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# The Biomechanics of the Foot

**by André Bähler**

*"The human foot is one of nature's works of art and as such, it has not yet been fully recognized and explained. It will require a deal of scientific investigation before this structure is fully understood."*

These words of the old master of orthopaedics, Georg Hohmann, from his book "Fuss und Bein" are still applicable today. Thirty years later, the biomechanics of the foot have still not been completely explained, and there are many questions yet unanswered.

The many, more or less articulated connections of the foot allow a variety of changes which make it difficult to understand the movement as a homogeneous process. Too many factors can only be qualified, but not quantified.

Nor may we forget the reciprocal influence of the position of the foot, knee, and hip joints. Each change in the position of one of these joints automatically involves a change in the position of the other two joints.

For example, in the upright position, the neck of the femur forms a posteriorly open angle of approximately 20 degrees. This is determined by the anatomical factors in relation to the frontal plane of the body. The direction of the axis of the hip joint corresponds fairly accurately to the connection inner-malleolus/outer-malleolus, which have an exterior rotation of approximately 20 to 30 degrees in relation to the frontal plane. Consequently, there is a conformity between the ankle axis and the hip axis.

In the upright position, the knee is practically locked due to the automatic rotation and so the position of this axis is of minor importance. When walking, the pelvis rotates approximately 20 degrees forward. As the lower leg also rotates inwardly in relation to the upper leg during flexion, the ankle axis rotates inwardly and the foot takes up a straight position in the swing phase.

## CHARACTERISTICS OF THE FOOT

The foot has the characteristics of a triple axial joint which allows it to assume any position. The three main axes of movement converge in the talus area (Figure 1). Particularly during rotational movements to adapt the foot to an uneven surface, all the joints are involved to some extent; nevertheless, the ankle joint,

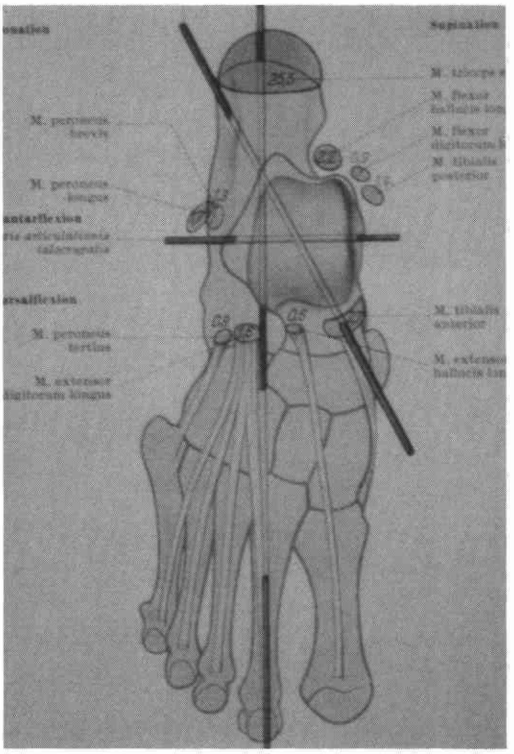

**Figure 1.**

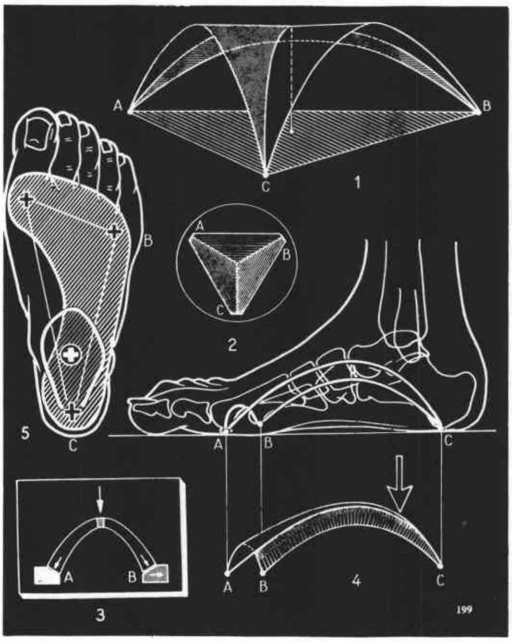


Figure 2.

although formed as a hinge joint, forms the main joint for locomotion.

