantar calcaneonavicular ligament
5. calcaneocuboid ligament
6. ligament neglectum.

Table 11-26. Centres of intersection helical axes NACA 10° with vertical plane and differences between max. and min. of coördinates.

	Phase	X	Y	Z		Phase	X	Y	Z
	2	86	60.03	70.19		2	86	66.54	60.80
	3	86	56.54	67.34		3	86	59.67	63.29
1 R	4	86	55.22	67.64	6 R	4	86	56.83	62.75
	5	86	56.69	67.47		5	86	56.66	62.06
	6	86	62.63	71.61					
min/max diff.			7.41	4.27	min/max diff.			9.88	2.49

	Phase	X	Y	Z		Phase	X	Y	Z
	2	91	53.00	60.05		2	88	45.99	63.00
	3	91	50.99	59.80		3	88	46.25	64.18
2 R	4	91	47.36	66.89	7 R	4	88	47.88	65.50
	5	91	46.94	69.46		5	88	49.16	64.95
	6	91	50.75	66.17					
min/max diff.			6.06	9.66	min/max diff.			3.17	2.50

	Phase	X	Y	Z		Phase	X	Y	Z
	2	75	61.51	52.44		2	95	57.00	73.03
	3	75	53.78	49.66		3	95	64.88	68.37
3 R	4	75	47.95	43.78	8 L	4	95	65.45	69.49
	5	75	47.29	47.32		5	95	59.47	74.36
	6	75	51.29	56.38					
min/max diff.			14.22	12.60	min/max diff.			8.45	5.99

	Phase	X	Y	Z		Phase	X	Y	Z
	2	90	60.16	58.02		2	79	56.29	61.10
	3	90	47.58	58.15		3	79	56.95	60.28
4 R	4	90	44.90	64.08	9 L	4	79	55.93	59.92
	5	90	52.15	69.52		5	79	53.74	60.60
	6	90	58.93	72.16		6	79	52.10	60.97
min/max diff.			15.13	14.04	min/max diff.			4.85	1.18

	Phase	X	Y	Z		Phase	X	Y	Z
	2	80	71.00	50.20		2	80	54.24	69.79
	3	80	57.02	51.47		3	80	54.79	67.62
5 R	4	80	52.56	52.00	10 L	4	80	54.86	66.57
	5	80	55.60	52.06		5	80	53.03	66.58
	6	80	58.63	54.40		6	80	50.35	65.48
min/max diff.			18.44	4.20	min/max diff.			4.51	4.31

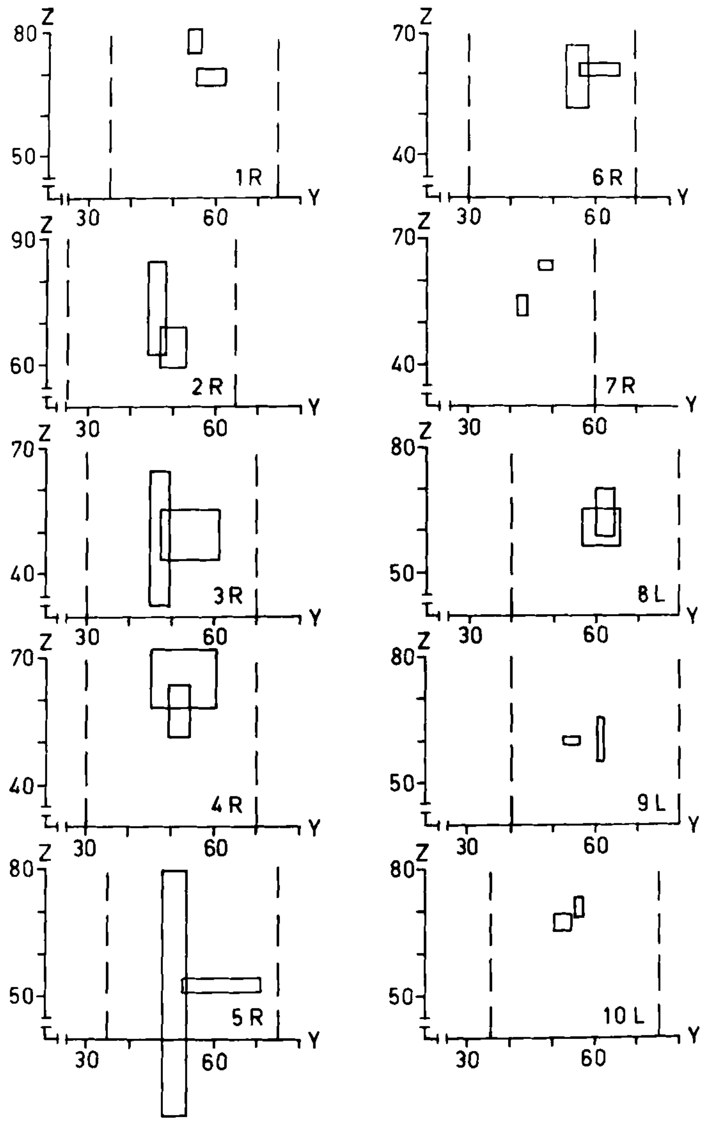


Figure 11-24. Areas of intersection helical axes NACA 10° with frontal plane combined with areas of intersection helical axes CUCA 10° with another frontal plane (except spec. 1, 10).

have determined the position of the axode bundle with a vertical intersection plane for the calcaneocuboid joint, we have now, in an identical manner, intersected the naviculocalcaneal 10° axode with a vertical calcaneal intersection plane.

For each of the 10 specimen we determined that frontal plane of which the points of intersection with the CUCA axode were situated most closely together. In 8 cases, this proved to be a different frontal plane from the CUCA frontal plane; in 5 instances it was situated in front of the frontal plane of CUCA.

Table 11-26 shows the X, Y and Z coordinates of the points of intersection of each of the 10 axodes with their frontal plane. A noticeable element is the sometimes considerable variation in the Y direction.
Among the 10 specimens the Y coordinate difference ranged from 3.17 mm to 18.44 mm. The mean Y coordinate difference was 9.21 mm.
The Z coordinate differences ranged from 1.18 mm to 14.04 mm, with a mean of 6.12 mm.
Figure 11-24 for the 10 specimens shows the frontal planes of intersection, the areas delimited by the minima and maxima of the Y and Z coordinates. In Figure 11-24, we have also indicated the 'borderline area' for the NACA points of intersection and the CUCA borderline areas. Each time, two frontal planes are projected in one drawing. We find that these 'borderline areas' do not overlap completely; for NACA there is a fairly broad borderline area lying in the Y direction, for CUCA a narrower one, lying in the Z direction.
No direct correlation between the degree of NACA-CUCA overlap and the magnitude of the relative cuboidnavicular rotation (see also Chapter 11.6) can be deduced.

11.4.2 Rotations and translations along naviculocalcaneal axes, partial range

1. The rotations, α NACA 10°, without phase 1 (Table 11-27)
The rotation α around the relative naviculocalcaneal axis ranged from a minimum of 3° to a maximum of 11.4°. In all preparations the rotation shows a gradual increase which may or may not be followed by a gradual decrease. As regards the directions of rotation: in the 7 right-foot specimens it was counter-clockwise (viewed in the a-p direction) and in the 3 left-foot specimens it was clockwise.
In view of the positions of the axes, the navicular bone moves with a combined inversion-adduction motion in relation to the calcaneus. Since the inclination of the naviculocalcaneal axes decreases as the motion proceeds, the inversion component of the navicular movement increases.

2. The translations, t NACA 10°, without phase 1 (Table 11-27)
The relative naviculocalcaneal translation ranged from 0.0 mm to 1.1 mm. As regards the directions of the translation: in most cases the translation was negative, in other words: the navicular bone shifted in the posteroinferior direction in relation to the calcaneus. In 3 specimens (nrs 1, 2 and 6) we 5 times observed a positive translation in the earliest phases, and only once a positive translation in phase 4 (specimen nr 2).

3. A critical comparison with data from the literature is not possible; the relative naviculocalcaneal movements are not described in the literature.

Table 11-27. Naviculocalcaneal rotations (NACA α 10°) and translations (NACA t 10°), partial range.

Specimen		R 1	R 2	R 3	R 4	R 5	R 6	R 7	L 8	L 9	L 10	
	Phase											
t	1	2.0	0.3	-0.1	-0.2	-0.6	0.3	-0.1	-0.4	-0.4	-0.5	NACA mm
α		3.6	2.3	1.8	2.9	1.7	2.6	3.8	4.0	5.4	7.0	NACA°
t	2	0.1	0.2	-0.2	-0.3	-0.5	0.2	0.0	-0.4	-0.3	-0.6	NACA mm
α		3.9	5.5	4.2	5.7	3.0	6.6	6.2	5.9	7.3	8.3	NACA°
t	3	0.1	0.0	-0.2	-0.7	-0.3	-0.2	-0.1	-0.3	-0.1	-0.7	NACA mm
α		4.2	7.4	6.4	8.6	4.8	9.9	6.3	7.2	7.9	8.8	NACA°
t	4	-0.2	0.2	-0.1	-0.6	-0.2	-0.5	-0.3	-0.7	-0.1	-0.8	NACA mm
α		5.2	8.3	7.6	10.1	7.5	10.0	5.8	7.8	6.7	8.8	NACA°
t	5	-0.8	-0.1	-0.5	-0.8	-0.3	-0.4	-0.3	-1.0	-0.4	-0.9	NACA mm
α		6.1	8.6	7.8	9.3	10.2	8.2	4.8	7.1	4.9	8.6	NACA°
t	6	-1.1	-0.9	-0.1	-0.7	-0.5				-0.5	-0.9	NACA mm
α		8.2	8.7	8.9	7.0	11.4				3.4	8.8	NACA°

4. Comparison of the α NACA with the α CUCA shows that the α NACA always slightly exceeds the α CUCA. This means that the navicular bone always supinates slightly more than the cuboid. (See also Chapter 11.6).

