CHAPTER IX

THE PRESENTATION OF THE CALCULATED PARAMETERS OF THE TARSAL HELICAL MOVEMENTS

GENERAL INTRODUCTION, METHOD OF PRESENTATION OF CALCULATED RESULTS

In this chapter we shall discuss both the absolute tarsal discrete helical movements (i.e. the helical movements in relation to the fixed axis system with origin 0 in the cage) and the relative helical movements (i.e. the helical movements of one tarsal bone in relation to another). These relative helical movements, therefore, provide information on the movements 'in the joint in question'. The absolute helical movements have been computed for the tibia (TI), calcaneus (CA), talus (TA), navicular bone (NA) and cuboid (CU).

The relative helical movements have been computed for the talus in relation to the calcaneus (TACA = subtalar helical movements), for the talus in relation to the navicular bone (TANA = Chopart helical movements), for the talus in relation to the tibia (TATI, talocrural helical movements), for the navicular bone in relation to the calcaneus (NACA), in relation to the cuboid (NACU) and finally for the cuboid in relation to the calcaneus (CUCA).

As mentioned before, the tibia was laterorotated by steps of 5° through a total of 30° (in two preparations) or 35° (in eight preparations), without the forefoot being carried along in the abduction movement. The rotation was stopped when during manual rotation a high resistance was felt or when, as happened in a few cases, the foot tilted and the calcaneus slipped from its support.

We shall discuss the computed helical axes both for these stepwise changes of position and for the transition from the initial to the end position.

Data relating to the movement as a whole will be designated by the addition 30°/35°.

For all stepwise movements, *absolute or relative,* we have opted for a step size of 10°, for the following reasons:

Since the experiments should also show whether in the tarsal joints there occur single-axial hinge movements or more complicated movements around a series of instantaneous helical axes with changing directions and positions, the directions and positions of these axes have to be determined with sufficiently high accuracy. As stated in the preceding chapter, this accuracy itself depends on the magnitude of the differences between the discrete positions into which the continuous movement was broken down, as they manifest themselves in the computed values for the angle of rotation α. Since for a number of intertarsal joints these values of α that correspond to a step size of 5° tibial laterorotation proved to be so small that maximal deviations of a few degrees in determining the positions of these axes are to be expected (see Chapter 7), we have based our discussion solely on the results of computations referring to a step size of 10° tibial laterorotation. Since in addition the movements had a certain 'starting phase', giving the impression that the mechanism had to be put in motion, the first step, also, was mostly discounted. For the sake of completeness, however, it *has* been included in the tables. All data concerning these stepwise changes of position are designated by the addition 10°.

Of a helical axis of a tarsal bone we have computed (see Figure 9-1):

1) the position of the helical axis (points of intersection of the axis with planes XY, XZ and YX);
2) the direction of the helical axis (the angle φ of the axis with the XY-plane and the angle π of the projection of the axis in this plane with the XZ-plane);
3) the angle of rotation α and the direction of rotation around the helical axis;
4) the magnitude of translation t and the direction of translation along the helical axis.

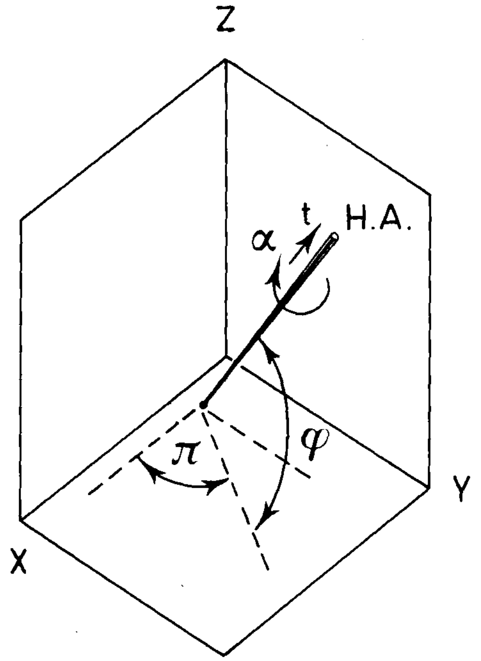

Figure 9-1. Helical axes (HA) with deviationangle (π), inclinationangle (φ), rotationangle (α) and translation (t).