According to Kapandji, the foot can be compared architectonically to a vault, which is supported by three arches. Other authors criticize this vault-concept on the basis that it is too static. However, the vault-structure is very meaningful as an aid to analyzing the foot in general (Figure 2). The arrow shows the direction and position of the main weight, which is first taken by the calcaneus (A) and then transferred to the forefoot: inside on metatarsal I (B) and outside on metatarsal V (C). The front transversal vault can also be understood as a supporting construction: on the one side the two corner stones (metatarsal I and metatarsal V) and on the other side, the transverse vault (metatarsal II, III, and IV). This construction enables the forefoot to take a great amount of weight and at the same time allows the foot to adapt to uneven surfaces.

Furthermore, it can be seen that when the feet are put together, the position of both calcanei can be regarded as a vault structure. The position of the calcaneus together with a slight valgus position serves to stabilize the body, particularly during the walking motion of the leg (Figure 3).

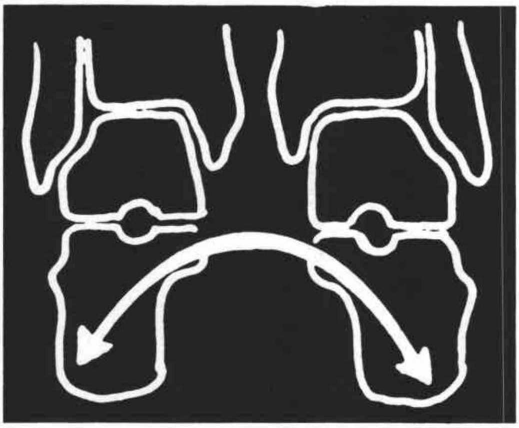

Figure 3.

# THE JOINTS

The joints themselves pose some problems. Let us take for example the development of the inclination of the trochlea of the talus, and the distal tibial epiphyseal cartilage to the longitudinal axis of the lower leg in the frontal plane as described by Lanz Wachsmuth.

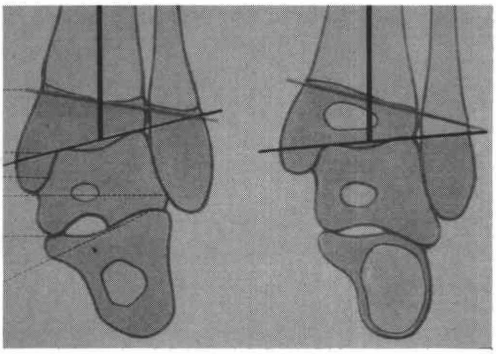

Figure 4.

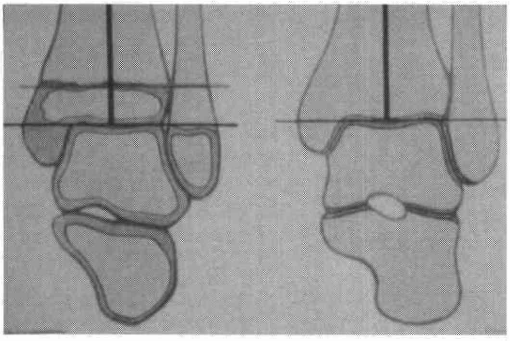

Figure 5.

Left in the infant and right in a two year old (Figure 4), it can be seen that the axes of the ankle joint and the talo-calcaneonavicular joint and that of the epiphyseal cartilage are developing. In the 12 year old, left, and in the adult, right, the axis becomes horizontal during normal growth process, stabilizing the support system of the foot (Figure 5). The changes in the various process-, movement-, and development-axes of the ankle during the development of the child are probably one reason for the controversial views over the biomechanics of the foot.

Biomechanically we are interested in the joints, and in particular, those used when walking.

## The Ankle Joint

The ankle joint (Figure 6) is of particular importance, because in at least one direction it secures a movement without which it would be impossible to walk. This joint could also be described as a hinge joint with a diagonal axis of rotation, which allows a movement of about 20 degrees up and down. This inclination of the ankle joint certainly contributes to stability when carrying weight and can only be fully understood when considered in connection with the talo-calcaneonavicular joint.

