

CHAPTER II

LITERATURE

2.1 HISTORICAL REVIEW

The movements of the tarsal joints have tempted a number of investigators to analyse them. Virtually all of them attempted to describe the tarsal movements as rotations around axes, sometimes in combination with translations along these axes.

Most investigators started from the theory of the bodies of revolution. This means: on the basis of a supposed analogy of the articular surface and a body of revolution, an axis of revolution was determined for the articular surface. This axis of revolution was then regarded as an axis of rotation, as well! In this reasoning, the movements were determined solely by the constantly congruent articular surfaces, with the ligaments only ensuring the necessary contact between the bones and possibly exerting a braking action while extreme positions were being reached. The occurrence of discongruences between articular surfaces during tarsal movements, as described by numerous authors (Weber (1836), Henle (1856), Meyer (1856, 1886), Virchow (1899), Henke (1855), Fick (1904), Dönitz (1903), Braus (1921), Huson (1961, 1965, 1966, 1973, 1977, 1983) and Inman (1976)), according to most of these authors originated from or, on the contrary was compensated by compressibility of the cartilage, or it was attributed to pathological conditions such as ligamentous and capsular laxity. The axes of revolution or of movement were frequently determined very simply, according to one of the four methods described below:

- a) Finding a non-moving point on the moving bone. At this point, a pin rotating around itself was erected and this pin represented the axis of rotation (Henke (1855), Dönitz (1903), Smith (1958), Inman (1976)).
- b) A modified version of a. Specifically: by erecting a pin on a bone in such a manner that this pin during the movement turns around itself as an axis of rotation and in addition turns within two guiding eyelets attached to the fixed bone (Hicks, 1953).
- c) The introduction of small pins, iron filings or granules of dye into the joint,

resulting in traces, Spurlinien, on the articular surface. From these traces, an axis of rotation was constructed (Henke (1855), Dönitz (1903) and Braus (1921)).

- d) A modified version of c. Specifically: the small intra-articular deflections were magnified by fixing pins to the surface of the bone in such a manner that they traced circular paths on a surface. From these, now magnified, deflections, an axis of rotation was deduced (Manter, 1941).

Even for the very recent detailed study by Isman and Inman, of 1976, these classical methods have still been used. All these authors always have regarded the experimental axes found as fixed hinge axes: throughout the movements the position and direction of the axis of rotation remained unchanged. Huson was the only one who rejected this view; on the basis of a number of functional-anatomical considerations he believed that mobile axes of motion had to be involved, or, in other words, that the intertarsal joints were polyaxial.

Interestingly, it was precisely Fick (1904, 1911) who in his textbook 'Kinematik der Gelenke' worked out the theory of the bodies of revolution in detail who disowned 'his' theory in the descriptions of the tarsal movements!

On this subject Fick writes: "Leider bin ich bei der Besprechung der Mechanik des unteren Sprunggelenkes gezwungen zunächst ganz von der Darstellung der Autoren denen allen mehr oder weniger von der Natur abweichende Schemen der Gelenkform zugrunde liegen, abzusehen" (unfortunately, for the discussion of the mechanics of the tarsal joint I am forced to begin by entirely rejecting the views of authors who have all based themselves on schemes of the articular shape that to a greater or lesser extent differ from nature).

Equally curious is Fick's consideration of the application of his 'Kompromis-Achse' to the tarsus. Fick asserts that precisely for the tarsal joints there definitely cannot exist fixed axes of rotation, because the articular surfaces do not resemble bodies of revolution. In these joints, according to Fick, there occurs summation of successive rotations around a large number of 'instantaner Achsen' or 'Augenblick-Achsen'. Fick also says about these axes that "deren Ermittlung einstweilen gänzlich unmöglich erscheint" (to determine them appears to be quite impossible for the moment).

