UC-BL DUAL-AXIS ANKLE-CONTROL SYSTEM AND UC-BL SHOE INSERT

Biomechanical Considerations [a] [b]

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ABSTRACT

The concept of the UC-BL Dual-Axis Ankle-Control System (brace and fitting aids) for the ankle and foot emerged naturally from basic studies of the functions of the ankle (talocrural) and subtalar (talocalcaneal) joints. The UC-BL Shoe Insert was developed as an adjunct to the brace in order to achieve better control of the foot within the shoe. Subsequently, the insert has been found to be of value, as an independent device, in treating certain abnormalities of the foot for which the brace is not indicated.

A résumé of the most important functions of the human ankle and foot is presented with the aim of promoting a clearer understanding of the anatomic structures and the motions to be supported by a brace. The axes of rotation and the ranges of motion in the ankle and the foot during walking are discussed. The material is selective and is limited to that which is pertinent to the function of the two devices.

I. INTRODUCTION

The concept of the UC-BL Dual-Axis Ankle-Control System (brace and fitting aids) for the ankle and foot emerged naturally from basic studies of the functions of the ankle (talocrural) and subtalar (talocalcaneal) joints (*1, 2*). The UC-BL Shoe Insert was developed as an ad-

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junct to the brace in order to achieve better control of the foot within the shoe. Subsequently, the insert has been found to be of value, as an independent device, in treating certain abnormalities of the foot for which the brace is not indicated.

The following résumé of the most important functions of the human ankle and foot is presented with the hope that a clearer understanding of the anatomic structures and the motions to be controlled by a brace will result. The résumé will include discussion of the axes of rotation and the ranges of motion in the ankle and the foot during standing and walking. Obviously, the material must be selective and cannot cover, in detail, all aspects of the functional anatomy of the ankle and foot. The material presented here will be restricted to that which is pertinent to an understanding of the UC-BL Dual-Axis Ankle-Control Unit (Brace) and the UC-BL Shoe Insert.

II. JOINT FUNCTION

Ankle (Talocrural) Joint

The ankle joint is considered by most anatomists to be a simple hinge joint, with the trochlea of the talus rotating in the mortice about a single axis. This is not precisely true (*3, 4, 5, 6*), but for purposes of brace design a single axis may be assumed.

As viewed from the front (projected on a vertical—coronal—plane), this axis is never horizontal in the normal subject but is inclined downward from the medial to the lateral aspect. In a study of 46 cadaver feet (*6*), the acute angle which it forms with the long axis of the tibia was found to vary from 68 to 88 deg., with a mean of 80 deg. If extended laterally and medially, the axis passes approximately 3 to 5 mm. distal to the distal tips of both malleoli. Thus, the axis may be envisaged in relation to these anatomic landmarks, and the so determined axis may be used for purposes of brace alignment.

It should be pointed out that the ankle-joint space seen in anteroposterior x-rays bears no definite relationship to the axis of the ankle joint (Fig. 1). This is because the curvature of the trochlea of the talus is a portion of the surface of a cone whose apex is always medial to the ankle (*1*); as shown in Figure 2, the size of the cone and the inclination of its axis may vary without any change in the orientation of its superior surface (trochlea), which articulates with the inferior surface of the tibia.

This inclination of the axis of the ankle joint results in the forepart of the foot being turned mediad on plantar flexion and laterad on dorsiflexion. The amount of this medial and lateral displacement depends on the inclination of the joint axis and the amount of plantar flexion

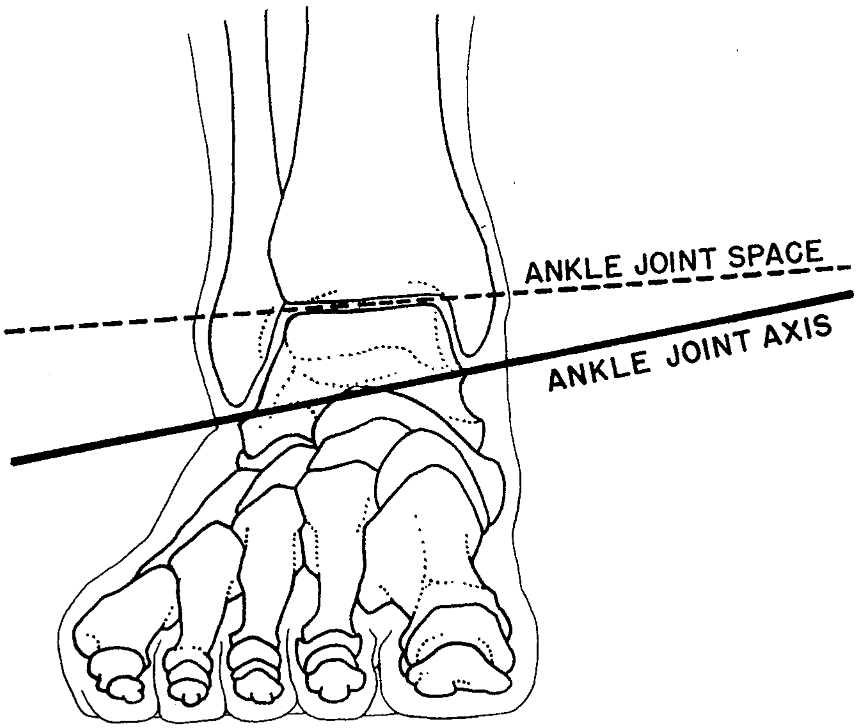

FIGURE 1.—Approximate angle between the axis of the ankle joint and a line drawn through the ankle-joint space, projected on a coronal plane.