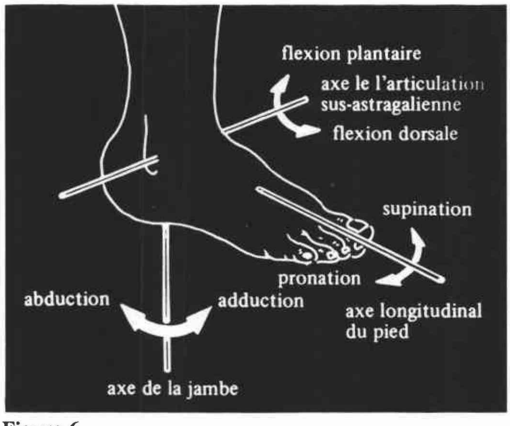


Figure 6.

## The Talo-Calcaneonavicular Joint

The movement of the talo-calcaneonavicular joint is decidedly more difficult to understand. Whereas the axis of the ankle joint can easily be defined, the axis of the talo-calcaneonavicular joint is drawn obliquely from lateral posterior to medial anterior. It is surprising that both articular surfaces of the talo-calcaneonavicular joint are congruent only in the mid-position. An incongruence develops between the two articular surfaces by both eversion and inversion. This incongruence cannot be maintained for long periods when carrying weight.

The ankle joint and the talo-calcaneonavicular joint must be regarded as a functional unit. The possible movements of these two joints can be compared to a spheroid joint which can be moved freely within its range of motion: flexion, supination, pronation, abduction and adduction which in some respects corresponds to a rotation.

## Chopart's Joint

The talo-calcaneonavicular joint, comprising the talus and the navicular, and the joint which is formed from the calcaneus and the cuboid, together all form a sort of working unit. These two joints comprise Chopart's joint which allows a rotational movement of the fore-foot.

## Lisfranc's Joint

The Lisfranc joint is a collective joint where the three cuneiform bones and the cuboid bone on the one side, and the five metatarsal bones on the other side, are united to form an articular connection. The small deflectionary movement can be described as in an obliquely situated hinge exhibiting dorsal and plantarflexion.

The Chopart and the Lisfranc joints are connected by taut ligaments so that there is hardly any friction between them. They serve primarily to give elasticity to the foot during pressure and allow it to adapt better to uneven surfaces.

## The Transversal Anterior Vault of the Foot

From metatarsal I to metatarsal V, the metatarsal bones form an oblique arch (Figure 7). This arch tends to drop due to excessive pressure, which can partly be attributed to walking on level ground. This "even" walking, which

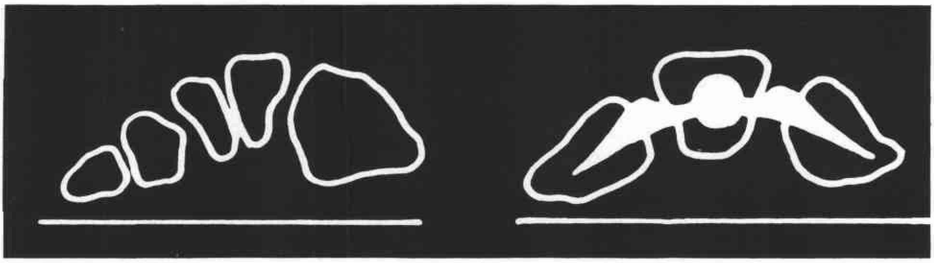

Figure 7.

always puts pressure on the same points of the foot, leads to over-exertion of the individual metatarsal heads.

## The Toe Joints

The toe joints are limited spheroid joints. That is, they are capable of sideways movement within certain limits, but are primarily intended as hinge joints with movement upwards and downwards.

## THE LIGAMENTS

It is known that the structure of the foot is held together with muscles and ligaments. These ligaments are so constructed as to be able to withstand the extreme pressures exerted on the foot (long jump and high jump).

## THE MUSCLES

Long and short muscles hold and move the foot. If one of the muscles gives way, it is immediately visible from the gait how important the interaction of each muscle group is for locomotion. However, descriptive anatomy is not the theme here and so a further discussion of this aspect must be omitted.

## THE MECHANICS OF DEPRESSION OF THE FOOT

Experience has shown that not every valgus of the calcaneus results in an equivalent drop of the longitudinal vault.