After this very well-considered description with which we can agree, Fick nevertheless attempted to introduce his 'Kompromis-Achse' using, for this purpose, Albert's data on the component rotations (see also the preceding chapter, p. 17). Fick then finds considerable interindividual variability but nevertheless postulates "gewisse gemeinsame Züge" (certain common features) in all 'normal individuals'. Fick also believed that the axes, during repeated movements under different loads were displaced, but he failed to state whether this occurred according to theoretical principles. From his, occasionally somewhat less than lucid descriptions we gain the impression that Fick, for a tarsal joint, on the one hand rather associates his 'Kompromis-Achse' with the concept of 'instantaner Achse', as an axis changing position with each phase of

the movement. On the other hand, Fick would be willing, for a tarsal joint, to accept one 'Kompromis-Achse' after all, with the restriction that it only roughly indicates a direction. In other words, around this 'Kompromis-Achse' the tarsal bones, for the change from starting to end position, may perform a combined movement of inversion, adduction and plantar flexion. Fick calls such a movement a 'Kompromis-Bewegung'; in this case Fick rather associates the 'Kompromis-Achse', as mentioned in the preceding chapter, with a discrete axis of rotation. Fick has indicated one 'Kompromis-Achse' for the talocalcaneal joint and one 'Kompromis-Achse' for the calcaneocuboid joint. The latter calcaneocuboid 'Kompromis-Achse' would then also represent the axis of rotation of Chopart's articulation.

Summing up we may conclude that although Fick initially asserted that the tarsal joints could not be regarded as having fixed axes of bodies of revolution but that they had instantaneous axes of rotation, changing position and direction with each phase of the movement, with his 'Kompromis-Achse' he actually introduced one single discrete axis of rotation. Subsequent investigators then have interpreted these Kompromis-Achsen as immobile axes of rotation and gradually relegated to the background the restrictions which Fick had initially attached to his concept. Only a few of the authors who have used the methods described above have made a study of the magnitude of the translation (Fick (1904), Manter (1941), Hicks (1953) and Inman (1976)).

The ranges of movement calculated by these authors will be discussed in the various paragraphs which deal with the range of movement calculated by us. At this point we only present a classification of the various measuring techniques applied by these authors:

- a) Skiagraphic cadaver studies (Kapandji (1970), Manter (1941), Inman (1976), Isman (1976) and Ambagtsheer (1978)). For these studies, pins were driven with one end into the tarsal bones, the other end projecting freely. The relative and absolute changes of the angles of these pins during movements of the preparation were measured in a projection plane.
- b) Skiagraphic investigation in vivo (Close (1967)). Into the tarsal bones of test subjects, two pins were introduced at right angles to the postulated axis of rotation, with their ends sticking out. The changes of their angles were measured during a number of phases of the walking cycle.
- c) Perimetric study in vivo (Fick (1904), Albert (1904), Beetham et al (1965)). In test subjects with a foot hanging free and bearing no weight, the ranges of movement of the foot as a whole were measured.
- d) Goniometric study in vivo (Inman (1976), Wright et al (1964) and McMaster (1976)). To a foot of test subjects, hanging free and bearing no weight, a goniometer was attached showing the changes of the angles after movement.
- e) Roentgenological measurements (Brantigan (1977), Cobey (1976), Feist and Mankin (1962), Gamble (1957) and Hlavac (1967)). In X-rays of the foot made

in several projections, the distances of the tarsal bones from fixed reference points were measured before and after their movements.

It will be clear that the type of measuring techniques as described above will considerably affect the measurements ultimately obtained. All authors with the exception of Ambagtsheer have interpreted the measurements found as rotations around some fixed axis in a particular joint. All authors indicated the direction of the various rotations in terms of ab-adduction, plantar or dorsal flexion, inversion or eversion. The qualitatively and quantitatively oriented methods of investigation hitherto mentioned do not allow an exact three-dimensional calculation of the individual tarsal movements in the weight-bearing situation.