11.4.3 Directions and positions of naviculocalcaneal axes, total range

Figure 11-25 shows the three projections of the single relative naviculocalcaneal helical axis as computed for the total movement for specimen nr 1. From the combination of the three projections it appears that the navicular bone in relation to the calcaneus moves around a single axis that runs approximately in the longitudinal direction of the foot and passes through the proximomedial part of the calcaneus, with a position halfway between the horizontal and the vertical and a direction from anteromediosuperior to posterolateroinferior. This position of the axis is consistent with a combined adduction inversion of the navicular bone in relation to the calcaneus.

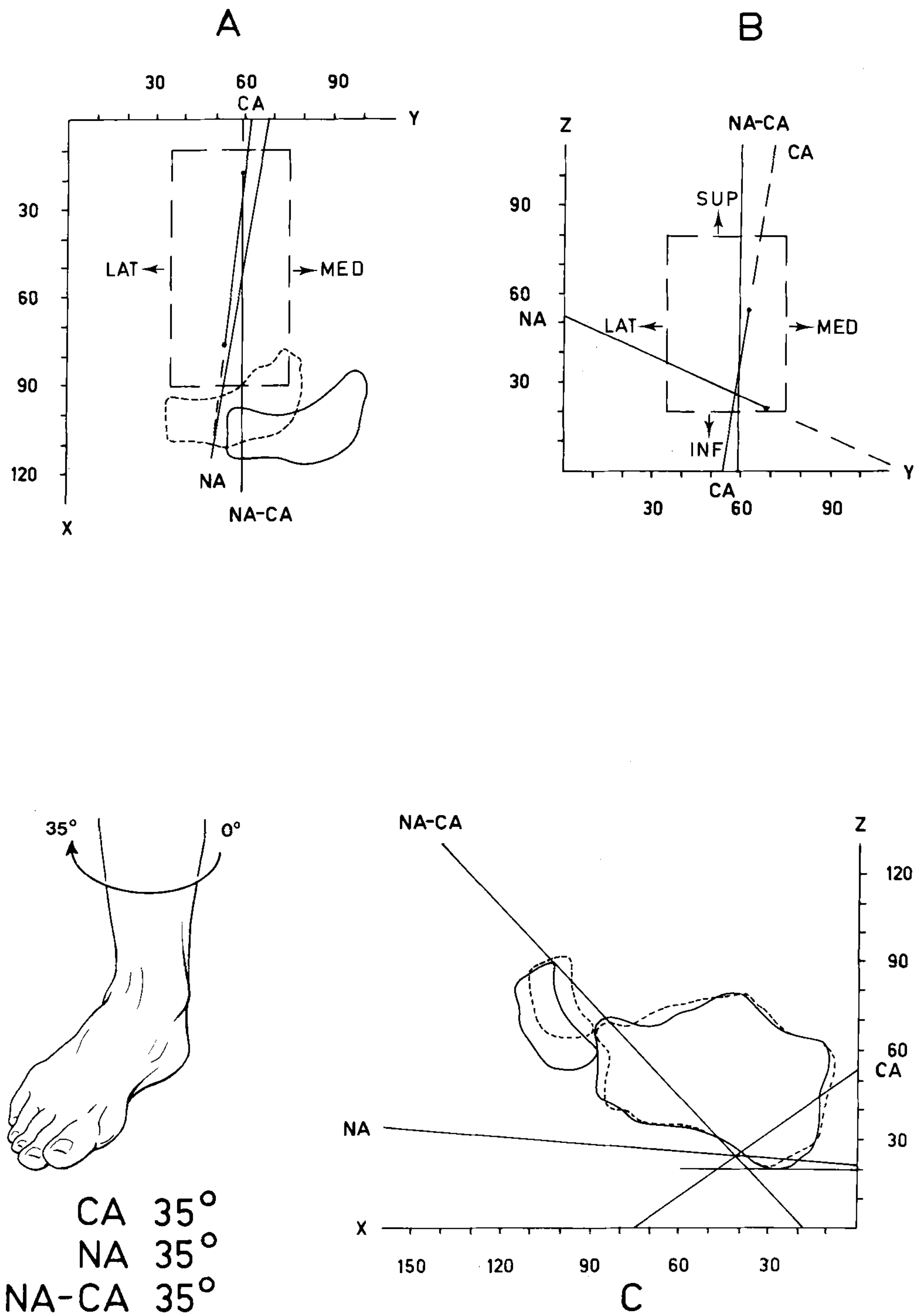


Figure 11-25. Projections of relative naviculocalcaneal (NACA 30°/35°), absolute navicular (NA 30°/35°) and absolute calcaneal (CA 30°/35°) helical axes, total range.

1. The deviation angles, π NACA 30°/35° (Table 11-28)
Taking into account the left-right difference, these angles ranged from -14.5° to 12.1°. The mean deviation angle amounted to -0.3°. (Mean value irrespective of the sign : 7.5°)
Accordingly, there is no similarity of direction in relation to the sagittal plane; a direction from anteromedial to posterolateral was seen 6 times and a direction from anterolateral to posteromedial, 4 times (cf. the partial range).

2. The inclination angles, φ NACA 30°/35° (Table 11-28)
These ranged from 22.6° to 56.1°.
The mean inclination angle was 38.1°.
For all preparations the axis has a value of φ that is consistent with a direction from anterosuperior to posteroinferior.

Table 11-28. Naviculocalcaneal deviation angles (π NACA 30°/35°) and inclination angles (φ NACA 30°/35°) total range.

Specimen	NACA π 30°/35°	NACA φ 30°/35°
1 R	0.1°	46.7°
2 R	7.6°	56.1°
3 R	12.1°	38.9°
4 R	6.6°	34.2°
5 R	8.9°	39.5°
6 R	0.7°	37.2°
7 R	- 12.2° (347.8°)	35.7°
8 L	9.2°	29.4°
9 L	14.5°	22.6°
10 L	2.9°	41.1°

11.4.4 Rotations and translations along naviculocalcaneal axes, total range

1. The rotations, α NACA 30°/35° (Table 11-29)
The rotations ranged from 14.4° (specimen nr 7) to 28.4° (specimen nr 10). The mean value of α was 20.5°. The direction of rotation of the navicular bone in relation to the calcaneus presumed stationary was counter-clockwise, viewed in the anteroposterior direction for the 7 right-foot specimens and clockwise for the 3 left-foot specimens. Considering the position and direction of the axis, the naviculocalcaneal movement consists in a combination of adduction and inversion.

2. The translations, t NACA 30°/35° (Table 11-29)
The translations ranged from a minimum of 0.4 mm (specimen nr 6) to a

Table 11-29. Naviculocalcaneal rotations (α NACA 30°/35°) and translations (t NACA 30°/35°) total range.

Specimen	NACA α 30°/35°	NACA t 30°/35°
1 R	17.2°	- 1.4 mm
2 R	21.9°	- 0.5 mm
3 R	20.0°	- 1.1 mm
4 R	23.1°	- 2.1 mm
5 R	21.5°	- 1.0 mm
6 R	20.6°	- 0.4 mm
7 R	14.4°	- 0.6 mm
8 L	17.6°	- 1.8 mm
9 L	19.6°	- 1.3 mm
10 L	28.4°	- 2.6 mm

maximum of 2.6 mm (specimen nr 10). The mean naviculocalcaneal translation in our series amounted to 1.3 mm.
The direction of the translation is negative; the navicular bone shifts in a postero-inferior direction along the naviculocalcaneal axis.

3. Comparison with the literature
We have found no data in the literature with which we could check our results.

11.5 RELATIVE TALONAVICULAR MOVEMENTS

11.5.1 Directions and positions of talonavicular axes, partial range

The relative talonavicular helical axes describe the movements of the talus in relation to the navicular bone presumed stationary.
Fig. 11-26a shows the dorsoplantar projection, in which a fan-shaped bundle can be discerned, running from anteromedial to posterolateral. In the frontal projection (Fig. 11-26b), the fan-shaped bundle runs from mediosuperior to lateroinferior.
Fig. 11-26c represents a sagittal projection, in which it is noted that the fan of axes is projected outside the navicular bone. From the combination of these three projections it appears that all axes pass through the neck of the talus in its initial position and cross there at short distances.
From the given direction of rotation (see below Chapter 11.5.2), we may conclude that the relative talonavicular movement has distinct abduction and eversion components.