The talipes valgoplanus is a collective term for different inadequacies which arise when the foot is under pressure. These can be classified according to different characteristics: (Figure 8)

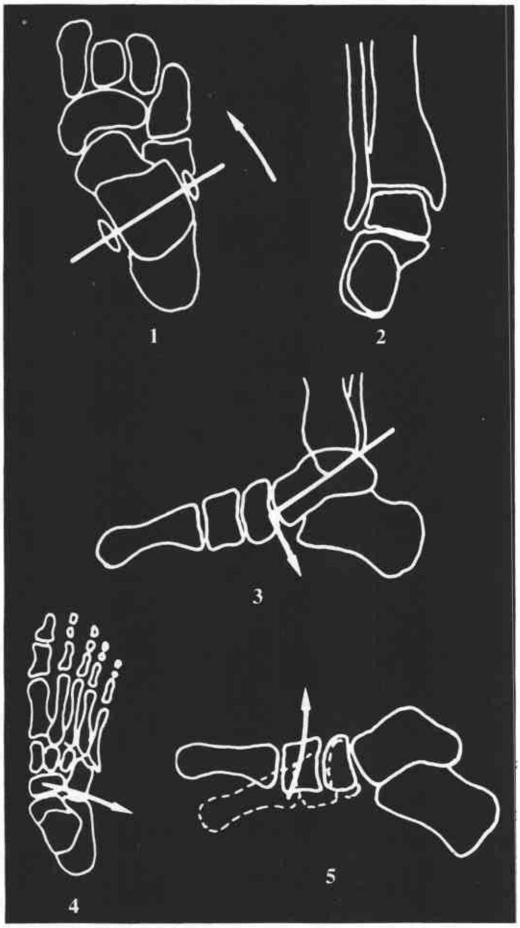


Figure 8.

1. The pronation position of the calcaneus;
2. Inward rotation of the ankle joint;
3. A forward and inward drop of the talus;
4. Abduction of the fore-foot; and
5. Supination, i.e., a turning upwards of the first metatarsal.

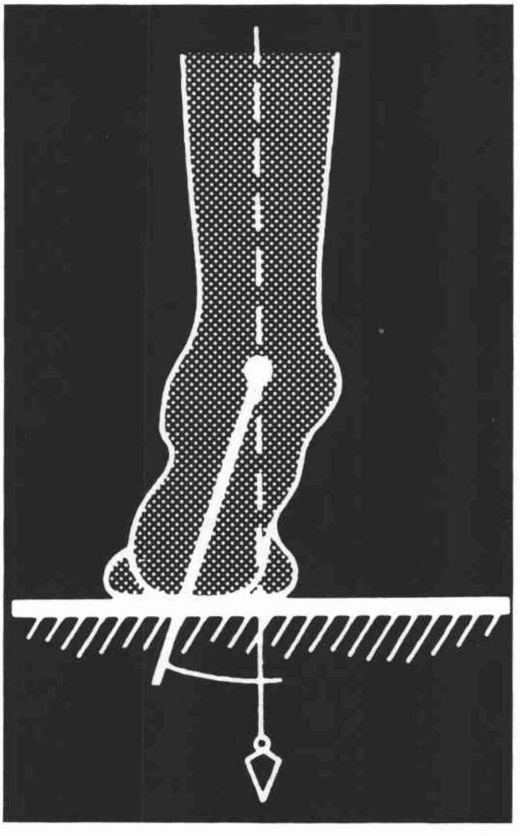

Figure 9.