We present these parameters with the aid of projections, transverse sections and tables, as follows:

1) The projections of the computed helical axes on the XY-, YZ- and XZ-planes. They provide, respectively, a dorsoplantar, a frontal and a sagittal projection. In these drawings we have always also indicated the site of the foot bones in question in relation to the axis system XYZ. For the sagittal projection, these are outlines borrowed from the lateral X-rays. The initial position of a bone is then outlined by an unbroken line, the end position by a broken line.
   N.B.: the projections of the helical axes are computed vertical projections; the skeletal outlines, however, are central projections and consequently slightly distorted. Some impression of this minor distortion may be gained by comparing the computed spatial positions of the balls in a bone (see Chapter 4) with the positions of those same balls in the lateral X-ray, measured by means of the comparator. For the drawing this is of no significance.
   In the dorsoplantar and frontal projections, for the determination of the site of the calcaneus, we have used the rectangular area which contains it in the initial position.
   The *length* (distance in the x-direction) was measured in the lateral X-ray as the distance between the farthest anterior point of the anterior calcaneal process and the farthest dorsal point of the posterior calcaneal process.
   The *height* (distance in the z-direction) was measured in the lateral X-ray as the distance between the highest point of the posterior calcaneal process and its lowest point. The latter was always situated at $Z = 20$ mm; this is the distance of the calcaneal support in the cage in relation to the XY-plane.
   The breadth has been measured of the real bones and proved to be 4 cm.
   The position of the calcaneal area in the XZ-plane was measured in the dorsoplantar X-ray as the shortest distance between the lateral calcaneal outline and the X-axis. For the determination of its distance in relation to the YX-plane, the lateral X-ray was used.

2) Horizontal and vertical sections through the tarsus.
   By indicating the point of intersection of an axis with the plane of intersection through the tarsus, a series of points of intersection is found. These, then, as it were, constitute a path travelled by the axes in the intersection planes. For the talocalcaneal joint and the subtalar movement we have made horizontal sections through the tarsal sinus and canal. For the more frontally directed calcaneocuboid joint, we have made vertical sections. For the talonavicular joint, we have made vertical sections through the head of the talus.

3) π and φ tables.
   In these, π is the angle between the projection of the rotation axis in the XY-plane and the X-axis (the angle in the basal plane), and φ the angle between the rotation axis and the basal plane (i.e. in relation to the basal plane). In accordance with Manter, we call π the deviation angle and φ the inclination angle.

The computed value of π changes from 0 - 360°, rotating counterclockwise in relation to the positive X-axis. These figures are placed in brackets in the tables in which, in order to obtain an anatomically usable presentation, converted values of π are listed. The basic concept was a spatial representation of the helical axes, in which these axes with a more or less widely spread bundle protrude upwards from the XY-plane of the basal plane. The bundle may rise steeply or be more oblique. However, when the direction of the bundle is practically horizontal, part of the bundle of axes may also point downward through the basal plane.

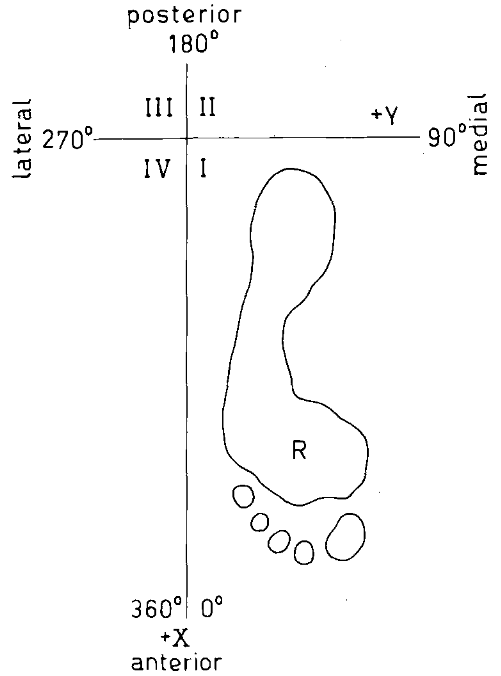

Figure 9-2. Position of the right foot in testing set up with axis system of the experimental cage with the four quadrants.