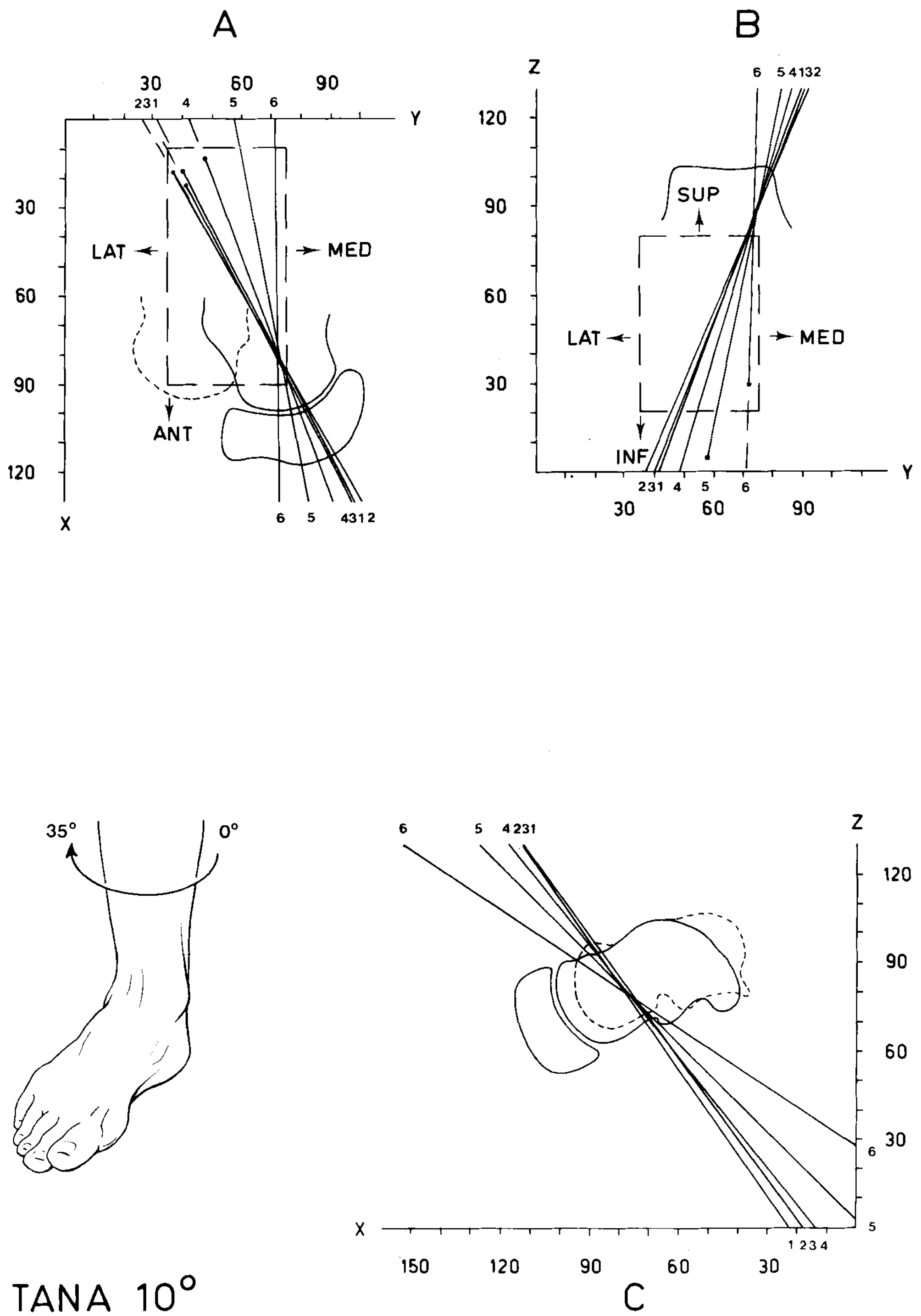


Figure 11-26. Projections of relative talonavicular helical axes (TANA 10°), partial range.

Table 11-30. Deviation angles of talonavicular axes (π TANA 10°) with summation, mean and range of deviation angles.

Specimen	R 1	R 2	R 3	R 4	R 5	R 6	R 7	L 8	L 9	L 10
Phase										
π 1	28.0	26.7	41.2	20.0	26.7	11.2	9.5	350.6	354.4	347.9
π 2	30.3	22.8	29.3	18.6	29.0	17.9	9.1	- 12.2 (347.8)	0.3	- 14.6 (345.4)
π 3	27.8	23.1	22.3	16.1	30.7	18.7	5.0	- 11.6 (348.4)	8.6	- 12.2 (347.8)
π 4	20.6	29.8	21.7	15.9	27.9	18.2	- 0.5 (359.5)	- 13.0 (347.0)	11.5	- 7.5 (352.5)
π 5	10.8	22.9	20.1	13.4	19.2	19.7	1.5	-6.5 (353.5)	9.0	-5.4 (354.6)
π 6	0.9	5.2	12.8	3.8	11.5				8.2	3.8
$\Sigma\ \pi$	90.4	103.8	116.2	67.8	118.3	74.5	14.1	- 43.3	37.6	- 49.7
$\overline{\pi}$	18.8	20.8	23.2	13.6	23.7	18.6	3.5	-10.8	7.5	- 9.9
R π	29.4	24.6	16.3	14.8	19.2	1.8	9.6	5.7	11.2	18.4

Table 11-31. Inclination angles of talonavicular axes (φ TANA 10°) with summation, mean and range of inclination angles.

Specimen	R 1	R 2	R 3	R 4	R 5	R 6	R 7	L 8	L 9	L 10
Phase										
φ 1	51.8	45.5	61.8	35.5	45.9	46.3	46.3	37.1	44.4	41.7
φ 2	49.9	46.4	49.4	31.4	37.8	41.4	51.1	34.4	41.4	43.3
φ 3	50.2	50.0	40.9	28.7	36.1	35.6	49.8	32.5	37.6	46.3
φ 4	49.5	55.0	40.3	32.8	35.4	35.1	40.4	27.6	36.6	49.7
φ 5	44.1	55.2	39.2	37.4	32.3	39.6	33.0	2.5	33.0	47.0
φ 6	33.3	41.6	33.3	34.7	30.2				28.1	39.0
$\Sigma\ \varphi$	227.0	248.2	203.1	165.0	171.8	151.7	174.3	97.0	176.4	225.3
$\overline{\varphi}$	45.4	49.6	40.6	33.0	34.4	37.9	43.6	24.3	35.3	45.1
R φ	16.9	13.8	16.1	8.7	7.6	6.3	18.1	31.9	13.0	10.7

1. The deviation angles, π TANA 10°, without phase 1 (Table 11-30)
In 9 specimens (nrs 1, 2, 3, 4, 5, 6, 7, 8 and 10), the axes nearly always run from anteromedial to posterolateral (in 2 of the 42 phases this is not the case). In one specimen (nr 9), the axial direction in all phases is from anterolateral to posteromedial.
The deviation angle taking into account the left-right difference ranged from -11.5° to 30.7°. The mean value of the deviation angle ranged from -7.5° to 23.7°. Accordingly, the relative talonavicular axis always makes an acute angle with the longitudinal axis of the foot. In the changes of π, no pattern could be discerned.

2. The inclination angles φ TANA 10° without phase 1 (Table 11-31)
In all specimens the axes made a distally open angle with the basal plane (positive sign); in other words, they run from anterosuperior to posteroinferior. In 9 of the 10 specimens this angle ranged in value between 24.3° and 49.6°. In one specimen (nr 8) the inclination angle in the last phase was exceedingly small (2.5°). The mean value of the inclination angle φ ranged from 34.4° to 55.2°. Accordingly, the relative talonavicular axes always made a reasonably large angle with the basal plane. No particular pattern could be observed in the changes of angle φ, either. The inclination angle for the relative talonavicular movement (φ TANA) has also been compared with φ NA (absolute navicular) and φ TA (absolute talar). In all 10 specimens, the values φ NA were lowest and the values φ TA highest, wheras the values φ TANA occupied an intermediate position.

3. The angles R π and R φ of the bundle width, the bundle angle (Tables 11-30 and 11-31)
The bundle angle of the talonavicular helical axis in the deviation direction R π ranged from 2.8° to 29.4°. In 7 specimens (nrs 1, 2, 3, 4, 5, 9 and 10), the bundle angle was larger than 10°; in 3 specimens (nrs 6, 7 and 8), it was smaller than 10°. The bundle angle in the inclination direction R φ ranged from 6.3° to 31.9°. In 7 specimens (nrs 1, 2, 3, 7, 8, 9 and 10), it was larger than 10°, and in 3 specimens (nrs 4, 5 and 6) it was smaller.

4. The angles between successive talonavicular helical axes (γ)
These angles γ are listed in Table 11-32. The angle between two successive axes ranged from 0.6° to 25.8°. These successive angles were added up per specimen and these totals ranged from 13.1° to 32.9°.

5. Before starting the discussion of the relationships between the helical axes and the talonavicular joint, first a few remarks concerning the talonavicular joint and the ligaments that enclose it (from Huson, Volkmann and Schmidt).
The talonavicular joint is classically described as an articulation of the ball-and-socket type, in which the head of the talus is far larger than the concave navicular articular surface. Also, the position of the head in relation to the socket can

Table 11-32. Angles between the successive axes γ TANA 10°.