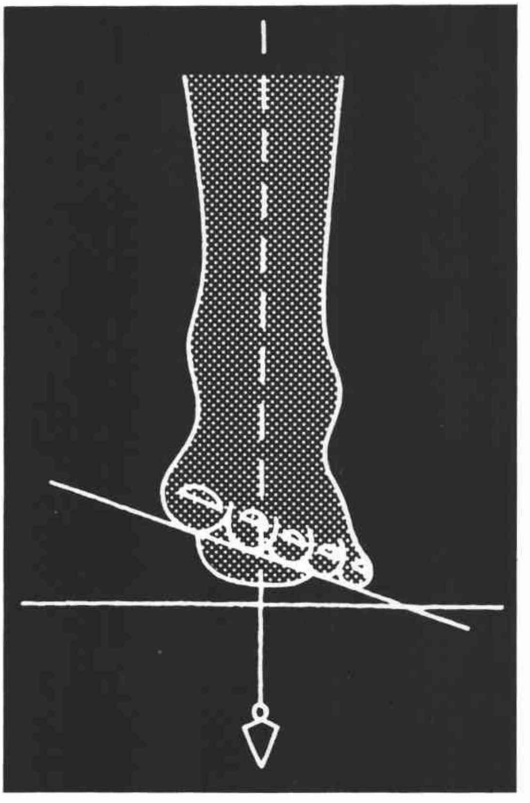

Figure 10.

These five basic characteristics of the talipes valgoplanus lead to a variety of outward manifestations, which must be taken into consideration when deciding on a course of action. This wide variety is one reason why the kinematics of the foot eludes an exact biomechanical and mathematical analysis.

When pressure is applied in valgoplanus, the calcaneum gives way but the fore-foot remains flat on the ground, regardless of the extent of the flexion. Congenital and ischaemic valgoplanus are exceptions to this but they are not included in the discussion here (Figure 9).

Between the calcaneus, rear-, and fore-foot there is a distortion or rotation. If pressure is removed from the foot, the calcaneus falls into a vertical position, but the fore-foot then rotates to the same degree. Consequently the position of the rear-foot relative to the fore-foot remains a constant deformity (Figure 10).

What then is the role of the shoe in the standing position and swing-phase? In the standing position, more pressure is exerted medially on the rear part of the shoe (the counter and the heel), depending on the extent of the valgoplanus. However, the front of the shoe remains flat on the ground regardless of the extent of the deformity.

In the swing-phase, the distortion between the fore- and rear-foot influences the alignment of the shoe. If the heel is too big or badly fitting, the fore-foot dictates the position of the shoe and as a result there is an unwanted deflection of the heel of the shoe from the heel of the foot.

This means that the heel-strike is lateral and as pressure is exerted, it then turns inwards and adapts to the surface whereby it has returned to the original standing position. The distortion between the fore- and rear-foot, combined with an inadequate heel counter, produces a potential risk of injury. A stone on an inclined surface can easily lead to a strained joint (Figure 11). This phenomenon is particularly signifi-

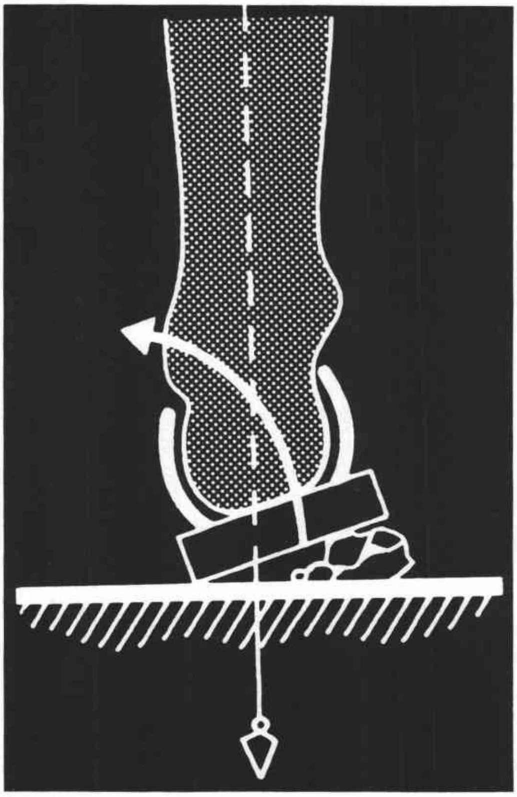

Figure 11.

cant for sportsmen and joggers who train in open country. After suffering such strains, the fear of further injury can hinder training.

# DEFORMITY OF THE FORE-FOOT (TALIPES TRANSVERSOPLANUS)

During growth, there is a slight biomechanical change in the lateral metatarsal arch. The first metatarsal rotates pronatorally and this leads to a greater arching in adults.