In Figure 9-2 a right foot is placed in respect of the four quadrants.

If the axis projections are situated mostly in the first or the third quadrant, π has a positive sign. If most axis projections of a bundle are situated in the fourth quadrant, and a few in the third or the second, we have for π always computed the supplementary angle up to 360° and given it a negative sign. An advantage of this presentation is that it makes it easy to see whether an axis in relation to a foot in our set-up has an anteromedial or an anterolateral position, the left-right difference being taken into account. Thus, a positive value of π for a right foot corresponds to an axial direction from antero*medial* to postero*lateral*, but for a left foot to an axial direction from antero*lateral* to postero*medial*. These corrected values of π have also been used for the computation of the mean values. The bundle of axes has a width and a

direction. The bundle width is characterized by the following parameters:
- R π, as the difference between the extreme values of π;
- R φ, as the difference between the extreme values of φ;
- Σ γ, as the sum of the angles between successive axes.

The bundle direction is characterized by the mean values of π and φ as computed on the basis of the 10° steps of tibial laterorotation, with omission of step 1. The direction of the bundle may also be approximated from the direction of the single discrete axis, computed over the total range of movement (π 30°/35° and φ 30°/35°), but in that case, the first and the last axes of the bundle should indeed represent the extreme positions, and the other axes should be distributed fairly evenly within the bundle. In order to achieve a consistent representation of these parameters, the following rules were observed in conversion.

The conversion of π

The vertical projection of the bundle of axes may be situated completely or almost completely within one, two, three or four quadrants of the basal plane. If it is situated:
- in one quadrant, π may be plotted from each of the two coordinates that delimit the axial quadrant (Figure 9-3);
- in two quadrants, π may be plotted from each of the two jointly delimiting coordinates, or in relation to the coordinate situated in between the two quadrants with changing sign (Figure 9-4);
- in three quadrants, π may be plotted from each of the two coordinates delimiting the three quadrants, or from one of the two enclosed coordinates with changing sign (Figure 9-5);

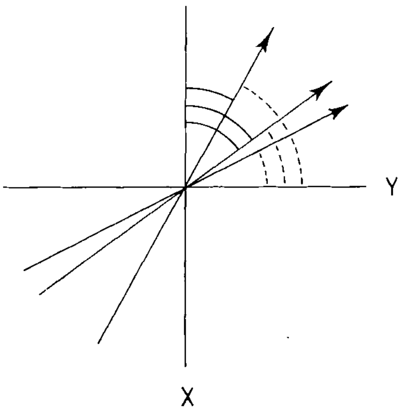

Figure 9-3. π Within one quadrant.

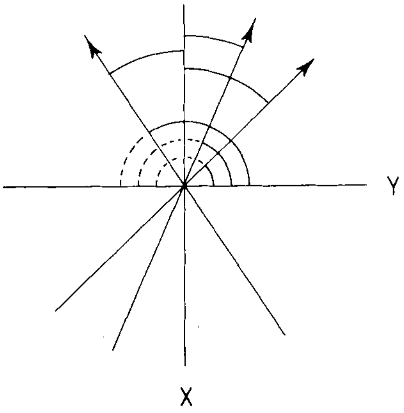

Figure 9-4. π Within two quadrants.

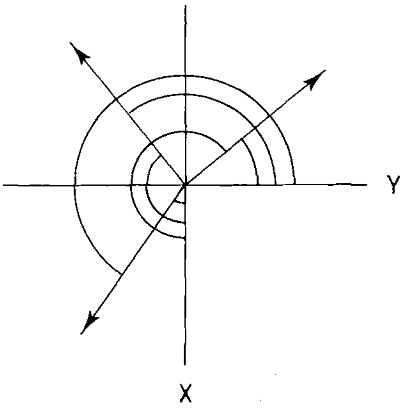

Figure 9-5. π Within three quadrants.