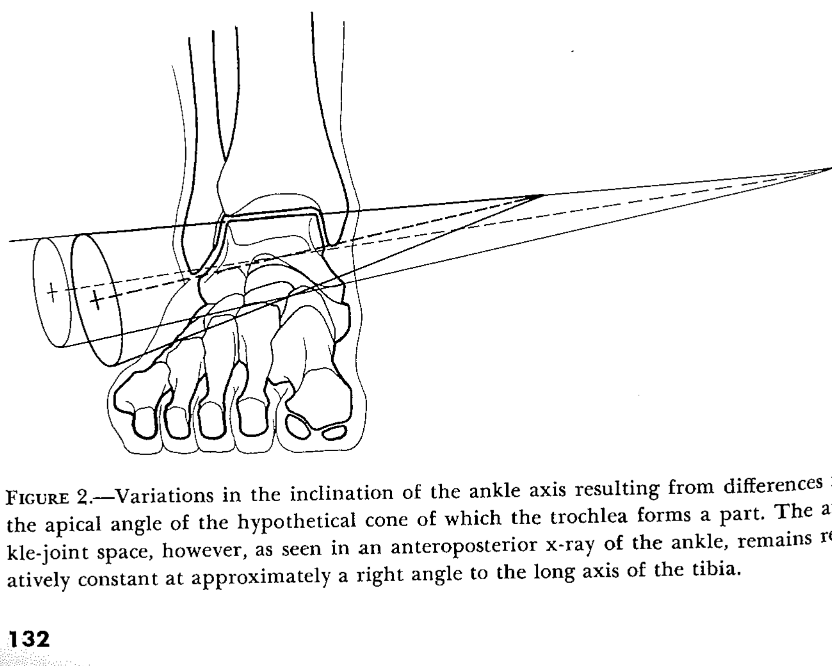

FIGURE 2.—Variations in the inclination of the ankle axis resulting from differences in the apical angle of the hypothetical cone of which the trochlea forms a part. The ankle-joint space, however, as seen in an anteroposterior x-ray of the ankle, remains relatively constant at approximately a right angle to the long axis of the tibia.

and dorsiflexion of the ankle. The smaller the angle between the axis and the long axis of the tibia, the greater will be the medial or lateral displacement of the forefoot for each degree of motion of the joint (Fig. 3).

Several interesting clinical observations are explained by consideration of the angle, as projected on the coronal plane, of the axis of the ankle joint. In walking, during the period from heel-strike to foot-flat, plantar flexion occurs, with resulting toe-in. The amount of toe-in during this phase is dependent upon the inclination of the axis of the ankle joint. It is very obvious in some individuals. It also follows that most persons with flatfoot and associated toe-out, if the axis is inclined to any extent, will show improvement if they wear higher heels, since elevation of the hindfoot causes greater plantar flexion in the ankle and therefore greater toe-in.

In addition to variations in the inclination of the axis of the ankle joint as measured in a coronal plane, the angle between the axis and the long axis of the foot (Morton's (7) *functional axis*[d]) varies as

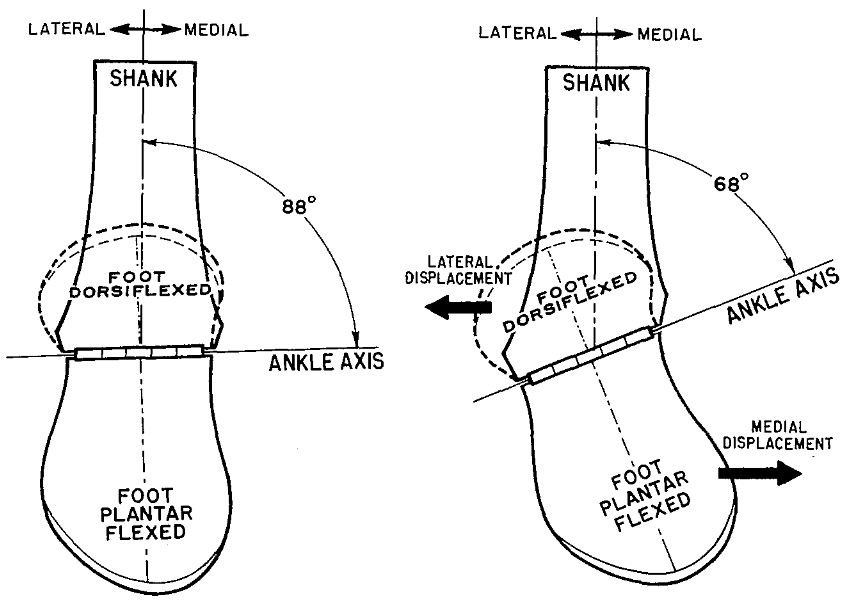

FIGURE 3.—Diagram showing the effects of differing angles of the ankle joint on displacements of the forefoot during plantar flexion and dorsiflexion.