Apart from the more or less empirical methods of investigation mentioned above, the literature also contains descriptions of two- and threedimensional calculation methods for articular movements. The two-dimensional methods *could* not, the three-dimensional methods so far *have* not been applied to the tarsus. Fick never described a Reuleaux analysis of the tarsal movements. Neither has a Reuleaux analysis of the tarsal movements been made by Dempster, Williams and Lissner or Frankl and Burnstein.

Several authors, on the other hand, have carried out a two-dimensional analysis of, for instance, the knee joint. The joint centres, functional joint centres and instant centres of rotation found in this case also are just discrete centres of rotation.

According to these authors, these polode constructions rendered it possible to gain an impression of the various positions of the axis of rotation of the knee for the flexion movement. Polode constructions for the knee have been described, among others, by Schwarz (1944), Groh (1955), Frankl (1970), Huson (1974, 1976), Menschik (1974), Nietert (1977) and Soudain (1979). It is interesting to note that many of them report very high degrees of individual variability; adequate comparison of polodes was not possible! It was therefore understandable that Nietert (1977) questioned the value of such constructions. As we have seen, use of these polode constructions in various ways limits the validity of the determination of an axis of rotation in this manner. Another major objection is that the three-dimensional movement of the knee was reduced to a two-dimensional movement!

Soudain and Van Audekercke (1979) and Panjabi (1979) pointed out the great influence of errors in calculations of centres of rotation (poles). For the two-dimensional analysis of motion they calculated that minor errors in the measured coordinates of marking points may lead to major differences in positions of poles. Irrespective of the validity of a polode analysis for the knee joint, such an analysis can definitely not be validly performed for the movements of the tarsal joints.

Three-dimensional methods of calculation for the study of articular movements

were already used in the last century. For instance, Braune and Fisher in 1891 described a mathematical analysis of a joint: "Die Bewegungen des Kniegelenkes nach einer neuen Methode am lebenden Menschen gemessen" (the movements of the knee joint measured in vivo in man by a new method). In their experimental set-up, the lower leg of a test subject was encased in plaster to which once again three pins projecting in three different directions were attached. First, the projected coordinates of the ends of these pins in relation to the three body planes were measured while passing through the flexion movement. Subsequently, the spatial coordinates of these three pin tips were calculated from these projection coordinates.

Braune and Fischer, also, attempted to deduce axes of movement from the changes of these spatial coordinates. They simplified the calculation method by postulating one single point of intersection for all axes of rotation of the flexion movement of the knee. Braune and Fischer defended this simplification by remarking that the calculation of the spatial coordinates had posed so many problems already!

Although Braune and Fischer were assisted by a 'professionellen Rechner mit Rechenmaschinen' (professional calculator using calculating machines), this calculation method was not suitable for practical application and it has accordingly been abandoned.

In 1966, Massolais described a method which enabled him to calculate the three-dimensional movements of bones. As an example he described the method as applied to this scaphoid bone. Stereo X-rays were made of one position of the scaphoid (the starting position). The surfaces of these two contours of the scaphoid were plotted with the aid of a comparator. In this manner, 2.235 points on the scaphoid were measured (free interval approx 0.5 mm). Using a digital computer, the three-dimensional coordinates were calculated for each point plotted. Subsequently, an X-ray moving picture in a single projection was made of the same scaphoid during flexion of the wrist.

Thereafter, a mathematical description of all the X-ray frames of the scaphoid was recorded by means of the plotter. The digital computer then constantly compares the projection of the scaphoid on a frame with the collection of points of the two stereo X-rays. Using the computer, the cluster of points in the stereo X-rays was turned until its projection in one frame appeared possible: subsequently, the rotations and translations required for that change could be calculated. According to Massolais, the method offered the major advantage that it could be applied to live test subjects. A major problem, on the other hand, is to choose or find recognizable points in the stereo X-rays.

Massolais used the trabecular structure of the scaphoid for this purpose. Massolais is not clear about the accuracy of his method: according to a listing in one of his tables, an error of 15° rotation and 15 mm translation would be possible for the test object. So far, we have not encountered any further elaboration of this method or applications of it in the literature.

