CHAPTER XII

CONCLUSIONS

SOME CHARACTERISTICS OF THE TARSAL MECHANISM AS THEY EMERGE FROM OUR ANALYSIS

The X-ray stereophotogrammetric analysis demonstrated that the intertarsal joints are not 'complicatedly structured but functionally simple hinge joints'. Movements are found to take place around an axis which *moves continuously,* and the position of which could be approximated with the aid of a bundle of discrete helical axes. The accuracy of the helical movements depends on the magnitude of the rotation. When a rotation equals or exceeds 5°, the direction of the helical axis is computed with an accuracy of approx 1°. The accuracies of the rotation α around, and the translation t along the helical axis amounted to approx 0.1° and approx 0.07 mm, respectively.
Although a total of 10 preparations studied is too small a number to base a standard description of the movement characteristics on, it sufficed to give an overall impression of the movements. This holds true, on the one hand, of the directions and widths of the axes and bundles found, and on the other of the movements of the axes within the bundles, as revealed by the paths of the points of intersection.
Virtually always, the characteristics of axes and paths of left- and right-foot preparations were each other's mirror image. Rotations and translations of linked parts in the chain may differ from each other in extent (talotibial rotation surplus, vertical displacements), if the absolute axes of the linked parts differ from each other in position (see Chapter 10.1, 10.2).
The relative axes within a bundle proved to approach each other more closely at characteristic sites in the tarsus. For the TACA axes, this was the region of the tarsal sinus and canal, for the NACA and CUCA axes it was the neck-shaped region of the calcaneocuboid joint, while for the TANA axes it was the central portion of the head of the talus.

For the tarsal and intertarsal movements, we always computed different helical axes with different directions and positions. A fine example of bundles of crossing axes can be found in Figure 12-1 in which we have drawn the

TACA, NACA and CUCA bundle. Nevertheless it proved possible to find a direction of predilection for all computed axes (bundles of axes).
In Table 12-1 for all 10 specimens we have grouped the axes for all movements

Table 12-1. Quadrant positions, π and φ for tarsal and intertarsal rotation axes.

TI:	φ about 90°	$\pi < 45^\circ$	1-3-6	IV
	steep axes		2-4-8-10	IV/I
			7-9	I
			5	III/IV
TA:	φ about 90°	$\pi > 45^\circ$	1-3-5-6	I
	steep axes		2-4	I/III
			8-9	I/II
			7	I/II /IV
			10	I/III/IV
CA:	φ 25° to 60°	$\pi > 135^\circ$	1-3-5-8-9-10	II
	oblique axes		2-7	III
			4-6	II/III
CU:	φ +16° to -10°	$\pi < 45^\circ$	3-4-5-6-7-8-9-10	IV
	approx horizontal		1	II/IV
			2	I/IV
NA:	φ +16° to -17°	$\pi < 45^\circ$	1-4-5-6-7-8-9-10	IV
	approx horizontal		2-3	I/IV
TACA:	φ 23° to 56°	$\pi < 45^\circ$	1-2-3-4-5-6-7-8-10	I
	oblique axes		9	I/IV
CUCA:	φ 43° to 72°	$\pi < 45^\circ$	2-3-5	I
	oblique axes		1-4-6-9-10	I/IV
			7-8	IV
NACA:	φ 18° to 60°	$\pi < 45^\circ$	3	I
	oblique axes		1-2-4-5-6-10	I/IV
			7-8-9	IV
TANA:	φ 24° to 50°	$\pi < 45^\circ$	1-2-3-4-5-6-8	I
	oblique axes		7-10	I/IV
			9	IV
TATI:	φ <30°	$\pi > 45^\circ$	1-2-4-5-10	I/II
	φ >45° (2x)		3-6	II
			7	I
			8-9	III/IV