[d] This axis is an extension in both directions of a line connecting a point midway between the heads of the second and third metatarsals with the midpoint of the calcaneus (see Fig. 4).

viewed from above (i.e., projected on a horizontal [e] plane). In the 46 cadaver feet mentioned above (*6*), it was found to vary from 68 to 99 deg. with a mean of 84 deg. (Fig. 4). The significance of this angle is twofold, depending upon which segments are fixed. When considered alone and under static conditions, with the foot fixed flat and the leg vertical, the size of the angle may be interpreted as indicating the amount of tibial torsion. If, on the contrary, the tibia and fibula are

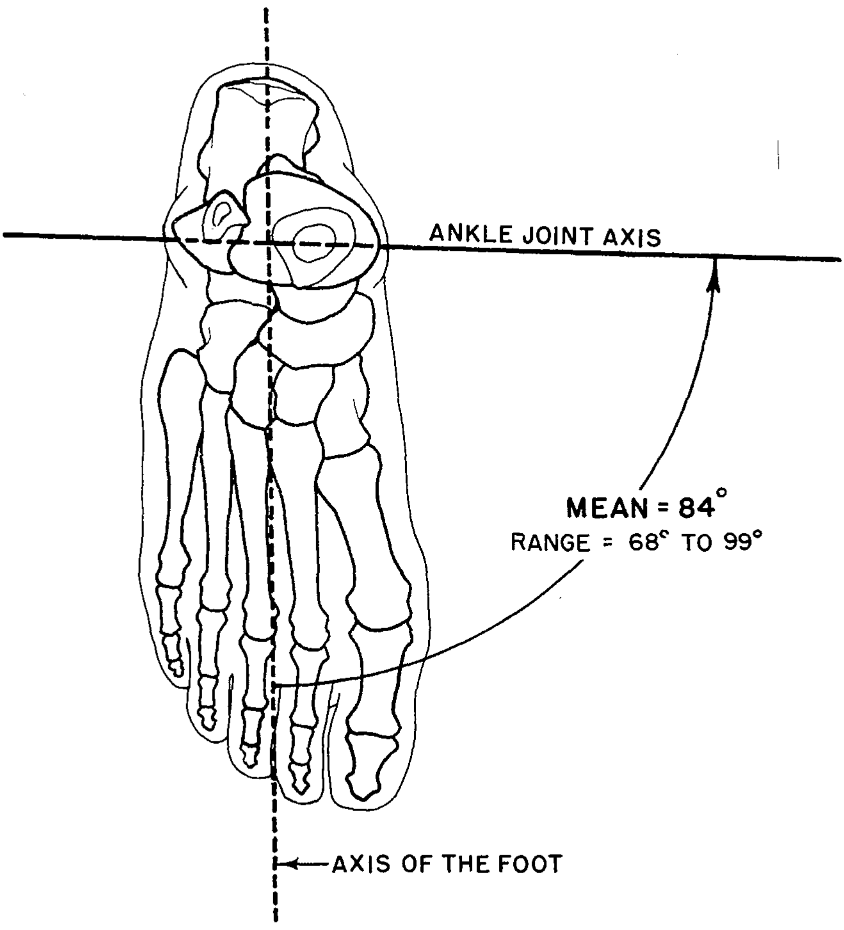

FIGURE 4.—Angle between the axis of the ankle joint and the long axis of the foot, projected on a horizontal plane.

[e] In the following, the *horizontal plane* is the plane of or parallel to the floor or other surface on which the foot is placed. The *coronal plane and the sagittal plane* are at right angles to the horizontal plane and to each other.

fixed in a standard position, this angle will affect the degree of toe-in or toe-out that the foot will adopt.

In the UC-BL Dual-Axis Ankle Brace, it is necessary to align the axes of the anatomic and brace joints with sufficient accuracy to prevent relative motion between the brace and the leg, which may lead to discomfort, and to prevent the development of large stresses in the brace components. It is also necessary to insure unrestricted motion at the ankle joint and to prevent irritative movements between the cuff and the skin of the leg. Such an alignment can be achieved, as mentioned above, by positioning the axis of the brace joint so that it passes 3 to 5 mm. distal to the tips of the malleoli.

Subtalar (Talocalcaneal) Joint

It is not generally appreciated that the extent of motion occurring in the subtalar joint may approximate that of the ankle joint (*8*) in normal locomotion. Walking on inclined surfaces or irregular ground may require an even greater range of motion at the subtalar joint, and specific activities such as getting into a car or turning the body while standing may require the full range.

The joint is well designed for these activities. It functions essentially as a single-axis joint (*4, 6, 9*) and its angle (viewed from the side, i.e., projected on a vertical—in this case sagittal—plane) is such that it acts like a mitered hinge (Fig. 5). Axial rotations of the leg are directly transmitted to the foot and vice versa. Internal rotation of the leg causes pronation of the foot and external rotation causes supination.