In recent years, detailed kinematic studies of joints have been described, of which we mention a number of examples. Vertebral movements have attracted considerable attention: calculations of axes of rotation for vertebral movements have been performed by several authors (Panjabi and Wight, 1973 and Olsson, 1976).

Chao (1978) has published a detailed description of an axis of rotation for the elbow joint.

Selvik (1974, 1976 and 1977) has published a calculation method that has much in common with the method we ourselves have applied. He described uses of X-ray stereophotogrammetry, such as the exact recording of the growth of bones, the determination of the success or failure of fusions of bones (especially spondylodesis), the calculation of mandibular movements and of tumour volumes. Selvik, also, made use of marking balls introduced into the bones. By making X-rays in two projections, calculation of the spatial coordinates of the balls was made possible. Selvik has made no study of movements in the tarsus by means of X-ray stereophotogrammetry.

Van Dijk (1983) used this method and described, among other things, the flexion movement of the knee in 5 knee preparations.

As mentioned before, we have divided the tarsal movements into a number of successive helical movements obtained by calculation. In the literature, also, the concept of helical movement for the intertarsal motions is frequently encountered.

As early as 1855, Henke stated that the talus performs a helical movement in relation to the calcaneus. In 1886, Meyer wrote that the 'talus' 'screwed' into the navicular bone during weight-bearing of the foot.

Braus (1930), Von Lanz and Wachsmuth (1938) in their discussions of the tibiotarsal joint call it 'ein Ginglymus mit geringer Schraubebewegung' (a ginglymus with slight helical movement).

Manter (1941) described a helical movement of the talus in relation to the calcaneus; at 10° rotation the talus according to him translated 2.1 mm! In this respect it should be noted that the above-named authors, although admittedly speaking of helical movements, always assumed these movements to take place around a fixed screw axis. The helical movement is believed to be more or less compatible with a screw-shaped surface of joints; actually, all these discussions are based on axes of revolution, with a translation along these axes of revolution being accepted. Such screw axes have no connection at all with the discrete helical axes for the various tarsal joints that we have calculated!

Several authors for various reasons have queried whether axes of rotation of joints should be determined at all. For instance, Petersen (1918) asserted that in axes of rotation for joints "wohl eine theoretische Lösung vorliegt, aber keine Lösung um sich die empirisch vorkommenden Bewegungen anschaulich zu machen" (these

axes provide a theoretical solution but no solution to visualize the empirically occurring movements).

Knese (1950) stated that although determinations of the axes are possible in theory, they are not actually feasible owing to the high degree of accuracy required.

Knese concludes his views of this topic as follows:

"die Angaben von Drehachsen ist nicht allein wertlos, sondern sogar tauschend und damit abzulehnen, da auf diese Weise eine Anlehnung an Maschinenelementen gesucht wird!" (to indicate axes of rotation is not just useless, but even deceptive and accordingly to be rejected because in this manner, a modelling upon machine parts is sought).

De Vogel (1970) wants to interpret the concept of axis of rotation only as a fixed, immobile axis. In view of his findings concerning the motions in the tibiotarsal joint, he proposes to entirely abandon the concept of axis for articular movements, because in his view 'postulating a moving axis is carrying things rather far'.

Nietert (1977) declined the construction of articular axes because the interindividual variability of the position of these articular axes would lead to differences of such magnitude that comparison would not be really feasible.

In contradiction to the authors mentioned above, we ourselves are of the opinion that the determination of axes of rotation of joints may certainly be useful, provided two conditions are fulfilled:

- 1) the testing apparatus for cadaver studies should be constructed in such a manner that the passive movements of the bones in relation to each other closely approaches the situation *in vivo*;
- 2) the method should be devised in such a manner that a minimum of a priori restricting conditions are imposed upon the position of the axes of rotation to be calculated.