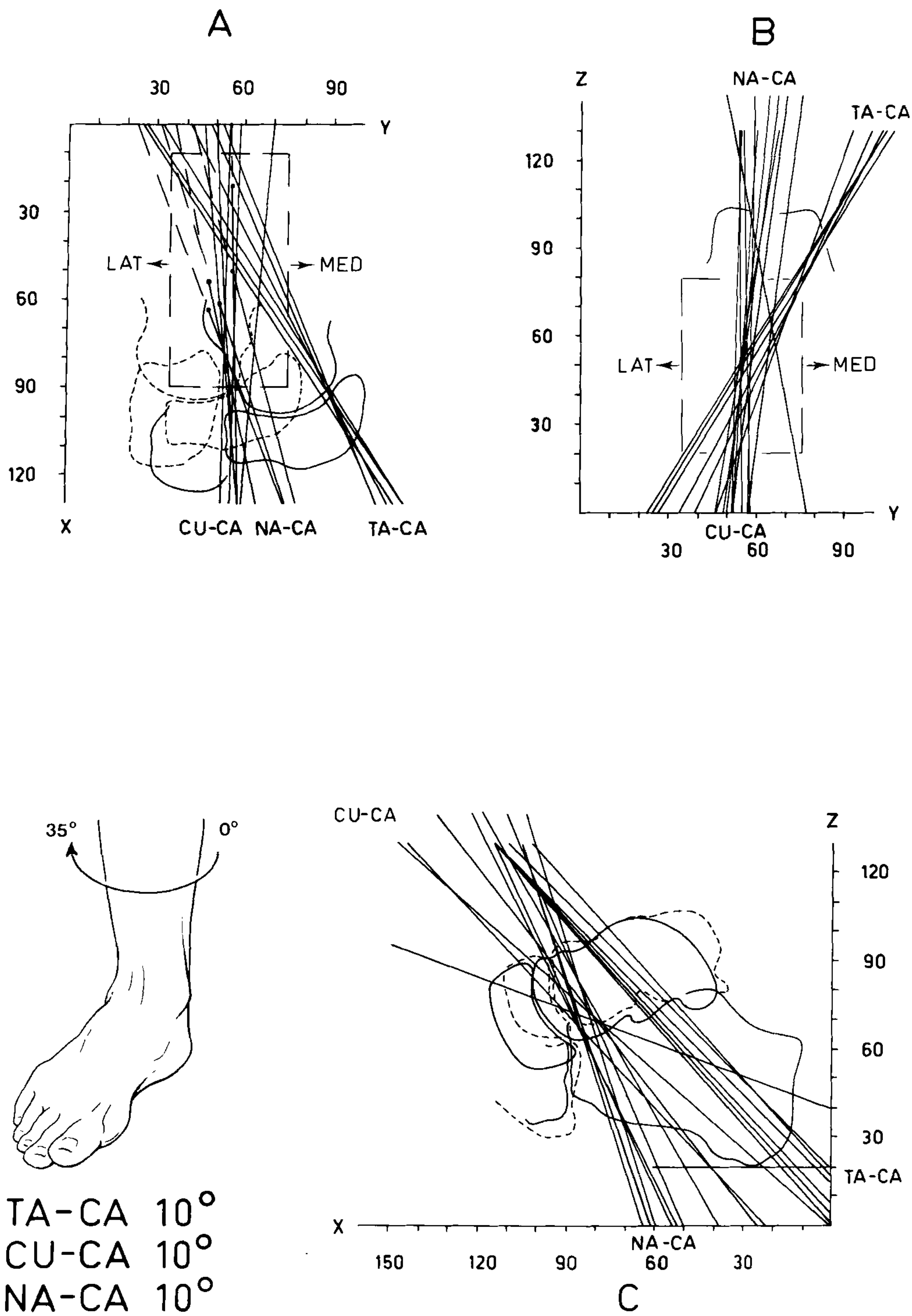


Figure 12-1. Projections of talocalcaneal helical axes (TACA), cuboidcalcaneal helical axes (CUCA) and naviculocalcaneal helical axes (NACA), partial range.

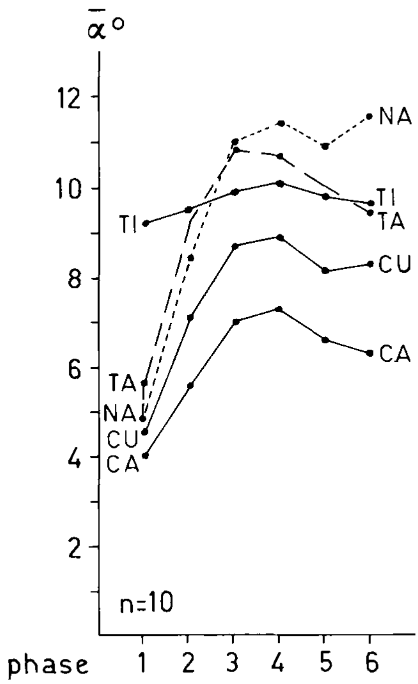
computed, with liminal values for π and φ and the quadrant positions. In order to obtain comparable results, the signs have been changed for the left-foot specimens. It appears from this table that the axes of TI and TA are very steeply inclined vertically, while CU and NA and most TATI axes are fairly horizontal and the other axes are oblique. The CA axes run approximately longitudinally and incline backward; the TATI axes run approximately in the transverse direction, although in two instances they are fairly steep, as well. The other axes run approximately longitudinally and incline forward. The NA and CU axes are mostly inclined toward lateral, the TACA and TANA axes mostly toward medial, the CA axis shows a slight predilection for the medial direction; the CUCA and NACA axes are situated on either side of the sagittal plane and the TATI axes on either side of the frontal plane.
To sum up, most axes prove to have an approximately longitudinal position, slanted obliquely forward.