If (still as viewed from the side) the angle between the axis of the subtalar joint and the horizontal is 45 deg. with the foot flat on the floor and the leg vertical, the coupled axial rotations of the leg and the foot are equal in magnitude although acting in planes at right angles to each other. However, the inclination of the axis of the subtalar joint shows great individual variations. The angle has been found to be as small as 20 deg. and as large as 68 deg., with a mean of 41 deg. (*6*) (Fig. 6).

The effect of these variations in the angle of the axis is to alter the relation between the amount of pronation and supination of the foot and the amount of rotation of the leg about its long axis. These rotations will vary as the tangent of the angle of inclination of the axis of the subtalar joint. The less the angle of inclination (when the axis is closer to the horizontal) the greater the pronation and supination imposed upon the foot by a given amount of rotation of the leg. Such an inclination of the axis is found in persons with flatfeet and is probably one of the factors that leads to increased pronation and supination of the foot and breakdown of the shoe. In the cavus foot the axis of the subtalar

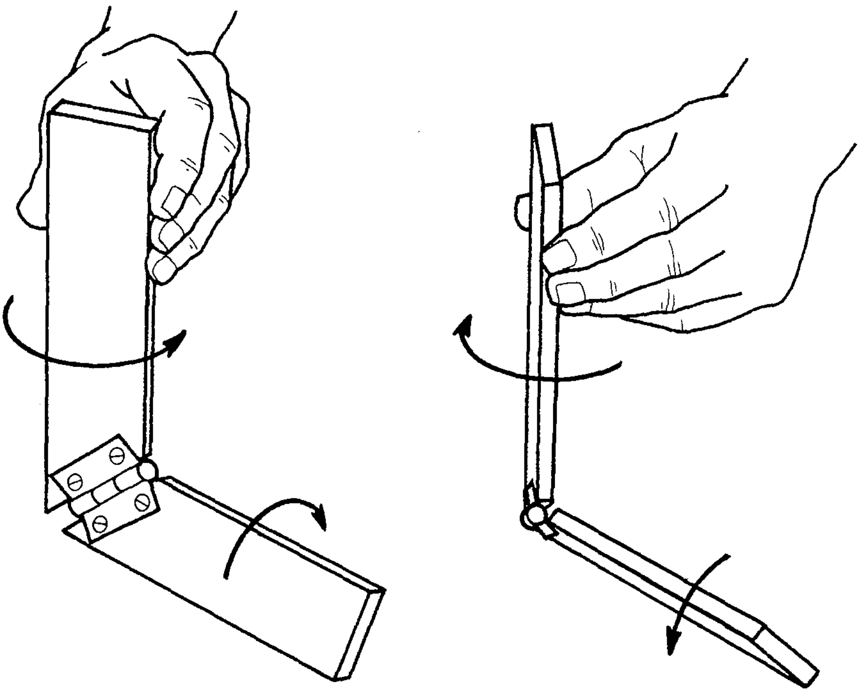

FIGURE 5.—Movements of segments connected by a mitered hinge.

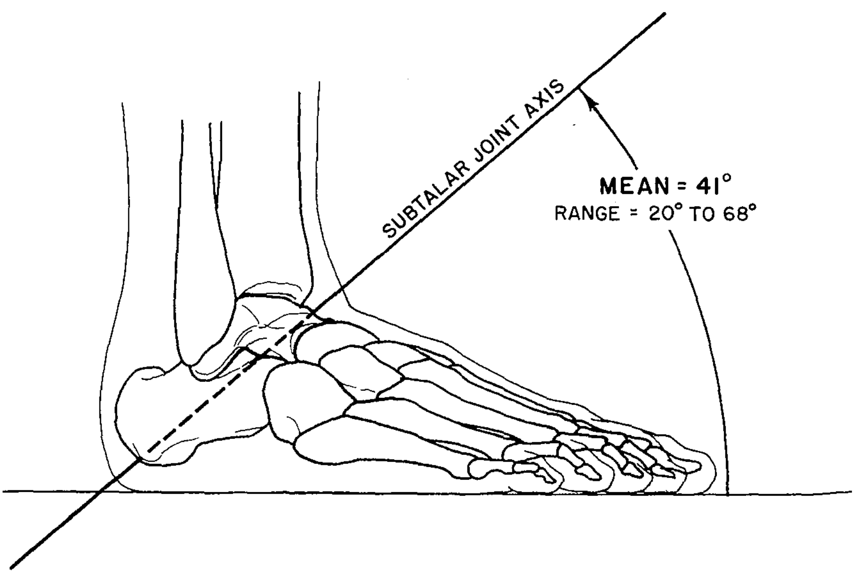

FIGURE 6.—Angle between the axis of the subtalar joint and the horizontal.

joint is closer to the vertical, and a specified amount of rotation of the leg about its long axis results in less pronation and supination of the foot. In the transmission of forces in the other direction, mild pronation or supination of the cavus foot will impose a large rotatory force on the leg.

The axis of rotation of the subtalar joint as projected onto a horizontal plane (viewed from above) also shows great individudal variations in the angle it forms with the long axis of the foot (*6*) (Fig. 7). The mean angle found by Isman and Inman was 23 deg. (according to Manter (*9*), 16 deg.) with a range of 4 to 47 deg. While all the functional implications of the variations in this plane are not completely understood, it appears clear that the greater the angle between the axis of the subtalar joint and the long axis of the foot, the greater will be the elevation (with adduction), and depression (with abduction), of the lateral side of the foot.