Specimen	R 1	R 2	R 3	R 4	R 5	R 6	R 7	L 8	L 9	L 10
Phase										
γ 2-3	1.7	3.7	9.8	3.4	2.2	5.9	2.9	2.0	7.3	3.5
γ 3-4	4.7	6.4	0.8	4.2	2.4	0.6	10.2	5.1	2.5	4.6
γ 4-5	8.6	4.0	10.6	5.0	7.8	4.6	7.6	25.8	4.2	3.0
γ 5-6	13.3	17.9	8.3	8.2	6.9				4.9	10.5
$\Sigma\ \gamma$	28.3	32.0	20.5	20.8	19.3	13.1	20.7	32.9	18.9	21.6

change considerably. The head of the talus has two main curvatures at right angles to one another and that differ markedly in width and in its radius; it is definitely not a sphere, although each of the two curvatures in itself is practically circular.

A particular aspect of the talonavicular articular socket is its underside; this, namely, is formed by a ligament, the calcaneonavicular ligament. It renders the socket highly pliable, suitable to allow the very considerable distances over which the talus and the navicular bone move in relation to each other.

Of the ligaments surrounding the talonavicular joint, the bifurcate ligament, the calcaneonavicular ligament and the dorsal talonavicular ligament have already been described in the discussion of the naviculocalcaneal movement. The last named ligament consists of a strong lateral and a weak medial limb, which pass on either side of the head and neck of the talus, running toward the superior aspect of the navicular bone, where they fuse.

6. The relationship of the talonavicular helical axes and the talonavicular joint

For each of the 10 preparations, we determined that frontal plane of which the points of intersection with the TANA axode were situated most closely together. Table 11-33 lists the X, Y and Z coordinates of the points of intersection of each of the 10 axodes with the plane in question.

In Figure 11-27 and 11-28, we have drawn the respective helical axes in a dorsal projection for each of the 10 specimens. The drawing suggests that the axes cross at short distances, and that there is a concentration of axes at the borderline between the talar neck and head. As Table 11-33 shows, in the 10 specimens a very strong concentration of axes was indeed computed, ranging in the Y direction from 0.21 mm to 1.44 mm and in the Z direction, from 0.65 mm to 4.81 mm. In this respect, a comparison of the talar head to a functional ball-and-socket joint strongly suggest itself.

This is certainly curious, considering that Henle, and later Huson as well, established by measurements that the talar head definitely does not have a typical spherical shape. From this we may conclude that it is not only impossible

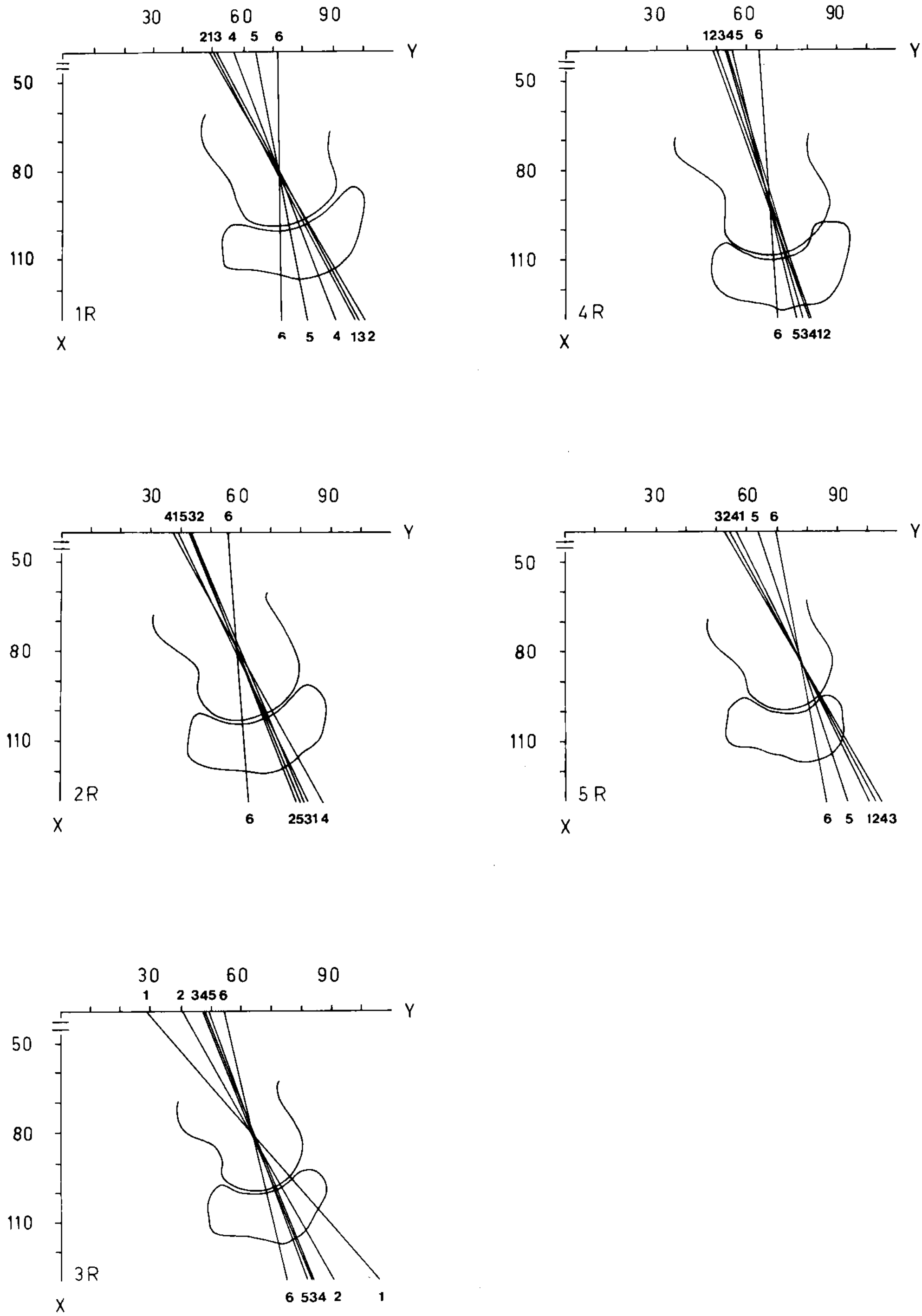


Figure 11-27. Dorsoplantar projections helical axes TANA 10°, partial range. Specimen 1, 2, 3, 4, and 5.

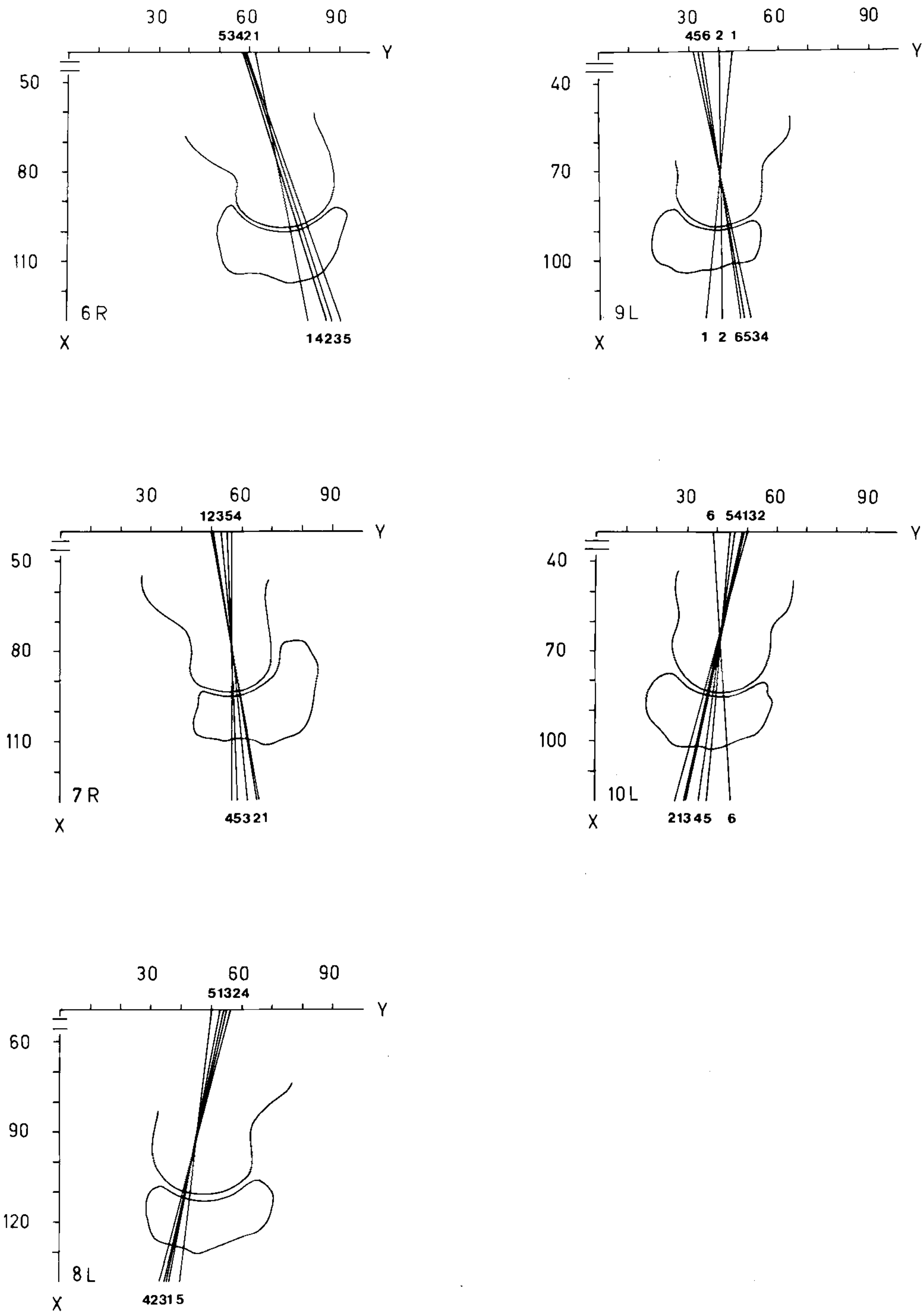


Figure 11-28. Dorsoplantar projections helical axes TANA 10°, partial range. Specimen 6, 7, 8, 9 and 10.