We have also compared the rotations for the tarsal movements (see Table 12-2 and Figure 12-2). From the mean rotation per phase ($\bar{\alpha}$) a regularity of magnitude emerges: the absolute tibial rotations $\bar{\alpha}$ TI 10° in all phases are found to be approximately one and a half times as large as the absolute calcaneal rotations $\bar{\alpha}$ CA 10°; the absolute cuboid rotations $\bar{\alpha}$ CU 10° occupy an intermediate position between $\bar{\alpha}$ TI 10° and $\bar{\alpha}$ CA 10°.
The mean talar rotations of $\bar{\alpha}$ TA 10° slightly exceed the mean tibial rotations $\bar{\alpha}$ TI 10°.

Table 12-2. Mean values $\bar{\alpha}$ for the absolute tibial movements (TI), absolute talar movements (TA), absolute calcaneal movements (CA), absolute navicular movements (NA), absolute cuboid movements (CU), 10 specimina.

Phase	1	2	3	4	5	6
$\bar{\alpha}$ TI	9.2	9.5	9.9	10.1	9.8	9.6
$\bar{\alpha}$ TA	5.6	9.2	10.8	10.7	10.0	9.4
$\bar{\alpha}$ CA	4.0	5.6	7.0	7.3	6.6	6.3
$\bar{\alpha}$ NA	4.8	8.4	11.0	11.4	10.9	11.6
$\bar{\alpha}$ CU	4.5	7.1	8.7	8.9	8.1	8.3

It was an interesting finding that the mean values for the absolute navicular rotations $\bar{\alpha}$ NA 10° were so high, higher than the tibial and other tarsal mean rotations. The mean navicular rotations nearly constantly exceed the mean cuboid rotations. In other words, some rotation takes place in the cuboid-navicular amphiarthrosis. This phenomenon will once more be observed when we compare the CUCA and NACA rotations and the relative CUNA movement. There exist distinct interindividual differences (see Figure 12-3, in which the rotations α for the absolute tarsal rotations, specimen nr 1, are listed).



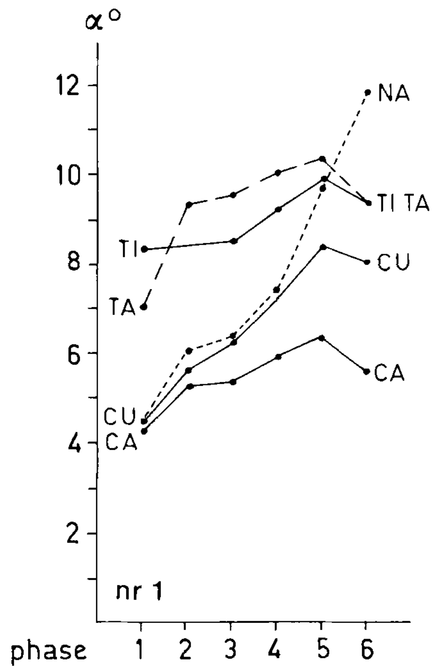


Figure 12-2. Mean values α for absolute tibial movements (TI), absolute talar movements (TA), absolute calcaneal movements (CA), absolute navicular movements (NA), absolute cuboid movements (CU), 10 specimen.

Figure 12-3. Values α for absolute tibial movements (TI), absolute talar movements (TA), absolute calcaneal movements (CA), absolute navicular movements (NA), absolute cuboid movements (CU), specimen no. 1.

No conclusions concerning the relative movements should be drawn from Figure 12-2. The fact that graphically, the distance between CU and NA increases further more than the distance between CU and CA does not mean that the relative CUNA rotation exceeds the relative CUCA rotation. These deceptive images may result from pronounced differences in directions of axes of tarsal bones.

We have also made a comparative survey of the rotations per phase for all relative movements computed. We computed the mean rotation angles α in degrees and as percentages of the mean rotation angle of TANA as computed for the 10 foot-lower leg preparations for the movements in the talocalcaneal, calcaneocuboid and talonavicular joints, as well as for the movement between the navicular bone and the calcaneus (Table 12-3).

These values of $\bar{\alpha}$ 10° have also been plotted graphically in Figure 12-4. It can be concluded from the table and the figure that there exists a distinct correlation between the values calculated for $\bar{\alpha}$ CUCA and $\bar{\alpha}$ NACA. Considering the very

Table 12-3. Mean tarsal rotation angles ($\bar{\alpha}$) in degrees and in % of the mean angle of rotation of TANA, mean deviation angles ($\bar{\pi}$) and mean inclination angles $\bar{\varphi}$.