- in four quadrants, in which case there is no longer a real bundle and each of the coordinates chosen as point of origin will result in a different position for the mean value of π! The axis will then have to fall in the quadrant with the lowest mean value of φ.

In our experiment many projections of the axes make an acute angle with the positive X-axis. They are then mostly situated in the first or the fourth quadrant. Since in the literature, the deviation angle is always stated in relation to the X-axis (i.e. the longitudinal axis of the foot) with values ranging from 0 to 90°, we have constantly corrected the values of (π) in relation to the X-axis with a positive or negative sign.

As regards the inclination angle φ, it is not always computed between 0° and 90°, as usual in the literature, but stated between 0° and 180°.
If π is localized in quadrants two and three, $90° < \varphi < 180°$.

The conversion of φ

In the conversion of φ, factors to be considered are the bundle width and the question whether the axes point up from or down through the basal plane.

- All axes 'point' in the same direction: upward (away from the basal plane). If the mean values of π and φ are selected as parameters for the direction of the bundle as a whole, few problems arise if all values of π are found to be situated in one, or in two adjoining quadrants. In that case, bundle width is less than 180° and the values of φ will all be less than 90° because the bundle as a whole is situated in one side of an imaginary plane through the Z-axis. The mean value of φ can then be calculated directly from the values of φ supplied by the computation program. The situation changes as soon as all values of φ are situated in three or four quadrants or in two diagonally situated quadrants. In that case, the bundle has a width $<180°$ and after a change of position toward the origin, the bundle will be situated *around* the Z-axis but not on one side of it. Such a situation is shown in Figure 9-6. The mean value of π has also been drawn in and a line perpendicular to the mean π-axis now indicates which axes of the bundle fall on the other side of the Z-axis. The axes has a $\varphi < 90°$ within the quadrant in question, but in relation to the whole of the wide bundle they should, conversely, be given a value $>90°$. Only then will they make the correct contribution to the computation of the mean values of φ for the bundle as a whole. Summing up, this means that the bundle lies over the area that is delimited by: $(\pi + 90°)$ and $(\pi - 90°)$ and all axes with a $(\pi - 90°) < \pi < (\pi + 90°)$ have a $0° < \varphi < 90°$, while the axes with $(\pi - 90°) > \pi > (\pi + 90°)$ have a φ with a value of $90° < \varphi < 180°$. This value is then computed by taking the supplement of φ $(180° - \varphi)$.