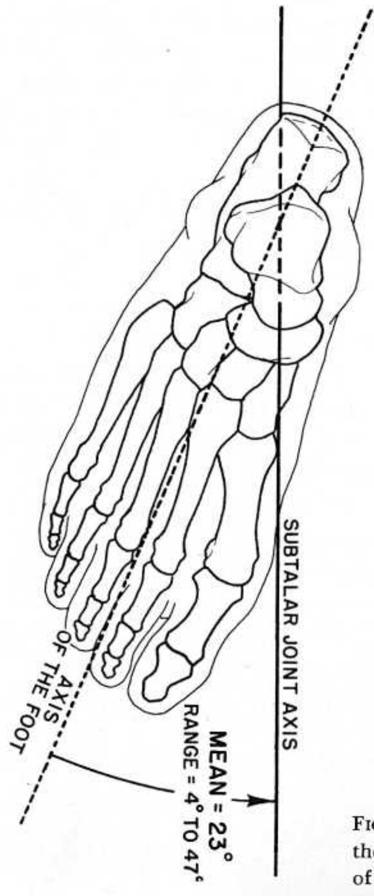

FIGURE 7.—Angle between the axis of the subtalar joint and the long axis of the foot.

During normal locomotion, the segments of the thigh and shank undergo a series of rotations about their long axes. The rotation of the shank averages 19 deg., with extremes of 13 and 26 deg. (*10*); during stance phase, these rotations are only possible because of the action of the subtalar joint. The linkage provided by this joint (see Fig. 5) requires that pronation or supination of the foot accompany the transverse rotations of the leg (Fig. 8). The total angular changes in the an-

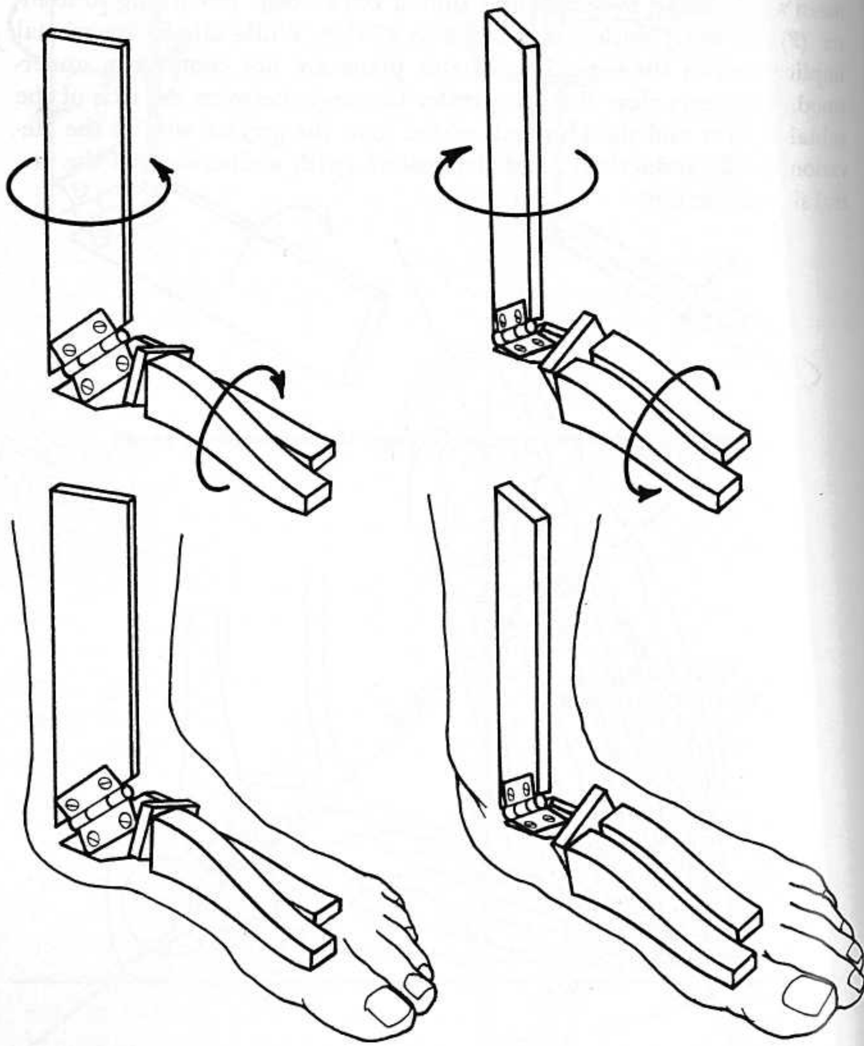

FIGURE 8.—Pronation and supination of the foot absorbing transverse rotations of the leg.

kle and subtalar joints that occur with each step are sometimes equal in magnitude (*7*). Whereas motion at the ankle joint is readily perceived, the simultaneous motion of the subtalar joint is more difficult to see but is of equal importance in normal walking. To date it has not been found possible to determine, in the living subject, the location of the axis of the subtalar joint by means of anatomic landmarks.