Congenital ligament or tissue weakness can cause this lateral arch to flatten under pressure and so result in a broadening of the fore-foot. Here, the length of the various metatarsal bones compared to the different patterns of pressure exerted on the fore-foot is of significant importance. Depending on the type of foot, the first or second metatarsal will be under greater pressure depending on which is the longer of the two. Instability between the fore- and rear-foot can also result if the inclination between metatarsal one and metatarsal five is too great. This type of foot tends to tilt sideways during the propulsion process of walking.

In the case of the high-arched foot, the angle between the metatarsal and the ground increases, resulting in a greater load to the individual metatarsal heads.

# THE SHOE

From a biomechanical point of view, the shoe plays a significant part in the process of walking and standing. The height of the heel as well as the thickness of the sole greatly influence the conveyance of the weight and consequently influence locomotion itself. This sphere of influence must be duly considered, particularly in cases of static deformity. A build-up of the shoe, i.e., constructing a rocker bottom must be compensated for at the heel, otherwise the relationship between the heel-height and sole-thickness in the front of the shoe will be disturbed, thus having a negative effect on the roll-over process (Figure 12).

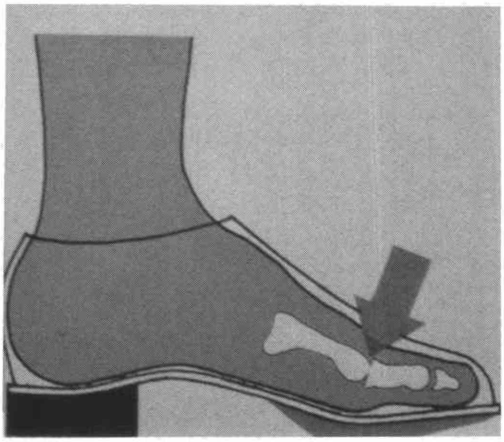

Figure 12.

## CUSHION-HEEL

The attachment of a cushion-heel also changes the roll-over process in that it acts as a shock absorber at heel strike and at the same time increases the roll-over (Figure 13).

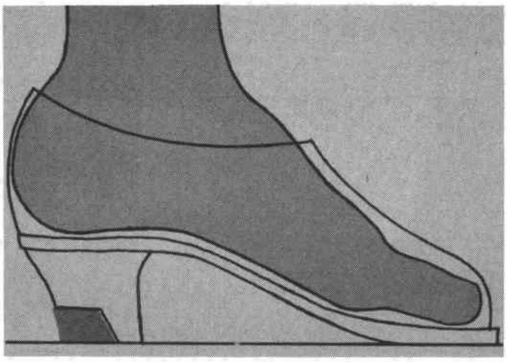

**Figure 13.**

## HEEL-TO-TOE-ROLL FOR THE WHOLE SOLE

A heel-to-toe roll sole can be attached to the shoe to protect the ankle joint and Chopart's joint. Measured radially from the knee, this allows a complete roll of the foot (Figure 14).

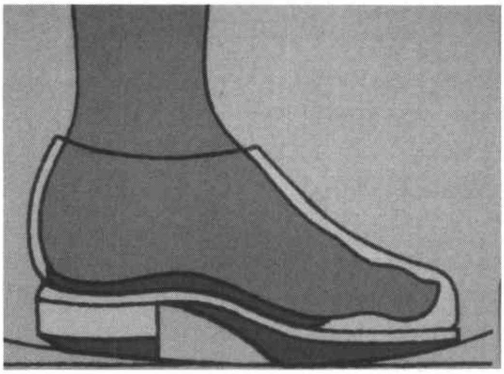

**Figure 14.**

## THE USE OF INSOLES

The insole and the shoe must form a unit with the level ground. Whether the foot is neutral, in pronation or supination, is of no significance.

When insoles are made of solid material, their length and shape are important. It is of particular importance with handicapped patients that the insoles are kept somewhat longer in order to reduce the risk of tilting sideways. This pronatory support, especially in the forefoot region, gives the patient a feeling of security.

The correction of the talipes valgus should be differentiated from the correction of the talipes varus. With talipes valgus, the rear of the foot should be supinated and the fore-foot pronated in order to achieve a rotation of the foot. With talipes varus, this is not possible. Here, the whole foot must be pronated, i.e., the rear- and fore-foot must be included in an homogenous correction.

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