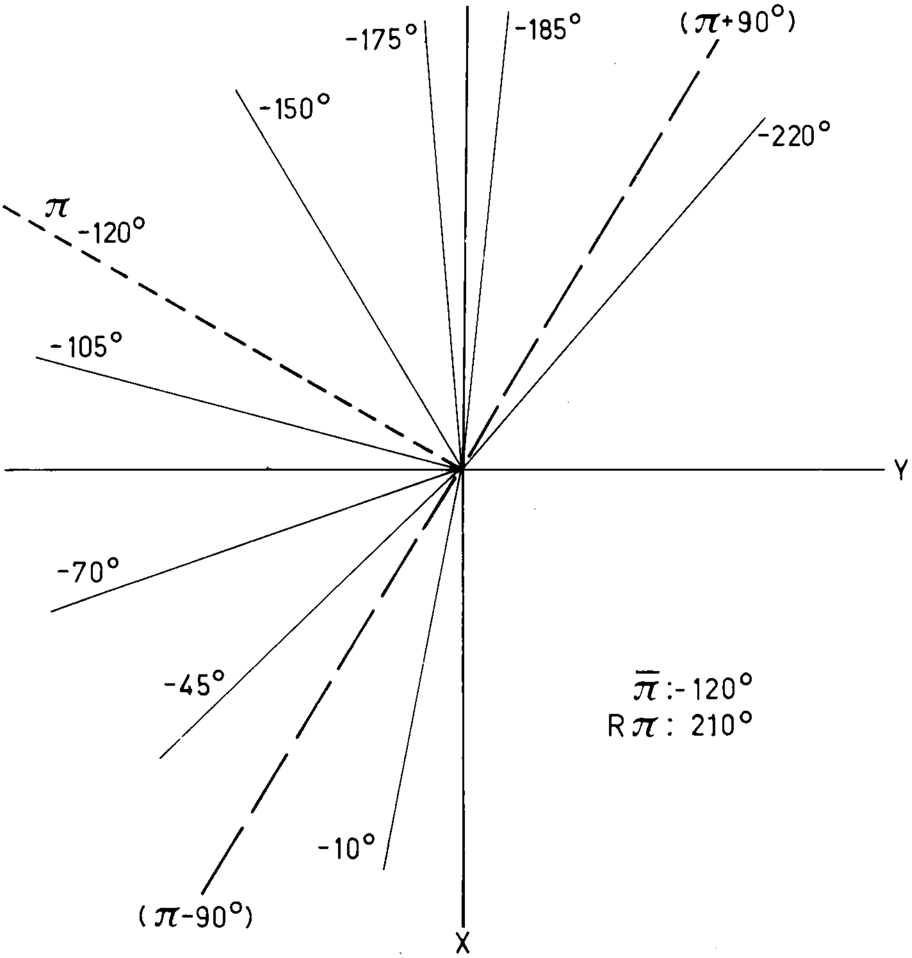

Figure 9-6. Values for helical axes, mean value (π) and width of bundle (Rπ).

$\pi = -120°$.
R$\pi = 210°$.
Larger part of the bundle lies between -30° and -120°.

- One or more axes do not 'point' in the same direction: some point up (away from the basal plane), others point 'down' (to the basal plane; see Figure 9-7). Whether an axis points up or down is indicated in the program by the sign of the Z-coordinate of the directional vector; a positive Z-coordinate means pointing away from the basal plane, a negative Z-coordinate means pointing to the basal plane.

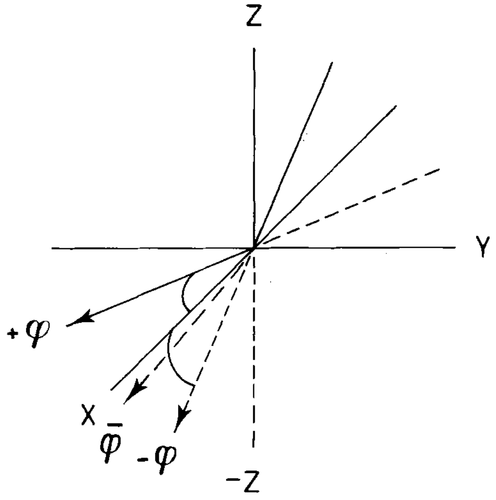

Figure 9-7. Positive (+ φ), negative (- φ) and mean inclinationangle (φ).

The mean φ is then determined in relation to a horizontal plane. For instance φ TATI 10°; φ CU 10° and φ NA 10°. The angle φ corresponding to the axis pointing away from the basal plane is given a positive sign; the angle φ corresponding to an axis that points to the basal plane (passes through the basal plane) is given a negative sign.

4) Rotation-translation tables

In these diagrams, α stands for the rotation angle in degrees and t for the translation in mm.

A special problem arises in regard to the designation of the direction of rotation of a bone around a helical axis. In the literature, it is customary to describe rotations of bones as rotations in regard to axes parallel to the body coordinate axes which then are regarded as rotation axes, as well.

In our computations, the position of rotation axes has been accurately determined three-dimensionally, and not a single axis proved to parallel the body coordinate axes.

We also described the direction of rotation of a tarsal bone in the generally used terms of ad/abduction, flexion/extension and inversion/eversion.