Table 11-33. Centres of intersection TANA helical axes (TANA 10°) with vertical plane and differences between max. and min. of coördinates.

	Phase	X	Y	Z		Phase	X	Y	Z
	2	80	72.95	84.83		2	70	67.07	62.32
	3	80	73.12	85.01		3	70	67.46	64.09
1 R	4	80	72.83	83.86	6 R	4	70	67.99	65.12
	5	80	72.76	82.82		5	70	68.13	64.56
	6	80	72.73	81.69					
	min/max diff.		0.39	3.32		min/max diff.		1.06	2.80

	Phase	X	Y	Z		Phase	X	Y	Z
	2	77	59.22	75.84		2	76	55.77	77.37
	3	77	59.45	75.26		3	76	55.84	77.89
2 R	4	77	58.94	75.81	7 R	4	76	56.18	77.84
	5	77	58.01	72.66		5	76	55.79	77.24
	6	77	58.93	71.03					
	min/max diff.		1.44	4.81		min/max diff.		0.41	0.65

	Phase	X	Y	Z		Phase	X	Y	Z
	2	80	63.31	74.09		2	95	44.78	88.52
	3	80	63.68	73.40		3	95	44.70	88.79
3 R	4	80	63.91	73.61	8 L	4	95	45.24	90.07
	5	80	63.92	73.52		5	95	44.45	93.03
	6	80	62.54	72.10					
	min/max diff.		1.38	1.99		min/max diff.		0.79	4.51

	Phase	X	Y	Z		Phase	X	Y	Z
	2	90	67.76	82.66		2	72	50.30	75.81
	3	90	67.92	82.84		3	72	50.06	75.13
4 R	4	90	67.79	82.56	9 L	4	72	49.38	74.08
	5	90	67.42	81.42		5	72	49.13	73.07
	6	90	67.60	81.20		6	72	49.23	72.44
	min/max diff.		0.50	1.64		min/max diff.		1.17	3.37

	Phase	X	Y	Z		Phase	X	Y	Z
	2	82	77.57	72.65		2	75	40.89	79.96
	3	82	77.47	74.07		3	75	40.98	79.89
5 R	4	82	78.31	74.90	10 L	4	75	41.10	79.94
	5	82	78.20	74.00		5	75	41.04	79.47
	6	82	77.60	72.02		6	75	40.98	77.40
	min/max diff.		0.84	2.88		min/max diff.		0.21	2.56

to deduce according to the theory of the solids of revolution the axes of motion from the articular surface, but that the reverse applies equally! When the axes of movement have been computed, as, for instance, for the TANA helical movements, and they all appear to intersect at practically the same point, this does not justify the conclusion that the head of the talus has a spherical surface. Another consequence is that if in the tarsal kinematic chain a functional ball-and-socket joint is involved, while this chain in all possesses 7 degrees of freedom that have to be divided among TANA, TACA and CUCA, three of these degrees belong to TANA, while TACA and CUCA share the remaining four, the most plausible division then being two to TACA and two to CUCA (Huson, 1982).

11.5.2 Rotations and translations along talonavicular axes, partial range

1. The rotations, α TANA 10°, without phase 1 (Table 11-34).
The rotation around the relative talonavicular helical axis ranged from 6.4° to 23.9°. The 'course' in all 10 specimens was mountainshaped. It was only in specimen nr 7 that the α in phase 2 slightly exceeded that in phase 3 (difference 0.4°). Here again it holds true that large rotations might correspond to high as well as to low values of γ; therefore is this case there is no reason to assume that the relative TA-NA axis actually constitutes a fixed hinge.
The directions of rotation: in the 7 right-foot specimens, the direction of rotation was counter-clockwise (viewed in the a-p direction) while in the 3 left-foot

Table 11-34. Talonavicular rotations (TANA α 10°) and translations (TANA t 10°), partial range.

Specimen		R	R	R	R	R	R	R	L	L	L	
		1	2	3	4	5	6	7	8	9	10	
	Phase											
t	1	0.4	0.4	-0.1	0.3	0.4	-0.1	0.2	0.4	0.3	0.4	TANA mm
α		8.7	10.9	2.9	5.6	4.0	6.0	8.7	7.6	10.1	12.1	TANA°
t	2	0.5	0.4	0.1	0.5	0.4	0.1	0.3	0.7	0.3	0.5	TANA mm
α		12.5	16.9	9.9	15.3	8.6	15.1	13.6	13.8	12.5	15.6	TANA°
t	3	0.5	0.4	0.1	0.9	0.3	0.4	0.3	1.0	0.3	0.5	TANA mm
α		13.2	17.5	18.5	23.9	11.9	22.1	13.2	18.6	12.6	16.2	TANA°
t	4	0.6	0.0	0.2	0.9	0.4	0.2	0.2	0.9	0.3	0.5	TANA mm
α		14.3	16.4	21.4	22.8	19.0	22.4	10.6	14.5	10.9	15.4	TANA°
t	5	0.6	0.1	0.4	0.6	0.5	0.1	0.1	0.7	0.4	0.5	TANA mm
α		15.5	14.9	18.8	16.8	25.4	17.7	8.2	6.4	8.6	14.2	TANA°
t	6	0.5	0.3	0.4	0.4	0.5				0.3	0.5	TANA mm
α		15.2	13.4	16.3	11.4	23.5				7.4	12.2	TANA°

specimens it was clockwise. Since the relative talonavicular axes occupy a position halfway between the horizontal and the vertical, as well as a fairly sagittal position, there occurs a combined abduction-eversion of the talus in relation to the navicular during the standard movement. If angle π is larger, the movement has an extension component as well.

2. The translations, t TANA 10°, without phase 1 (Table 11-34)
The translation along the relative talonavicular helical axis ranged from 0.0 mm to 1.0 mm.
The direction of the translation was positive in all preparations. In other words: in relation to the navicular bone presumed stationary, the talus moved away from the origin, in the anterior direction.

3. No comparison with data from the literature is possible since talonavicular rotations and translations in phases have never been described before.

11.5.3 Directions and positions of talonavicular axes, total range

Figure 11-28 shows the three projections of discrete relative talonavicular helical axes as computed for the total movement of specimen nr 1.
The combination of these three projections shows that this helical axis has a direction similar to that of the correspondig bundle of axes, i.e. from anteromediosuperior to posterolateroinferior, with a position halfway between the horizontal and the vertical. In view of the direction of rotation, this position of the axis is consistent with a combined abduction-eversion movement of the talus in relation to the navicular bone presumed stationary.

1. The deviation angles, π TANA 30°/35° (Table 11-35)

Table 11-35. Talonavicular deviation angles (π TANA 30°/35°) and inclination angles (φ TANA 30°/35°) total range.

Specimen	TANA π 30°/35°	TANA φ 30°/35°
1 R	17.4°	43.3°
2 R	20.1°	47.4°
3 R	21.4°	39.0°
4 R	13.7°	32.0°
5 R	21.2°	32.7°
6 R	18.4°	38.8°
7 R	6.1°	44.0°
8 L	- 11.8° (348.2°)	27.7°
9 L	3.8°	36.7°
10 L	- 7.3° (352.7°)	43.3°