Transverse Tarsal Joint

Although the calcaneocuboid and talonavicular articulations both possess some independent motion, from a gross functional standpoint they may be considered together to comprise the transverse tarsal joint. In the living foot, this joint permits some degree of flexion and extension. The amount of this motion is proportionate to the immediate relationships prevailing at the time of testing between, in the hindfoot, the head of the talus and the calcaneus, and, in the midfoot, the navicular and the cuboid. If the heel is everted and the forefoot supinated, motion in the transverse tarsal joint is maximal. With the heel inverted and the forefoot pronated, motion is suppressed. This "unlocking" and "locking" of the transverse tarsal joint is the result of the changes in the relationship between the talonavicular and the calcaneocuboid articulations (*11*) (Fig. 9).

Since the flexibility or rigidity of the midfoot is dependent upon the movement permitted in the transverse tarsal joint and since the range of motion in that joint depends upon the instantaneous relationship of the talus to the calcaneus, the key to the entire mechanism lies in the control of the calcaneus (*13*).

Eversion of the calcaneus (heel), with the forefoot fixed through the transmission of body weight to the floor, causes the articular structures of the midfoot to remain movable, with the stability of the foot depending primarily upon the plantar fascia and the musculature. This can be demonstrated on any living foot by passive manipulation (Fig. 10*A*). When the heel is thus everted, forceful (passive) dorsiflexion of the ankle by pressure on the forefoot causes the plantar fascia to become taut. Conversely, inversion of the heel creates a mechanical locking of the midfoot. Now forceful dorsiflexion causes no tightening of the plantar fascia (Fig. 10*B*). This mechanism has long been recognized by persons interested in the function of the human foot and has been a basis for certain types of appliances and therapeutic procedures.

Metatarsophalangeal Break

As the heel is raised, the body weight is transmitted to the metatarsal heads. The metatarsal break, or a line joining the second and fifth metatarsal heads, is, however, oblique to the long axis of the foot (*6*) (Fig.

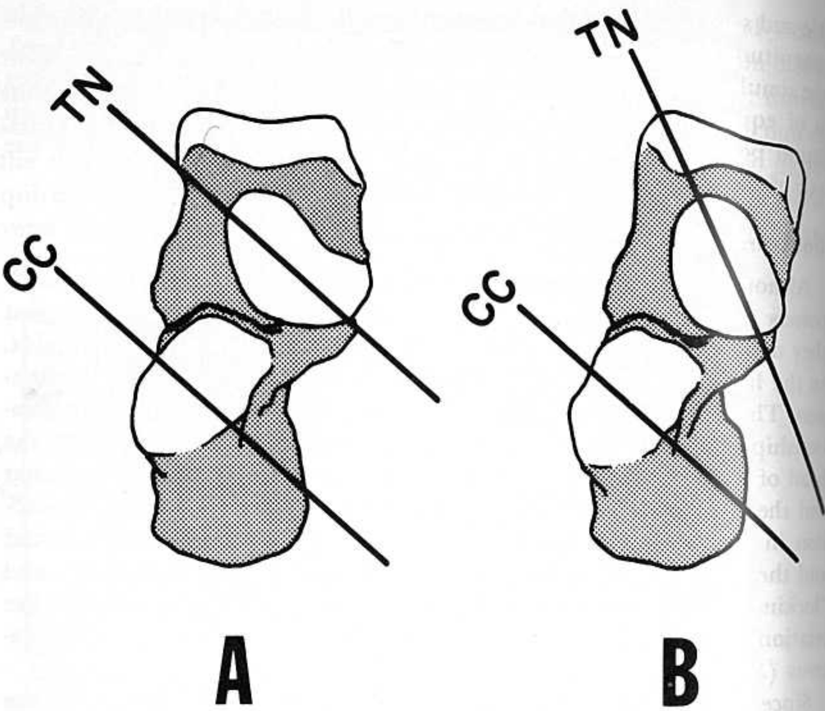

FIGURE 9.—Lines representing axes of rotation of the calcaneocuboid and talonavicular joints. *A*, pronated foot. The axes are parallel to each other, permitting maximal free motion at the talonavicular and calcaneocuboid joints. *B*, supinated foot. The axes are divergent, restricting motion in the transverse tarsal articulation since each individual joint has a different axis of rotation. (Redrawn, with permission, from Mann and Inman (*12*).)

11). Isman and Inman found it to have a mean angle of 62 deg., with a range of 53 to 72 deg. To distribute the weight simultaneously through the heads of the metatarsals, the foot would, if there were no subtalar joint, deviate laterally from a vertical plane and be supinated slightly (Fig. 12). In fact, however, the leg remains relatively vertical (in the plane of progression) because of the presence of the subtalar joint.