In agreement with the international SFTR method, we define these terms according to Russe and Gerhard (1975), see Figure 9-8:

- adduction as that movement of a tarsal bone in which the distal part of this bone moves towards the median body plane;
- abduction as the movement in the opposite direction;
- flexion as that movement of a tarsal bone in which the distal part of that bone moves in the plantar direction;
- extension as the movement in the opposite direction;
- inversion as that movement of a tarsal bone in which the 'under surface' of the bone moves towards the median body plane;
- eversion as the movement in the opposite direction.

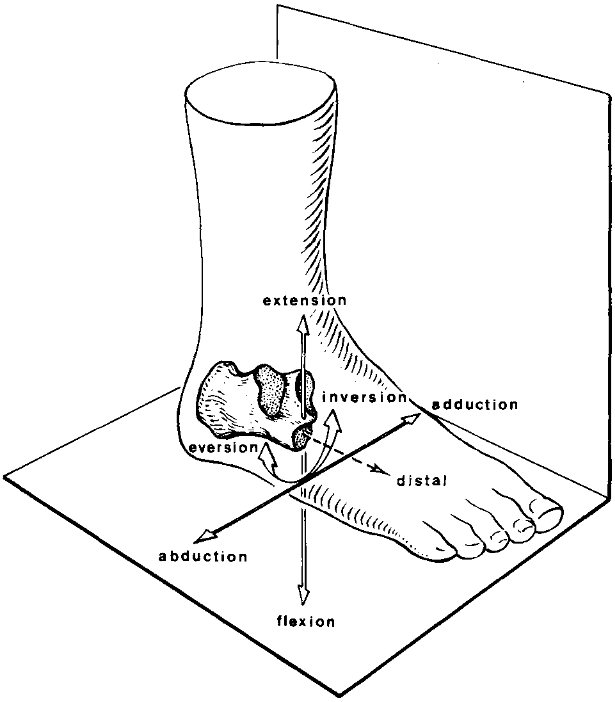

Figure 9-8. Definitions of movements for a tarsal (calcaneal) bone respective to the body planes.

We reserve the terms of supination and pronation for combined movements of, respectively, adduction, flexion, inversion and abduction, extension, eversion.

Using the values of π, φ and the rotation direction, it is always possible to give a description of the direction of rotation of a tarsal bone in regard to the body plane.

When angles π and φ are small, a tarsal axis makes an acute angle with the 'longitudinal axis' of the foot and the axis is fairly horizontal; in that case there is a strong in- or eversion component. When angle π is narrow and φ is wide, a strong ad-or abduction component is involved. When π is wide and φ is narrow, there is a strong flexion or extension component.

From our computations there always follows a clockwise or counterclockwise direction of rotation viewed in the anteroposterior direction. In the program, the directions of rotation and translation are indicated by the sign of the Z-coördinate of the directional vector. The helical movement takes place around the helical axis in the direction of the directional vector (with either a positive or a negative sign, according to the corkscrew rule). When a translation is preceded by a negative sign, the pitch of the helical movement has been negative.

5) γ-Tables

In these tables, γ stands for the angle between two successive axes. The computed changes of the deviation and inclination angles and the resulting differences between the highest and lowest values as a measure of the socalled bundle width of the bundle of axes ($R\pi$ and $R\varphi$) give a global impression of the extent to which the intertarsal joints impose movements around a series of successive instantaneous axes instead of around a single fixed hinge axis. Still, this is only a global approach, for two reasons. Firstly, the parameters in this case apply to the projections of these axes and not to the true positions in space. The differences between angles π and φ are the differences between the projections of the actual angle γ between two axes. Mostly, these projections will give smaller angles than the projected angle. For this reason, this method as a rule results in bundles that are too narrow. Since the axes do not move in one plane, and the possibility cannot be excluded either that on the way they have moved backwards and forwards, the angle γ between the successive discrete axes appears to constitute a useful data. The sum of these angles would adequately approximate the magnitude of the 'swing' described by the instantaneous axis. However, this parameter, also, has an inevitable limitation, because the instantaneous axes undergo not only changes of angle but they shift as well: they do not intersect in space, but cross. In addition it applies to all above-named parameters $R\pi$, $R\varphi$ and $\Sigma\gamma$ that the bundle of axes 'contracts' when a presentation is used which is actually based on discrete axes. This 'shrinkage' increases as the step size used increases as well until, when one discrete axis is computed on the basis of the starting position and the end position there no longer *is* a bundle.
Finally, the required degree of accuracy also interferes with a realistic representation of the bundle of axes. As mentioned above, the bundle contracts if, for the sake of a more accurate determination of direction,