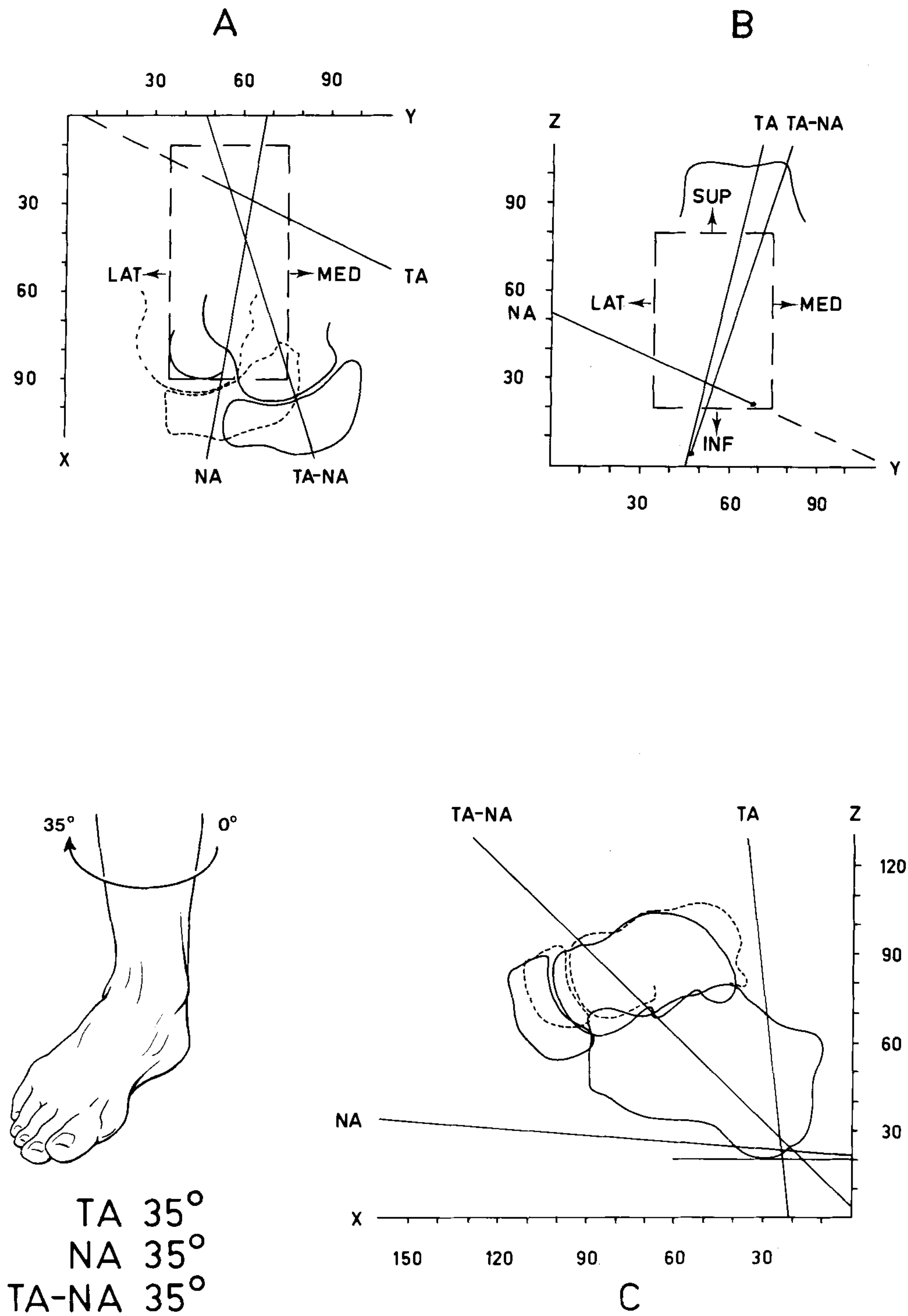


Figure 11-29. Projections of relative talonavicular (TANA 30°/35°), absolute navicular (NA 30°/35°) and absolute calcaneal (CA 30°/35°) and helical axes, total range.

Taking into account the left-right difference, these ranged from 3.8° to 21.4°. The mean deviation angle was 14.1°. Accordingly, in 9 preparations the directions in relation to the sagittal plane were similar.

2. The inclination angles, φ TANA 30°/35° (Table 11-35)
These ranged from 27.0° to 47.4°. The mean inclination angle amounted to 38.5°. In all specimens the axis has a value of φ that corresponds to a direction from anterosuperior to posteroinferior.

3. Comparison with the literature
For the talonavicular joint several authors have computed articular axes for the transition from starting to end position.
Henke (1855) published a detailed description of his determination of the axis of the talonavicular joint. To this purpose, Henke used 'Spurlinien'; these were lines scratched in an articular surface by implanting a pin in the articular surface facing it and then moving the bone.

On the assumption that these traces lay in a horizontal plane, (which holds true only if the rotations occur around a fixed axis without translation along that axis, if, in other words a pure hinge movement was involved), the head of the talus was sawn through in this plane. Then, lines were drawn perpendicularly to the circumference of this section profile. Henke's profile doubtless resembled an arc, since he found that all these lines had a single common point of intersection! In this point of intersection Henke erected an axis perpendicularly to the section plane: the rotation axis of the talonavicular joint. Henke then tried to describe the shape of the head of the talus as a solid of revolution, whose axis of revolution would also be the talonavicular articular axis. The revolution profile would then be the largest arc rotated around its chord.

An objection against Henke's axis is that the 'Spurlinien' consisted only of minute scratches. This renders it impossible to determine with adequate accuracy whether all these curved lines lay in a single plane, nor could the direction of the plane be determined sufficiently accurate. Henke regarded the talonavicular joint as the most important of all tarsal joints. He presumed that the talonavicular, the talocalcaneal and the calcaneocuboid movements all three took place around this single talonavicular axis. The position of this 'talotarsal' axis as Henke saw it was fairly steep through the head of the talus from anterosupero-medial to posteroinferolateral. In other words, Henke's axis is steeper than the talonavicular helical axis computed by us but has a similar direction, from anteromediosuperior to posterolateroinferior.
In a paper by Virchow (1899) we find the same axis as described by Henke, which Virchow called 'Chopart's axis', around which the navicular bone and the cuboid rotate together.

Dönitz (1903) describes not only a talonavicular, but also a talocalcaneal and a

calcaneocuboid axis (referred to before). Dönitz determined the talonavicular axis by wedging in the navicular bone. An eyelet was implanted in the dorsal aspect of the navicular bone. A pin through the head of the talus was fixed in such a position that when the talus rotated, this pin rotated inside the eyelet. The pin then indicated the direction and position of the relative talonavicular articular axis. Dönitz's relative talonavicular axis resembles Henke's tarsal axis; it passes through the head of the talus with a direction from anterosuperomedial to posteroinferolateral (see Figure 11-15).
However, Dönitz's axis is somewhat less steep than Henke's and the direction and position of his axis are similar to those of the relative talonavicular rotation axis computed by us, where the sagittal projection is concerned.

Fick (1904) gives a description of the movements of the head of the talus in relation to a fixed navicular bone. Fick regarded the talonavicular joint as an ovoid joint; cf. the wrist joint. This means: an egg-shaped solid of revolution.
Two axes of revolution were determined for this. One was for the elongated faint curvature running obliquely from laterodistodorsal to medioproximoplantar. According to Fick, the axis of revolution ran "in gewissem Sinne umgekehrt" (in a way, inverted), i.e. from mediodistodorsal to lateroproximoplantar. The axis supposedly entered into the neck of the talus.
Then there was a second axis for the short pronounced curvature. This second curvature axis accordingly has a direction identical to that of the longitudinal axis of the ovoid body, namely, oblique from laterodistodorsal to medioproximoplantar.
Fick called the rotation around the first ovoid axis of the talonavicular joint an adduction, plantar-flexion and supination of the head of the talus (cf. supination of the hand).
Fick called rotation around the second ovoid axis of this joint a dorsoflexion, adduction and supination when the talus moved in the mediosuperior direction.

In Fick's opinion, a rotation around only one of these two axes was not possible; any movement would be a combination movement. Fick then continues his considerations with a nomenclature of the movements of the bones of the foot in which he no longer speaks of the axes of revolution. The talus in his view rotated simultaneously in relation to the navicular and the calcaneus; the rotation took place around the socalled talocalcaneal navicular joint. In this joint, allegedly, a "Kompromiss Bewegung" (compromise movement) would take place in which the various components of the movements are represented (see Chapter 2). In this manner, Fick found one talocalcaneonavicular axis, somewhat resembling Henke's and Dönitz' axes. However, when Fick discusses Chopart's joint, he states that a rotation is involved between the talus and navicular on the one hand and the calcaneus and cuboid on the other. Rotation in this articulation of Chopart would take place around a rotation axis, approximately in the longitudinal direction of the foot, passing through the calcaneocuboid joint. He fails to make clear the position of the (own) axis of the talonavicular joint around which rotation is also possible.

Braus (1921) and Von Lanz and Wachsmuth (1938) again speak of the talotarsal joint. The talus was presumed to rotate around a complex of the navicular, cuboid and calcaneus, the socalled subtalar foot-plate. This talotarsal joint was presumed to have a single talotarsal rotation axis, again in the well-known oblique position, passing through the head of the talus.

Manter (1941) has also determined rotation axes for Chopart's articulation. See experimental setup, Chapter 2, literature.
Manter, also, states his view that the navicular bone and the cuboid move together with the forefoot in relation to the talus and the calcaneus. He found two rotation axes for Chopart's articulation, "the first and the second axis of the transverse tarsal joint". "The first axis (longitudinal axis)" had a small inclination of 15° and a deviation angle of 9°. The movement round this first axis "involves screw-like action rather than simple rotation".
"The second axis (oblique axis) is steeply inclined vertically and slanted obliquely across the foot", passing through the head of the talus with an inclination angle of 52° and a deviation angle of 57°. In Manter's view, *no* helical movements took place around this second axis. Movement around this second axis consisted of a combination of dorsoflexion and abduction or plantar-flexion and adduction of the forefoot with the navicular bone and the cuboid in relation to the talus and the calcaneus. It is only where its inclination is concerned that this second axis resembles the relative helical talonavicular axis computed by us; the position and deviation angle are clearly different.

Hicks (1953), see Chapter 2, literature, again found a single rotation axis for the talocalcaneal navicular joint, the well-known oblique axis through the head of the talus. For Chopart's joint he found two rotation axes, viz. "the oblique midtarsal axis" and "the anteroposterior midtarsal axis". These axes have already been described in the discussion of the calcaneocuboid joint.
Hicks described the talonavicular joint as a ball-and-socket joint in which the three axes, the talocalcaneonavicular, the oblique midtarsal and the anteroposterior midtarsal axis intersected in one point. However, Hicks' drawings fail to show that these axes pass through a single point in the head of the talus!
The navicular bone allegedly always rotated around one of these three axes, "the motion remains a simple hinge movement in each case"!
Hicks then continues "often of course, action at both of these complexes, talocalcaneonavicular or midtarsal occurs simultaneously. A spherical surface for the articulation between talus and navicular is one way of enabling all these hinge movements to take place"! Of these axes of Hicks' the oblique midtarsal axis and the talocalcaneonavicular axis resemble the relative talonavicular helical axis computed by us.