III. PRACTICAL APPLICATIONS

The successful employment of any orthotic device depends upon the following factors (*14*):

1. Proper evaluation of the pathological condition for which the device is being prescribed.

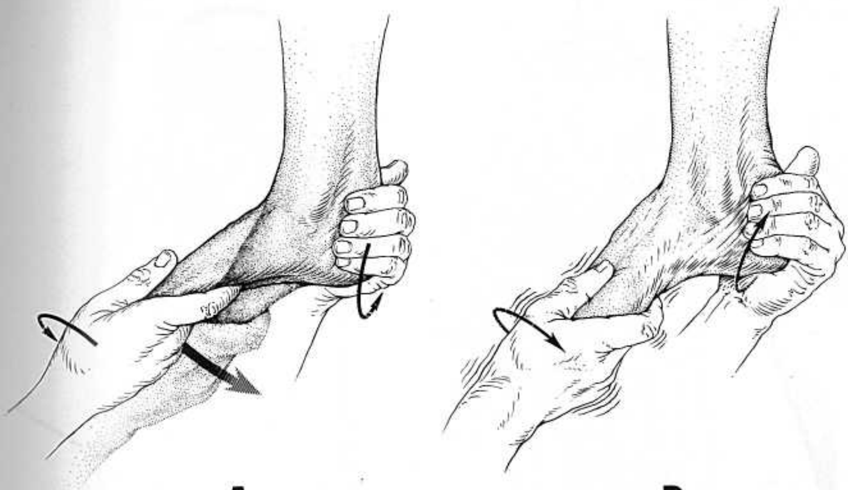

FIGURE 10.—Unlocking and locking of the foot caused by forceful eversion (*A*) and inversion (*B*) of the heel, with fixation of the forefoot.

2. A clear definition of what is required of the device.
3. Sufficient understanding of the mechanics and function of the device to determine its potential, including consideration not only of its desirable functions but also of its possible disadvantageous effects.

Unfortunately, a physical instrument such as a brace is often prescribed without a clear conception of the principles involved in its development and use; all too often a device is blamed for failures when the original prescription is at fault. It is mandatory that the functional anatomy of the part to be braced be clearly understood and the precise therapeutic objectives be defined before the prescription is worked out. The final selection of the type of appliance should be made on the basis of its ability to fulfill the desired functional and/or therapeutic requirements with a minimum of disturbance to other functions.

UC-BL Dual-Axis Ankle-Control Unit (Brace) (Fig. 13)

Because of the importance of the subtalar joint in normal locomotion and its essential contribution to the proper functioning of the foot, it was concluded that any leg brace should provide motion at the subtalar as well as at the ankle joint. Such motion is provided in the basic model of the UC-BL Dual-Axis Ankle Brace (*15, 16*). When the axes of this

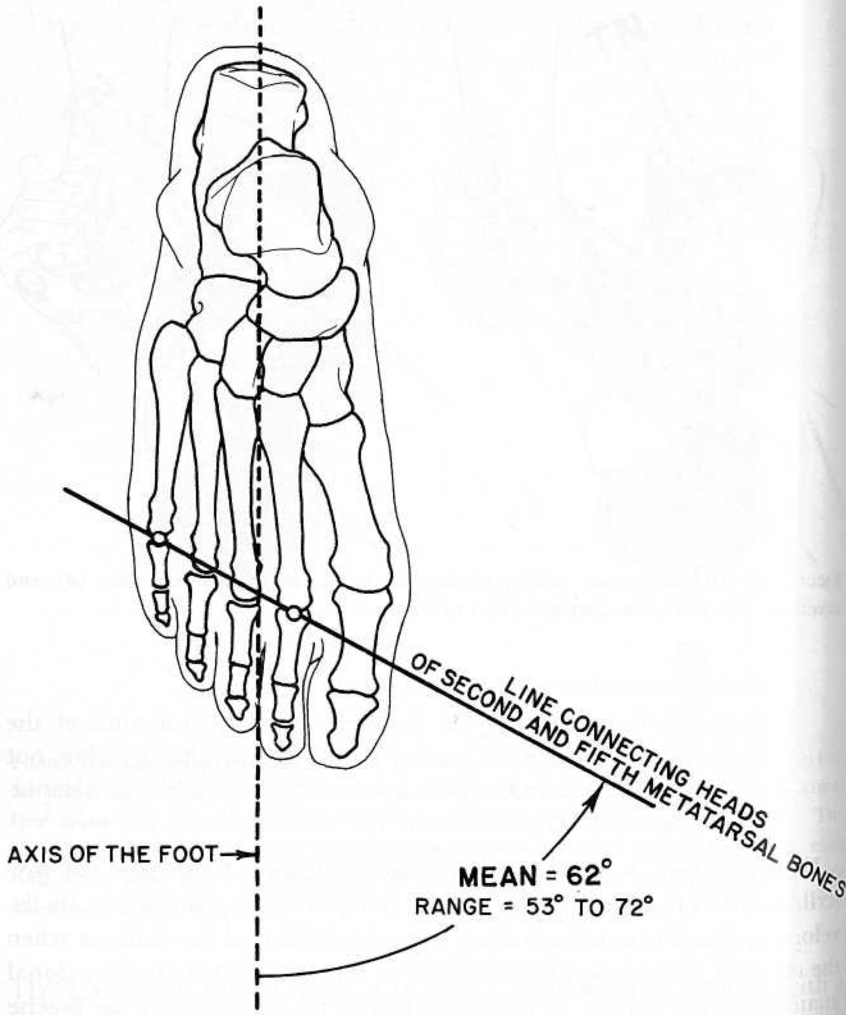

FIGURE 11.—Angle of metatarsal break: angle between the long axis of the foot and a line joining the second and fifth metatarsal heads.