discrete axes are computed on the basis of a larger step size, whereas small steps, although in principle giving a better approximation of the actual bundle width, at the same time, because of their increasing inaccuracy, leave us in doubt regarding the actual validity of the findings obtained.

6) Data concerning the total relative movement (step size 30°/35°)
In presenting the data concerning the total relative movements from the starting to the end position, the question arises whether a difference exists between the group with a 30° range of laterorotation and that with a 35° range. The former might consist of 'more rigid' specimen. Where parameters π and φ for the axial positions are concerned, such a distinction appears rather irrelevant, unlike parameter α for the rotations. The following review (Table 9-1) lists the values of α for the 30° group and the 35° group which both are admittedly small, with only three and seven preparations, respectively.

Table 9-1. Mean intertarsal rotations for 30° group and 35° group, total range.

	$\bar{\alpha}$ TACA	$\bar{\alpha}$ CUCA	$\bar{\alpha}$ NACA	$\bar{\alpha}$ TANA	$\bar{\alpha}$ TATI	$\bar{\alpha}$ CUNA
30°:	19.53°	11.70°	17.53°	35.57°	10.53°	7.20°
35°:	25.30°	17.53°	21.67°	45.48°	7.60°	6.56°

The assumption expressed above at first glance appears to be valid for TACA, CUCA, NACA and TANA. It is then invalid only for TATI and CUNA. CUNA, now, is an amphiarthrosis with predominantly a 'deformation laxity' and hardly any 'free laxity'.
Should joints TACA, CUCA, NACA and TANA of the 30° group have a relatively limited range of motion, which can be defined as 'free laxity', the limit of the 'deformation laxity' might be reached sooner in the movement as a whole, and the latter in these preparations would also account for a larger proportion of the total range of movement. Unfortunately, where the magnitude of the rotating moment applied is concerned, no objective data are available that might give an indication of it.
A different criterion of the relative 'rigidity' of the preparations consists of the mean values of rotations per 10° step computed over five and six steps, respectively (or when the first step is discounted, over four and five steps, respectively). See Table 9-2.
This survey does not confirm the postulate that the 30° group indicated by indeed systematically presents lower values for α 10° than the 35° group.

Table 9-2. Mean intertarsal rotations for 30° group and 35° group, partial range.

Specimen	$\bar{\alpha}$	$\bar{\alpha}$	$\bar{\alpha}$	$\bar{\alpha}$	$\bar{\alpha}$	$\bar{\alpha}$
	TACA	CUCA	NACA	TANA	TATI	CUNA
1	8.36°	4.02°	5.20°	13.23°	2.73°	1.45°
2	8.58°	5.87°	6.80°	15.00°	2.47°	1.93°
3	8.78°	4.63°	6.12°	14.63°	4.67°	2.42°
4	8.95°	6.32°	7.27°	15.97°	3.00°	1.77°
5	9.30°	4.37°	6.43°	15.40°	5.52°	2.58°
6*	9.70°	4,90°	7.46°	16.66°	5.28°	2.84°
7*	5.96°	3.18°	5.38°	10.86°	2.50°	2.60°
8*	6.86°	4.68°	6.40°	12.18°	5.06°	2.64°
9	5.02°	4.65°	5.93°	10.35°	1.37°	3.30°
10	6.22°	7.32°	8.38°	14.28°	1.85°	1.90°