Elftman (1960) has also discussed the transverse tarsal joint, see also Chapter 2.3 and Figures 11-17, 11-19.
Elftman stated "the talonavicular joint, being condyloid, has two axes passing through the talus". These again are axes of revolution, just as those mentioned by Fick, viz. TN-1 for the major curvature and TN-2 for the minor curvature.
Elftman simply assumes that these axes of revolution also have to be the rotation axes for the talonavicular joint! For Chopart's articulation, Elftman found only one transverse tarsal joint axis which would be "the resultant of the two talonavicular and the subtalar axis".
Elftman's axis of Chopart's articulation in any case passes through a point on the line at right angles to the axes of revolution of the cuboid which allegedly just fail to intersect, and further through a point on the head of the talus. From Elftman's drawing in the dorsoplantar direction this perpendicular axis appears to project more or less in the longitudinal direction of the foot. An arrow starting at this line indicates the direction of the Chopart axis, approximately the same as the direction of the cuboid axis CC-1 and passing through the head of the talus. The only conclusion to be drawn from this drawing is that Elftman's axis of Chopart's articulation has a direction from anterosuperior to posteroinferior, passing medially through the head of the talus with an angle of deviation. Elftman presents *no* further analysis of the talonavicular movements.

Feist and Mankin (1962) in their radiological study described the talonavicular joint as a "ball-and-socket joint, almost perfectly concaveconvex". In their view, the talonavicular joint allows both "gliding" and "rotation", and the talonavicular joint is one of the "joints of inversion". Motion in the talonavicular joint is mostly rotational, with some adduction and plantar-flexion". No attempt was made to determine an axis.

Mann (1964) refers to the paper by Elftman (1960) discussed above. Mann states that Elftman had determined one axis of rotation for the transverse tarsal joint. However, Mann in his drawing indicates a single "resultant axis of rotation", called TN-1, for the talonavicular joint, with a direction from laterosuperior to medioinferior, in a frontal view. In addition, there would be a second "resultant axis" for the calcaneocuboid joint, which in the pronated foot would run parallel to the talonavicular axis.
Comparing Mann's drawings with those which Elftman included in his original article, we observe distinct differences. Mann's "resultant axis" (TN-1) resembles Elftman's axis of revolution (TN-2) for the small radius of curvature of the talonavicular joint.
Mann presents only one drawing for the 'transverse tarsal joint' with rotation axes. The direction of this talonavicular axis can never be the same as that of Elftman's axis for Chopart's articulation; the latter axis in a frontal view would always have to have a direction from mediosuperior to lateroinferior! In this frontal view of a right foot through the head of the talus and the calcaneus, Mann's "resultant axis" for the talonavicular joint can have an infinite number of

directions which all lie in a plane perpendicular to the plane of the drawing and pass through the drawn line TN-1. Mann presents no description of the talonavicular movements, either. In any case, his representation of Elftman's drawings and descriptions is incorrect. Elftman, namely, had described one single "resultant axis for the two navicular axes *and* the subtalar axis" which then in its turn would be identical to "the resultant of both calcaneocuboid axes" in the pronation situation.

The descriptions presented by Kapandji (1970) require only brief comment. Kapandji stated that "the subtalar and the transverse tarsal joints are mechanically linked and together form a single joint with one degree of freedom around one axis". In other words: the hinge movement around Henke's classical axis!
For that matter, this is contradictory to the various skiagraphic results obtained by Kapandji for which he describes a number of individual talonavicular, calcaneocuboid and talocalcaneal rotations which cannot possibly take place around one axis!

Nothing new is offered by Morris (1977), either.
Where the 'transversal tarsal joint' is concerned, he merely reproduces Mann's drawing.

11.5.4 Rotations and translations along talonavicular axes, total range

1. The rotations, α TANA 30°/35° (Table 11-36)
The lowest value of α was 29.9°, specimen nr 7; the highest value of α was 50.7°, specimen nr 5. The mean value of α amounted to 43.1°; range 20.8°.
As regards the direction of rotation of the talus around the relative talonavicular helical axis, the talar rotation was clockwise (viewed in the a-p direction) for the 7

Table 11-36. Talonavicular rotations (α TANA 30°/35°) and translations (t TANA 30°/35°) total range.

Specimen	TANA α 30°/35°	TANA t 30°/35°
1 R	43.8°	1.7 mm
2 R	49.3°	0.9 mm
3 R	47.3°	0.6 mm
4 R	50.2°	1.9 mm
5 R	50.7°	1.4 mm
6 R	45.7°	0.4 mm
7 R	29.9°	0.6 mm
8 L	31.3°	1.9 mm
9 L	34.6°	1.1 mm
10 L	47.7°	1.7 mm

right-foot and counter-clockwise for the 3 left-foot preparations. This means that the movement was a combined one of abduction and eversion.

2. The translations, t TANA 30°/35° (Table 11-36)
The translations t ranged from 0.4 mm to 1.9 mm. The mean value was 1.2 mm; range 1.5 mm.
The direction of the translation was positive for all specimens, in other words, the talus moved away from the origin. The talus translated in the anterosuperior direction.

3. Comparing our data with those in the literature, we once more find that only a few authors have stated the rotations in the talonavicular joint in degrees of rotation and/or millimetres of translation. Moreover, different authors have categorized the talonavicular joint in different combinations of joints; rotations around several articular axes are described.
On the basis of their classification of the talonavicular joint, we can distinguish three groups of authors.

a) The group of authors who regarded the talonavicular movement as united with the talocalcaneal movement to form a single movement in the socalled talocalcaneonavicular joint or subtalar articulation. In addition they presume a talonavicular rotation during the rotation around the axis (or axes) of Chopart's articulation. Descriptions of this nature have been given by Fick (1911), Hüter, Shephard (1951), Töndery (1968), Hicks (1953) and Manter (1941). A characteristic statement was made by Shephard: "the only joints with a material range of movement are the subtalar, the talonavicular and the calcaneocuboid joint". "The two functional combinations are the peritalar and the midtarsal joint", i.e. the talus in relation to a naviculocuboid-calcaneal complex in the socalled peritalar articulation and in addition, a rotation of the talus in relation to the navicular in the midtarsal joint.
Fick describes a rotation in the talocalcaneonavicular joint from 20° to 45°; according to him, the rotation of the talus in relation to the navicular in Chopart's articulation is approx 20°. Hicks describes a rotation of 24° in the talocalcaneo-navicular joint, a rotation of 22° around the oblique midtarsal axis and one of 8° around the anteroposterior midtarsal axis.

b) The group of authors who regarded the talonavicular movement as united with the talocalcaneal and the calcaneocuboid movements, that is to say, subtalar and Chopart movements combined to form a single talotarsal movement. In that case there is rotation around a single talotarsal rotation axis (Henke, 1855; Virchow, 1899; Albert, 1882; Strasser, 1917; Braus, 1921; Lanz and Wachsmuth, 1938, 1974; Poirier). Von Lanz and Wachsmuth describe a rotation of 60° round this axis, namely, 30° pronation and 30° supination.

c) The group of authors who described the talonavicular rotation as a rotation

around a single talonavicular axis (Dönitz, 1903; Mann, 1964 and Morris, 1977). None of these authors states the rotation in degrees.
Comparing these data from the literature with the data from our own experiments, we note that we in our series have found relatively extensive talonavicular rotations. This in contrast to, e.g., Manter, who wrote: "their (tarsal) movements were not extensive". Manter must have based this remark simply on his impressions, because he subsequently stated in his article that "no special attempts were made to measure the extent of movements in the joints"!
All in all, the rotations which Fick measured in Chopart's articulation are closest to our data; Fick's values are slightly lower than ours.

11.6 RELATIVE CUBOIDNAVICULAR MOVEMENTS

11.6.1 Directions and positions of cuboidnavicular axes, partial range

11.6.2 Rotations and translations along cuboidnavicular axes, partial range

The movements between the cuboid and the navicular are very slight, as appears from Table 11-37. Rotations of 5° or more were seen only twice in the 47 phases. Since, when α has a low value, the computation of π and φ is not very reliable, we have decided to discuss only the total cuboidnavicular movements, not the stepwise movement.
It is not surprising that the movement between the cuboid and navicular during supination is only slight, because the bundles of axes for the CUCA and NACA movements lay closely together.

Table 11-37. Cuboidnavicular rotations (CUNA α 10°) and translations (CUNA t 10°), partial range.