brace are properly aligned with the anatomic axes, the appliance can be worn by a normal person without restriction of any motions of the ankle or foot; it is essentially an external analog of the internal skeletal parts. The provision of two joints has two major advantages. Since normal movements are permitted, no appreciable stresses are created in the component parts of the brace. Furthermore, it makes possible independent control of two important articulations, the ankle and the subtalar joints. Muscle weakness can be compensated for by springs or

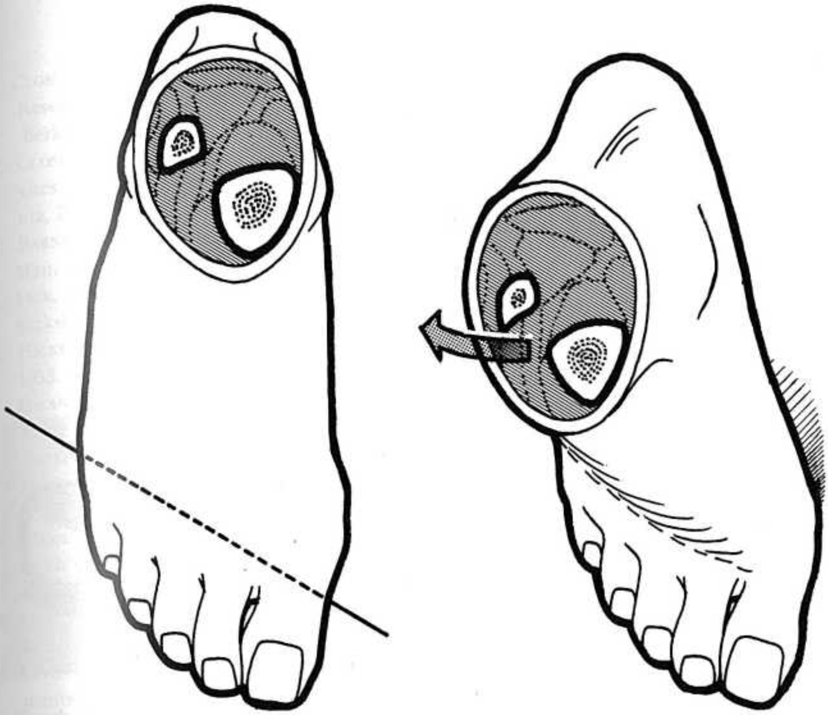

FIGURE 12.—Lateral deviation of the foot which would result from rising on the toes if there were no subtalar joint (view from above).

rubber bands to assist in toe-lift (ankle function) or inversion or eversion of the heel (subtalar function).

UC-BL Shoe Insert (Fig. 14)

It was found that the UC-BL Dual-Axis Ankle Brace lost some of its therapeutic efficiency because of the play between the shoe and the foot. A more intimate relationship between the brace and the foot, particularly between the brace and the calcaneus, was considered desirable and in some cases necessary. This could be achieved by the use of a snug-fitting plastic insert (*17*) which when worn in a shoe provides a more intimate linkage between the brace and the heel. Forces applied by the brace to the shoe are transmitted directly to the foot and not lost by a loose or ill-fitting shoe. In addition, the insert has proved to be useful in holding the foot within the shoe in a predetermined position relative to the brace.

Whenever the control of the floor reactions on the foot is the only important factor to be considered in treatment, the insert, used independ-

FIGURE 13.—UC-BL Dual-Axis Ankle-Control Unit (Brace), showing the design allowing motion at the ankle and subtalar joints.

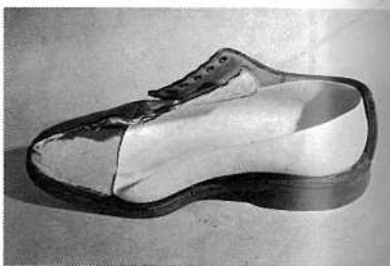

FIGURE 14.—UC-BL Shoe Insert, showing the design for firm grip of the heel.

ently, has proved efficacious in controlling the movement of the heel in the shoe. For example, it has been demonstrated (*12*) that eversion (valgus position) of the heel decreases the skeletal stability of the longitudinal arch and that its maintenance becomes more dependent upon fascial and muscular support. When overstressed, these structures cause discomfort. This occurs in symptomatic pes planus and in the condition known as "painful calcaneal spur." The latter is caused by prolonged abnormal tension of the plantar fascia at its attachment to the calcaneus. Prompt relief of both these disorders can be obtained by the use of the UC-BL Shoe Insert, which prevents the calcaneus from assuming an everted position. This imparts greater skeletal stability to the foot and relieves the fascia and musculature of the task of furnishing the principal support to the longitudinal arch.

In pes cavus with an adducted forefoot, the shoe insert can be employed to hold the heel in eversion so that the body weight is transmitted medial to the subtalar joint and a corrective force is imposed upon the foot by the superincumbent body weight.

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