Specimen	$\bar{\alpha}$ TACA	$\bar{\alpha}$ CUCA	$\bar{\alpha}$ NACA	$\bar{\alpha}$ TANA	$\bar{\alpha}$ TACA + NACA
1	8.36°	4.02°	5.20°	13.23°	
	63%	30%	39%	100%	102%
2	8.58°	5.87°	6.80°	15.00°	
	57%	39%	45%	100%	102%
3	8.78°	4.63°	6.12°	14.63°	
	60%	32%	42%	100%	102%
4	8.95°	6.32°	7.27°	15.97°	
	56%	40%	46%	100%	102%
5	9.30°	4.37°	6.43°	15.40°	
	60%	28%	42%	100%	102%
6	9.70°	4.90°	7.46°	16.66°	
	58%	29%	45%	100%	103%
7	5.96°	3.18°	5.38°	10.86°	
	55%	29%	49%	100%	104%
8	6.86°	4.68°	6.40°	12.18°	
	56%	38%	52%	100%	108%
9	5.02°	4.65°	5.93°	10.35°	
	48%	45%	57%	100%	105%
10	6.22°	7.32°	8.38°	14.28°	
	43%	51%	59%	100%	102%
$\bar{\alpha}$	55%	37%	47%	100%	102%
$\bar{\pi}$ 30°/35°	25.75°	2.67°	5.04°	14.12°	
$\bar{\varphi}$ 30°/35°	41.47°	51.94°	38.14°	38.49°	

slight freedom of movement in the joint between the cuboid and the navicular, this is not surprising. In addition, we find that the sum of the values of $\bar{\alpha}$ TACA and $\bar{\alpha}$ NACA very closely approximates the value of $\bar{\alpha}$ TANA. This may be attributed to the high degree of similarity in direction of the axes of these three movements. In this connection, special attention should be given to the inclination angle φ. The assumption that here rotations are involved around one and the same axis that might be regarded as a joint axis for the three joints is refuted by the distinct differences in the correspondig deviation angles $\bar{\pi}$ of which, interestingly, $\bar{\pi}$-TANA occupies an intermediate position between $\bar{\pi}$-NACA and $\bar{\pi}$-TACA.

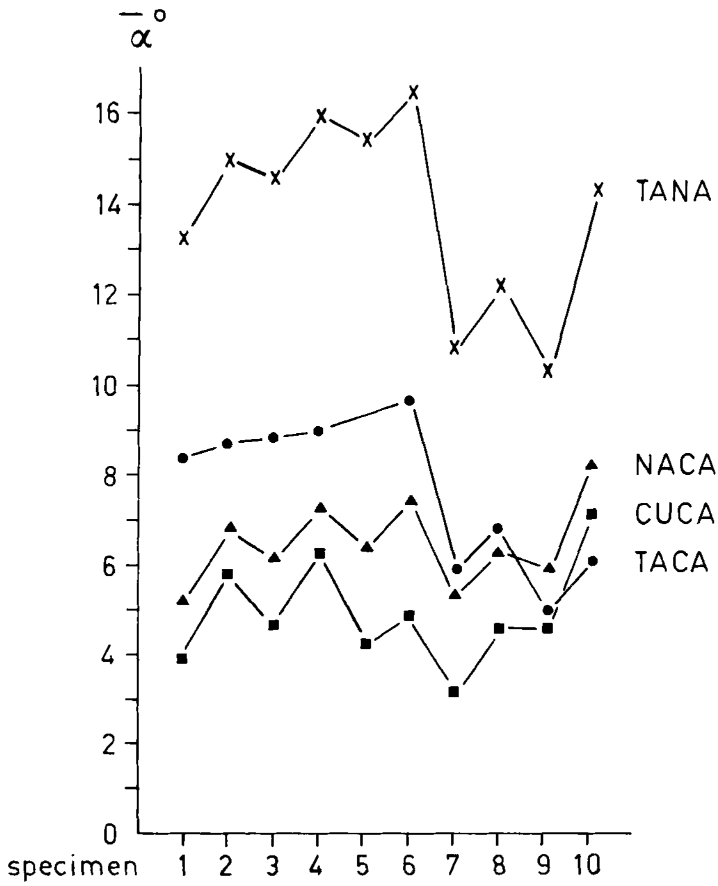


Figure 12-4. Mean talocalcaneal rotationangles $\bar{\alpha}$ TACA 10°, mean cuboidcalcaneal rotationangles $\bar{\alpha}$ CUCA 10°, mean naviculocalcaneal rotationangles $\bar{\alpha}$ NACA 10° and mean talonavicular rotationangles $\bar{\alpha}$ TANA 10°.