Specimen		R	R	R	R	R	R	R	L	L	L	
		1	2	3	4	5	6	7	8	9	10	
	Phase											
t	1	0.2	-0.6	0.1	0.2	-0.6	-0.1	-0.4	-0.4	-0.1	-0.3	CUNA mm
α		0.5	1.9	0.7	0.9	0.4	0.3	1.5	0.8	0.9	0.4	CUNA°
t	2	0.0	-0.6	-0.7	0.1	-0.9	-0.6	-0.6	-0.5	-0.5	-0.2	CUNA mm
α		0.8	2.6	1.3	0.5	0.8	1.5	2.3	1.8	2.7	1.1	CUNA°
t	3	-0.1	-0.5	-0.4	-0.3	0.3	-0.8	-0.6	-0.2	-0.6	-0.2	CUNA mm
α		1.0	2.8	4.1	2.0	0.7	3.8	2.9	2.8	4.8	1.3	CUNA°
t	4	0.1	0.0	-0.4	-0.3	0.2	-0.7	-0.3	-0.1	-0.5	-0.2	CUNA mm
α		1.2	1.2	3.7	3.1	1.7	4.6	3.3	3.2	5.0	1.6	CUNA°
t	5	-0.1	-0.1	-0.1	-0.3	-0.6	-0.4	-0.1	-0.3	-0.2	-0.2	CUNA mm
α		1.3	0.7	2.1	1.2	5.9	4.0	3.0	4.6	3.4	2.4	CUNA°
t	6	-0.1	-0.5	0.0	-0.5	-0.9				0.0	-0.2	CUNA mm
α		3.9	2.4	2.6	2.9	6.0				3.0	4.6	CUNA°

11.6.3 Directions and positions of cuboidnavicular axes, total range

In Figure 11-30 we show the three projections of this axis for specimen nr 1. From the combination of these three projections, it appears that the cuboid in relation to the navicular has rotated around an axis running approximately in the longitudinal direction of the foot, virtually horizontally. The direction of the axis is from anterolaterosuperior to posteromedioinferior. From the direction of rotation stated, we may conclude that the relative cuboid-navicular movement has a very marked eversion component; the other components of the movement (abduction/plantar-flexion) are so small that they may be ignored. Eversion of the cuboid in relation to the navicular accordingly means inversion of the navicular; in other words, the inversion of the navicular proceeds still further in relation to the cuboid. The transverse arch is flattened very slightly.

1. The deviation angles, π CUNA 30°/35° (Table 11-38)
Taking into account the left-right difference, the angles varied from -39.9° to 7.1°. The mean value was 8.4°, the range, 47°. For 9 specimens, a direction of the axis from anterolateral to posteromedial was found; in one specimen (nr 4) this direction was from anteromedial to posterolateral.

2. The inclination angles, φ CUNA 30°/35° (TABLE 11-38)
The angle varied between 2.6° to 25.2°, with an average of 13.2° and a range of variation of 22.6°.
The axes, accordingly, are fairly horizontal; the direction for 6 of the 10 specimens was from anterosuperior to posteroinferior (specimens nrs 1, 2, 3, 5, 6, and 7) and from posterosuperior to anteroinferior for 4 of the 10 (specimens nrs 4, 8, 9 and 10).

Table 11-38. Cuboidnavicular deviation angles (π CUNA 30°/35°) and inclination angles (φ CUNA 30°/35°) total range.

Specimen	CUNA π 30°/35°	CUNA φ 30°/35°
1 R	- 8.0° (352.0°)	17.7°
2 R	- 4.7° (355.3°)	7.5°
3 R	- 3.8° (356.2°)	2.6°
4 R	+ 7.1° (187.1°)	8.5°
5 R	- 6.1° (353.9°)	25.2°
6 R	- 0.5° (359.5°)	20.4°
7 R	- 9.4° (350.6°)	11.7°
8 L	+ 7.6° (187.6°)	11.1°
9 L	+ 39.9° (230.1°)	15.6°
10 L	+ 16.8° (196.8°)	11.5°

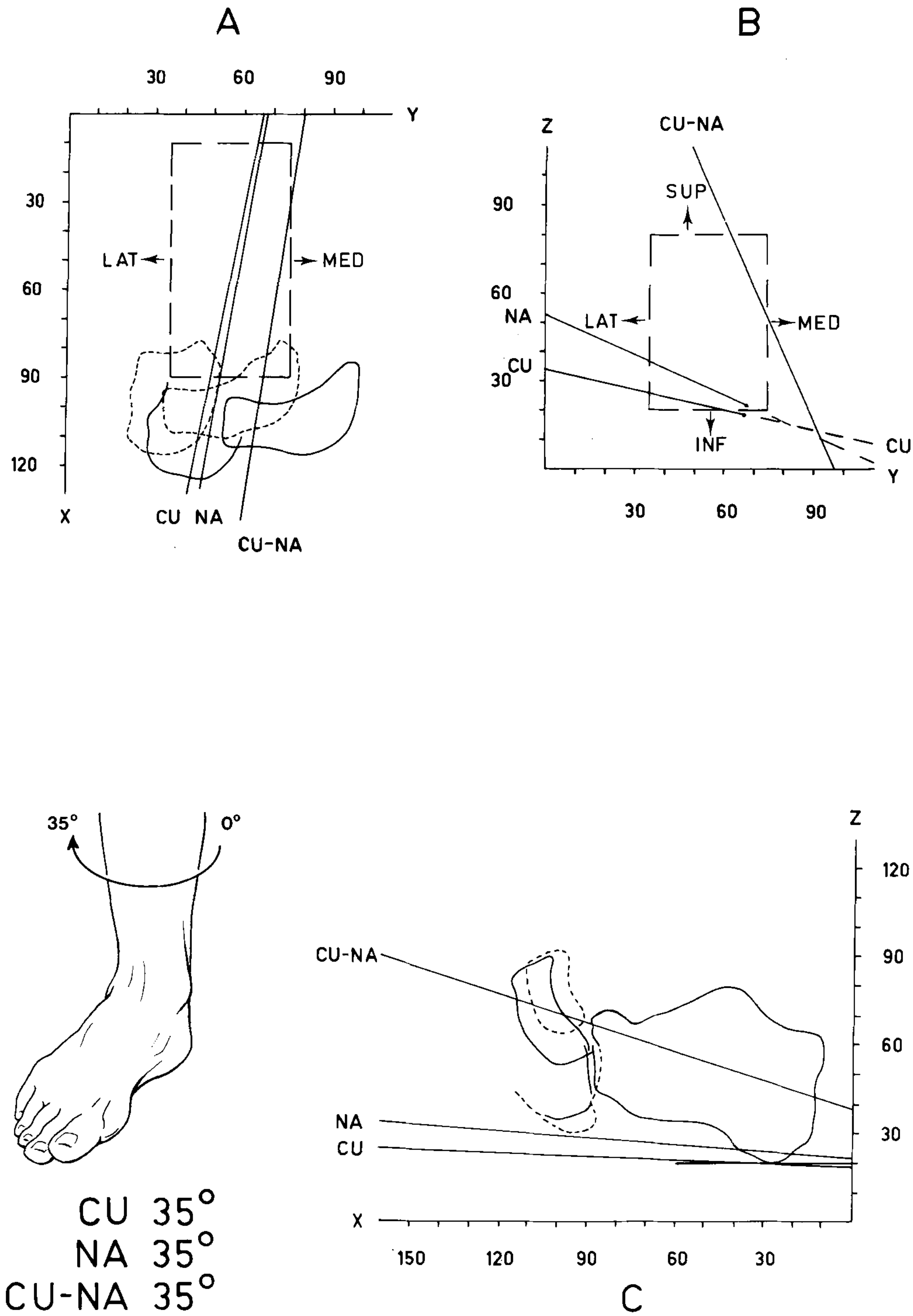


Figure 11-30. Projections of relative cuboidnavicular (CUNA 30°/35°), absolute cuboid (CU 30°/35°) and absolute navicular (NA 30°/35°) helical axes, total range.

3. Comparison with the literature
Studying the available literature, we have found no descriptions of a movement of an axis of movement between the navicular bone and the cuboid. In the anatomical literature, mention is made of sporadic observations of a tiny articular surface between the navicular and the cuboid.

11.6.4 Rotations and translations along cuboidnavicular axes, total range

1. The rotations, α CUNA 30°/35° (Table 11-39)
The rotations ranged from 3.9° to 9.9°. The mean rotation amounted to 6.8°, range of variation 6.0°.
The direction of the rotation of the cuboid in relation to the navicular presumed stationary was clockwise (viewed in the a-p direction) for the 7 right-foot specimens and anti-clockwise (also viewed in the a-p direction) for the three left-foot specimens. In view of the position and direction of the cuboidnavicular axes, this means that the movement was predominantly one of eversion, with a slight abduction/plantar-flexion component.

2. The translations, t CUNA 30°/35° (Table 11-39)
The translations t varied from 0.4 mm to 1.6 mm.
The mean value was 0.9 mm, the range of variation, 1.2 mm.
The direction of the translation was negative for all specimens, i.e. the cuboid moved in the posterior direction.

Table 11-39. Cuboidnavicular rotations (α CUNA 30°/35°) and translations (t CUNA 30°/35°) total range.

Specimen	CUNA α 30°/35°	CUNA t 30°/35°
1 R	3.9°	- 0.6 mm
2 R	6.6°	- 1.6 mm
3 R	7.0°	- 0.8 mm
4 R	4.7°	- 1.0 mm
5 R	7.8°	- 1.0 mm
6 R	7.9°	- 1.6 mm
7 R	6.6°	- 1.1 mm
8 L	7.1°	- 0.4 mm
9 L	9.9°	- 0.8 mm
10 L	6.0°	- 0.9 mm

3. In the literature we have found no data with which to compare our findings. The view generally held in the literature is that no relative cuboid-navicular movement takes place: the navicular and the cuboid rotate "as one unit in relation to the calcaneus".